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Distributional impacts of reaching ambitious near-term climate targets across households with heterogeneous consumption patterns

A quantitative macro-micro assessment for the 2030 Climate Target Plan of the EU Green Deal

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Contents

Abstract

This report enriches economy-wide modelling with household-level microdata to assess the distributional impacts of climate policy in the broader context of the EU Green Deal. The first part of the report provides a detailed exploration of the EU Household Budget Survey data in the light of its use in analysing climate policy impacts across households with heterogeneous consumption patterns. The second part of the report describes the macro-micro framework to combine the Household Budget Survey with the JRC-GEM-E3 model. The third part studies scenarios that cover three different policy configurations – ranging from a regulation-based to a pricing-based approach – all of which reach a reduction in greenhouse gas emissions of 55% in 2030 relative to 1990. Results provide insights into the potential distributional implications across EU households of an upward revision of the 2030 targets, a key aspect in achieving a Just Transition to climate neutrality. Regulation-based policies can mitigate price changes observed by households, while pricing-based policies raise revenue that have the potential to offset regressive impacts. Careful design of targeted complementary measures will therefore be required to reconcile social and environmental sustainability.

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Executive summary

The transition to climate neutrality will require an evolution towards low-carbon production and consumption patterns. As current consumption patterns vary significantly across households in the EU, the efforts to achieve this transition are not necessarily distributed equally. This report aims to quantify the household expenditure-driven variation in welfare impacts of climate policy.

Policy context

The ***EU Green Deal*** sets out a framework to achieve ambitious climate policy goals. One of the initiatives under this framework, the 2030 ***Climate Target Plan***, serves to discuss appropriate greenhouse gas emission reduction targets by 2030, in the light of the climate neutrality target for 2050. A ***Just Transition*** will seek to achieve environmental and social sustainability simultaneously, reconciling the need for an ambitious climate policy with principles of fairness.

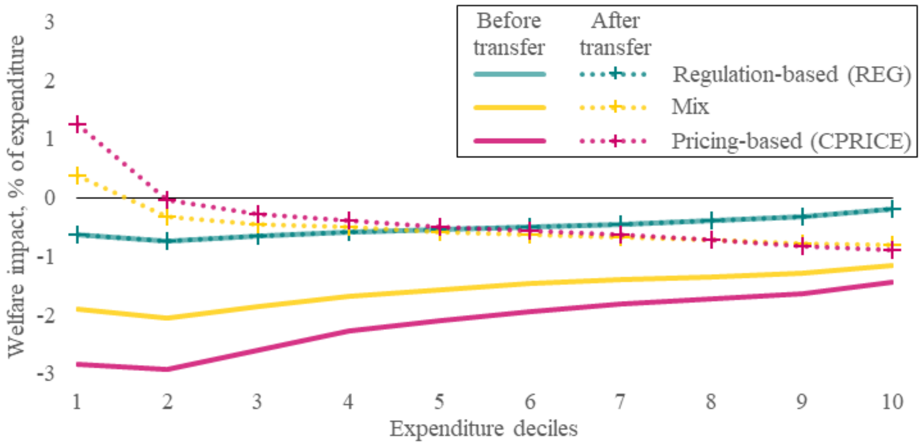
Key conclusions

Climate policy can have regressive impacts when raising the costs of energy for households. As expenditures on residential energy typically take up a larger share of the budget for low-income households, relative welfare impacts can be more pronounced for the poor. Importantly, a carbon tax or the auctioning of emission permits raises revenues. Redistributing all additional revenues at national level on an equal-per-household basis has the potential to fully offset the regressive effect, as an equal monetary transfer implies stronger welfare impacts for poor households when expressed relative to income. Real-world policies could be designed to target more directly the needs of low-income households, creating room for using part of the carbon tax revenue for other purposes. The careful design of targeted complementary measures will thus be important in achieving a Just Transition while reducing energy poverty.

Main findings

We assess three policy settings to achieve a 55% emission reduction in 2030 relative to 1990 levels. The distributional impacts shown in Figure 1 are obtained by combining economy-wide modelling with micro-level data. We first derive consumption price changes and additional government revenues from simulations with the economy-wide JRC-GEM-E3 model. These feed into an analysis based on the Household Budget Survey, which enables us to break down macro results to the household level. All scenarios imply regressive impacts before tax revenue recycling due to differences in consumption patterns. This is driven largely by expenditures on residential energy, while price changes of transport fuels are likely to impact households in the middle of the income distribution in most countries. The scenarios with additional government revenue (CPRICE and MIX; see 'Quick Guide' for a brief scenario description) show progressive effects after lump sum revenue redistribution, with the 10% lowest-spending households being better off than before the policy reform, on average. Our results furthermore indicate a wide impact variety within deciles of households with similar expenditure levels, which can only be addressed by targeted complementary measures that are more refined than lump sum redistribution of tax revenues.

Figure 1. Distributional impacts of a 55% emission reduction target, 2030, EU27_2020 excl. Austria and the Netherlands



The welfare indicator is Compensating Variation, which is defined as the monetary transfer required to make a person as well off as before the policy reform. Positive values indicate that this decile is better off after the policy reform. Expenditure deciles bundle the EU population in 10 groups of equal number of households according to their total consumption expenditure, ranging from low- (decile 1) to high-spending households (decile 10). Source: JRC-GEM-E3 model.

Related and future JRC work

This assessment builds further on previous JRC-GEM-E3 modelling work carried out in the context of the Long-Term Strategy – Clean Planet for All (EC, 2018) and the corresponding Global Energy and Climate Outlook (GECO 2018, Keramidas et al., 2018). More particularly, the report provides more background to the model-based assessment done for the Impact Assessment (EC, 2020a) accompanying the 2030 Climate Target Plan (EC, 2020b).

Quick guide

The methodological toolbox combines macro- and micro-level assessments:

- *JRC-GEM-E3*: sector-specific, economy-wide model used in climate and energy policy assessment.
- *Household Budget Survey*: micro-data on expenditure patterns of EU households.

Three scenarios are studied, reaching 55% reduction of greenhouse gas emissions by 2030 relative to 1990:

- The *REG* scenario is based on regulatory measures that increase ambition on energy efficiency, renewables and transport, while keeping the scope of the EU ETS and carbon pricing unchanged.
- The *CPRICE* scenario assumes a strengthening of the carbon price signal and its extension to transport and the buildings sector. It assumes a moderate intensification of transport policies, but no intensification of energy efficiency and renewables policies.
- The *MIX* scenario lies between the REG and the CPRICE scenarios. As under CPRICE, the buildings sector and transport are subject to carbon pricing. However, the scenario also includes an intensification in both transport and energy policies, though to a more limited extent than under REG. The strengthening in the carbon price is therefore lower than under CPRICE.

1 Introduction

Aggregate macro-economic indicators give only very partial picture of individual, micro-level impacts of policy reforms. For instance, per capita average income, by definition, does not provide any information about income disparity among households within countries. Similarly, macro-economic models often consider only one or few representative consumer(s) in modelling household behaviour. Given that in most advanced nations the share of consumer spending is about 60% of their GDP, a breakdown of households that adds detail and acknowledges the diversity we observe in society can be a meaningful addition to an ex ante policy assessment.

Thus, for the purposes of economic policy evaluation it is critically important to account for consumers' heterogeneity along various dimensions such as their differing socio-demographic characteristics, such as income, age, household size and activity status. This allows focusing on sub-groups of the population that are of particular relevance when designing a policy, for example, households that are living in (energy) poverty. A comprehensive analysis of policy implications could therefore include details for specific groups to reveal whether proposed measures risk placing a disproportionately large burden on the shoulders of the poor (regressive impacts). Although this issue has been recognised earlier either explicitly or implicitly by economic modellers, it became the main focus of researchers and policy makers only recently (see e.g. van Ruijven et al., 2015; Kim et al., 2015). Such attempts led to what is now often referred to as macro-micro integrated modelling approaches (for details, see Box 1 in this report).

The main aim of this report is twofold. First, for future modelling purposes, it is of utmost importance to explore and better understand the details of the relevant micro data. Here, we explore the strengths and limitations of the Household Budget Survey (HBS) of the EU households for the reference year of 2010. Given the current global climate and environmental challenges, understanding the consumption patterns of energy and related goods of households in the EU countries is of particular interest. These include housing-related energy consumption (electricity, gas, liquid fuels, solid fuels, heat energy), operation of personal transport equipment (especially, fuels and lubricants consumption), and transport services such as expenditure on passenger transport by different modes of transport (road, air, railway, sea and inland waterway). Moreover, an extensive exploration of the HBS data allows us to validate the micro data, if necessary harmonise them for our purposes (e.g. include or exclude imputed rents or net income variables), and importantly understand which type(s) of macro-micro integrated modelling approaches are feasible in the face of the advantages and limitations of the HBS data at hand.

Second, we use the HBS data to carry out a micro-simulation analysis of price changes obtained from the JRC-GEM-E3 model to assess the distributional impacts of achieving the proposed 55% reduction of greenhouse gas emissions by 2030 compared to 1990 levels (EC, 2020b). Given the characteristics of the HBS data and our main focus on near-term[2] welfare impacts, we adopt a top-down micro-accounting (non-behavioural) approach in this second stage of a macro-micro integrated exercise. The obtained results shed more light on the household-specific distributional impacts of higher climate ambition, which cannot be obtained from the macro modelling itself. As such, our microsimulation proves the usefulness and policy relevance of macro-micro integrated modelling.

[2] We use the word 'near-term' here for a decadal time horizon, more in line with the interpretation in the climate modelling community, where considered time frames typically extend much beyond, such that 10 years is considered to be near-term.

2 Exploring and validating HBS micro-data

Of key importance for this study is a deeper understanding of the patterns of consumption expenditures of the EU households along various demographic and socio-economic dimensions, especially for the purposes of future integrated macro-micro modelling. Hence, we use the Household Budget Survey (HBS) of the EU households for the reference year of 2010. This is the latest available harmonised wave of the HBS data. Against the background of the Green Deal proposed by the European Commission with the aim of a "Just Transition" towards a climate-neutral society, particular attention is dedicated to a better understanding of the consumption patterns of residential energy and fuel consumption in transport.

A crucial determinant of consumer behaviour and different lifestyles is consumers' affluence. To highlight the role of affluence-related heterogeneity of households in modelling assessments, three main variables can be used: income, expenditure, and wealth. All these indicators have their own strengths and limitations. So far, income (e.g. disposable income) has been used mostly in empirical studies on distributional impacts of economic and environmental policies, as income is considered to be a good proxy for the resources available to an individual or household to consume or save. However, income as a flow variable is not a good affluence indicator when the study focus is e.g. people who no longer work, but are wealthy due to their accumulated savings. In such cases, expenditure better captures the affluence level of the latter group of consumers. Generally, it can be argued that consumption is a better measure of achieved living conditions as people satisfy their needs and wants through consumption of goods and services. Total consumption expenditure may provide a more appropriate and less volatile proxy of expected lifetime resources (see Blundell and Preston, 1998, for a discussion). This might explain the fact that often regression analyses of households' carbon footprints have much higher predictive power when the corresponding regressors include household expenditure rather than household income (see e.g. Weber and Matthews, 2008; Sager, 2019). The latter result might also be due to data quality issues and deficiencies of income data as compared to the consumption expenditure data. On the other hand, poor households often finance their consumption incurring debt, which raises the question of sustainability of such consumption patterns. Finally, wealth – accumulated financial and non-financial assets – is also an important factor affecting consumers' lifestyles.

All in all, all these three affluence dimensions are complementary and together give a much better understanding of the households' economic vulnerability and material well-being, and inequality issues. This is the reason why Eurostat has recently launched a section on its website for dissemination of its experimental statistics on Income, Consumption and Wealth (ICW).

In what follows, we first look into the details of household income and expenditure variables in the HBS 2010 wave. The HBS includes two income variables of interest: monetary net income (HH095) and net income (HH099). The first basically represents household net disposable income and is defined as total monetary income from all sources minus income taxes. Net income additionally includes non-monetary income, which also enters in the consumption expenditure side. These non-monetary elements include benefits in kind from employment (wages and salaries in kind), internal or own production, and imputed rents. On the expenditure side, the variable of interest at this stage is total consumption expenditure (HE00). To make valid comparisons of incomes and expenditures across households with different size and composition and to account for economies of scale when individuals share household resources, these variables are divided by the corresponding equivalised household size (i.e. the number of adult equivalents in the household) using the modified OECD scale. The modified OECD scale assigns a value of 1 to the first adult in the household, of 0.5 to the second and each subsequent person aged over 13, and of 0.3 to each child aged 13 or under. Since wealth data cannot be extracted from the HBS, this dimension is not analysed in this study, but could be explored in future work.

In the following sections, we dive into the HBS data from both income and expenditure angles, with a focus on energy-related consumption expenditures.

2.1 Sources of non-monetary income

Table 1 shows the mean values and confidence intervals of non-monetary income sources as percentage of monetary net income (all expressed per adult equivalent), appropriately accounting for the sampling weights.[3] The corresponding EU averages (across the 25 countries reporting the relevant income data) are 1.7%, 3.8% and 17.7% for wages and salaries in kind, internal production, and imputed rents, respectively. This shows the overall significance of imputed rents among the three reported non-monetary income sources. Home ownership is particularly important non-monetary source for households in Bulgaria (where imputed rents, on average, are equivalent to 31.1% of monetary net income), Romania (30.4%), Spain (27.0%), Croatia (26.1%), Cyprus (22.5%), Lithuania (21.9%), Luxembourg (21.5%) and Hungary (21.3%).

Table 1 furthermore illustrates that there are substantial differences across EU countries in terms of the other two non-monetary sources. On equivalised household basis, wages and salaries in kind are important sources of non-monetary income (after imputed rents) in Belgium, which are, on average, worth 11.5% of monetary net income. This item is also reported to be non-negligible for Hungarian households (5.9%). In Romania, income in kind from non-salaried activities are, on average, as high as 20.4% of the reported monetary net income. This source of income is also relatively significant for Croatia (9.4%), Belgium (7.2%), Hungary (6.0%), Lithuania (6.0%), Portugal (5.5%) and Czech Republic (5.2%).

Given that several EU countries do not provide all non-monetary income elements (the biggest concern being imputed rents), while the reported corresponding figures for other Member States could be quite significant, it is not obvious to make cross-country analysis with variables in HBS 2010 wave that include the components of non-monetary income. For these reasons, the net income variable as such will not be used for the purpose of studying distributional impacts in this report. In the remainder of this study, we will use the terms 'income' and 'monetary net income' interchangeably for the sake of brevity.

Table 1. Equivalised non-monetary income sources as percentage of equivalised monetary net income: mean and +/- 95% confidence interval

	Wages and salaries in kind			Internal production			Imputed rent		
	Mean (%)	95-CI (%)	Obs.	Mean (%)	95-CI (%)	Obs.	Mean (%)	95-CI (%)	Obs.
BE	11.5	1.00	814	7.2	1.01	830	17.0	0.32	4,975
BG	0.0	0.02	2,978	2.6	0.19	2,978	31.1	1.24	2,978
CY	3.4	0.62	405	2.1	0.46	169	22.5	0.75	2,417
CZ			0	5.2	0.56	2,932			0
DE	0.0	0.00	53,873	0.2	0.01	53,873	10.3	0.14	53,873
DK	0.5	0.11	2,484	0.0	0.02	2,484	7.1	0.38	2,484
EE	1.5	0.44	3,632	1.1	0.11	3,632	11.7	0.55	3,632
EL	1.6	0.71	29	1.8	0.22	880	17.8	0.58	2,829
ES	0.4	0.05	22,135	0.5	0.06	22,135	27.0	0.38	22,135
FI	0.8	0.15	3,550	0.3	0.02	3,550	11.7	0.58	3,550
FR			0	1.7	0.15	15,618	11.9	0.28	15,618
HR	3.0	1.07	53	9.4	0.60	1,856	26.1	0.67	3,400
HU	5.9	0.21	3,698	6.0	0.23	4,280	21.3	0.37	9,935
IE	1.0	0.10	5,873	0.1	0.03	5,873			0
LT	0.3	0.07	6,090	6.0	0.31	6,090	21.9	0.93	6,090
LU			0			0	21.5	0.75	3,492
LV	0.5	0.09	3,790	4.7	0.32	3,790	10.2	0.51	3,790
MT	0.2	0.04	3,731			0			0
PL	0.5	0.04	37,372	0.9	0.03	37,372	15.5	0.16	37,372
PT	0.8	0.15	9,489	5.5	0.38	9,489	19.3	0.52	9,489
RO			0	20.4	0.41	31,284	30.4	0.40	31,284
SE	0.5	0.07	2,044			0			0
SI	1.3	0.12	3,919	3.6	0.24	3,919			0
SK	0.1	0.05	6,143	1.2	0.08	6,143	1.1	0.03	6,143

Note: Sampling weights are taken into account. 95-CI and Obs. refer, respectively, to +/- confidence intervals at 95% (assuming that the mean ratio statistic follows normal distribution) and the number of observations (or number households with reported corresponding income source data). Income data is missing entirely for Italy. Source: Own calculations based on the 2010 wave of the HBS.

[3] Since the ratio statistic is non-linear, its variance estimate is approximated here by linearisation using a Taylor-like expansion. We apply equation (4) in Eurostat (2015, p. 49) as an estimate of ratio variance. Then multiplication of square root of this estimate by 196 gives 95% confidence interval (+/- percentage points).

2.2 Distributions of equivalised income and consumption expenditure

Descriptive statistics for income and total consumption expenditures, both expressed per adult equivalent, are presented in Table 2. Both variables are skewed to the right as their means are larger than the corresponding medians for all countries: on average, the mean is larger than the median across all EU countries by 16.1% and 14.2% for income and total expenditure, respectively. However, unsurprisingly income is more skewed than expenditures as savings accumulate in higher income groups. The mean-to-median percentage differences for income range from 9.0% for Sweden to 30.7% for Portugal, while the corresponding consumption expenditure figures range from 6.8% for Czech Republic to 20.9% for Estonia.

In terms of variability, the relative standard errors of the means (RSEs) for income and total consumption expenditure are generally below 2%. The RSEs are only marginally larger than 2% in Estonia (2.13%) and Latvia (2.03%) for the income variable, and in Estonia (2.27%) for expenditures. These numbers imply that the survey data likely provides a fairly good representation of the entire population for total income and consumption.

Finally, we observe that the reported minimum values allow for negative entries not only for monetary net income (which might not be surprising), but also (or even) for total consumption expenditures. The only such case is observed for Estonia. It turns out that this particular household has large negative transport-related expenditure, namely “Purchase of second-hand motor cars” (with COICOP code of HE07.1.1.2), that overcompensates all the other (positively recorded) expenditures. We assume these entries point to households that have sold their car in the corresponding period.

On negative expenditure recording in HBS, European Communities (2003, p. 39) indicates two “borderline cases” related to transactions in so-called existing goods, which are defined in the European System of Accounts 2010 (ESA 2010) as “goods that already have had a user (other than inventories)”:

1. Financial leasing: “If the lessee does not buy the durable under a financial leasing construction at the end of the leasing period, the ownership of the durable reverts to the lessor and ESA 3.150d rule applies. This rule says that negative final consumption expenditure should be recorded, equalling the nominal price offered by the lessor at the end of the contract period”;
2. Consumer durables: “Most consumer durable goods, such as a second hand car, require specific treatment to be re-used for final consumption. In ESA 95, the transfer of existing goods is recorded at the time ownership changes as a negative expenditure for the seller and a positive expenditure for the purchaser (ESA 95, 3.149).”

The mentioned rules of 3.149 and 3.150d in ESA 1995 correspond to the rules 3.181 and 3.182d in the new ESA 2010. It is important to note that “transactions in existing goods are recorded at the time of change of ownership” (ESA 2010, 3.183). Thus, the second case described above explains the negative total consumption expenditure for Estonia.

Table 2. Descriptive statistics of equivalised household monetary net income, net income and total consumption expenditure

	Equivalised monetary net income (EUR)						Equivalised total consumption expenditure (EUR)						Missing income observations (%)
	Obs.	Min	Median	Mean	Max	RSE (%)	Obs.	Min	Median	Mean	Max	RSE (%)	
BE	7,167	-34,134	19,807	22,448	439,741	1.05	7,177	3,091	19,742	22,091	250,871	0.92	0.14
BG	2,978	50	2,124	2,366	14,132	1.42	2,982	403	2,543	2,816	14,052	1.43	0.13
CY	2,702	336	16,071	18,939	206,577	1.60	2,707	1,906	18,388	21,293	156,020	1.50	0.18
CZ	2,932	1,047	7,394	8,180	51,526	0.81	2,932	433	5,803	6,195	50,902	0.86	0.00
DE	53,873	99	18,017	21,354	211,737	0.37	53,996	2,861	16,974	19,793	280,645	0.36	0.23
DK	2,484	-133,875	28,628	32,189	506,768	1.71	2,484	4,884	24,363	26,750	115,472	1.32	0.00
EE	3,632	255	4,601	5,548	46,016	2.13	3,632	-216	4,170	5,040	38,557	2.27	0.00
EL	3,512	160	11,751	14,658	173,200	1.63	3,512	2,503	13,493	16,001	98,824	1.47	0.00
ES	22,135	837	11,570	13,512	144,000	0.73	22,203	1,009	14,995	17,124	157,057	0.69	0.31
FI	3,550	-1,723	20,990	23,238	248,872	1.42	3,551	3,091	18,928	21,849	207,445	1.54	0.03
FR	15,618	-32,513	18,985	22,400	1,205,088	1.09	15,797	223	17,590	19,852	177,769	0.87	1.13
HR	3,459	-6,049	5,416	6,171	47,346	1.24	3,461	1,270	6,578	7,200	34,881	1.00	0.06
HU	9,935	-1,685	4,392	4,991	37,205	0.76	9,937	984	4,847	5,347	32,983	0.72	0.02
IE	5,873	13	21,052	25,791	287,789	1.02	5,891	2,052	20,328	22,167	112,975	0.87	0.31
IT							22,246	1,420	15,375	18,102	243,945	0.77	100.00
LT	6,090	-2,381	4,267	5,049	48,770	1.91	6,103	595	4,845	5,498	57,097	1.80	0.21
LU	3,492	4,704	31,568	35,739	477,024	1.14	3,492	5,422	30,631	34,880	194,987	1.14	0.00
LV	3,790	-470	3,386	4,174	59,123	2.03	3,798	555	4,009	4,837	54,072	1.72	0.21
MT	3,731	-5,334	10,160	11,537	215,781	1.16	3,732	996	9,309	11,244	111,920	1.33	0.03
PL	37,372	-40,032	4,440	5,261	306,113	0.51	37,412	553	4,519	5,306	100,238	0.39	0.11
PT	9,489	414	8,400	10,975	120,400	1.67	9,489	591	9,812	11,843	134,471	1.48	0.00
RO	31,284	-2,697	2,184	2,513	57,786	0.70	31,336	199	2,731	3,085	48,930	0.60	0.17
SE	2,044	-33,913	19,919	21,720	307,089	1.78	2,047	1,173	16,985	18,715	88,502	1.76	0.15
SI	3,919	167	10,047	10,963	75,342	1.25	3,924	2,236	11,541	13,121	61,371	1.41	0.13
SK	6,143	202	5,866	6,429	41,178	1.08	6,143	838	5,271	5,832	109,191	1.11	0.00
UK	5,254	-87,040	17,516	21,656	404,228	1.36	5,263	469	13,178	15,804	174,278	1.07	0.17

Note: All statistics are expressed in EUR, except for the relative standard error of the mean (RSE) indicator, which is given in %. Households' sample weights reported in HBS are appropriated accounted for in the derivation of the presented descriptive statistics (except for the number of observations). The sample size for income could be a little smaller than that for expenditures because of missing data and when income is "top-coded" as 0 and 1. Italy does not report income data. Besides Italy, as the last column shows, the largest number of missing income data is found for France, where 1.13% of households' monetary net income is not reported and/or codified. For other countries, if such non-reporting and/or anonymisation exists, it does not exceed 0.31% of the sample size for consumption expenditure. Source: Own elaboration based on the 2010 wave of the HBS data.

Looking into the underlying consumption categories at the 2-digit COICOP Divisions level, we find more cases of negative expenditure recording in five EU countries (Table 3). As in Eurostat (2015), the corresponding twelve consumption categories are abbreviated as follows:

CP01: Food and non-alcoholic beverages

CP02: Alcoholic beverages, tobacco and narcotics

CP03: Clothing and footwear

CP04: Housing, water, electricity, gas and other fuels

CP05: Furnishings, household equipment and routine maintenance of the house

CP06: Health

CP07: Transport

CP08: Communication

CP09: Recreation and culture

CP10: Education

CP11: Restaurants and hotels

CP12: Miscellaneous goods and services

Table 3. Proportion of negative consumption entries, with and without sampling weights (%)

	CP01	**CP03**	**CP04**	**CP05**	**CP07**	**CP08**	**CP09**	**CP12**
	Population proportion of negative consumption entries (%)							
DK	0.02			0.12	0.66	0.02	0.09	
EE					0.93			
LU					0.31			
LV					0.20			
SE		0.02		0.31			0.18	0.16
UK			0.02					
	Sample proportion of negative consumption entries (%)							
DK	0.04			0.08	0.60	0.04	0.08	
EE					1.02			
LU					0.29			
LV					0.21			
SE		0.05		0.20			0.24	0.05
UK			0.02					

Note: Own elaboration using Eurostat's HBS 2010 wave.

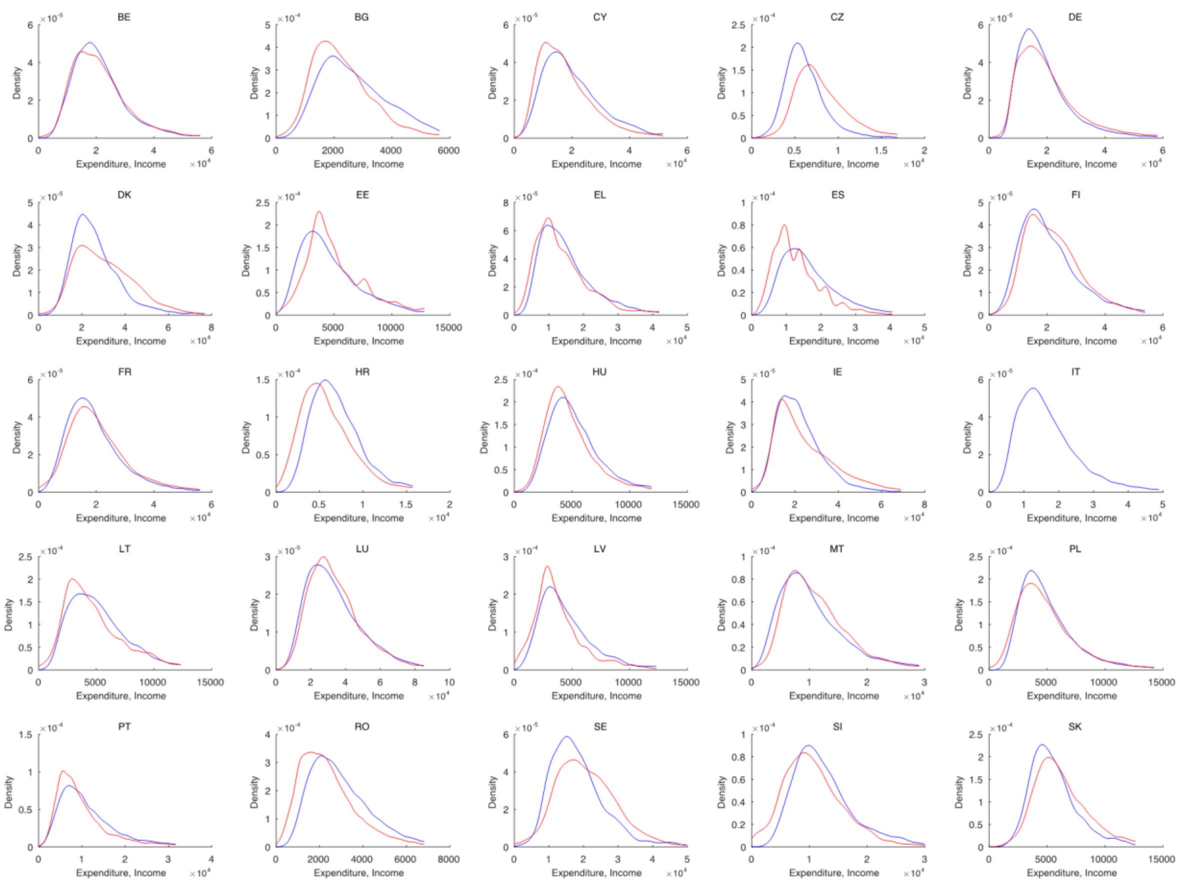
In Denmark, negative consumption expenditure for many food products is recorded for one household. Similarly, one Swedish household reports negative expenditure on garments for children and infants (HE03.1.2.3). For CP05, 4 to 12 households reported negative expenditures on consumer durables included in at least one of its subcategories. The largest number of households (in total 182 households) report negative consumption for category "Purchase of vehicles" (HE07.1), related to the issue discussed earlier for Estonia. However, there are also negative entries recorded for "Maintenance and repair of personal transport equipment" (HE07.2.3) in Luxembourg, and for "Passenger transport by railway" (HE07.3.1) in Sweden.[4] Since the conceptual base of the HBS is the concept of "household final consumption expenditure" (HFCE), the last two records probably refer to "items treated as intermediate consumption or gross fixed capital formation" (ESA 2010, 3.96b), which, according to SEA, need to be excluded from HFCE. For example, the Swedish case

[4] Note that the latter case is not indicated in Table 3. In fact there are more such cases for different consumption categories and countries that report negative expenditures at 3- or higher digit COICOP levels that do not show up at the 2-digit COICOP Divisions level as in the process of aggregation to the latter 2-digit level the underlying positive entries dominate the corresponding negative expenditures.

most probably is related to the "expenditures by households owning unincorporated enterprises when incurred for business purposes — e.g. on durable goods such as vehicles, furniture or electrical equipment (gross fixed capital formation), and also on non-durables such as fuel (treated as intermediate consumption)" (3.96b(1)). Without going further over all the cases appearing in **Table 3**, it is crucial to note that the HBS expenditure recoding rules follow the ESA principles. Anyhow, since there may be more than one explanation feasible for the cases considered, it would not be possible to find the definitive reason for negative recording in each particular case. However, **Table 3** shows that the number of negative consumption expenditures are very small, whose proportion is strictly less than 1% of "population" observations in each country concerned. As such we conclude that whenever there might be an issue with having negative consumption expenditures e.g. for economic modelling purposes, all households with such entries could be safely excluded from the analysis.

Although the reference source of income data at the EU level is the EU Statistics on Income and Living Conditions (EU-SILC), it is interesting to have a closer look at the overall distributions of the EU households' monetary net income and total consumption expenditure as reported in the HBS, both expressed per adult equivalent. **Figure 2** shows the corresponding densities, which also account for household sample weights. The plots of joint distributions of income and consumption expenditures per adult equivalent are also shown in Figure A.1 in the Appendix.

Figure 2. Densities of equivalised household income and total expenditure for the EU countries



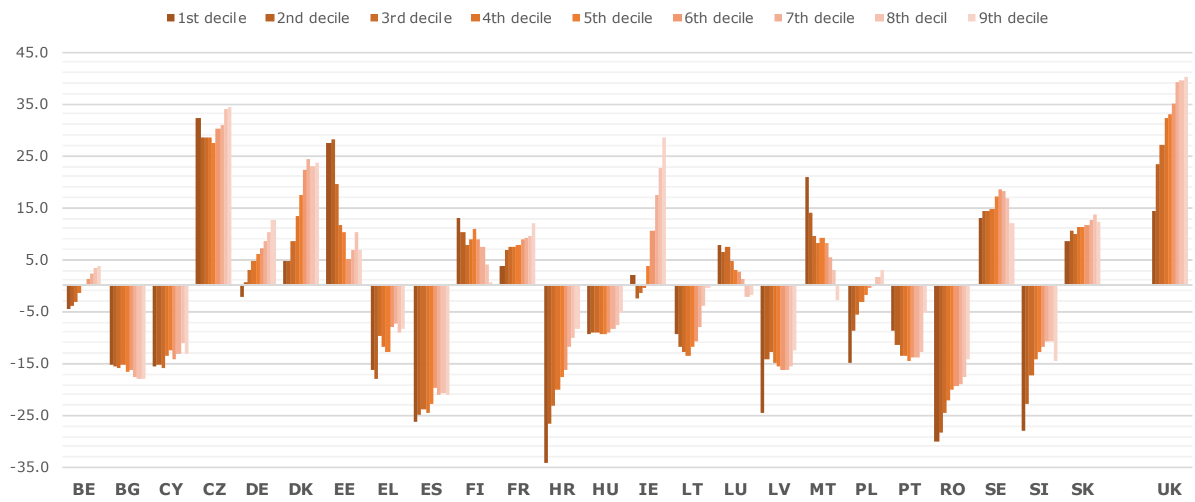
Note: Blue lines indicate the densities of equivalised total consumption expenditure. Red lines indicate the densities of equivalised income. For better visualisation, the lower and upper bounds of the variables were limited to, respectively, zero and the 97.5-th percentile of equivalised income or total expenditure, whichever is greater. Source: Own elaboration using Eurostat's HBS 2010 wave.

Ignoring the extreme values, the general shapes of both income and total expenditure densities seem to be overall consistent with each other for most of the EU countries. In terms of correlation, the largest weighted correlation coefficient of 0.726 between the equivalised income and total expenditure (including all extreme values) is found for Greek households. This "top list" includes Romania (with corresponding weighted correlation coefficient of 0.694), Bulgaria (0.684), Germany (0.641) and Hungary (0.622). On the other hand, these two variables are least correlated – again accounting for the survey weights – for Malta (0.347), Denmark (0.381), Belgium (0.400), Sweden (0.436) and Luxembourg (0.449). According to the unweighted Spearman's rank correlation, households' income and total expenditures (per adult equivalent) are most correlated for Germany (0.749), Romania (0.748), Cyprus (0.687), Czech Republic (0.680) and Slovakia (0.669), and least rank-correlated for Malta (0.424), Estonia (0.512), Lithuania (0.517), Portugal (0.529) and Slovenia (0.540).

For completeness, equivalised income and total expenditure deciles are presented in **Table 4**. There could be large differences of a particular income and/or expenditure decile across countries, partly also because these figures are expressed in current EUR. To adjust for price level differences across the EU countries, we will group EU households into (expenditure or income) deciles after converting these (expenditure or income) values in Purchasing power standards (PPS) when presenting the results in Section 4.2.

To see the within-country differences of income vs. expenditure deciles, in **Figure 3** we present the percentage differences between the two, i.e. [(y-th income decile)/(y-expenditure decile)-1]*100 for y=1,...,9. Ignoring the potential problem of income deciles being less than the corresponding expenditure deciles, the following common outcome for most of the countries is observed: income-to-expenditure deciles ratios are increasing as one moves from the lower to upper levels. This result should not be surprising as it is related to the stylised fact that generally the (average) propensity to consume is decreasing in income, i.e. richer households are able to save a larger share of their income.

Figure 3. Percentage differences between equivalised income and consumption expenditure deciles



Source: Own elaboration using Eurostat's HBS 2010 wave. Obtained from the deciles presented in **Table 4**.

The notable exceptions to this rule are found for Estonia, Luxembourg and Malta. However, one should be cautious in the interpretation of the absolute levels of the income-to-expenditure deciles differences in **Figure 3** because of the limitations of HBS income data. In this respect, e.g. Eurostat (2015) gives the following context: "Even though efforts have been made by countries to increase income comparability between HBS and EU-SILC, one cannot expect the household income collected from HBS to be as accurate as with EU-SILC. For instance, seasonal income components or small amounts can be under-represented in the HBS" (p. 41). Hence (and also given our results so far), for modelling purposes, these arguments go in favour of using HBS expenditure levels rather than the corresponding HBS income levels in analysing the distributional consequences of energy, economic and/or environmental policies. Combining HBS data with EU-SILC data could be a fruitful avenue for future work. Nonetheless, in what follows, results related to different income levels will also be presented in order to provide a complementary view.

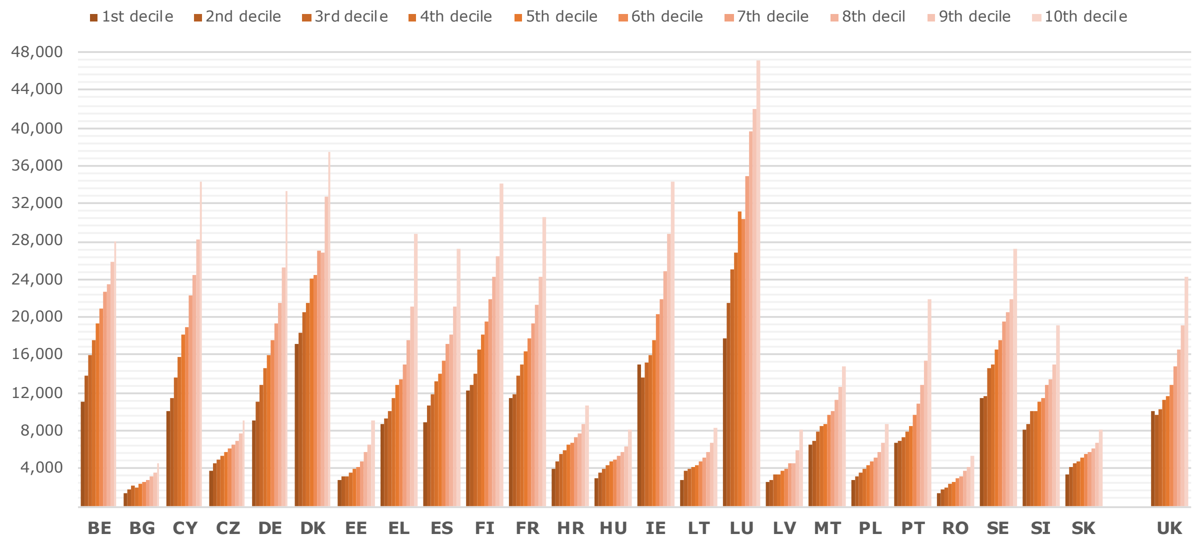
Table 4. Equivalised household income and total consumption expenditure deciles (EUR)

	Equivalised household total consumption expenditure									Equivalised household monetary net income								
	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
BE	11,146	13,703	15,801	17,765	19,742	21,860	24,441	27,855	34,795	10,652	13,159	15,290	17,521	19,807	22,133	24,998	28,806	36,150
BG	1,374	1,680	1,967	2,217	2,543	2,878	3,302	3,831	4,596	1,167	1,418	1,654	1,878	2,124	2,409	2,723	3,145	3,774
CY	9,453	11,839	13,993	16,185	18,388	21,325	24,485	28,728	36,564	7,969	10,033	11,777	13,992	16,071	18,334	21,264	25,526	31,742
CZ	3,676	4,345	4,838	5,318	5,803	6,287	6,966	7,682	9,109	4,863	5,580	6,219	6,838	7,394	8,188	9,126	10,299	12,229
DE	9,661	11,642	13,401	15,120	16,974	19,081	21,643	25,346	32,323	9,460	11,714	13,822	15,852	18,017	20,434	23,480	27,931	36,396
DK	14,743	17,501	19,768	21,884	24,363	26,826	29,963	34,725	40,858	15,471	18,314	21,455	24,823	28,628	32,805	37,266	42,751	50,505
EE	1,923	2,513	3,052	3,573	4,170	4,862	5,739	6,956	9,107	2,454	3,221	3,652	3,988	4,601	5,113	6,135	7,669	9,714
EL	7,177	8,769	10,166	11,853	13,493	15,386	17,773	21,521	27,757	6,000	7,189	9,171	10,476	11,751	14,186	16,475	19,580	25,453
ES	7,898	9,833	11,566	13,267	14,995	16,937	19,527	23,007	28,570	5,824	7,386	8,820	10,008	11,570	13,584	15,417	18,267	22,553
FI	10,226	12,603	14,709	16,769	18,928	21,767	24,719	29,007	36,566	11,553	13,894	15,864	18,234	20,990	23,712	26,586	30,163	36,812
FR	9,032	11,560	13,637	15,585	17,590	19,796	22,649	26,402	33,156	9,372	12,353	14,670	16,745	18,985	21,567	24,724	28,896	37,186
HR	3,739	4,532	5,234	5,887	6,578	7,337	8,184	9,330	11,350	2,467	3,323	4,027	4,712	5,416	6,156	7,215	8,409	10,426
HU	2,771	3,397	3,894	4,356	4,847	5,393	6,059	6,944	8,456	2,515	3,091	3,546	3,955	4,392	4,903	5,554	6,421	8,010
IE	10,637	13,259	15,539	17,932	20,328	22,700	25,811	29,675	36,159	10,859	12,940	15,323	17,830	21,052	25,110	30,308	36,375	46,456
IT	7,687	9,841	11,697	13,506	15,375	17,557	20,240	23,964	30,681									
LT	2,384	3,046	3,604	4,225	4,845	5,505	6,276	7,395	9,176	2,161	2,683	3,149	3,663	4,267	4,924	5,768	7,109	9,145
LU	16,119	20,106	23,425	26,945	30,631	35,049	39,917	47,298	58,806	17,404	21,405	25,200	28,225	31,568	35,956	40,488	46,325	57,818
LV	2,105	2,623	3,066	3,516	4,009	4,613	5,342	6,366	8,294	1,592	2,249	2,675	2,991	3,386	3,871	4,474	5,371	7,269
MT	4,489	5,797	7,041	8,185	9,309	10,773	12,545	15,118	19,452	5,434	6,608	7,725	8,846	10,160	11,661	13,249	15,581	18,874
PL	2,563	3,110	3,570	4,028	4,519	5,090	5,813	6,810	8,651	2,181	2,841	3,377	3,895	4,440	5,073	5,826	6,930	8,901
PT	4,603	5,995	7,217	8,443	9,812	11,350	13,398	16,268	21,483	4,200	5,320	6,240	7,304	8,400	9,800	11,560	14,200	20,356
RO	1,422	1,784	2,094	2,408	2,731	3,107	3,571	4,148	5,109	994	1,281	1,583	1,880	2,184	2,506	2,890	3,418	4,387
SE	9,877	11,826	13,772	15,510	16,985	19,037	21,131	24,040	29,334	11,158	13,533	15,745	17,804	19,919	22,539	24,998	28,111	32,881
SI	6,737	8,208	9,349	10,387	11,541	12,884	14,395	16,695	21,149	4,864	6,326	7,727	8,904	10,047	11,384	12,868	14,892	18,049
SK	3,377	3,940	4,409	4,815	5,271	5,779	6,372	7,174	8,651	3,669	4,359	4,854	5,352	5,866	6,448	7,172	8,151	9,732
UK	6,896	8,531	10,089	11,470	13,178	15,056	17,438	20,870	26,893	7,878	10,510	12,817	15,182	17,516	20,340	24,261	29,144	37,747

Note: Household survey weights are taken into account. D indicates "decile", thus e.g. D1 contains 10% of all households with the lowest incomes or expenditures. Obviously, 10th deciles are maximum values of the corresponding variables, which were already presented in **Table 2**. *Hence, the last are skipped from the current table, also because these figures may be less reliable due to the usual consumer survey problems (anonymisation, under- or non-reporting, etc.) with top-earning households. Source: Own elaboration based on the 2010 wave of the HBS data.*

Finally, **Figure 4** shows the distributions of median consumption expenditure over different income groups. For all countries, median consumption is observed to increase by income decile. On average in the EU, if the median consumption of households representing the second income group is larger than that of the first income decile by a factor of 1.15, the median consumption of the highest income earners is larger than that of the poorest households by a factor of 2.87. This median consumption ratio of the top-to-bottom income earners is found to be particularly pronounced for Romania (3.97), Germany (3.67), Cyprus (3.39), Bulgaria (3.38), Estonia (3.37) and Greece (3.29).

Figure 4. Median consumption expenditure (EUR) by income decile



Source: Own elaboration using Eurostat's HBS 2010 wave.

2.3 Structure of household consumption expenditure

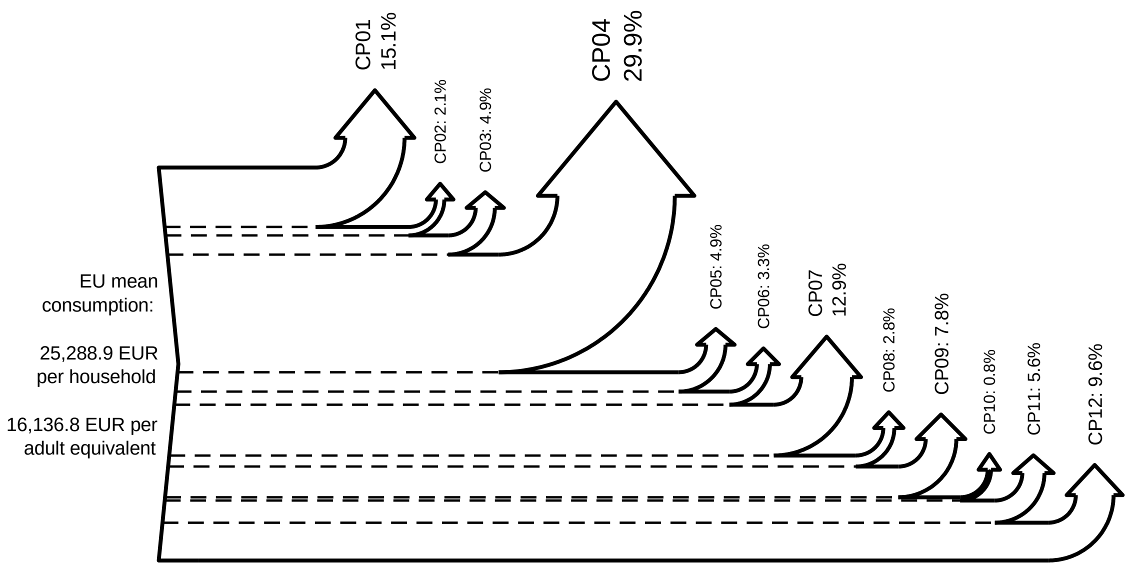
For this study, the key input from the HBS surveys is the structure of household consumption across its different categories. The total mean consumption expenditure for the considered 25 EU countries (excluding UK) in the HBS reference year of "around 2010" was 25,289 EUR per household, or 16,137 EUR per adult equivalent (i.e. without accounting for cross-country price differences). Its distribution among the different twelve 2-digit COICOP groups is illustrated by a Sankey diagram in the first panel of **Figure 5**.[5] At this level of consumption disaggregation, by far the largest consumption component is 'Housing, water, electricity, gas and other fuels' (CP04), which accounts for about 30% of the EU total mean consumption expenditure. The next two largest consumption categories include 'Food and non-alcoholic beverages' (CP01 with the average share of 15.1%) and 'Transport' (CP07, 12.9%). Thus, these top three expenditure categories, on average, make up 58% of the 25 EU households' total mean expenditure. In addition, categories with the average consumption shares within the range of 5 to 10% include 'Miscellaneous goods and services' (CP12, 9.6%), 'Recreation and culture' (CP09, 7.8%) and 'Restaurants and hotels' (CP11, 5.6%). Note that the HBS data on health (CP06) and education (CP10), which account only for, respectively, 3.3% and 0.8% of the EU total mean expenditure, do not represent the actual final consumption of households. The latter is derived from the HBS final consumption expenditures by adding the value of social transfers-in-kind received from the government and non-profit institutions serving households. Thus, the corresponding HBS figures are expected to be highly understated for countries, where the education and health expenditures are mainly paid through the tax system.

The second panel of **Figure 5** shows the country-specific structure of mean consumption expenditures for 26 countries with available HBS data. The dominance of the 'Housing, water, electricity, gas and other fuels' expenditure category is still valid for almost all countries, except for Latvia and Malta. In Latvia, CP04 with its average expenditure share of 24.6% comes second after the 'Food and non-alcoholic beverages' category that has the average expenditure share of 26.0%. In the case of Malta, about 55% of households' expenditure is spent on Food and non-alcoholic beverages (22.4%), Transport (13.1%), Miscellaneous goods and services (CP12, 10.4%) and Furnishings, household equipment and routine maintenance of the house (CP05, 8.8%).

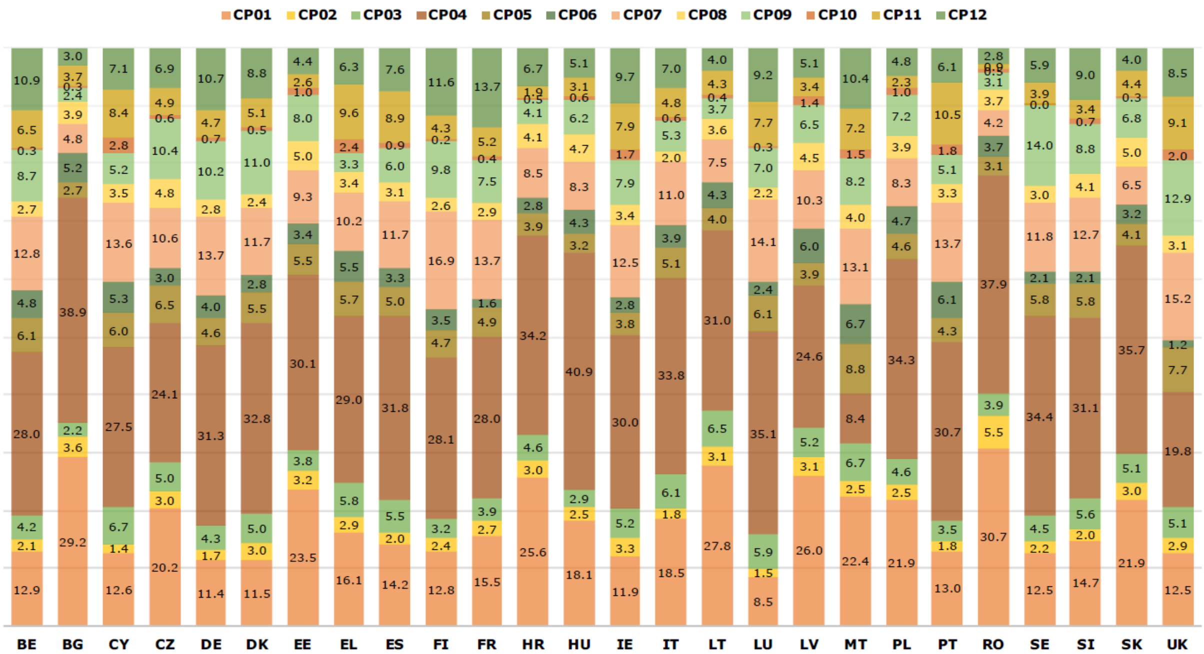
The above-presented mean values do not reveal the variability of the respective sample data. To get a better idea of the underlying sampling errors, the first graph of **Figure 6** shows the percentage differences of the relative standard errors of the mean expenditure shares from their corresponding RSE averages across all twelve expenditure categories. It shows that Education (CP10) has by far the largest RSEs variability compared to the rest of the expenditure groups. This suggests that Education is the least accurate expenditure category of the HBS 2010 wave in terms of representing the population-wide average. Note, however, that Education (CP10) shows also by far the smallest expenditure shares almost for all countries (**Figure 5**), which is related to our earlier discussion on the difference between the concepts of "actual final consumption" vs. "final consumption expenditure" (for details, see ESA 2010, pp. 69-72).

[5] We used an adopted version of a MATLAB function, developed by James Spelling (2020). drawSankey (https://www.mathworks.com/matlabcentral/fileexchange/26573-drawsankey), MATLAB Central File Exchange. Retrieved March 29, 2020.

Figure 5. The EU and country-specific structures of total mean consumption expenditures



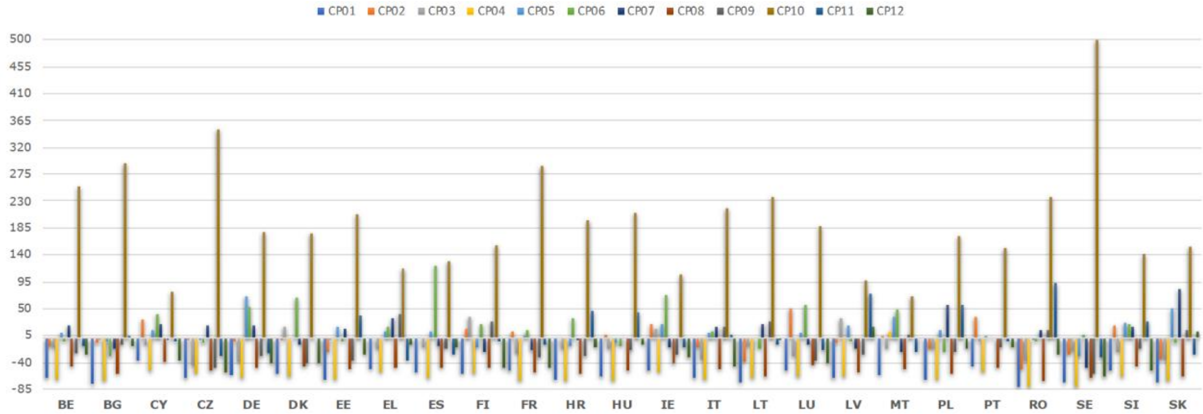
(a) Overall EU structure of total mean consumption expenditure



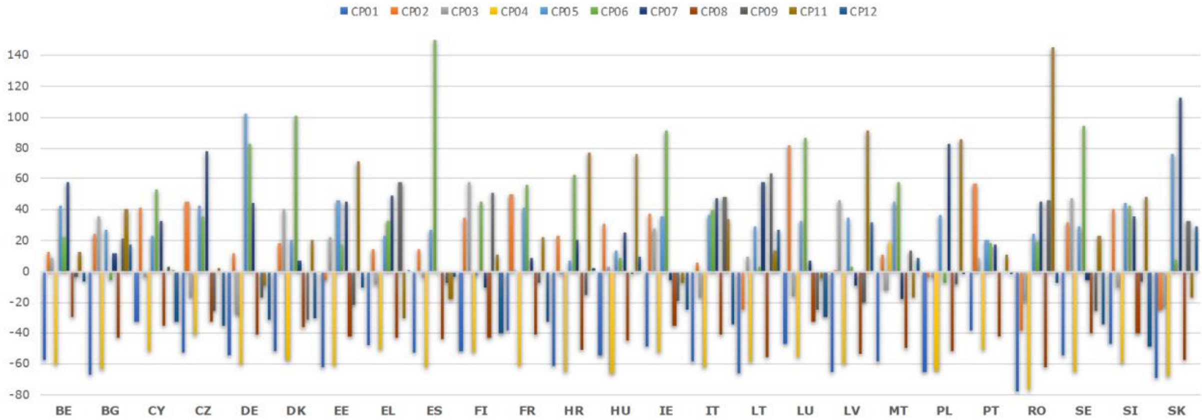
(b) Structure of total mean consumption expenditure by country

Note: Household weights are appropriately accounted for in deriving the EU (excluding UK) and country-specific structures of the mean consumption expenditures. CP01: Food and non-alcoholic beverages; CP02: Alcoholic beverages, tobacco and narcotics; CP03: Clothing and footwear; CP04: Housing, water, electricity, gas and other fuels; CP05: Furnishings, household equipment and routine maintenance of the house; CP06: Health; CP07: Transport; CP08: Communication; CP09: Recreation and culture; CP10: Education; CP11: Restaurants and hotels; CP12: Miscellaneous goods and services. Source: Own elaboration using Eurostat's HBS 2010 wave.

Figure 6. RSE differences of expenditure shares from their RSE average over all categories (%)



(a) RSE differences of expenditure shares, covering all twelve expenditure categories



(b) RSE differences of expenditure shares, excluding Education (CP10)

Note: In deriving RSEs of the expenditure shares, household survey weights are appropriately accounted for. CP01: Food and non-alcoholic beverages; CP02: Alcoholic beverages, tobacco and narcotics; CP03: Clothing and footwear; CP04: Housing, water, electricity, gas and other fuels; CP05: Furnishings, household equipment and routine maintenance of the house; CP06: Health; CP07: Transport; CP08: Communication; CP09: Recreation and culture; CP10: Education; CP11: Restaurants and hotels; CP12: Miscellaneous goods and services.
Source: Own elaboration using Eurostat's HBS 2010 wave.

Excluding Education (CP10) in the consumption expenditure shares data to order to zoom in on the other categories, the second panel in **Figure 6** gives the percentage differences of the expenditure shares' RSEs from their corresponding average RSEs (excluding RSEs of CP10). Thus, we may add to the list of least accurate (in terms of sampling errors) HBS data Health (CP06) and 'Furnishings, household equipment and routine maintenance of the house' (CP05), whose expenditure shares on average show, respectively, about 45% and 35% higher RSEs than their corresponding RSE average across all the considered 25 EU countries. High RSE's indicate that the survey average is less likely to approximate the population average. On the other hand, expenditure shares of 'Housing, water, electricity, gas and other fuels' (CP04), 'Food and non-alcoholic beverages' (CP01) and Communication (CP08) show the least relative variability and might be considered the most accurate HBS expenditure (shares) categories. The corresponding RSE-to-(mean RSE) differences of Housing, water, electricity, gas and other fuels (CP04), Food and non-alcoholic beverages (CP01) and Communication (CP08) for all 25 EU countries average to -56%, -55% and -44%, respectively. This result is encouraging for the current report, as our main focus is CP04, which includes residential energy expenditures and which is discussed in the next section.

2.4 Housing-related energy consumption expenditures

In what follows, we try to get a better understanding of the EU households spending patterns as regards the consumption of energy goods, also explicitly considering the role of other socio-economic and geographic factors. Although not all these factors will be discussed explicitly in the results section, we provide descriptive statistics here that illustrate the heterogeneity of residential energy expenditures along dimensions that go beyond total income or expenditure of the household. The category Housing, water, electricity, gas and other fuels (CP04 of COICOP classification) includes the following five expenditure sub-categories (i.e. 3-digit COICOP Groups):

CP041: Actual rentals for housing

CP042: Imputed rentals for housing

CP043: Maintenance and repair of the dwelling

CP044: Water supply and miscellaneous services relating to the dwelling

CP045: Electricity, gas and other fuels

Our main focus here is the last sub-category CP045, which represents energy goods. This sub-category in turn consists of the following 4-digit COICOP Classes:

CP0451: Electricity

CP0452: Gas

CP0453: Liquid fuels

CP0454: Solid fuels

CP0455: Heat energy

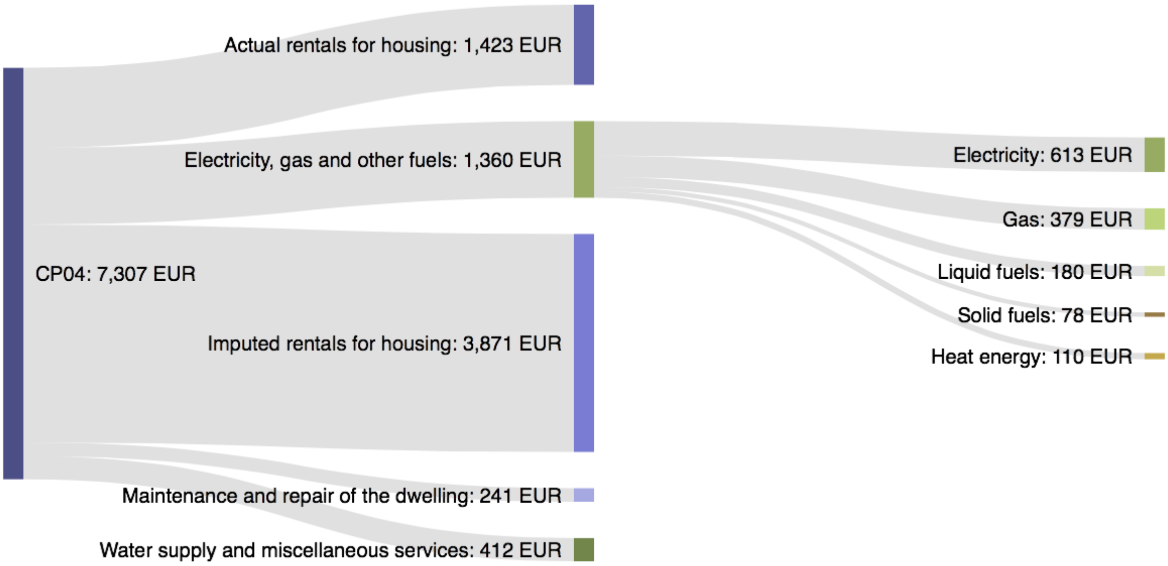
2.4.1 Structure and distributions of energy consumption expenditures

The energy-related mean consumption expenditures per household, appropriately accounting for household sampling weights, for 25 EU countries (excluding the UK) are shown in **Figure 7**. Imputed rentals for housing made up more than half (53.0%) of mean consumption expenditures on Housing, water, electricity, gas and other fuels (CP04) per household. The shown EU total mean expenditure on CP04 aggregate of 7,307 EUR falls short by 3.5% from the equivalent figure of 7,570 EUR (=25,288.94 x 0.2993) as derived from the first graph in **Figure 5**. This is due to the micro-data inconsistencies: for many households in Germany, Greece, Italy and Estonia, the reported values of CP04 aggregate do not match (namely, are higher than) the corresponding sums of its five subcategories CP041-CP045 as reported in the HBS. We have not corrected this discrepancy and instead used the latter 3-digit CP04 groups and their sums (substituting CP04 aggregate) to keep the values and structure of CP041 to CP045 unchanged across the "affected" households as reported in the HBS survey. In addition, the size of a few cases of negative consumption expenditures for CP041-CP045 are found to be negligible (see Table A.1 in the Appendix). Actual rentals for housing came second (19.5%), while Electricity, gas and other fuels (CP045, henceforth abbreviated as 'Residential energy') accounted, on average, for 18.6% of the mean total expenditure (per household) on CP04. The remaining two subcategories of CP04 – Maintenance and repair of the dwelling (CP043) and Water supply and miscellaneous services relating to the dwelling (CP044) – jointly contribute only 8.9% to the total CP04 consumption expenditures.

The mean residential energy consumption expenditure amounted to 1,360 EUR, on average, across the 25 considered EU countries. Given that the presented monetary values are not 'corrected' for price differences across the EU countries, there are considerable differences in the residential energy mean expenditures by countries; these country-specific average residential energy spending range from as low as 438 EUR in Bulgaria to a maximum of 2,853 EUR in Denmark.

According to the HBS data, the structure of the EU mean consumption expenditures on residential energy sub-category was as follows: Electricity – 45.1%, Gas – 27.9%, Liquid fuels – 13.3%, Heat energy – 8.1% and Solid fuels – 5.8%. Note that the dominance of electricity among the listed energy goods is in expenditure terms. In terms of quantities, EU final energy consumption in the residential sector is, on average, dominated by natural gas rather than electricity. For example, according to Eurostat (nrg_bal_c), in 2017 most of EU final energy consumption by households was covered by natural gas (36.0%) and electricity (24.1%). It is the higher electricity price that makes it more dominant than (natural) gas in the EU households' budget. Around 2010, the electricity prices in the EU were, on average, about 3 times higher than natural gas prices (see e.g. Eurostat Statistics Explained articles on electricity and natural gas price statistics, or European Commission, 2019).

Figure 7. The EU structure of mean residential energy consumption expenditure per household



Note: Household weights are appropriately accounted for in deriving the mean energy-related expenditure flows of the 25 EU countries (excluding the UK). *Source:* Own elaboration using Eurostat's HBS 2010 wave.

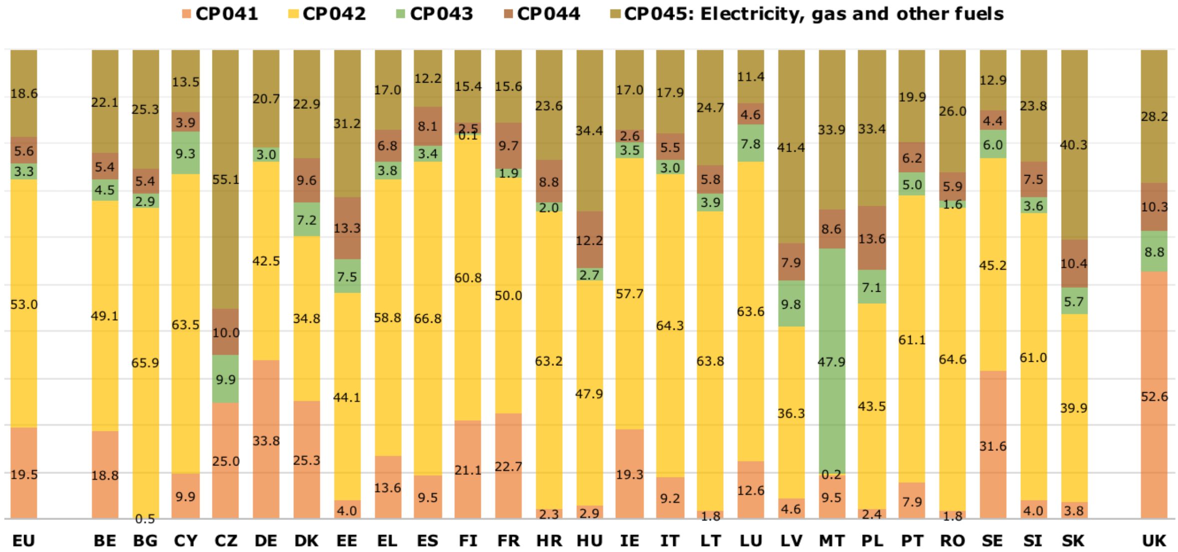
The structure of country-specific mean consumption expenditures (per household) on Housing, water, electricity, gas and other fuels (CP04) and residential energy (CP045) are, respectively, detailed in graphs (a) and (b) of **Figure 8**. The first graph confirms the importance of imputed rents in the COICOP Division of CP04 for almost all countries, with corresponding mean expenditure shares ranging from 34.5% in Denmark up to 66.8% in Spain. Apart from Czech Republic and the UK that do not provide any expenditure data on imputed rents, the three exceptions are Latvia, Malta and Slovakia. The residential energy category instead has the largest mean expenditure shares in Latvia and Slovakia of, respectively, 41.4% and 40.3%. In case of Malta, imputed data are reported only for 3.3% of households with the mean value of 85.2 EUR. Since these few and small in size numbers cannot represent the actual value of owner-occupied dwelling, it may be stated that imputed rents are also largely missing for Malta.

The residential energy category is the second largest expenditure item of CP04 for most of the countries whose mean expenditure shares for all EU countries average to 24.5%. Note, however, from **Figure 7** that when the HBS weights are taken into account, the corresponding residential energy average expenditure share becomes 18.6%. From graph (b) in **Figure 8** it follows that electricity is the largest component of the residential energy category for most of countries, where its mean expenditure shares range from 34.2% in Poland to 92.0% in Malta, with the simple average of 50.3%. Exceptions include:

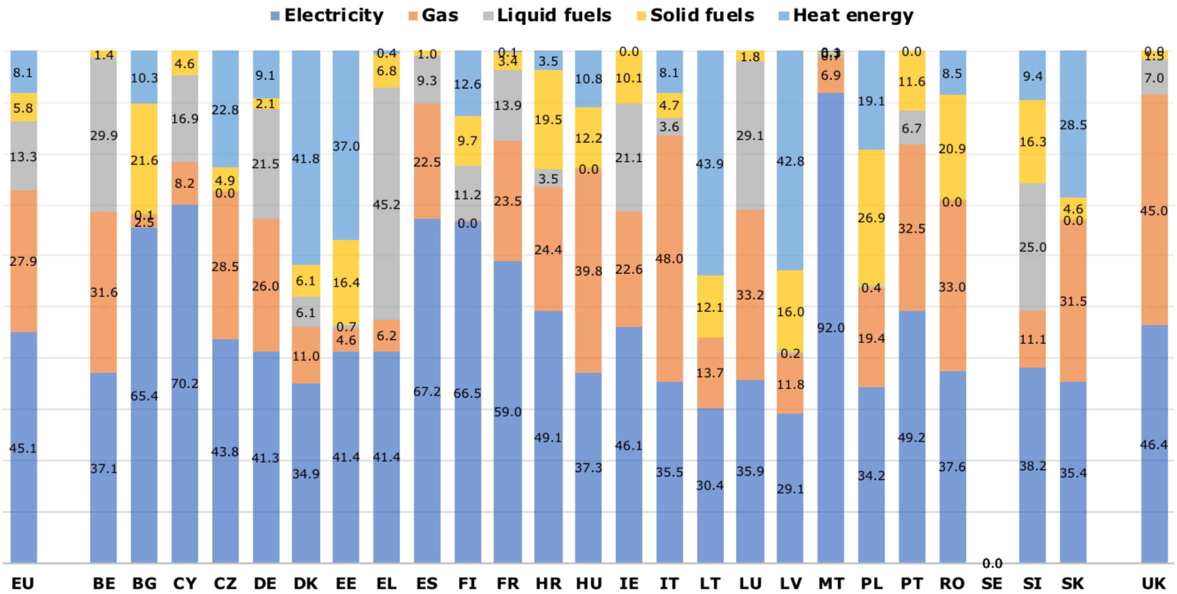
- Denmark, Lithuania and Latvia, where Heat energy makes up, on average, 41.8%, 43.9% and 42.8% of the residential energy expenditures, respectively;
- Greece, where Liquid fuels account, on average, for 45.2% of residential energy consumption spending; and
- Hungary and Italy, where mean expenditures on Gas are worth, respectively, 39.8% and 48.0% of corresponding total costs of the residential energy aggregate.

Observe that Sweden does not provide the details of 4-digit COICOP Classes for residential energy (CP045).

Figure 8. Structure of mean residential energy consumption expenditure per household



(a) Structure of mean consumption expenditures (per household) on CP04 aggregate



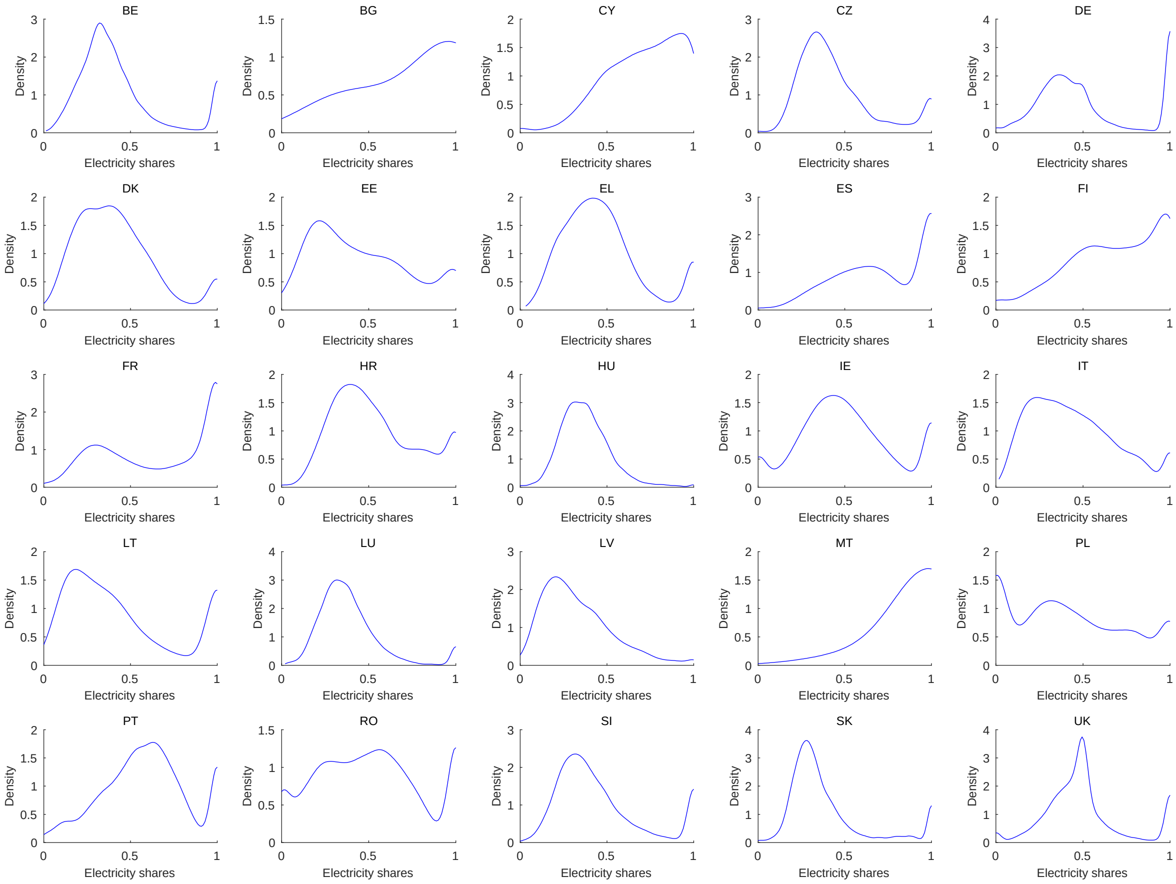
(b) Structure of mean residential energy consumption expenditure per household

Note: Household weights are accounted for in deriving the expenditure shares. Negative expenditures were excluded. EU excludes the UK. CP041: Actual rentals for housing; CP042: Imputed rentals for housing; CP043: Maintenance and repair of the dwelling; CP044: Water supply and miscellaneous services relating to the dwelling; CP045: Electricity, gas and other fuels. Source: Own elaboration using Eurostat's HBS 2010 wave.

The above-presented consumption expenditure shares only indicate the mean values of the respective figures for many surveyed households in each country considered. To get a better idea of the (sampling) variability behind these estimates, the densities of electricity consumption shares in residential energy expenditures are presented in **Figure 9**.

Electricity consumption shares in Belgium, Germany, France, Lithuania and Portugal, among others, have bimodal distributions (two 'peaks' in the density plots): in these countries, there are many households with electricity consumption expenditure shares between roughly 0.2 to 0.7 (depending on the country in question) and another large pool of people whose energy goods consumption include only electricity (leading to the second mode or 'peak' in the distribution at 100% electric residential energy use). The difference between these twin peaks may be, for instance, electric versus other heating systems. There are even cases of trimodal distributions (three peaks in the density plot), such as electricity consumption shares in Ireland and Romania. With multimodal distributions, however, applications of the usual summary statistics such as mean and median provide only limited information. Therefore, in integrated macro-micro modelling exercises that include such level of product disaggregation it is helpful to explicitly consider all the available (and useful) micro-data points in order to adequately infer conclusions relating to different aspects of households' heterogeneity. Computations and results based solely on the relevant distributions' summary statistics outcomes will not capture the full heterogeneity observed in the data. In **Figure 9**, for example, densities of electricity expenditure shares do not follow a normal distribution because households choose heating and cooking systems from a discrete set of options that largely determines the fuel share. When the distribution is multimodal, the average across all households (as would be captured by aggregate modelling) may provide a value that is infrequently observed and thus not representative for most households.

Figure 9. Densities of electricity expenditure shares in residential energy by country



Note: Household survey weights are appropriately accounted for. Negative expenditures, if any, are excluded. For each density, the residential energy components' expenditure shares range within zero and the corresponding maximum value. Source: Own elaboration using Eurostat's HBS 2010 wave.

2.4.2 Residential energy consumption expenditures and the degree of urbanisation

Since the HBS survey keeps track of the population densities of areas where its respondents are living, one can have a closer look into the details of residential energy expenditures by degree of urbanisation. The population density variable (HA09) consists of three density levels (besides '9 Not specified' category):

1. Densely populated (at least 500 inhabitants/km^2),
2. Intermediate (between 100 and 499 inhabitants/km^2), and
3. Sparsely populated (less than 100 inhabitants/km^2).

The HBS aggregated information available on the Eurostat website refers to these density levels, respectively, as 'Cities', 'Towns and suburbs' and 'Rural areas'. **Figure 10** reveals the nature of relationships between the mean residential energy consumption expenditures, residential energy individual components' mean expenditures, expenditure or income deciles, and the degree of urbanisation, all at the overall EU level. Besides excluding the UK, here the EU mean expenditures do not include Romania, for which the degree of urbanisation data is all included in the "9 Unknown" category, and Sweden because of missing residential energy components data. For average EU outcomes, the deciles are here defined to be relative, that is, the first decile includes all EU households who fall into the first decile category based on the corresponding nation-specific data (see **Table 4**). This allows to abstract from the differences in equivalised household income and expenditures across EU countries, and seems to be the most meaningful affluence categorisation if the focus is on the disparity issues within each EU Member State. To have a better idea about the accuracy and reliability of the presented mean values (i.e. about the sampling errors), the 95% confidence intervals of the corresponding mean expenditures are also explicitly shown by error bars. We consider both income deciles and expenditure deciles because as discussed earlier, the two are not generally equivalent; in fact, the Spearman's rank correlation coefficients between the corresponding categorised variables (whose values for each household accept integers from 1 to 10 referring to the corresponding decile) were found to range from 0.417 for Malta up to 0.740 for Germany, with the simple average over 25 such correlations of 0.594.

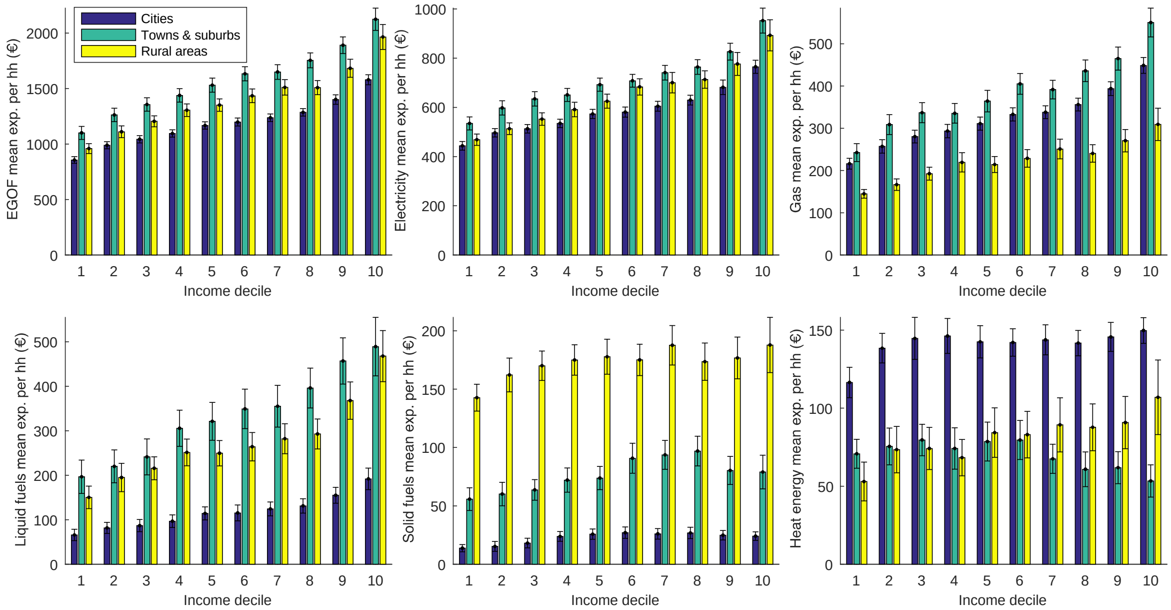
The very first subplot of graph (a) in **Figure 10** implies that, on average in the EU, the mean residential energy expenditures are higher for households living in towns and suburbs (with intermediate population density) than for the residents of cities or rural areas. This relation holds true for each income decile (and also each expenditure decile, as follows from graph b). The residential energy components subplots in graph (a) show that this is due to higher electricity, gas and liquid fuels mean consumption expenditures of households living in the intermediate populated areas. Especially, the difference in liquid fuels consumption expenditures is particularly large for households-residents of cities vs. those living in towns and suburbs (and rural areas), which further widens with increasing income decile. This could be explained by higher consumption demand for domestic heating, and lighting and cooking fuel oils – which is normally increasing with household income level due to e.g. occupying larger housing space – in towns, suburbs and rural areas rather than in cities. Note that liquid fuels for transportation are not included here (these are part of Transport category, which will be discussed in the next section).

Solid fuels (i.e. coal, coke, briquettes, firewood, charcoal, peat and the like), on the other hand, are mostly consumed in rural areas; the overall EU share of the corresponding mean expenditures for rural households ranges between about 10% to 15%. Similarly, heat energy (which includes hot water and steam purchased from district heating plants, ice used for cooling and refrigeration purposes, and associated expenditures) is mostly used by city residents. The average EU share of heat energy mean expenditure is within 10% to 14%.

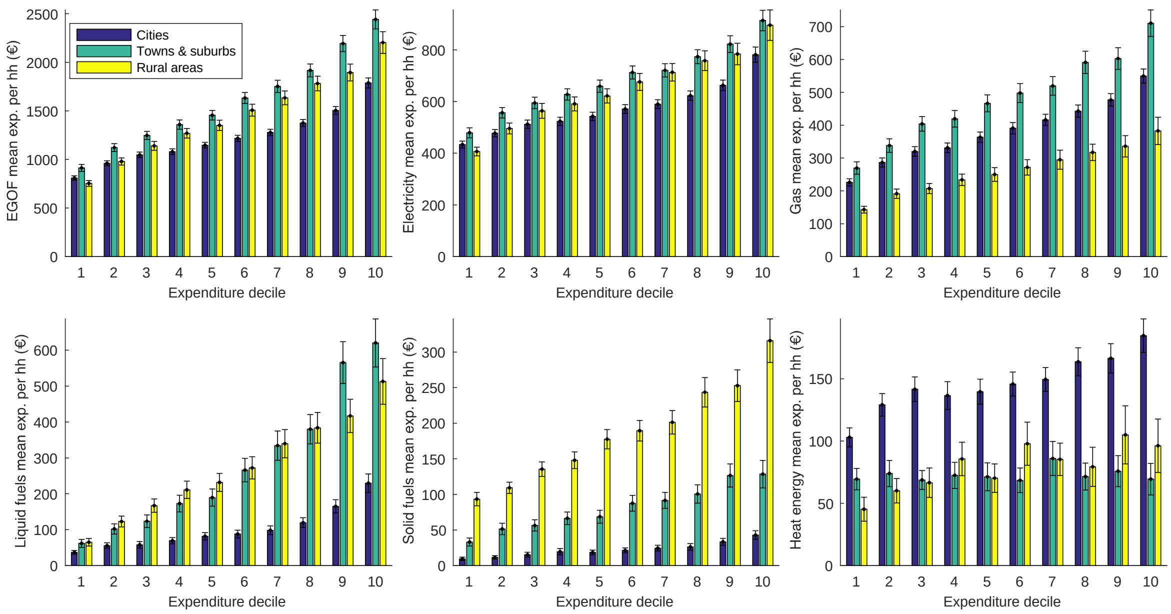
Finally, note that while the EU mean expenditures on electricity, gas and liquid fuels are increasing in households' income level, such (monotonic) affluence-expenditure relation is not observed for solid fuels and heat energy. The latter consumption expenditures are observed to be rather constant across different income levels.

Most of these observations remain valid when expenditure deciles are used instead of income deciles. The two notable distinctions between graphs (a) and (b) in **Figure 10** are the following: (1) there is not much difference between mean liquid fuels consumption expenditures between households living in intermediate and sparsely populated areas for all expenditure levels up to and including the eighth expenditure decile, and (2) EU mean solid fuels consumption expenditures are increasing in expenditure levels, which were found to be rather constant with income deciles. In general though, as regards the relationships between residential energy consumption expenditures, the degree of urbanisation and households' affluence at the overall EU level, using income deciles obtained from perhaps imperfect HBS monetary net income data seems to be largely appropriate.

Figure 10. The EU-wide mean residential energy consumption expenditures per household by income/expenditure decile and degree of urbanisation



(a) EU-wide residential energy mean expenditures (per household) by income decile and degree of urbanisation

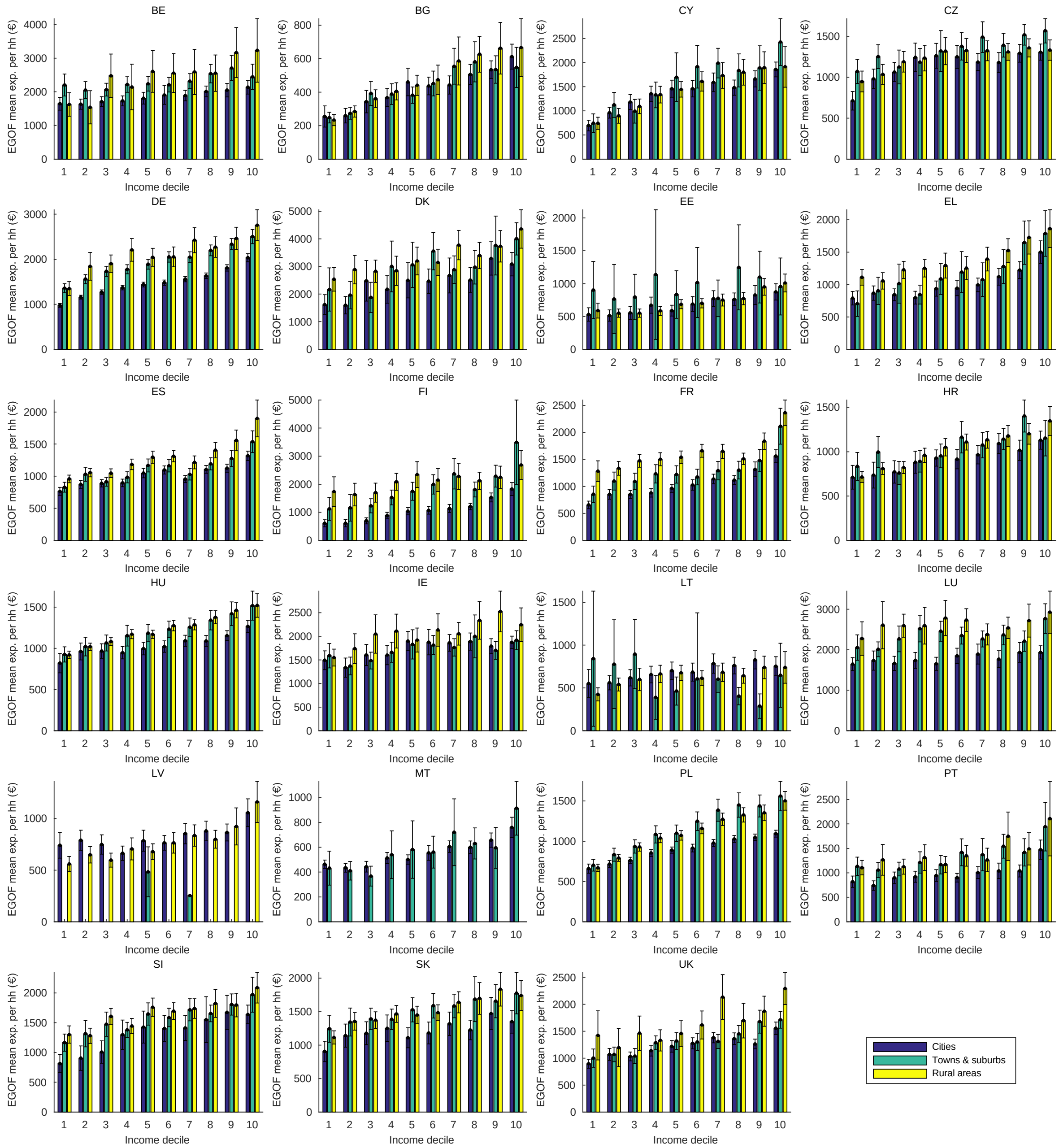


(b) EU-wide residential energy mean expenditures (per household) by expenditure decile and degree of urbanisation

Note: Household weights are accounted for. Error bars indicate the 95% confidence intervals for the corresponding mean expenditures. Negative expenditures are excluded. Besides excluding the UK, these overall EU mean residential energy expenditures do not include Romania and Sweden because of missing relevant data. Source: Own elaboration using Eurostat's HBS 2010 wave.

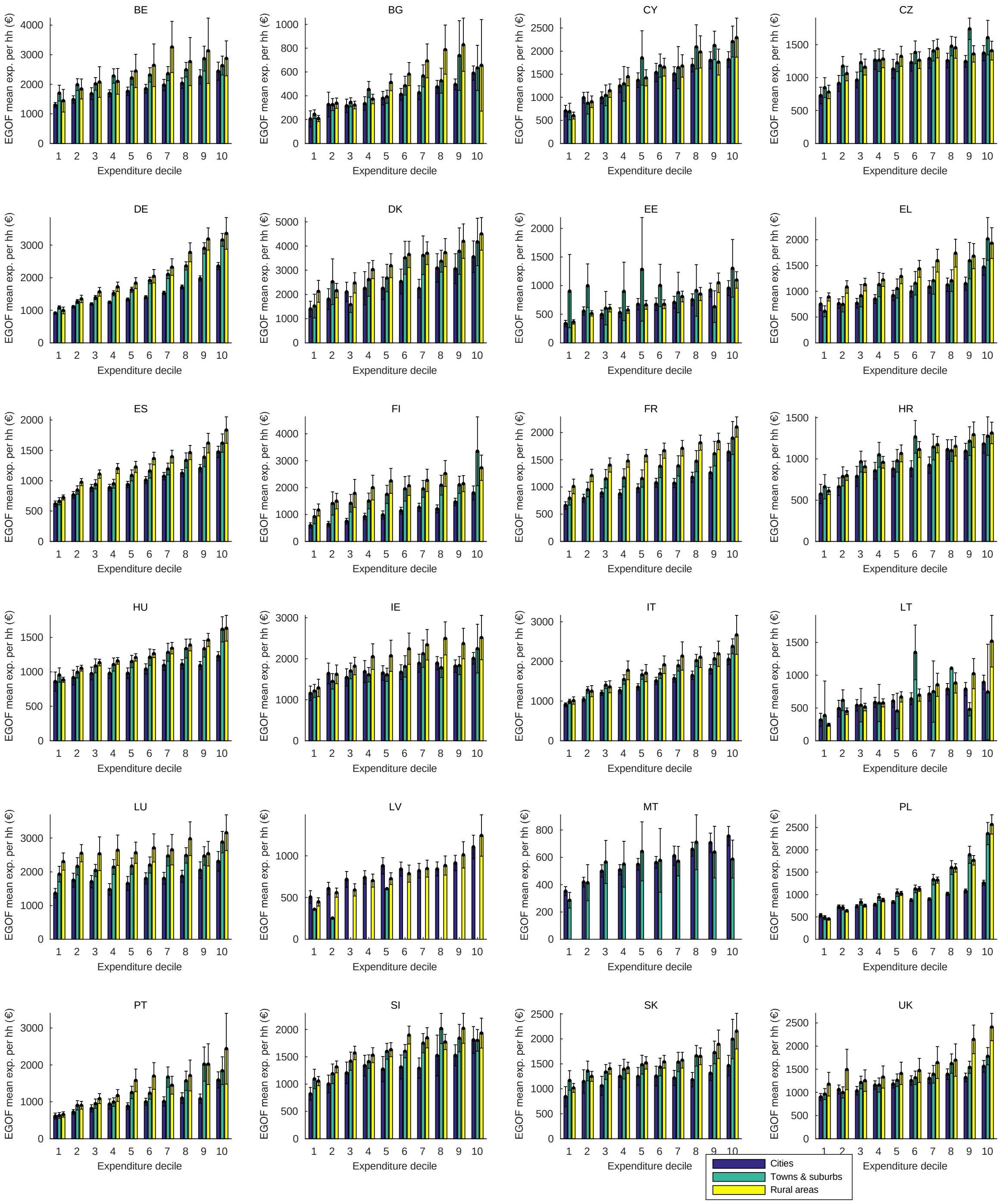
The country-specific graphs of the considered associations for mean residential energy consumption expenditures are presented in **Figure 11** and **Figure 12**. Besides other common variables, the first figure includes income deciles and the second expenditure deciles. One can observe that the above-discussed EU-wide results do not necessarily show up at the level of individual countries, while household affluence-related outcomes might also differ depending on whether income or expenditure deciles are used. The latter differences are normally observed for small economies, e.g. Malta, Estonia, Lithuania, and Latvia. We observe, however, that the confidence intervals are now wider, especially for small economies.

Figure 11. Mean residential energy expenditures per household by income decile and degree of urbanisation



Note: Household weights are accounted for. Error bars indicate the 95% confidence intervals for the corresponding mean expenditures. Negative expenditures are excluded. Expenditures of households with unknown urbanisation data for few countries (DK, FI, IT and UK) are also excluded. Romania and Sweden are excluded because of missing relevant data. Source: Own elaboration using Eurostat's HBS 2010 wave.

Figure 12. Mean residential energy expenditures per household by expenditure decile and degree of urbanisation



Note: Household weights are accounted for. Error bars indicate the 95% confidence intervals for the corresponding mean expenditures. Negative expenditures are excluded. Expenditures of households with unknown urbanisation data for few countries (DK, FI, IT and UK) are also excluded. Romania and Sweden are excluded because of missing relevant data. Source: Own elaboration using Eurostat's HBS 2010 wave.

2.4.3 Residential energy expenditures and socio-economic situation

Regarding the EU households' socio-economic situation, the HBS collects data about the activity and employment status of the reference person. Being different from the national concept of 'head of household', the notion of the 'household reference person' is central in the EU HBS as "it constitutes a socio-economic classification of households according to the profile of a member who is supposed to be "representative" (Eurostat, 2015, p.29). In particular, "the social group, occupation and employment status, income, gender and age etc. of the reference person are often used to classify the sample households for weighting classifications used in the derivation of the survey estimates" (HBS 2010 User Manual, 2016, p.7).

The HBS guidelines suggest using the following objective definition for the household reference person: the person aged 16 or more who most contributes to the household income. However, some countries use subjective criteria, such as e.g. the person in whose name the accommodation is owned/rented (Ireland), always the man in two-parent families (Czech Republic), the person who is designated as such by other members (Greece, Cyprus, Latvia, Slovakia); for further such details see Table 11 in Eurostat (2015). It thus implies that using inconsistent definitions of the household reference person may well jeopardise the cross-country comparability of HBS data and analysis.

2.4.3.1 Population coverage of the HBS household socio-economic situation category

In what follows, we use the aggregated classification of the socio-economic situation of the reference person (HC24), which distinguishes the following activity and employment categories[6]:

Z1 Manual worker except agriculture

Z2 Non-manual worker except agriculture

Z3 Self-employed person and farmer or agricultural worker

Z4 Unemployed

Z5 Retired

Z6 Other inactive (student or in national service, housewife or person engaged in a non-economic activity, and unable to work)

88 Not applicable (legal age to work not attained)

99 Not specified

For better readability, we will also interchangeably use for Z1-Z5 their respective Eurostat's abbreviations of:

MW_IS: manual workers in industry and services

NMW_IS: non-manual workers in industry and services

NSAL: employed persons except employees (non-salaried workers)

UNE: unemployed persons

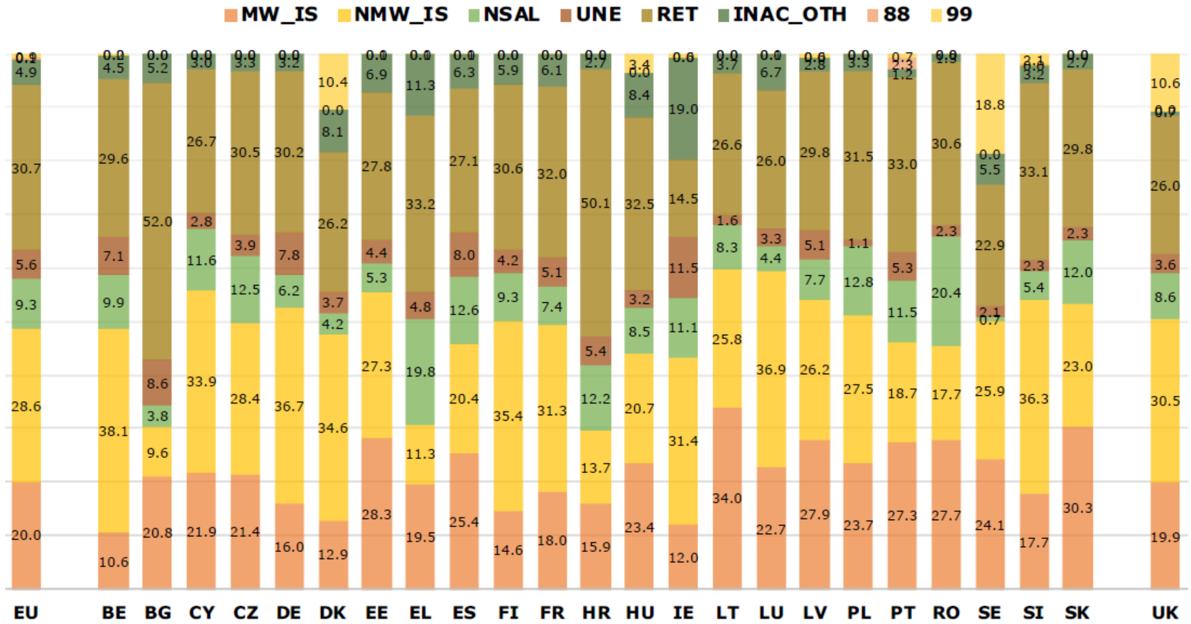
RET: retired persons

INAC_OTH: other inactive persons

To get a better idea of the relative coverage of each of these categories by the HBS data, Figure 14 shows the population (i.e. accounting for household survey weights) proportions (in %) of the listed activity and employment status for the EU and by individual countries.

[6] The underlying category (HC23) with more detailed information (besides 88 and 99, the latter includes 11 other categories) was not used here because the relevant data was fully missing/anonymised for Czech Republic, Germany, Estonia, Lithuania and the UK. Both HC23 and HC24 do not provide data for Italy and Malta, which are thus not covered here.

Figure 13. Socio-economic situation of the household reference persons (% of total households)



Note: Household survey weights are accounted for. Italy and Malta are excluded because of missing household socio-economic situation data. MW_IS: manual workers in industry and services; NMW_IS: non-manual workers in industry and services; NSAL: employed persons except employees (non-salaried workers); UNE: unemployed persons, RET: retired persons; INAC_OTH: other inactive persons. Source: Own elaboration using Eurostat's HBS 2010 wave.

The following observations are worth noting:

- At the EU level (excluding Italy, Malta and the UK), the households' reference persons are mostly retired (which make up 30.7% of total household population), non-manual workers in industry and services (28.6%) and manual workers in industry and services (20.0%).
- Over half of the surveyed households' "representatives" in Bulgaria and Croatia are retired persons, who make up, respectively, 52.0% and 50.1% of the corresponding household population size. Retired persons are also dominant households' reference persons in Greece (with the households' population share of 33.2%), Portugal (33.0%), Hungary (32.5%), France (32.0%), Poland (31.5%), Romania (30.6%), Czech Republic (30.5%), Latvia (29.8%) and Spain (27.1%).
- Non-manual workers in industry and services are dominant category in Belgium (38.1%), Luxembourg (36.9%), Germany (36.7%), Slovenia (36.3%), Finland (35.4%), Denmark (34.6%), Cyprus (33.9%), Ireland (31.4%), Sweden (25.9%) and the UK (39.5%).
- Manual workers in industry and services, on the other hand, are the largest activity and employment status category in Lithuania (34.0%), Slovakia (30.3%) and Estonia (28.3%).
- The largest percentage (of over 10% of population) of self-employed or agricultural workers as reference persons reside in Romania (20.4%), Greece (19.8%), Poland (12.8%), Spain (12.6%), Czech Republic (12.5%), Croatia (12.2%), Slovakia (12.0%), Cyprus (11.6%), Portugal (11.5%) and Ireland (11.1%).
- The largest percentage of unemployed reference persons are surveyed in Ireland (11.5%), Bulgaria (8.6%), Spain (8.0%), Germany (7.8%) and Belgium (7.1%).
- Finally, most reference persons in the 'other inactive' category are found in Ireland (19.0%), Greece (11.3%), Hungary (8.4%), Denmark (8.1%), Estonia (6.9%), Luxembourg (6.7%), Spain (6.3%), and France (6.1%).

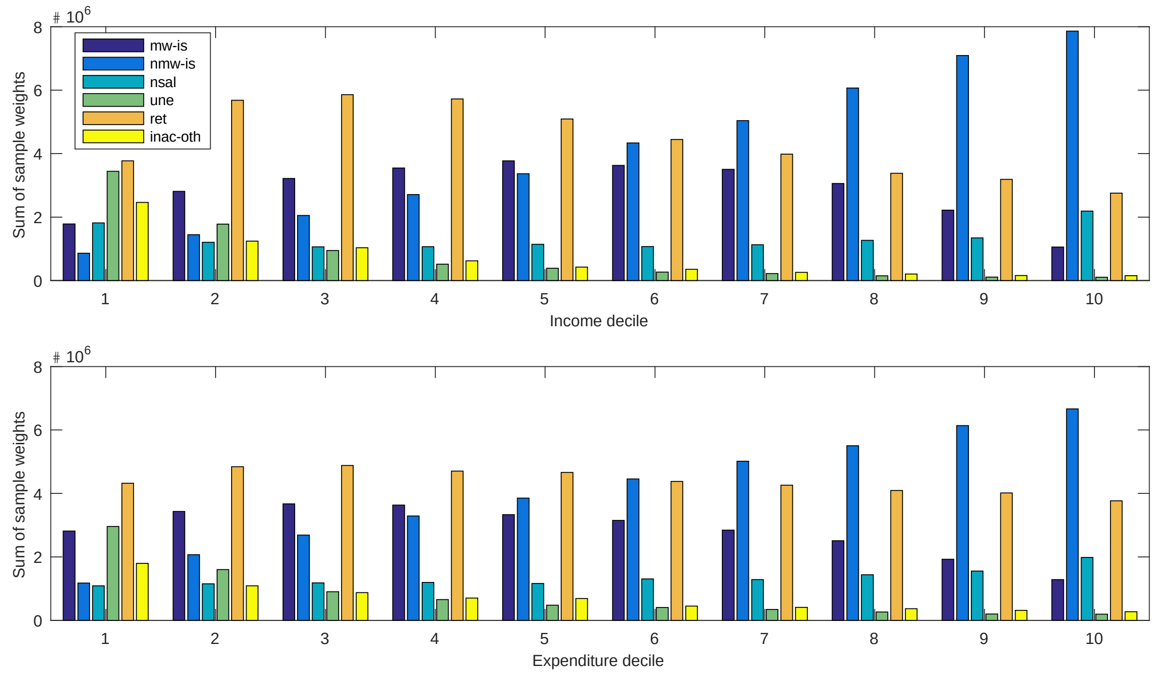
Any analysis of households' socio-economic situation using the HBS data thus needs to keep in mind the coverage nature of the above-presented numbers. In particular, given the large proportion of retired reference persons, one has to be cautious not to confuse the retired household "representatives" with the population proportion of retired people. For example, although over 50% of activity and employment status of households in Bulgaria and Croatia are represented by the retired persons, according to Eurostat (demo_pjanind) the proportion of population aged 65 years and more in these countries in 2010 were, respectively, 18.2% and 17.8%. Similar point is valid for all other EU countries, since the average EU (excluding the UK) proportion of elderly population is estimated at 20.3% for 2019, with the maximum proportion of 22.8% in Italy.

To make inference about distributional aspects of socio-economic situation of households, it is also useful to have a closer look at the distributions of estimated population households for each activity and employment status of the household reference person. The corresponding EU-wide details are presented in **Figure 14**. According to both income and expenditure deciles, the number of EU households "represented" by non-manual workers in industry and services is increasing with income/expenditure level, while those represented by the unemployed and other inactive reference persons are decreasing with income/expenditure level.

In case of manual workers in industry and services and retired reference persons categories, at the EU level there is an inverse U relationship between the total number of households and their income/expenditure level (per adult equivalent):

- For the retired category, the number of households first increases until the third income and expenditure level, and thereafter decreases with income/expenditure level;
- For manual workers in industry and services, the turning points differ between income and expenditure levels: the highest number of total EU households is observed at the fifth income level, but third expenditure level.

Figure 14. Estimated number of total population households in the EU by income/expenditure decile and socio-economic situation of the household reference person



Note: Categories '88' and '99' are not shown. MW_IS: manual workers in industry and services; NMW_IS: non-manual workers in industry and services; NSAL: employed persons except employees (non-salaried workers); UNE: unemployed persons, RET: retired persons; INAC_OTH: other inactive persons. Source: Own elaboration using Eurostat's HBS 2010 wave.

2.4.3.2 Residential energy expenditures by activity and employment status

The mean expenditures on residential energy and its components as corresponding averages for 22 EU countries with available relevant data, distinguished by household's affluence level and socio-economic activity of the reference person, are graphed in **Figure 15**. The first subplots in both graphs (a) and (b) show that the EU mean residential energy expenditures are increasing with both income and expenditure levels for all listed socio-economic categories. However, the increase in mean expenditure by affluence level is more pronounced for the self-employed and farmer, and pensioner categories. The corresponding graphs for each individual residential energy expenditures show that this larger (growth in) residential energy demand is due to higher mean expenditures on electricity, gas and liquid fuels by households represented by the self-employed, farmers and retired reference persons.

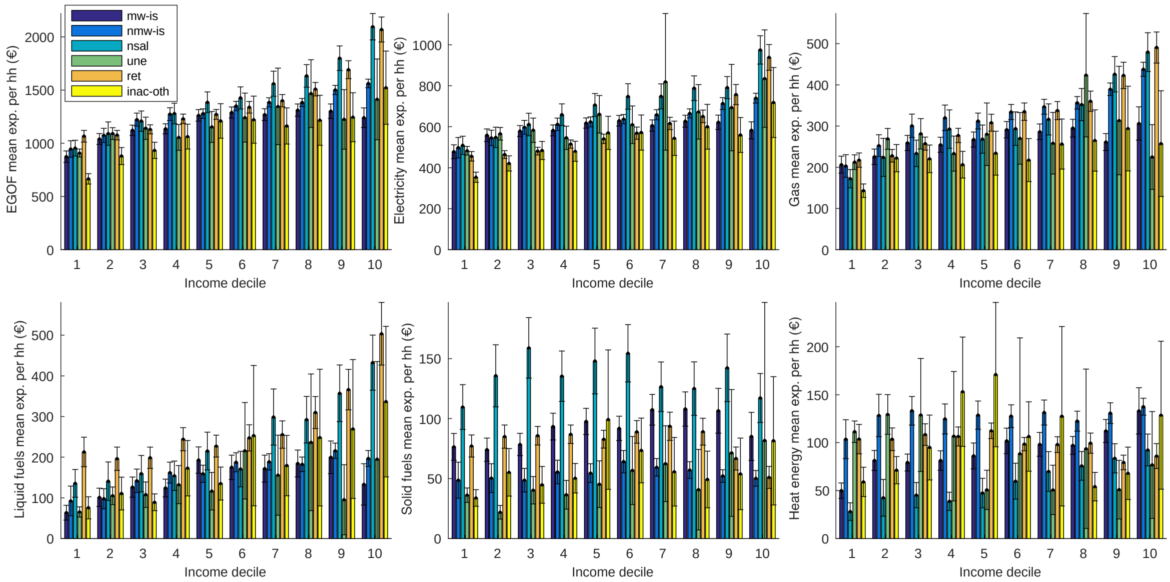
In terms of relative expenditure shares (not shown in the figure), electricity takes from 40% to 60% of the residential energy expenditures for all household socio-economic categories and all income and expenditure levels. With expenditure deciles, one additionally observes a general mild continuous decrease with expenditure level in electricity mean expenditure shares for all employment categories, which is however not observed for income deciles.

Supressing the income/expenditure deciles dimension, **Figure 16** gives a more vivid picture of the relationship between the mean residential energy expenditures and socio-economic situation of the household reference person by country. Besides the unsurprising outcome that electricity is generally found to be an important (also size-wise) energy expenditure item for all households with different socio-economic situation, the following country-specific observations can be made:

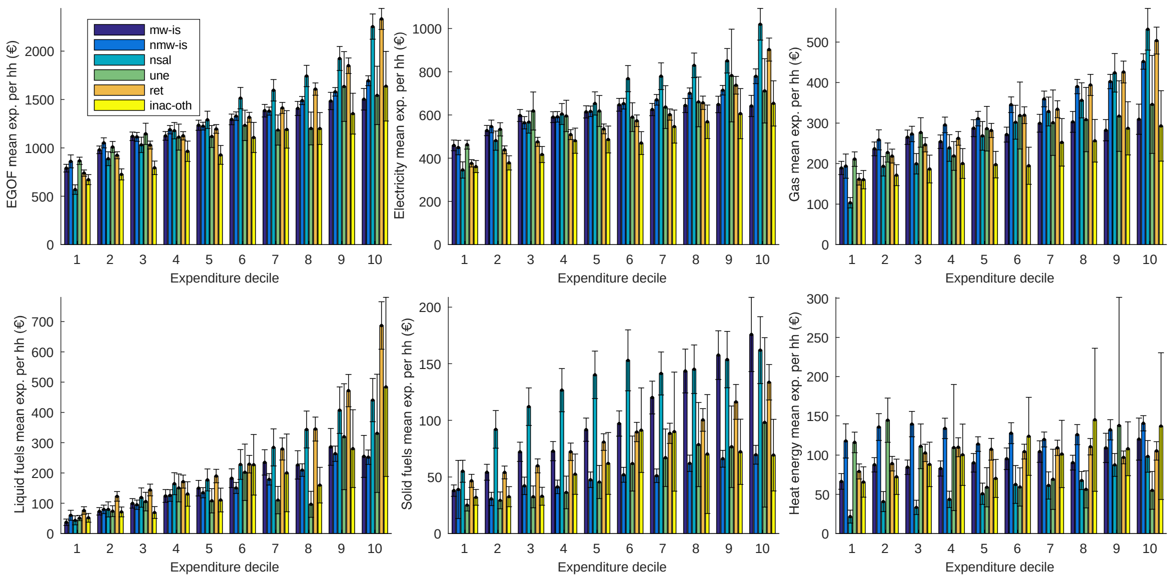
- Gas expenditures are also often of similar size as those of electricity for most of the listed household socio-economic situation categories in such EU countries as Belgium, Hungary, Luxembourg, Romania and Slovakia, which is also true for the UK. This result is consistent with Eurostat data on final energy consumption (in physical units) in the residential sector (nrg_bal_c): e.g. for 2017 the share of gas consumption was recorded to be 41% for Belgium, 47% for Hungary, 46% for Luxembourg, 32% for Romania, 55% for Slovakia, and 62% for the UK. Other large (natural) gas-dependent EU countries such as the Netherlands (with gas consumption share of 71% in 2017) and Italy (53%) are not included in our figures because of either missing relevant data (IT) or absence of access to the corresponding HBS survey (NL).
- Considerable liquid fuels expenditures are observed for households in Greece (especially for the self-employed and agriculture workers), Luxembourg (in particular, for retired and other inactive categories), and to a smaller extent for households in Slovenia (particularly, for non-manual workers in industry and services, self-employed/farmers, and pensioners).
- High heat energy expenses are paid by all considered types of households in Denmark, Estonia, Lithuania (particularly by manual and non-manual workers in industry and services), Latvia and Slovakia. This finding is again consistent with the fact that the shares of derived heat consumption in these countries is in most cases over 30%. According to Eurostat's final energy consumption in the residential sector also Finland's derived heat share for 2017 was about 29%, close to its electricity consumption share of 34%. However, the HBS data for 'around 2010' year do not seem to give the same message. The share of derived heat consumption is also quite high in Sweden (34% in 2017), but due to the missing residential energy expenditures data Sweden is not included in the analysis of this section.
- High solid fuels expenditures are recorded for households in Poland, particularly for manual workers outside agriculture, self-employed and pensioners as reference persons. Relatively high spending on solid fuels is also observed in Croatia, Romania (especially in households with self-employed/farmers, retired and manual workers in industry and services as reference persons) and Slovenia (especially, by manual workers outside agriculture and non-salaried workers).

The above results show that there is a high degree of heterogeneity in residential energy expenditure patterns of households across individual EU countries, especially as more than one relevant determinants are being examined. As a result, estimated distributional impacts of a policy measure in one country cannot readily be generalised to other EU countries.

Figure 15. The EU-wide mean residential energy consumption expenditures per household by income/expenditure decile and activity & employment status of the reference person (AESRP)



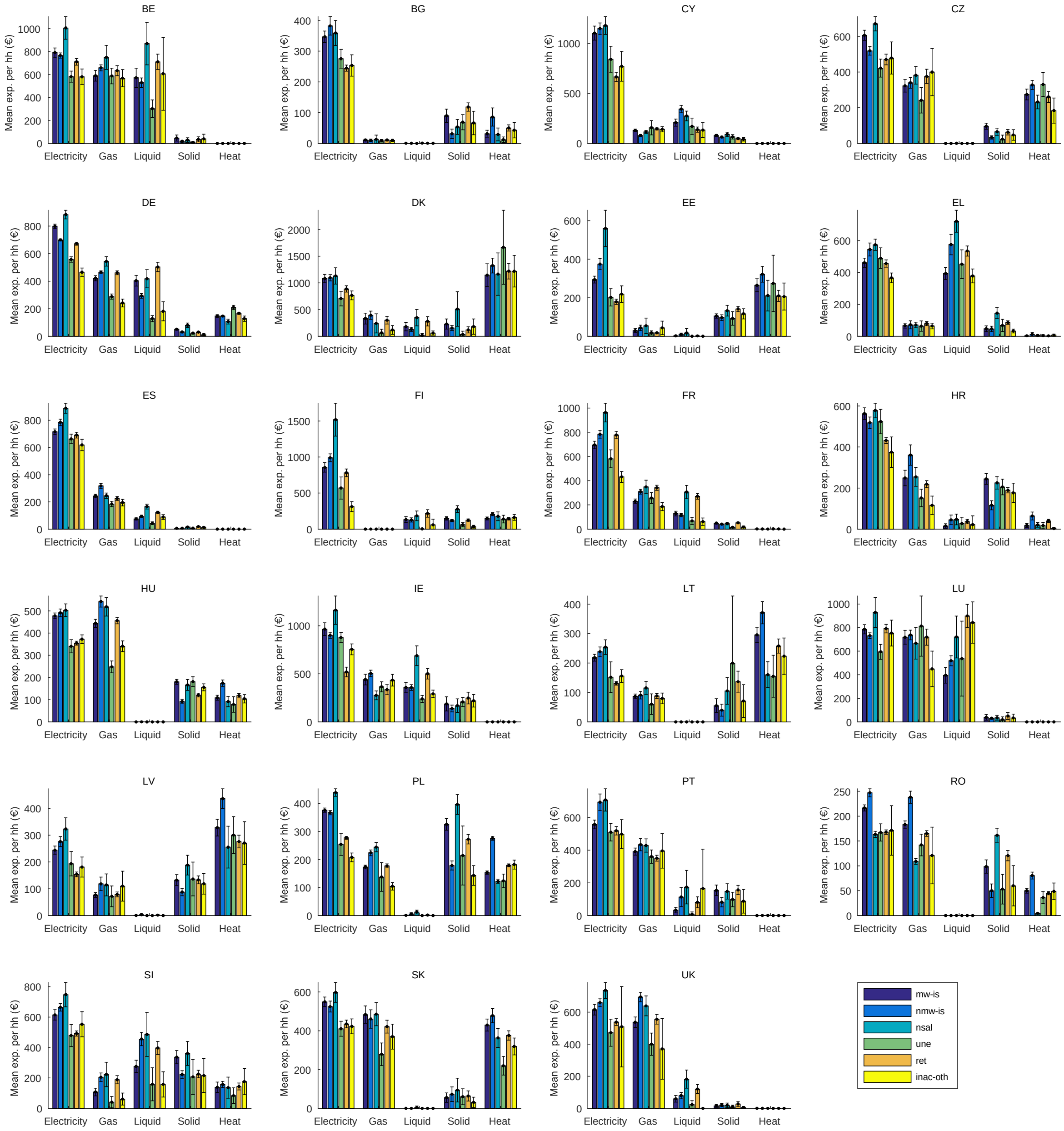
(a) EU-wide residential energy mean expenditures per household by income decile and AESRP



(b) EU-wide residential energy mean expenditures per household by expenditure decile and AESRP

Note: Household weights are accounted for. Error bars indicate the 95% confidence intervals for the corresponding mean expenditures. Negative expenditures are excluded. Besides excluding the UK, these overall EU mean expenditures do not include Malta, Italy and Sweden because of missing relevant data. Categories '88' and '99' are not shown. MW_IS: manual workers in industry and services; NMW_IS: non-manual workers in industry and services; NSAL: employed persons except employees (non-salaried workers); UNE: unemployed persons, RET: retired persons; INAC_OTH: other inactive persons. Source: Own elaboration using Eurostat's HBS 2010 wave.

Figure 16. Mean residential energy expenditures per household by socio-economic situation of the reference person



Note: Household survey weights are accounted for. Italy and Malta are excluded because of missing household socio-economic situation data. MW_IS: manual workers in industry and services; NMW_IS: non-manual workers in industry and services; NSAL: employed persons except employees (non-salaried workers); UNE: unemployed persons, RET: retired persons; INAC_OTH: other inactive persons. Source: Own elaboration using Eurostat's HBS 2010 wave.

2.4.4 Residential energy expenditures by type of household

2.4.4.1 Population coverage of the HBS household type category

The classification for the type of household used in this report is the following (which is coded as HB074 in the HBS data), where the age limit of children is set at 16 years of age:

A1:	one adult
A2:	two adults
A3:	three or more adults
A1_DCH:	one adult with dependent children
A2_DCH:	two adults with dependent children
A3_DCH:	three or more adults with dependent children
OTH:	other (unknown)

Figure 17 shows the population proportions (in %), accounting for household sampling weights, of the types of household for the EU and by individual countries. At the EU level (excluding Sweden which does not report types of households data), about 30% of population households are single person households. This category together with the categories of two adult persons households (27.4%) and two adults with dependent children (23.0%) make up 80.2% of EU households.

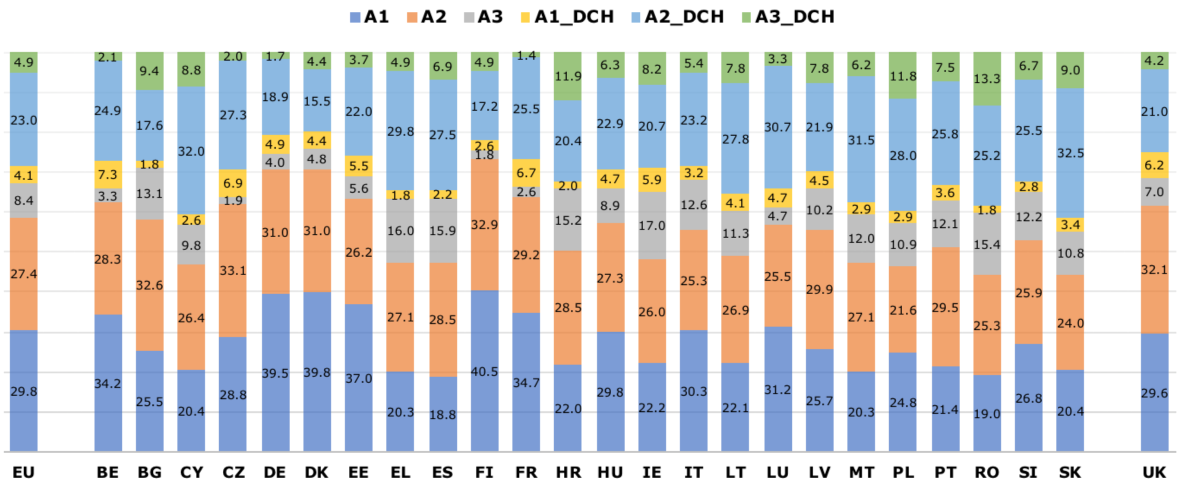
In most of the EU countries, one adult with dependent children constitutes the smallest household type category. However, the EU Member States are generally rather heterogonous with respect to their household composition. The following observations are worth mentioning:

- Two adults with dependent children is the largest household type category, according to the 2010 HBS survey, in Slovakia (32.5%), Cyprus (32.0%), Malta (31.5%), Greece (29.8%), Poland (28.0%) and Lithuania (27.8%). It is, however, the smallest household type category (within such cross-country comparison) in Denmark which includes 15.5% of Danish households.
- Households composing of three or more adults is the largest (over 15%) category, when comparing the individual EU countries, in Ireland (17.0%), Greece (16.0%), Spain (15.9%), Romania (15.4%) and Croatia (15.2%). On the other hand, according to the HBS data, this category includes less than 5% of households in Denmark (4.8%), Luxembourg (4.7%), Germany (4.0%), Belgium (3.3%), France (2.6%), Czech Republic (1.9%) and Finland (1.8%).
- Three or more adults with dependent children make up over 10% of households in Romania (13.3%), Croatia (11.9%) and Poland (11.8%), but is the smallest category in Germany (1.7%) and France (1.4%).

Overall and with very few exceptions, across the EU countries households with larger number of adults (with or without dependent children) are found to be more in economies that are relatively small or with lower GDP per capita.

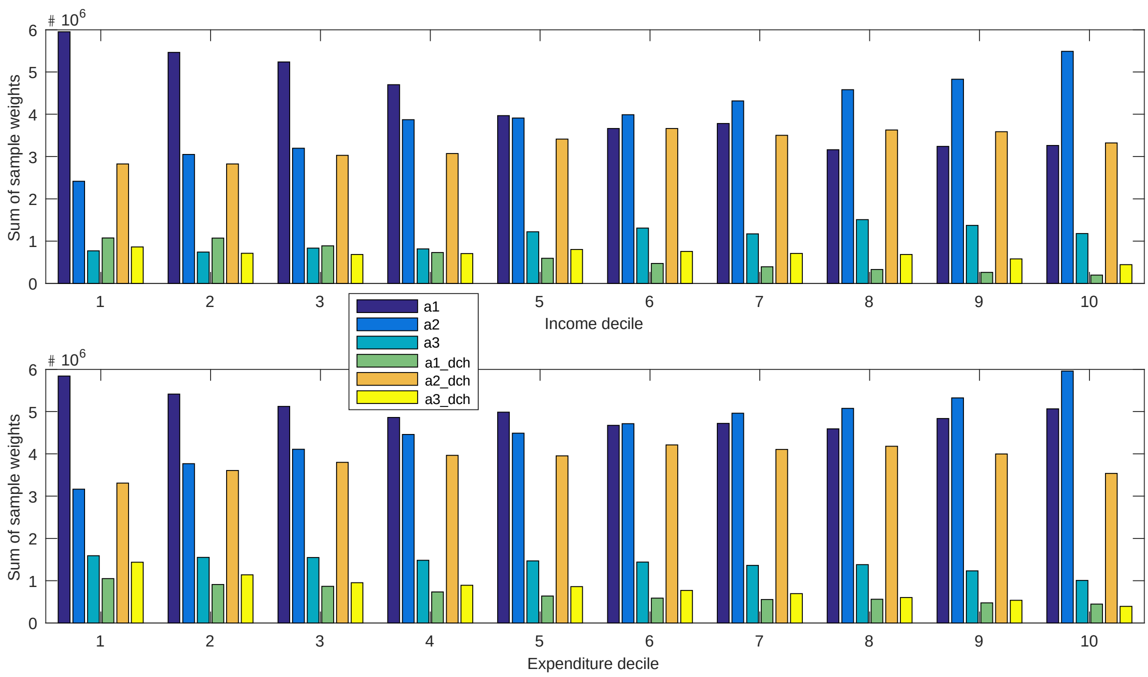
The survey-based estimates of the number of households within the individual EU countries by affluence level are shown in **Figure 18**. Not surprisingly, and in line with the previous figure, three household types of one-adult households, two adults households, and two adults with dependent children dominate in size in every income and expenditure decile. From **Figure 18** it follows that in the EU the number of two adults households is increasing with affluence level (both income and expenditure deciles).

Figure 17. Population proportion of the types of household (%)



Note: Household survey weights are accounted for. Sweden is excluded because all the households were reported of type 'Other'. The category 'Other' is not shown as (besides SE) there are very small number of households (<0.09%) in only Spain and Finland that do not identify the household type. A1: one adult; A2: two adults; A3: three or more adults; A1_DCH: one adult with dependent children; A2_DCH: two adults with dependent children; A3_DCH: three or more adults with dependent children; OTH: other (unknown). Source: Own elaboration using Eurostat's HBS 2010 wave.

Figure 18. Estimated number of households in total EU population by decile and household type



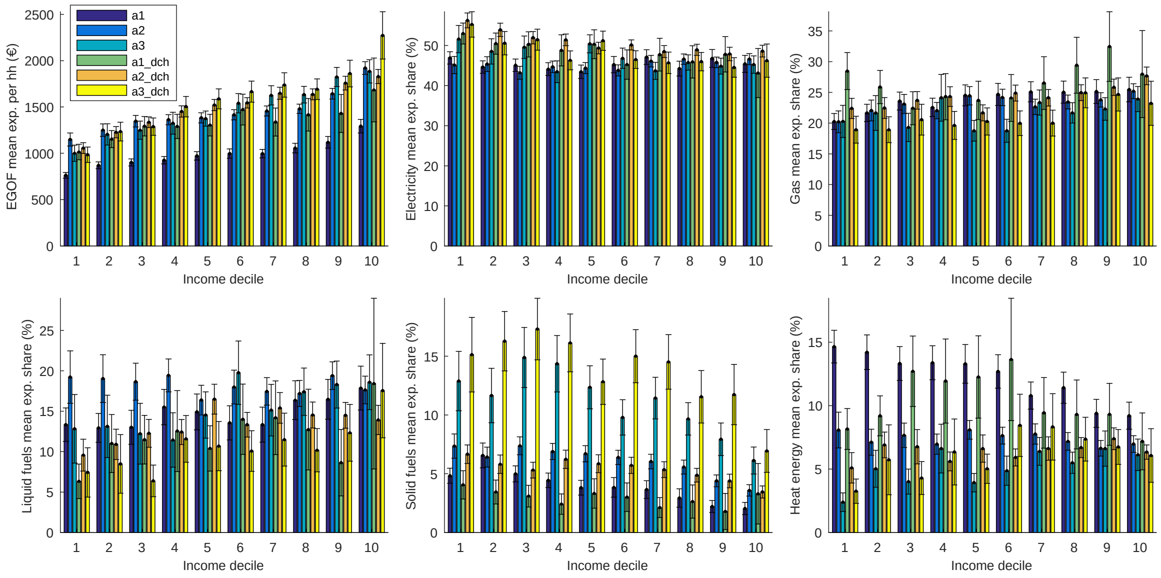
Note: Category 'Other' is not shown. A1: one adult; A2: two adults; A3: three or more adults; A1_DCH: one adult with dependent children; A2_DCH: two adults with dependent children; A3_DCH: three or more adults with dependent children; OTH: other (unknown). Source: Own elaboration using Eurostat's HBS 2010 wave.

2.4.4.2 Residential energy expenditures by type of household

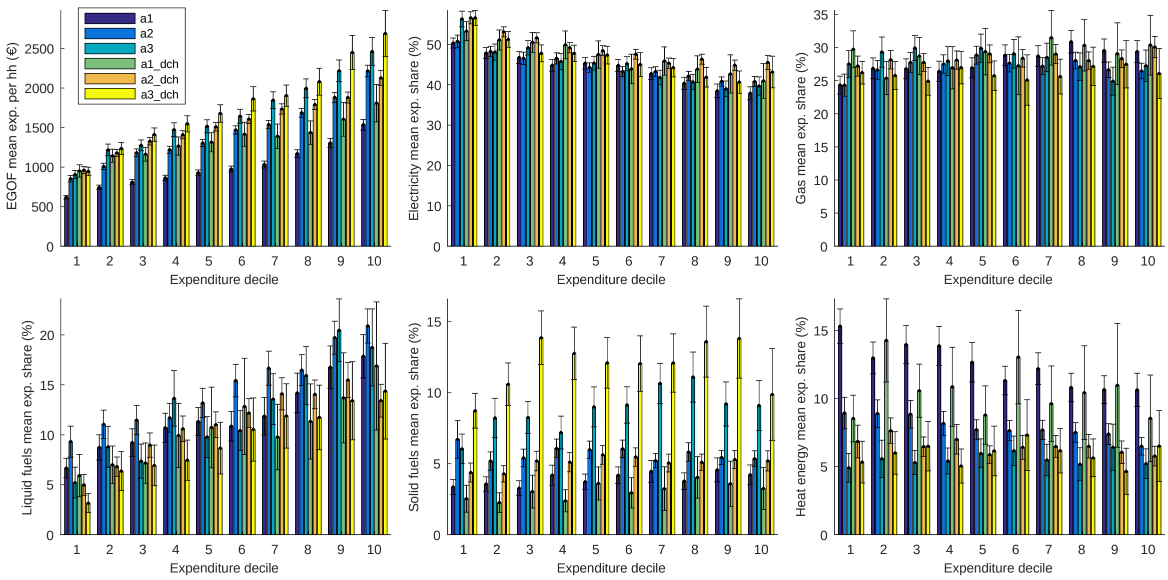
Within each income/expenditure decile, the mean residential energy EU-wide expenditures are lowest for one adult households and mostly highest for households with three or more adults with dependent children (**Figure 19**). Generally, the residential energy expenditures increase with household affluence level, and the largest growth is observed for households with three or more adults with dependent children. The figure also shows the EU mean shares of residential energy components (in total residential energy expenditures) by household type. One thus observes a mild decrease of electricity shares with increasing affluence level for all household types. No such pattern is found for the mean gas expenditure shares, which range between roughly 25% to 30% of total mean residential energy expenditures. With expenditure deciles, one observes increasing mean EU liquid fuels consumption shares with expenditure levels for most household types. This is, however, not so with income decile.

Finally, it is found that the EU-wide solid fuels mean consumption shares are much larger for three adults households and households with three or more adults with dependent children for all affluence levels compared to other household types. Similarly, heat energy consumption generally takes a larger part of the residential energy budget of one adult households and one adult with dependent children than that of other household types.

Figure 19. The EU-wide mean residential energy consumption expenditures per household by income/expenditure decile and household type



(a) EU-wide residential energy mean expenditures per household by income decile and household type



(b) EU-wide residential energy mean expenditures per household by expenditure decile and household type

Note: Household weights are accounted for. Error bars indicate the 95% confidence intervals for the corresponding mean expenditures. Negative expenditures are excluded. Category '9' is not shown. A1: one adult; A2: two adults; A3: three or more adults; A1_DCH: one adult with dependent children; A2_DCH: two adults with dependent children; A3_DCH: three or more adults with dependent children; OTH: other (unknown). EU aggregate excludes UK. Source: Own elaboration using Eurostat's HBS 2010 wave.

2.5 Transport consumption expenditures

The CP07 category (Transport) includes the following three expenditure sub-categories that make its 3-digit COICOP Groups:

CP071: Purchase of vehicles

CP072: Operation of personal transport equipment

CP073: Transport services

Next to the housing-related energy goods consumption, within the CP07 category we are particularly interested in the sub-category CP04722 – fuels and lubricants. The 4-digit COICOP Classes of Operation of personal transport equipment and Transport services categories are the following:

CP0721: Spare parts and accessories

CP0722: Fuels and lubricants

CP0723: Maintenance and repair of personal transport equipment

CP0724: Other services in respect of personal transport equipment

CP0731: Passenger transport by railway

CP0732: Passenger transport by road

CP0733: Passenger transport by air

CP0734: Passenger transport by sea and inland waterway

CP0735: Combined passenger transport

CP0736: Other purchased transport services

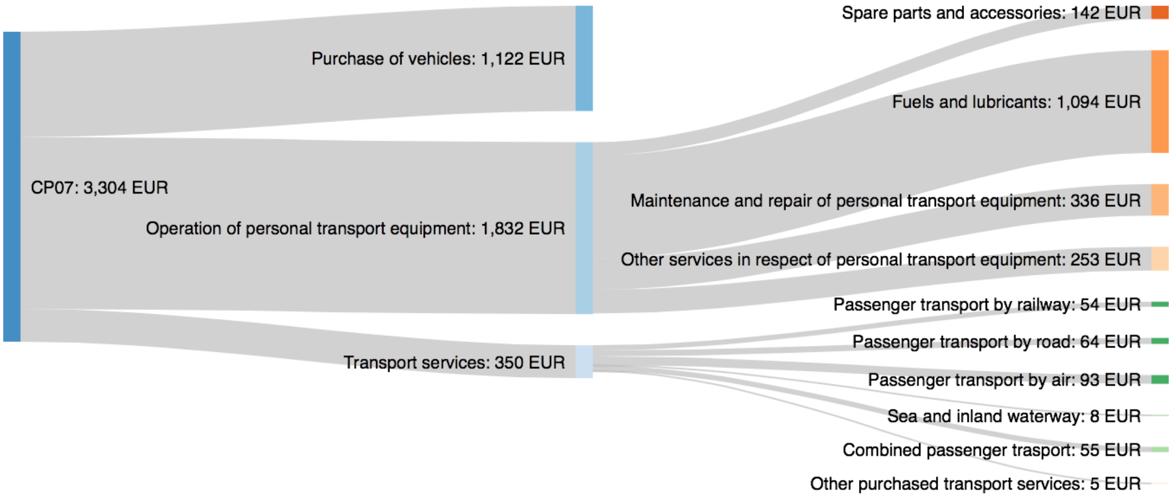
The size of a few cases of negative consumption expenditures for Transport sub-categories are found to be negligible, especially those for Operation of personal transport equipment and Transport services that are our main focus in this section (see Table A.2 in the Appendix). In what follows we briefly discuss the structure and distributions of transport expenditure sub-categories.

2.5.1 Structure of transport consumption expenditures

The EU transport-related mean consumption expenditure per household are presented in **Figure 20**. It shows that, on average, across the 25 EU countries more than half (55%) of Transport expenditures are related to 'Operation of personal transport equipment'. Next comes 'Purchase of vehicles' with the EU-wide average share of 34%, while the mean expenditures on Transport services account for the remaining 11% of the mean total transport consumption.

Fuels and lubricants make the largest sub-category of mean consumption of Operation of personal transport equipment, with the corresponding EU-wide average share of about 60%. Hence, in the assessments of various energy, climate and environmental policies, this particular category of fuels and lubricants used by households in operations of their personal transport equipment (not surprisingly) will be the most important transport consumption item, e.g. in terms of policy impacts on households. The mean expenditures on maintenance and repair of personal transport equipment make up, on average, 18.4% of mean consumption of Operation of personal transport equipment by all EU households. Finally, in the smallest sub-category of CP07 – Purchases of transport services, the largest item is related to passenger transport by air, road, and combined passenger transport. The latter category refers to the expenditures of services of two or more modes of transport – for example, intra-urban bus and underground or inter-urban train and ferry – which cannot be apportioned between them.

Figure 20. The EU structure of mean transport consumption expenditure per household



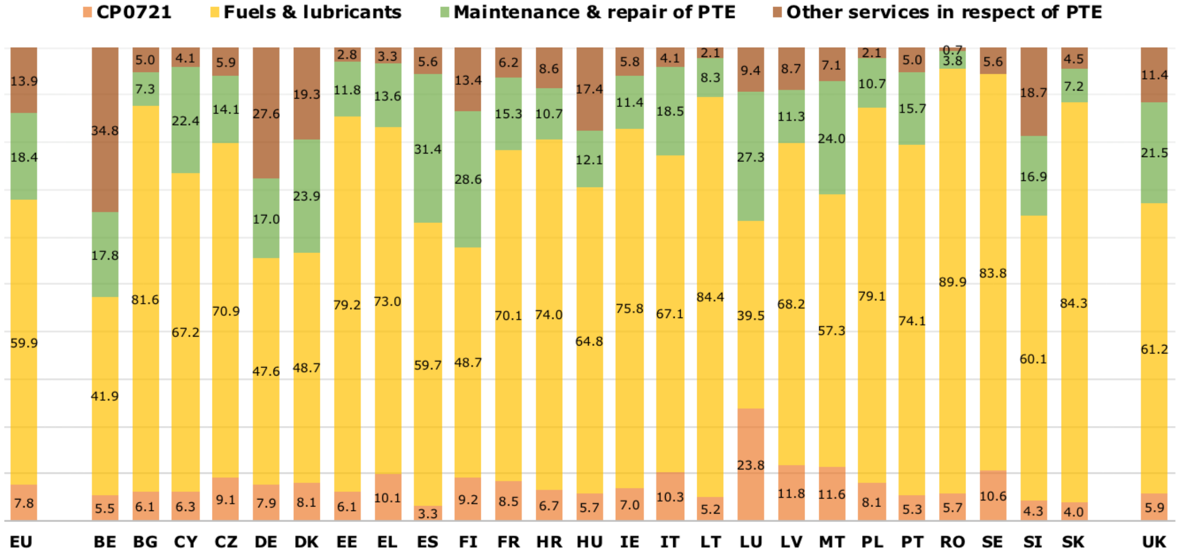
Note: Household weights are accounted for. EU excludes the UK. The components do not necessarily sum to the corresponding aggregate category value, showing the inconsistencies in the HBS data. *Source:* Own elaboration using Eurostat's HBS 2010 wave.

The structure of country-specific mean consumption expenditures (per household) on Operation of personal transport equipment and Transport services are depicted in **Figure 21**. The first graph confirms the importance of fuels and lubricants for personal transport equipment in the COICOP Division of CP07 for almost all countries, with corresponding mean expenditure shares ranging between 39.5% in Luxembourg and 89.9% in Romania. For most countries, however, the mean fuels and lubricants consumption is well above half of the total mean spending on Operation of personal transport equipment: the EU average (accounting for sampling weights) of fuels and lubricants mean share in Operation of personal transport equipment is about 60%. The average EU shares of other components of Operation of personal transport equipment are: maintenance and repair of personal transport equipment – 18.4%, Other services in respect of personal transport equipment – 13.9%, and Spare parts and accessories – 7.8%. Other services in respect of personal transport equipment is particularly large in Belgium (34.8%), which includes such household expenditure items as:

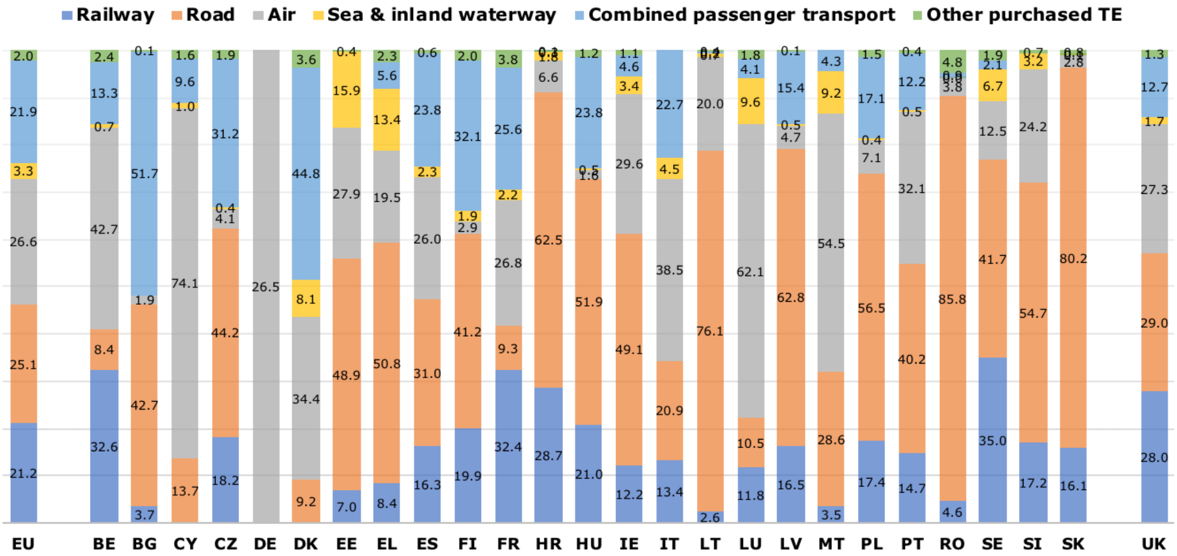
- hire of garages or parking spaces not providing parking in connection with the dwelling,
- toll facilities (bridges, tunnels, shuttle ferries, motorways) and parking meters,
- driving lessons, driving tests and driving licences,
- roadworthiness tests, and hire of personal transport equipment without drivers.

The second graph of **Figure 21** shows the average share (accounting for sampling weights) of the six components of Transport services. Obviously there might be large differences in these expenditures by country due to e.g. geographic factors. For example, passenger transport by air is largely dominating expenditure component in Cyprus (with the mean expenditure share of 74.1%), Luxembourg (62.1%) and Malta (54.5%). On the other hand, road passenger transport expenditures are particularly high for households in Romania (85.8%), Slovakia (80.2%), Lithuania (76.1%) and Latvia (62.8%). Finally, we observe that compared to other EU countries, railway passenger transport is apparently more popular mode of transport in Sweden, Belgium, France and Croatia (with the mean expenditure shares ranging between 29% and 35%).

Figure 21. Structure of mean Operation of personal transport equipment and Transport services expenditures per household



(a) Structure of mean Operation of personal transport equipment consumption expenditures per household



(b) Structure of mean Transport services (CP073) consumption expenditure per household

Note: Household weights are accounted for in deriving the expenditure shares. EU excludes the UK. Germany reports data only for one CP073 sub-category. CP0721: Spare parts and accessories. PTE: Personal transport equipment. TE: Transport equipment. Source: Own elaboration using Eurostat's HBS 2010 wave.

2.5.2 Fuels and lubricants for personal transport equipment

To observe the sampling variability behind the largest Operation of personal transport equipment component mean estimates, the densities of fuels and lubricants shares in total Operation of personal transport equipment expenditures are presented in **Figure 22**. Similar to our earlier discussions regarding electricity consumption shares (**Figure 9**), at lower product level one might well get multimodal distributions. For example, see the form of distributions of fuels and lubricants shares for Germany, Denmark, France, Hungary, Luxembourg and Slovenia in **Figure 22**. This implies that in such cases simple application of summary statistics such as mean and median only offer limited information. Therefore, integrated macro-micro modelling exercises with detailed product disaggregation can benefit from using all the available (and useful) micro-data points in order to adequately infer conclusions with regard to different dimensions of household heterogeneity. The detailed micro data offers opportunities to go beyond limited summary statistics.

Finally, let us see the relationship between fuels and lubricants consumption and household affluence level. **Figure 23** shows the share of fuels and lubricants for personal transport equipment in total expenditures for each EU country by income and expenditure decile. For most of the countries we observe that the share of fuels and lubricants for personal transport equipment in total expenditure is increasing with household affluence level. This is a usual finding from most of the expenditure surveys indicating e.g. more extensive use of personal transport equipment by richer households than poorer ones. It could be also due to higher number of personal transport equipment possessed (and used) by richer households. Note that here personal transport equipment also includes major tools and equipment for house and garden (CP0551) and recreational vehicles (CP0921).

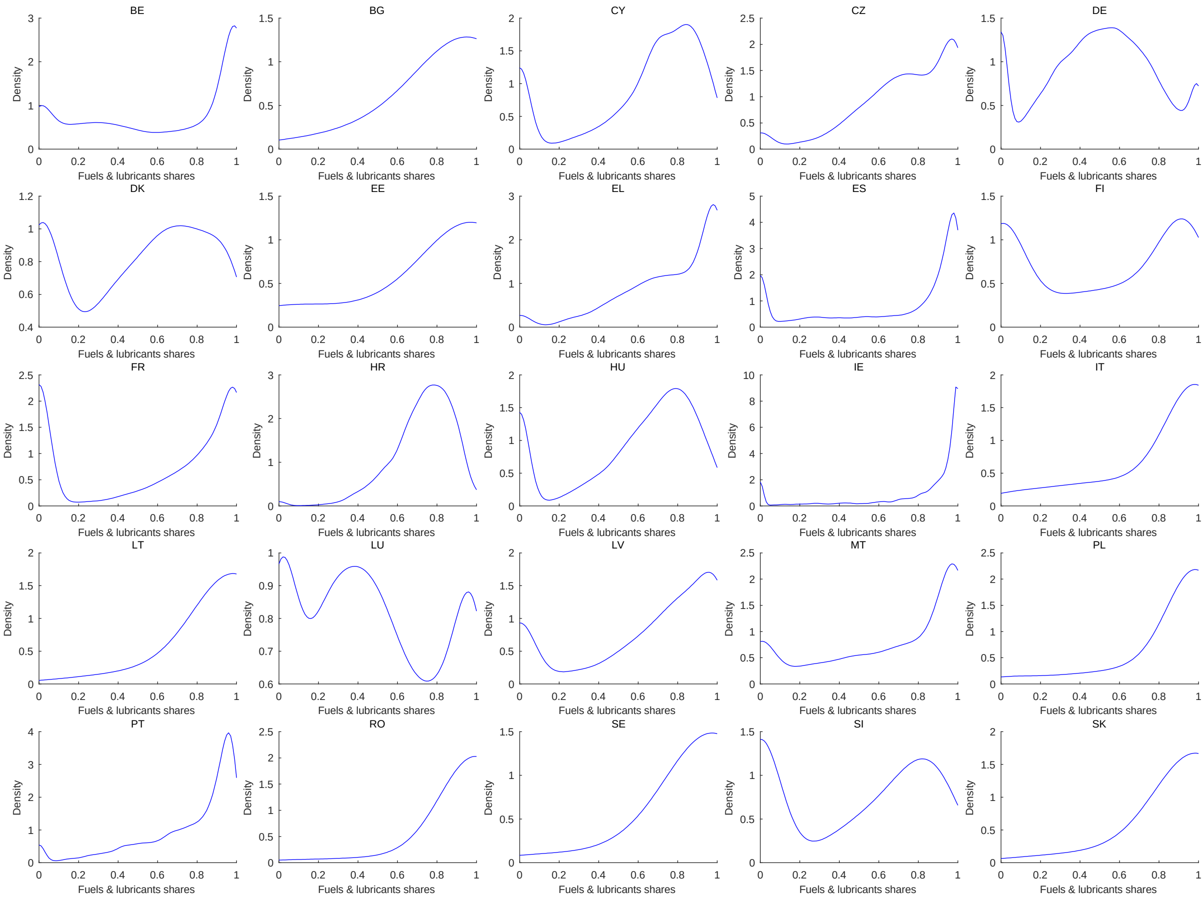
However, there are also a few exceptions. For example, we observe a clear inverse-U shape relationship in case of Germany, France and Ireland, where apparently the middle-income and middle-expenditure households have, on average, larger fuels and lubricants for personal transport equipment expenditure shares. A few other countries have first the usual increasing trend up to the 8th or 9th decile and then decreasing fuels consumption mean shares thereafter at the remaining top part of the distributions. In case of Luxembourg, we even observe a mild decreasing trend in the mean shares of fuels and lubricants with household affluence level.

In very few cases the considered relationship is different if one considers income decile vs. expenditure decile variable. In Malta and Sweden the mean expenditure share of fuels and lubricants is roughly constant over income deciles, while shows an inverse-U form for expenditure decile.

All these different forms will have policy implications when the policy shock affects households' consumption of fuels. In particular, an increase in price of fuels will have progressive impact in all countries with positive relationship between fuels and lubricants budget shares and household affluence level, and regressive impact where this relationship is negative. However, on average across all the EU countries this relationship is positive, implying that at EU level the welfare loss of a policy increasing the price of fuels, all other things being equal, will be on average larger for richer households than poorer ones.

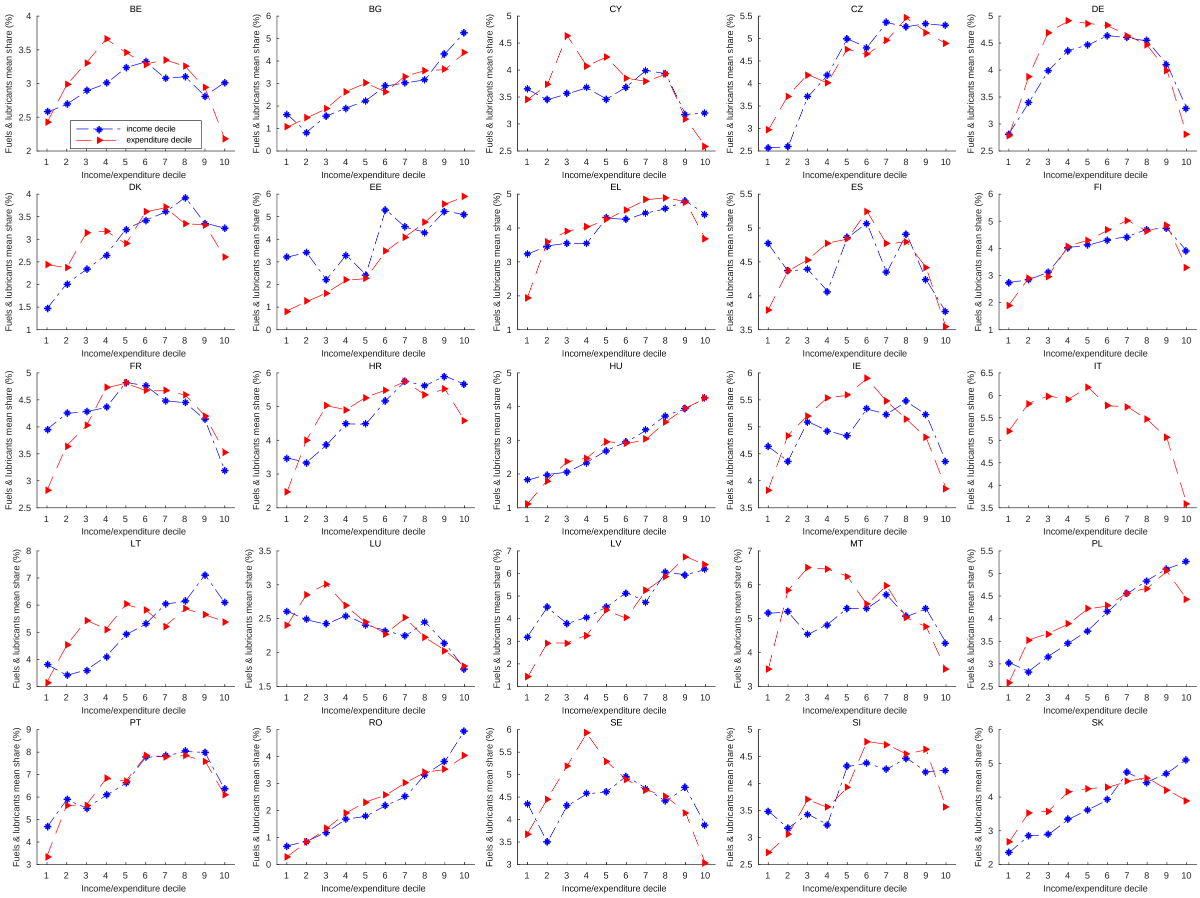
As a final note, however, it is worthwhile to remember that any insights for the top decile should be taken with great caution as data of top-earning and top-spending households is often less reliable due to the corresponding usual consumer survey problems such as anonymisation and under- or non-reporting.

Figure 22. Densities of fuels and lubricants expenditure shares in Operation of personal transport equipment by country



Note: Household survey weights are appropriately accounted for. Negative expenditures, if any, are excluded. For each density, the fuels and lubricants expenditure shares range within zero and the corresponding maximum value. Source: Own elaboration using Eurostat's HBS 2010 wave.

Figure 23. Mean share of fuels and lubricants in total expenditures by affluence level



Note: Household survey weights are appropriately accounted for. Negative expenditures, if any, are excluded. Source: Own elaboration using Eurostat's HBS 2010 wave.

3 A macro-to-micro application: Methodology

In this section, we describe the approach used in this report for combining the JRC-GEM-E3 model with the micro-level Household Budget Survey data. There are several approaches to macro-micro integrated modelling, which are discussed in Box 1 (for further details, see the references thereof). For our purposes, we use the so-called top-down micro-accounting (TD-MA) approach, which in the literature is also often referred to as arithmetic or non-behavioural sequential microsimulation model. Formally, this approach was first presented by Chen and Ravallion (2004), which led to many subsequent studies (see e.g. Boccanfusso and Savard, 2007; Chitiga and Mabugu, 2008; Ravallion and Lokshin, 2008; Araar et al., 2011; Buddelmeyar et al., 2012; Vandyck and Regemorter, 2014; Hertel et al., 2015; Phimmavong and Keenan, 2020). As discussed in Box 1, the TD-MA approach is particularly useful for immediate or near-term household-specific welfare distributional and poverty impacts due to product and factor price changes that are attributed to a specific policy of interest (e.g. reduction in tariffs, removing subsidies). Importantly, these price changes are unambiguously caused by the policy of interest (e.g. a trade policy reform) since they are based on a macro-model assessment of the policy. Thus such top-down approach avoids the typical identification problems encountered in econometric estimations of the distributional effects of the policy within a cross-country comparative setting.

In our HBS data, there are no separate product and factor price or quantity data for all products. The survey provides quantity data only for households' food consumption categories, allowing one to calculate the unit price of food items by dividing the corresponding expenditures by the quantities consumed. However, such data is not available for non-food categories, such as energy goods. Similarly, there is no data on factor prices or households factor endowments. However, "this data limitation does not matter in calculating a first-order approximation to the welfare impact in a neighbourhood of the household's optimum" (Chen and Ravallion, 2004, p. 33). In such cases, one can estimate the change in the welfare of households (in the HBS data) using the following formula:

$$\Delta W_h \cong -\sum_k p_k c_{hk} \frac{\Delta p_k}{p_k} = -\sum_k c_{hk} \Delta p_k \,, \tag{1}$$

where c_{hk} is household *h*'s initial (before a policy simulation) consumption of product *k*, p_k is the purchase price of product *k* (assuming that all households pay the same price for product *k*), and Δp_k is the corresponding price change due to a policy shock. This equation is the basis of the welfare analysis in this report, and defines welfare changes as the product of expenditures with percentage changes in prices by consumption category. Compared to the study by Chen and Ravallion (2004), in equation (1) we do not take into account changes in factor prices, since the HBS income data is largely incomplete for such purposes. However, as mentioned by Bourguignon and Bussolo (2013, pp. 1389-1390), equation (1) "corresponds to the 'equivalent variation' of income that makes consumer [*h*] indifferent between the initial and the new vector of prices".

More exactly, the negative of the right-hand side expression in (1) is the change in money income necessary to make the initial consumption bundle of household *h* affordable at the new prices. Hence, this additional income keeps the purchasing power of household *h* fixed in the sense of making the original bundle of consumption goods just affordable with new prices. However, the initial quantities of consumption goods generally do not constitute the optimal consumption bundle for households with the new income level (i.e. original income plus the "compensating" income level as derived from (1); if prices increase, the new income also has to be higher to keep purchasing power constant, and vice versa). In particular, the optimal consumption bundle generally will be different as households "substitute" one good for another when prices change but the purchasing power remains constant. Technically, staying with the initial basket of consumption goods at new prices ignores the so-called Slutsky substitution effect. The fact that expression (1) does not take into account the possibility of substitution towards relatively cheaper commodities implies that these first-order welfare loss estimates provide a maximum bound of the price change impact. However, if price changes are relatively small, then these first-order welfare loss evaluations are good approximations of the "true" welfare loss, hence maybe largely considered as sufficient for distributional and poverty analysis.

To include also the second-order impacts, the standard approach in microeconomics is to start with a minimum expenditure function, $e(u, \boldsymbol{p})$, which given the vector of existing prices *p*, gives the minimum cost of achieving a fixed utility level *u*. The second-order welfare loss can be approximated by a second-order Taylor series expansion of the minimum expenditure function as follows (Banks et al., 1996; Deaton and Muellbauer, 1980; Friedman and Levinsohn, 2002):

$$\frac{-\Delta W_h}{E_h} \cong \sum_k w_{hk} \frac{\Delta p_k}{p_k} + \frac{1}{2} \sum_k \sum_l w_{hk} \varepsilon_{kl} \frac{\Delta p_k}{p_k} \frac{\Delta p_l}{p_l}, \quad (2)$$

where ε_{kl} is defined as the compensated price elasticity of good *k* with respect to good *l*'s price change. Since the second-order impacts account for substitution effects, it is not surprising to find that to implement (2) in empirical evaluations one has to have the estimates of own- and cross-price elasticities. Unfortunately, the nature of the HBS data at hand does not allow estimating the ε_{kl} terms. As such in our empirical exercise we will use the *first-order compensating variation* given in (1). This is consistent with the TD-MA approach adopted here, as the latter does not model consumer behavioural responses to price changes. In addition, in the next section we will assume that the price changes of COICOP products that are *sub-categories* of aggregate sectors represented in the macro model (i.e. JRC-GEM-E3) are assumed to be equal to the corresponding aggregate price changes as obtained from the JRC-GEM-E3 model. That is, the price shocks at the micro level are basically assumed to be of equal relative size for all potentially substitutable goods at the micro level. This allows for substitution effects within the macro model within a COICOP category, e.g. between electricity, gas, liquid fuels, solid fuels, and heating energy within "Fuels and Power". When comparing a scenario to a baseline, the substitution within a COICOP category is then assumed to be modelled in the macro model. The resulting price change of the COICOP category on particular groups is then evaluated in the micro analysis. As such, compared to solely partial equilibrium analyses, the second term in (2) may not matter much within the framework of our macro-micro integrated modelling approach.[7] One potential drawback of the approach is that there is only one average price change for the COICOP category, disregarding heterogeneity in the shares of sub-categories within the COICOP category between different household groups.

In summary, our methodological framework relies on deriving price changes by consumption category with the JRC-GEM-E3 model in a first step. The underlying conversion between statistical classifications is done based on Cai and Vandyck (2020), with further detail added for energy goods. Then, we pass on these price effects to the micro-level Household Budget Survey data to calculate household-specific welfare impacts as described above, from which it is straightforward to calculate mean or median values per decile. Additional carbon tax or permit auctioning revenue relative to the baseline is allocated to households on an equal-per-equivalent-household basis. We use the 2010 wave of the HBS data without addressing potential inconsistencies with the National Account data. As a result, aggregating the micro-level welfare impacts over all households would give a number that does not necessarily match the welfare outcome for the aggregate, representative household as calculated in the economy-wide JRC-GEM-E3 model. To address this issue, we add an additional two-step adjustment to the procedure. In the first step, we rescale household-level impacts to match country-specific welfare impacts from the macro model. We do this in a way that the distributional pattern over income groups in terms of Compensating Variation relative to income is unaffected (equal percentage point shift for all). A second step then repeats this rescaling but on the EU aggregate level. Implicitly, the rescaling also reflects source-side impacts (changes in labour and capital income), as these contribute to the welfare impacts in the macro model, but are not represented explicitly on the micro level. The rescaling procedure brings consistency in aggregate outcome while maintaining the distributional patterns derived directly from the micro data. Therefore, the distributional impacts can readily be interpreted as a breakdown of the macro-economic results. For lump sum transfers to households, we deflate the 2030 values to 2010 by income per capita growth.

(7) Using a microeconomic, partial equilibrium QUAIDS demand framework in analysing the effects of environmental taxes on household welfare and carbon emissions for the case of Mexico, Renner et al. (2018) conclude that "first-order approximations of welfare effects provide reasonable estimates, particularly for carbon taxes" (p. 222).

Box 1. A typology of macro-micro integrated models

There are different approaches to macro-micro integrated modelling, each having their own strengths and weaknesses (see e.g. Brown et al., 2007; Bourguignon and Bussolo, 2013; van Ruijven et al., 2015). Focusing on computable general equilibrium (CGE) models as one (though widely used) class of macro-models, Cockburn et al. (2014) presents the following typology of the main macro-micro simulation approaches.

— *The representative household approach* (RH) is the traditional approach to merging microeconomic analysis to a macro-CGE model by applying microeconomic theory to representative households. The number and nature of RHs depend on the study focus, and may include such dimensions as income deciles, skill levels, education levels, urban/non-urban residents, male/female categories, etc. Hence, one of the drawbacks of such an approach is that the RH study is limited by one or very few categorisation of households, which makes it impossible to explore other, possibly equal important, socio-demographic characteristics of households. In particular, by construction, the RH is not ideal for distributional studies as "the distributional impact of the measures being considered should inform on the identity of winners and losers, the possibility of compensating the latter" (Bourguignon and Bussolo, 2013, p. 1384).

— *The fully integrated approach* (FI) replaces RHs in a CGE model with large number of actual households directly taken from a household budget survey. Thus, compared to the RH approach, the FI can address the within-group distributional issues. However, several challenges arise which might impede from a widespread use of the approach. First, one has to harmonise the national accounts data behind the CGE model with the household survey data, which is a time-consuming procedure. Second, computing equilibria in a numeric model with large number of households can become computationally challenging, which however may be less of a problem over time with continuous improvement in computing processors. Finally, the structure imposed on individual households by a CGE model does not generally allow households/individuals to switch from one sector to another, from one occupation to another, move in or out of employment, etc. Such discrete choice behaviour calls for sequential macro-micro modelling, where at the micro level the desired behaviour of households/individuals is modelled using advanced econometric estimation techniques on household-level data.

— *The top-down micro-accounting approach* (TD-MA) is nowadays a widely used approach useful for quantifying first-order or near-term welfare effects at the micro level of a shock implied by the corresponding top-level macro-model. That is, often the relative changes in product and factor prices as obtained by a CGE model are fed into micro-data, implying individual household-specific changes in incomes and expenditures. In particular, the TD-MA approach is appropriate for distributional and poverty analysis, as it "applies standard methods of fist-order welfare analysis to measure the gains and losses at the household level" (Chen and Ravallion, 2004, p. 31). For a medium or longer-term analysis, projected employment changes as estimated by a macro model are linked down to the micro-data through reweighting or altering the household sampling weights (see e.g. Buddelmeyar et al. 2012). Strictly speaking, the TD-MA approach, does not require (full) reconciliation of national accounts and household budget data, and is applicable even if the initial commodity and factor price data are missing in the household survey. It is called arithmetic because households behaviour or response to price changes is not (rigorously) modelled at the micro level. Hence, "the change in employment and consumption is not due to the characteristics of the individual households in the micro-simulation but only determined by the representative household in the CGE" (van Ruijven et al., 2015, p. 536). The main limitations of the use of the TD-MA approach for short-term impact analysis include the assumption of small changes in prices, no rationing in commodity and/or factor markets, and non-convexities in consumption and/or production.

— *The top-down with behaviour approach* (TD-WB) is more flexible in terms of modelling household behaviour compared to the TD-MA approach. That is, within the TD-WB framework behavioural responses of households to price changes is explicitly modelled, often involving consumer choices and labour supply decisions. Typically the core part of a TD-WB microsimulation is a micro-level income generation model that consists of econometric reduced form equations for individual earnings, household income from self-employment and the occupational choice of all household members of working ages (see e.g. Bourguignon et al., 2005). Then the changes of the typical macro-to-micro "linkage variables" of product prices, wages and aggregate employment variables are fed into the micro-model generating changes in individual wages, self-employment income and employment status. This allows for "more heterogeneity between households and hence richer income distributional analysis" (Cockburn et al., 2014). The main criticism of both TD-MA and TD-WB approaches is the *lack of feedback effects* from the micro to the macro model, i.e. the second-round macro effects of individual responses are not taken into account.

Whether this is indeed a problem depends on the aggregation properties of the households' behavioural functions in the micro model. For instance, the top-down approach will be sufficient in the sense of consistent changes in the macro and micro aggregate consumption and aggregate labour if it is assumed that all households have identical behaviour (but have different socio-demographic characteristics) and is specified as a linear expenditure model of consumption and leisure. Generally, however, the micro behavioural functions will not sum up to the corresponding macro aggregates, which is especially the case with the TD-WB models. For example, if the micro labour supply decision is modelled through a discrete regime switching function that, by construction, cannot be incorporated into the CGE model, the two modelling levels will be inconsistent. Yet, the approach is still useful as it informs policymakers about the first-round effects of the policy change, which in some cases might be an adequate approximation of the "full" effects of the policy under consideration.

— *The bottom-up approach* (BU) is opposite to the top-down approach in that first a micro-relevant policy (e.g. a tax-benefit system reform) is assessed within the micro model, and then the aggregates of the micro-behavioural changes are fed into the macro model to analyse the overall effects in the economy (see e.g. Brown et al., 2007). Similar to the TD approaches, the BU approach lacks feedback effects, but now in the other direction: from macro to the microsimulation model. However, one can argue that this problem, i.e. the lack of the two-way linkage between the macro and micro models, is more severe for the BU approach; with the TD models all kinds of (indirect) macro price-quantity effects are already taken into account within the top macro model, though possibly not in a fully consistent way with the micro-model's assumptions and outcomes. For related discussions, see e.g. Bourguignon and Bussolo's (2013, pp. 1391-1392) remarks on the BU model of Brown et al. (2007).

— *The iterative approach* (IA) fully links the TD-WB approach to the CGE model by introducing two-ways feedback linkages between the two modules of the whole procedure. The *top-down/bottom-up (TD/BU)* variant of the IA approach was first presented by Savard (2003) and worked as follows: first, similar to TD-WB, a macro policy shock generates price changes within a CGE framework that are fed into the micro-simulation model to calculate households' consumption and labour supply; then, unlike the TD-WB approach, the latter aggregates are fed back as new exogenous variables into the CGE model to generate new vector of price changes; consequently, the iteration process continues until the results of the two models converge (for further details of this approach, see Bourguignon and Savard, 2008). An alternative variant of the AI approach is the so-called *bottom-up/top-down* (BU/TD) approach when the micro-macro feedback loops are closed within the BU approach. The BU/TD approach is more appropriate for the assessment of policies that are targeted specifically at modifying individual behaviour. For example, Tibeti et al. (2013) examines the economy-wide impact of reforming the existing child support grant in South Africa using the BU/TD approach. Thus given the nature of the approach, the AI outcomes, e.g. households' real consumption and adult labour supply, reflect not only the direct effect of the child support transfer but also the general equilibrium effects generated by the simulated reform scenarios. The main drawback of the IA is that the convergence of the underlying micro and macro outcomes is not guaranteed. This problem in fact puts additional constraint on the IA, as compared to other sequential approaches, in the sense of requiring stronger consistency between the behaviour of households in the CGE and microsimulation models.

All in all, one may safely conclude that there is no 'one-size-fits-all' modelling approach. All the above presented micro-macro integrated approaches have their own strengths and weaknesses, and varying degrees of appropriateness to a specific economic assessment situation. Ultimately, the right choice of the approach depends on the multitude of factors, including the nature of the research question/purpose and of the existing constraints such as data availability and time constraints.

4 Distributional impacts of reaching revised 2030 climate targets

This section presents a detailed household-level distributional impact analysis accompanying the Climate Target Plan (EC, 2020b), for which the European Commission assessed the impacts of 50% and 55% emission reduction below 1990 emission levels (EC, 2020a). The JRC-GEM-E3 model is used in this context to assess the overall macro-economic impacts as well as effects on different sectors. The CGE model is closely aligned with the energy system model PRIMES and operated in a toolbox of models, as is typical for a comprehensive assessment of climate scenarios (Weitzel et al., 2019). This model alignment improves the responses in the CGE model of some key sectors in response to carbon prices or standards. In this context, PRIMES information was also used for the decarbonisation of household heating and private transportation. With this analysis of distributional impacts, the model toolbox is extended to also encompass distributional consequences of decarbonisation scenarios.

The impact assessment of the 2030 Climate Target Plan defines three main energy-modelling scenarios that reach 55% reduction levels on the basis of various combinations of policy instruments. Each of these are assessed here for their distributional consequences relative to a baseline scenario:

- The REG scenario, which is based on regulatory measures that increase ambition on energy efficiency, renewables and transport. It keeps the scope of the EU ETS unchanged and does not expand carbon pricing to new sectors of the economy. Fossil fuels purchased by households are therefore not subject to a new carbon price signal. On the other hand, households have to bear increased cost resulting from efficiency measures, e.g. from more energy efficient appliances and expenditures from renovations.
- The CPRICE scenario, which assumes a strengthening of the carbon price signal and its extension to transport and the buildings sector. It assumes a moderate intensification of transport policies, but no intensification of energy efficiency and renewables policies. The carbon price in this scenario rises above the level of the baseline scenario and as it is assumed that households will pay a carbon price on fossil fuels, this leads to higher energy prices for households than under the REG scenario.
- Finally, the MIX scenario lies between the REG and the CPRICE scenarios. As under CPRICE, the buildings sector and transport are subject to carbon pricing. However, the scenario also includes an intensification in both transport and energy policies, though to a more limited extent than under REG. The strengthening in the carbon price is therefore lower than under CPRICE.

4.1 Price shocks and average EU budget shares

With the JRC-GEM-E3 model, we derive price changes compared to the baseline for the three scenarios presented above. The details of macro-modelling stage will not be discussed here. The resulting price changes for 14 consumption sectors represented in JRC-GEM-E3 model are presented in **Table 5** (See **Table A.3** in the Appendix for JRC-GEM-E3 sectoral classification). For Residential energy, standard JRC-GEM-E3 output has been adjusted to account for additional expenditure on energy-efficient heating and cooking appliances as per PRIMES model input. In the macro-micro link, we allocate these additional expenditures to the category of residential energy expenditures, which arguably is the best proxy available in the HBS data to allocate these additional investments to households. This approximation implies that we allocate the additional expenditures compared to baseline on heating and cooking appliances (averaged over the period 2020-2030) in proportion to households' expenditures on residential energy.

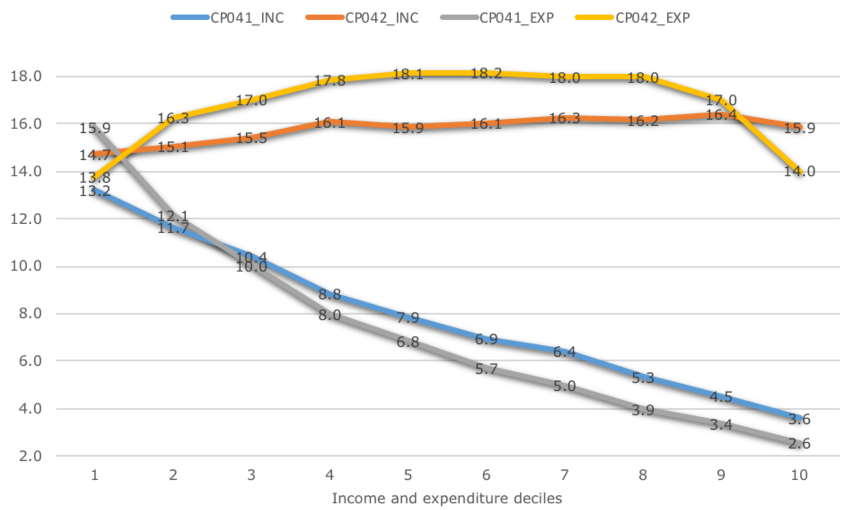
The largest price changes are found for energy-related sectors 'Residential energy', 'Operation of personal transport equipment' and 'Transport services' in the pricing-based scenario (CPRICE). While the consumption category 'Residential energy' exclusively includes fuels purchased by households, the 'Operation of personal transport equipment' also includes non-fuel components such as vehicle maintenance which are effected much less by a carbon price, thus muting the effect on this consumption sector. The regulation-based approach (REG) limits energy cost increases experienced by the households, while requiring higher expenditures on Housing, reflecting among others the additional costs related to building insulation based on inputs from the bottom-up energy system model PRIMES. 'Operation of personal transport equipment' indicates a negative sign as the effective unit cost of private transport decreases due to more efficient vehicles being purchased.

Table 5. Price changes derived with the JRC-GEM-E3 model (%, median across 25 countries, excl. AUT and NLD)

		REG	MIX	CPRICE
1	Food	0.1	0.1	0.1
2	Clothing	0.1	0.1	0.1
3	Housing	2.1	1.5	0.1
4	Residential energy	1.2	3.8	9.9
5	Equipment	0.1	0.1	0.1
6	Heating & cooking appliances	0.1	0.1	0.1
7	Health	0.1	0.1	0.1
8	Vehicles	0.4	0.9	0.9
9	Operation of personal transport equipment	-0.9	1.4	2.8
10	Transport services	0.2	1.1	1.6
11	Communication	0.1	0.0	0.0
12	Recreation	0.1	0.2	0.2
13	Miscellaneous	0.1	0.0	0.0
14	Education	0.1	0.0	-0.1

It is important to note that we have excluded 'Imputed rentals for housing' (CP042) from our micro evaluation as imputation techniques differ across countries. This issue is especially relevant for distributional analysis, since compared to richer consumers, households in the bottom decile will generally have lower budget share for services of owner-occupied housing due to actual renting rather than owning homes. Hence, one would expect that instead poor households will have much larger share of actual rentals for housing than richer households. **Figure 24** confirms these observations for all households of 23 EU countries that report both the actual and imputed rentals data (survey weights are taken into account). For space consideration, however, country-specific mean budget shares by income and expenditure deciles are not reported and further analysed here.

Figure 24. Mean EU budget shares for actual and imputed rentals for housing



Note: EU does not include Czech Republic and Malta which do not report imputed rents data. CP041 and CP042 denote, respectively, actual and imputed rentals for housing. INC and EXP refer to income and expenditure deciles, respectively.

Table 6 gives an overview of the relative size of 52 products in household total expenditures, reporting the corresponding mean EU (excluding UK) budget shares (accounting for sampling weights). There are, of course, differences in mean budget shares across the individual EU countries (which are not reported), nonetheless the table gives a general understanding of their typical patterns for the EU households.

Table 6. Mean EU budget shares for all 52 considered COICOP products (%)

COICOP-HBS classification	All EU households	Income deciles			Expenditure deciles		
		1st decile	5th decile	10th decile	1st decile	5th decile	10th decile
cp011	21.57	25.34	21.25	14.31	28.11	22.71	12.56
cp012	1.74	1.96	1.71	1.29	2.11	1.84	1.11
cp021	1.29	1.33	1.29	1.38	1.10	1.36	1.22
cp022	1.72	2.50	1.86	1.17	2.34	1.78	1.05
cp031	3.95	3.08	3.56	4.64	2.52	4.01	4.77
cp032	1.29	1.11	1.19	1.32	1.01	1.34	1.30
cp041	7.41	13.27	7.96	3.68	15.88	6.92	2.64
cp043	0.94	0.60	1.02	1.18	0.31	0.81	2.06
cp044	2.77	2.87	2.81	2.58	3.37	2.82	2.04
cp0451	3.91	5.02	4.10	2.82	5.89	3.99	2.11
cp0452	2.39	2.19	2.16	1.61	2.80	2.51	1.54
cp0453	0.75	0.78	0.87	0.70	0.54	0.75	0.70
cp0454	0.74	0.99	0.90	0.32	0.77	0.83	0.48
cp0455	0.89	0.95	0.99	0.74	0.87	0.93	0.64
cp051	1.17	0.68	1.11	1.92	0.41	0.88	2.77
cp052	0.36	0.25	0.36	0.48	0.16	0.35	0.56
cp053	0.80	0.63	0.83	0.89	0.47	0.80	1.13
cp054	0.38	0.22	0.32	0.42	0.25	0.38	0.48
cp055	0.43	0.27	0.44	0.54	0.21	0.42	0.55
cp056	1.77	1.40	1.55	2.43	1.33	1.72	2.29
cp061	2.48	2.12	2.58	2.02	2.15	2.59	2.31
cp062	1.46	0.94	1.30	2.09	0.70	1.29	2.57
cp063	0.15	0.10	0.15	0.36	0.06	0.11	0.40
cp071	2.24	0.96	2.27	4.49	0.27	1.00	9.82
cp0721	0.50	0.28	0.50	0.47	0.17	0.46	0.80
cp0722	4.90	3.24	4.81	4.97	2.98	5.45	4.37
cp0723	1.21	0.74	1.23	1.39	0.41	1.14	1.66
cp0724	0.94	0.74	1.04	1.35	0.46	0.99	1.09
cp0731	0.24	0.38	0.19	0.34	0.19	0.21	0.29
cp0732	0.44	0.62	0.51	0.35	0.52	0.45	0.33
cp0733	0.19	0.20	0.10	0.39	0.07	0.15	0.53
cp0734	0.03	0.02	0.02	0.03	0.01	0.03	0.04
cp0735	0.25	0.28	0.19	0.28	0.22	0.25	0.24
cp0736	0.02	0.02	0.02	0.02	0.01	0.02	0.03
cp081	0.12	0.13	0.12	0.11	0.11	0.12	0.10
cp082	0.10	0.10	0.09	0.10	0.08	0.11	0.11
cp083	3.91	4.50	4.14	3.39	5.01	4.06	2.48
cp091	1.15	0.98	1.19	1.61	0.67	1.18	1.52
cp092	0.13	0.07	0.12	0.31	0.03	0.07	0.47
cp093	1.57	1.16	1.66	1.78	0.85	1.62	1.79
cp094	2.34	2.05	2.45	2.77	1.89	2.37	2.45
cp095	1.42	1.31	1.46	1.69	1.04	1.51	1.48
cp096	1.13	0.44	1.14	2.28	0.21	0.84	2.70
cp10	0.74	0.74	0.70	1.06	0.34	0.74	1.02
cp111	4.73	3.96	4.54	6.64	2.75	4.82	5.79
cp112	0.73	0.28	0.54	1.31	0.11	0.54	1.64
cp121	3.19	2.85	3.13	3.23	2.60	3.41	3.05
cp123	0.52	0.35	0.49	0.75	0.23	0.48	0.89
cp124	0.35	0.23	0.43	0.48	0.26	0.38	0.36
cp125	5.06	3.40	5.01	7.32	4.11	5.14	5.12
cp126	0.22	0.25	0.24	0.32	0.25	0.21	0.20
cp127	0.76	0.51	0.74	1.18	0.25	0.58	1.83

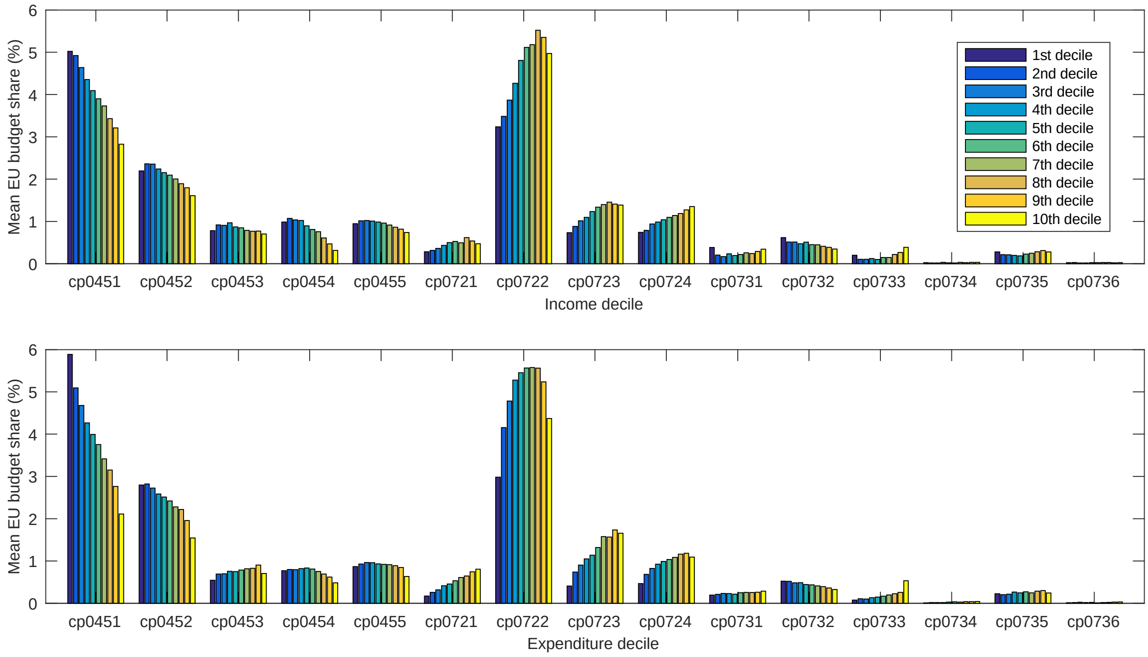
Note: EU includes 25 EU countries (excluding UK). Household sampling weights are accounted for. For COICOP-HBS classification see Table A.3 in the Appendix. Highlighted products are subject to the largest price shocks (yellow for 'fuels and power' in JRC-GEM-E3 classification, orange for 'operation of personal transport equipment', and green for 'transport services').

Besides displaying the mean budget shares for all EU households, **Table 6** also reports the mean budget shares for the bottom, median and top deciles of both household income and expenditures. This better highlights the heterogeneity in consumption patterns across the EU households. Food (CP011) has the largest mean budget share (of 21.6%) for all EU households, but is much more important commodity for households in the bottom income and expenditure deciles (with respective mean shares of 25.3% and 28.1%) than for the top income and expenditure deciles (14.3% and 12.6%, respectively).

As regards the 15 energy-related products that are subject to the largest price increases in our micro assessment, Electricity (CP0451) is, on average, the most important consumption item for households in the bottom income and expenditure deciles (with respective budget shares of 5.0% and 5.9%), which is less relevant for the richest households (resp. 2.8% and 2.1%). On the other hand, among the products in question 'Fuels and lubricants' (CP0722) is the most important commodity for the richest households with the mean budget share of 5.0% and 4.4% for the 10th income and expenditure deciles.

In general, one finds housing-related energy goods' mean EU expenditure shares are decreasing with household affluence (both income and expenditure) level, while the reverse relationship is observed for all the categories of operations of personal transport equipment (**Figure 25**). We also observe, however, that for 'Fuels and lubricants' this relationship is of inverted and horizontally-flipped J nature, as the maximum mean budget share of EU households corresponds to 7th or 8th decile. This is related to certain country-specific differences in this relationship already discussed in previous section in **Figure 23** (the difference, however, being that in the earlier section, total expenditures include imputed rents, while this is not the case here). Thus, one may expect that housing-related energy goods' price increases, on average across the EU, will have regressive effects as opposed to price increases for motor fuels and other categories of operations of personal transport equipment, which will have, on average, progressive welfare effects. Such kinds of counteracting distributional effects, not surprisingly, imply that it is not possible to make precise conclusions on the distributional impacts of the considered price changes without the direct use of the corresponding detailed household expenditure data.

Figure 25. Mean EU budget shares of energy-related goods by household affluence level



Note: Survey weights are taken into account. UK is excluded. The residential energy sub-categories do not include Sweden for data unavailability. Germany has a similar issue for missing data for Transport services sub-categories. CP0451: Electricity; CP0452: Gas; CP0453: Liquid fuels; CP0454: Solid fuels; CP0455: Heat energy; CP0721: Spare parts and accessories; CP0722: Fuels and lubricants; CP0723: Maintenance and repair of personal transport equipment; CP0724: Other services in respect of personal transport equipment; CP0731: Passenger transport by railway; CP0732: Passenger transport by road; CP0733: Passenger transport by air; CP0734: Passenger transport by sea and inland waterway; CP0735: Combined passenger transport; CP0736: Other purchased transport services. Source: Own elaboration using Eurostat's HBS 2010 wave.

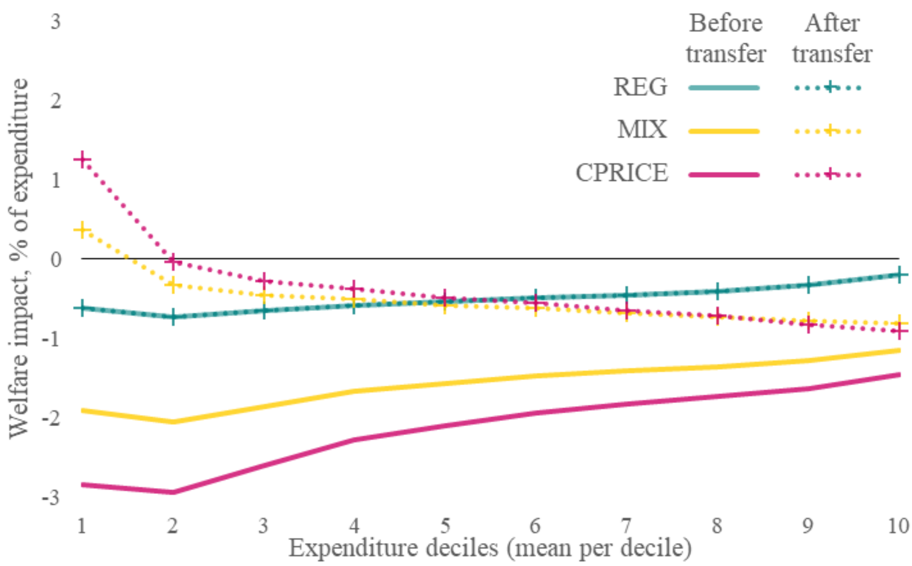
4.2 Results of macro-micro assessment

The sectoral price shocks in **Table 5** were first translated into price changes for 52 products of our micro-analysis focus using the JRC-GEM-E3 consumption sectors and COICOP-HBS products mapping (Table A.3). All sub-categories of the same JRC-GEM-E3 aggregate sector are assumed to experience identical relative price changes as that of the aggregate sector concerned. This implies that the distributional analysis abstracts from the particular fuel used by a household, e.g. for residential energy purposes. While in the real world households may choose to substitute away from fossil fuels as a response to price signals, our micro-accounting framework does not allow for behavioural responses. Including fuel-specific price changes without modelling the possibility of shifting to low-carbon fuels may overestimate the impact for a household. Therefore, we consider only the price change of an aggregate bundle of residential energy fuels. We furthermore do not capture behavioural responses of substitution *between* consumption categories in the micro-level analysis.

The resulting welfare impact relative to total expenditure is shown in **Figure 26**. Deciles are constructed on an EU-wide basis, which implies we rank all EU households according to purchasing power-adjusted total expenditures (or income) and then split the entire population into ten groups of equal number of households, irrespecitve of country of residence or origin. We first observe that pure expenditure-side impacts ('Before transfer') show a regressive pattern across deciles for all three scenarios. Second, the pricing-based scenarios (CPRICE, and to some extent MIX) are perhaps slightly more regressive than the regulation-based scenario, although the pattern is very similar. As the increases in consumption prices relative to baseline is strongest in the CPRICE scenario (**Table 5**) for several key consumption categories, this scenario shows the largest welfare impacts before accounting for transfers.

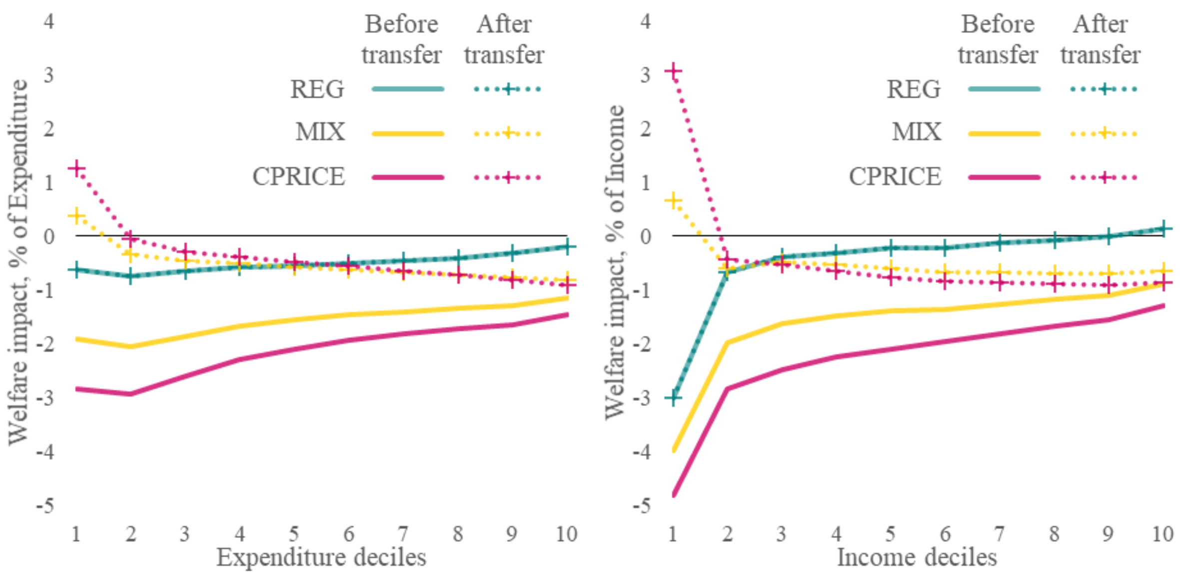
Looking at the 'After transfer' result, we see that in the pricing-based scenarios MIX and CPRICE the transfer of additional tax revenue to households can offset the regressive effects of climate policies. For the poorest households, the transfers can also offset negative welfare effects from price changes. As the regulation-based scenario generates no additional revenue, the results before and after transfer are identical. The regulation-based policy approach may have alternative complementary measures. For instance, stricter building effiency requirements could be accompanied with means-tested subsidies, targeting directly those households affected. In our scenarios, however, these and other complementary policy design aspects are not considered explicitly.

Figure 26. Distributional impacts of three scenarios to reach 55% greenhouse gas emission reductions



Source: JRC-GEM-E3.

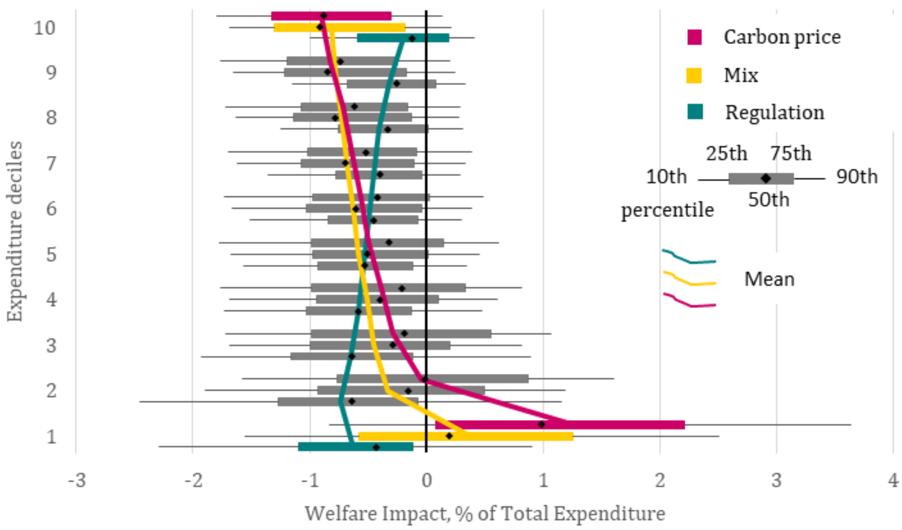
Figure 27. Income versus expenditure basis for assessing distributional impacts



Source: JRC-GEM-E3

Figure 27 compares distributional impacts when expressed relative to income or expenditure. The exploration in Section 2 suggests that the expenditure basis may be the more robust one, but nevertheless the income dimension adds a useful and complementary perspective. As could be expected, results tend to be more regressive when presented relative to income. The reason is that households at the bottom end of the income distribution may have negative savings, while for richer households income tends to exceed expenditures, such that consumption-based taxes (as opposed to income- or savings-based) show a regressive impacts when expressed relative to income. Note that also the deciles are based on expenditure or income, corresponding with the chosen denominator for the welfare impacts. This implies that the income and expenditure deciles will not contain the same households, such that the sign of the impact may differ between the left- and right-hand side panels in **Figure 27**. Although the number is very small, the 10% richest households are gaining in absolute terms when results are presented on an income basis for the REG scenario, despite the increasing price for the majority of consumption categories displayed in **Table 5**. Two remarks can help further understand this result. First, **Table 5** shows only median price changes across all countries. Member State-specific price changes may deviate from the median value. A second explanation follows from the methodological approach to address inherent inconsistencies between the static micro-level data and the (recursive) dynamic macro-level modelling. The rescaling to obtain consistent welfare impacts on the aggregate household level, explained in Section 3, applies to households equally without restrictions on the sign of the welfare impact. For example, if a country experiences rapid improvements in energy efficiency over the next decade, then the overall impact in the macro-level assessment may show a more limited effect than suggested by the micro-level analysis (before rescaling). A positive rescaling factor would then shift the curves displayed in **Figure 27** upward to achieve consistency, and in some instances this could result in a sign change of the welfare effect. Further exploring the sensitivity of results with respect to different scaling or data harmonisation methods can be a topic for future research, along with the potential inclusion of income-side effects via wages and capital returns.

Figure 28. Distributional impacts within and across deciles



Source: JRC-GEM-E3.

One of the advantages of our approach is that it preserves the heterogeneity of the micro data. This enables a closer look into how impacts vary according to socio-economic characteristics of households. In **Figure 28**, we illustrate the heterogeneity by showing the variation within deciles in addition to the impact differences across deciles. The figure shows welfare impacts as measured by the compensating variation, a metric that is defined as the money transfer that would make the household as well off as before the policy reform. Positive values indicate that a household is better off after the policy reform than before, which we refer to as a welfare gain. Expenditure deciles, aggregating the EU households into 10 groups according to their total consumption expenditures, are shown on the vertical axis, while welfare impacts relative to total expenditures are displayed on the horizontal axis. This presentation is chosen to reflect – literally – the concepts of vertical (across deciles) and horizontal (within deciles) equity. Whiskers cover the range from the tenth to the ninetieth percentile, while the box represents the interquartile range. Black squares indicate the median within a decile, and the coloured lines connect the mean impact values of the different deciles.

The figure clearly shows that there is substantial impact heterogeneity within deciles. As such, the figure illustrates the benefit of extending economy-wide modelling tools with detailed household-level microdata. Although the bottom expenditure decile – Europe's 10% lowest-spending households – is better off than before the policy reform *on average* in the pricing-based scenario (CPRICE), this does not apply to *all* households in the bottom decile. In Section 2, and in particular in Section 2.4, we have presented a deep dive into various factors other than total income or expenditures that may affect the household-level impacts. The degree of urbanisation of the residence location, the socio-economic situation of the household reference person, and the type of household are among the characteristics that drive heterogeneity both within and across deciles.

As already highlighted in other studies (e.g. Rausch et al., 2011, Cronin et al., 2019, Pizer and Sexton, 2019), the impact differences within deciles can be significant, and even larger than the variation across deciles. Interestingly, the regulation-based scenario (REG) somewhat limits the within-decile variation as observed by the interquartile range. Therefore, this scenario may perform relatively well compared to the pricing-based scenarios in terms of horizontal equity considerations, which consider fairness on principles of impacting similar households in a comparable way. These findings confirm recent work of Fischer and Pizer (2019) on the horizontal equity effects of pricing-based (Pigouvian) energy policies.

5 Conclusions

This report presents an approach to extend economy-wide impact analysis to cover the rich diversity among households in Europe. To ensure a Just Transition to climate neutrality, quantitative assessments need to look beyond the surface of aggregate economic effects. Here, we take a deep dive into the heterogeneity of households that stems from differences in consumption patterns, and the corresponding variation in impacts from ramping up ambition levels of 2030 climate targets in the context of the EU Green Deal. The report therefore provides more background to the results presented in the Impact Assessment (EC, 2020a) accompanying the 2030 Climate Target Plan (EC, 2020b).

Results illustrate that climate policy-driven price changes may imply regressive effects, with higher welfare impacts relative to total expenditure for low-income households. These effects are driven by residential energy consumption, while fuel price increases for transport are more likely to affect middle income groups in most EU countries. The regressive pattern is more pronounced when impacts are expressed relative to income, as high-income households tend to save a larger proportion of their income. However, pricing-based climate policy generates tax revenue that has the potential to offset the regressive effect, as illustrated in our scenarios by redistributing on an equal-per-household basis. In this case, our results indicate that the 10% poorest households are better off after the policy reform on average, although this does not apply to each of these households as our results illustrate substantial impact heterogeneity within deciles. A lump sum tax recycling scheme redistributes tax revenue to all households, irrespective of income level, and is arguably a blunt instrument to achieve an equitable climate policy. Real-world policies can target compensatory measures more directly to low-income households to assist in the transition towards a low-carbon future. This would at the same time open up the scope for using part of the tax revenue for other purposes, such as sectoral and labour market restructuring to facilitate the decarbonisation of the economy in the coming years. Regulation-based climate policy can mitigate price-driven expenditure-side impacts in comparison to the pricing-based approach, but remains slightly regressive as there is no additional tax revenue that can be redistributed.

The approach presented here provides a meaningful way to enrich macro-analysis with micro detail, while ensuring a consistent aggregate welfare outcome. The top-down micro-accounting approach we develop for this exercise is perhaps more appropriate for near-term distributional impact assessment purposes, as we use the 2010 wave of the HBS and do not account for potential differences in behavioural reactions to price changes across income groups. We see various ways to improve the current set-up for future work. First, the impacts of a policy can occur on both the uses and sources side. On the sources side, factor prices would be affected by a carbon policy in potentially different ways, which will have differential impact on households in terms of their income receipts. A combination of expenditure, income and wealth data could be considered in future work. In addition, revenue might be collected from e.g. auctioning of emission permits that can be used to either lower other (e.g. labour) taxes or could be redistributed to households in various forms. The current study focused solely on the uses side of the policy impact, but ignored the sources side impacts – on wages, employment and return to capital – due to data constraints. Second, and related to the first point, due to data unavailability we could not take into account the benefits of self-produced agriculture, which may be particularly relevant for rural households in some of the EU countries who produce part of their own food. However, given the imposed small food price shocks, we generally expect the corresponding bias to be small. Third, the second-order impacts due to substitution possibilities are not accounted for in this second stage of macro-micro integrated approach. At the same time, given the assumption of identical price changes at the lower product level, this issue is expected to be less relevant compared to solely microeconomic partial equilibrium approach. At the more aggregate product/sector level, the substitution possibilities are already appropriately accounted for within the JRC-GEM-E3 model. Fourth, by construction, the top-down micro-accounting approach ignores the two-side feedback linkages between its macro and micro modules. More complex macro-micro models attempt to account for such inter-linkages (see Box 1). More refined labour supply modelling and interactions with tax and benefit systems can be covered in this way. Our approach offers a practical, reduced-complexity way forward that captures well the first order effects, in our view. The analysis sheds light on potential near-term welfare impacts, identify households affected most by the policy, and quantify the range of household-specific welfare implications within and across income or expenditure deciles. Hence, the framework we develop goes one step towards adding the Equity dimension as a fourth 'E' to the name of the JRC-GEM-E3 model, where the three E's currently represent Energy-Environment-Economy. The approach is capable of offering useful insights on the nature and effects of potential complementary policy responses in order to ensure that the transition to a climate-neutral economy leaves no one behind. Clearly, all limitations of this study mentioned here need to be kept in mind when conveying the key messages.

References

Araar, A., Dissou Y. and J-Y. Duclos (2011). Household incidence of pollution control policies: a robust welfare analysis using general equilibrium effects, *Journal of Environmental Economics and Management*, Vol. 61, No 2, pp. 227-243.

Banks, J., Blundell, R. and A. Lewbel (1996). Tax reform and welfare measurement: do we need demand system estimation? *Economic Journal*, Vol. 106, No 438, pp. 1227–1241.

Blundell, R., & Preston, I. (1998). Consumption inequality and income uncertainty. *The Quarterly Journal of Economics*, 113(2), 603-640.

Boccanfuso, D. and L. Savard (2007). Poverty and inequality impact analysis regarding cotton subsidies: A Mali-based CGE micro-accounting approach, *Journal of African Economies*, Vol. 16, No 4, pp. 629-659.

Bourguignon, F. and M. Bussolo (2013). Income distribution in computable general equilibrium modelling. In Dixon, P.B., Jorgenson, D.W. (Eds.), *Handbook of Computable General Equilibrium Modelling*, North Holland, Elsevier B.V., pp. 1383–1437.

Bourguignon, F. and L. Savard (2008). Distributional effects of trade reform: An integrated macro-micro model applied to the Philippines. In: Bourguignon, F., Bussolo, M. and L. Periera da Silva (Eds.), *The Impact of Macroeconomic Policies on Poverty and Income Distribution: Macro-Micro Evaluation Techniques and Tools*, World Bank and Palgrave, Washington DC, pp. 177-211.

Bourguignon, F., Robilliard, A.S. and S. Robinson (2005). Representative versus real households in the macroeconomic modelling of inequality. In Kehoe, T.J., Srinivasan T.N. and J. Whalley (eds.), *Frontiers in Applied General Equilibrium Modelling*, Cambridge, Cambridge University Press.

Brown, L., Harris A., Picton M., Thurecht L., Yap M., Harding A., Dixon P. and J. Richardson (2007). Linking microsimulation and macro-economic models to estimate the economic impact of chronic disease prevention". In Zaidi, A., Harding A. and P. Williamson (Eds.), *New Frontiers in Microsimulation Modelling*, Ashgate Publishing Limited, UK.

Buddelmeyer, H., Hérault, N., Kalb, G. and M. van Zijll de Jon, (2012). Linking a microsimulation model to a dynamic CGE model: Climate change mitigation policies and income distribution in Australia, *International Journal of Microsimulation*, Vol. 5, No 2, pp. 40-58.

Cai, M., & Vandyck, T. (2020). Bridging between economy-wide activity and household-level consumption data: Matrices for European countries. *Data in brief*, 105395.

Chen, S. and M. Ravallion (2004). Welfare impacts of China's accession to the world trade organization, *The World Bank Economic Review*, Vol. 18, No 1, pp. 29-57.

Chitiga, M. and R. Mabugu (2008). Evaluating the impact of land redistribution: A CGE microsimulation application to Zimbabwe, *Journal of African Economies*, Vol. 17 No 4, pp. 527-549.

Cockburn, J., Savard L. and L. Tiberti (2014). Macro-micro models. In C. O'Donoghue (ed.), *Handbook of Microsimulation Modelling* (Contributions to Economic Analysis, Volume 293), Emerald Group Publishing Limited, pp. 275 - 304.

Cronin, J. A., Fullerton, D., & Sexton, S. (2019). Vertical and horizontal redistributions from a carbon tax and rebate. *Journal of the Association of Environmental and Resource Economists*, 6(S1), S169-S208.

Deaton, A. and J. Muellbauer (1980). *Economics and Consumer Behavior*, Cambridge University Press: Cambridge.

European Commission (2019). *Energy prices and costs in Europe*, SWD(2019) 1 final, 9 January 2019, available at: https://ec.europa.eu/transparency/regdoc/rep/10102/2019/EN/SWD-2019-1-F1-EN-MAIN-PART-1.PDF

European Commission (2018). In-depth assessment accompanying COM (2018) 773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.

European Commission (2020a). Impact Assessment accompanying COM (2020) 562: Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people, *Staff Working Document* SWD(2020) 176 final.

European Commission (2020b). Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people. *Communication from the Commission* COM (2020) 562.

European Communities (2003). *Household Budget Surveys in the EU: Methodology and recommendations for harmonisation - 2003*, Office for Official Publications of the European Union, Luxembourg.

Eurostat (2015). Household Budget Survey 2010 Wave, EU Quality report, Version 2 July 2015. Eurostat Directorate-General of the European Commission.

Fischer, C. and W.A. Pizer (2019). Horizontal equity effects in energy regulation. *Journal of the Association of Environmental and Resource Economists*, Vol. 6, No S1, pp. S209-S237.

Friedman, J. and J. Levinsohn (2002). The distributional impacts of Indonesia's financial crisis on household welfare: a "rapid response" methodology. World Bank Economic Review, Vol. 16, No 3, pp. 397–423.

Hertel, T., Verma, M., Ivanic, M., Magalhaes, E., Ludena C. and A.R. Rios (2015). GTAP-POV: A framework for assessing the national poverty impacts of global economic and environmental change, *GTAP Technical Paper No. 31*, Revised September 2015.

Keramidas, K., Tchung-Ming, S., Diaz-Vazquez, A. R., Weitzel, M., Vandyck, T., Després, J., Schmitz, A., Rey Los Santos, L., Wojtowicz, K., Schade, B., Saveyn, B., Soria-Ramirez, A. (2018). Global Energy and Climate Outlook 2018: Sectoral mitigation options towards a low-emissions economy – Global context to the EU strategy for long-term greenhouse gas emissions reduction, *JRC Science for Policy Report*.

Kim, K., Kratena, K. and G.J.D. Hewings (2015). The extended econometric input-output model with heterogeneous household demand system, *Economic Systems Research*, Vol. 27, pp. 257-285.

Phimmavong, S. and R.J. Keenan (2020). Forest plantation development, poverty, and inequality in Laos: A dynamic CGE microsimulation analysis. *Forest Policy and Economics*, 111, 102055.

Pizer, W. A., & Sexton, S. (2019). The distributional impacts of energy taxes. *Review of Environmental Economics and Policy*, 13(1), 104-123.

Rausch, S., Metcalf, G.E. and J.M. Reilly (2011). Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households, *Energy Economics*, Vol. 33, pp. S20-S33.

Ravallion, M. and M. Lokshin (2008). Winners and losers from trade reform in Morocco. In: Bourguignon, F., Bussolo, M. and L. Periera da Silva (Eds.), *The Impact of Macroeconomic Policies on Poverty and Income Distribution: Macro-Micro Evaluation Techniques and Tools*, World Bank and Palgrave, Washington DC, pp. 27-60.

Renner, S., Lay, J. and H. Greve (2018). Household welfare and CO2 emission impacts of energy and carbon taxes in Mexico, *Energy Economics,* Vol. 72, pp. 222-235.

Sager L. (2019). Income inequality and carbon consumption: Evidence from environmental Engel curves, *Journal of Production Economics,* Vol. 84, in press.

Savard L. (2003). Poverty and income distribution in a CGE-household micro-simulation model: Top-down/bottom-up approach, CIRPÉE Working Paper 03-43, Université Laval, Québec, Canada.

Tiberti, L., Maisonnave, H., Chitiga, M., Mabugu, R., Robichaud, V. and S. Ngandu (2013). The economy-wide impact of the South African child support grant: A mirco-simulation-computable general equilibrium analysis, CIRPÉE Working Paper 13-03, Université Laval, Québec, Canada.

van Ruijven, B.J., O'Neill, B.C. and J. Chateau (2015). Methods for including income distribution in global CGE models for long-term climate change research, *Energy Economics*, Vo. 51, pp. 530–543.

Vandyck, T. and. D. Van Regemorter (2014). Distributional and regional economic impact of energy taxes in Belgium, *Energy Policy*, Vol. 72, pp. 190–203.

Weber, C.L. and H.S. Matthews (2008). Quantifying the global and distributional aspects of American household carbon footprint, *Ecological Economics*, pp. 379-391.

Weitzel, M., Vandyck, T., Keramidas, K., Amann, M., Capros, P., den Elzen, M., Frank, S., Tchung-Ming, S., Vázquez, A.D. and B. Saveyn (2019). Model-based assessments for long-term climate strategies. *Nature Climate Change*, Vol. 9, No 5, pp.345-347.

List of abbreviations and definitions

CGE	Computable General Equilibrium
COICOP	Classification of Individual Consumption by Purpose
ETS	Emission Trading System
HBS	Household Budget Survey
JRC-GEM-E3	Joint Research Centre's General Equilibrium Model for Economy-Energy-Environment
PRIMES	Price-Induced Market Equilibrium System
TD-MA	Top-down micro-accounting
QUAIDS	Quadratic Almost Ideal Demand System

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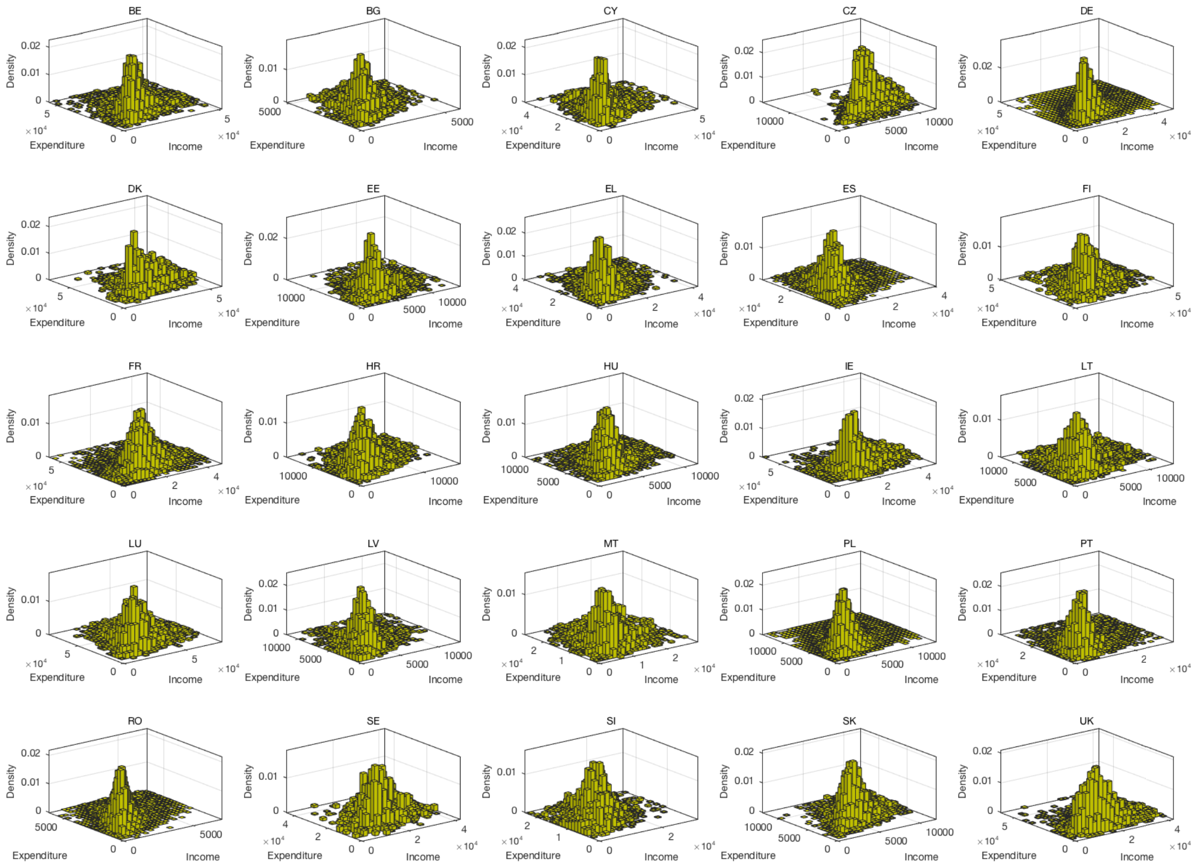
Annex 1. Supplementary figures

Figure A.1. Joint distributions of equivalised income and consumption expenditure



Annex 2. Supplementary tables

Table A.1. Proportion of negative expenditures for CP04, with and without sampling weights (%)

	CP041	CP042	CP043	CP044	CP045	CP0451	CP0452	CP0455
	Population proportion of negative consumption expenditures							
CZ				0.01	0.03	0.03	0.22	0.06
DK	0.18	0.09			0.79	0.21	0.06	1.62
FR	0.01							
SE			0.06					
UK					0.45	0.43	0.34	
	Sample proportion of negative consumption expenditures							
CZ				0.03	0.03	0.03	0.27	0.07
DK	0.20	0.12			0.68	0.24	0.04	1.65
FR	0.01							
SE			0.05					
UK					0.42	0.44	0.30	

Note: Own elaboration using Eurostat's HBS 2010 wave.

Table A.2. Proportion of negative expenditures for CP07, with and without sampling weights (%)

	CP071	CP072	CP073	CP0723	CP0724	CP0731	CP0733
	Population proportion of negative consumption entries (%)						
CZ							0.03
DK	2.08						
EE	1.52						
FI					0.05		
LU		0.50		1.05			
LV	0.30						
SE	2.21		0.07			0.07	
SI					0.12		
	Sample proportion of negative consumption entries (%)						
CY							
CZ							0.03
DK	2.09						
EE	1.73						
FI					0.08		
LU		0.52		1.15			
LV	0.29						
SE	2.74		0.05			0.05	
SI					0.13		

Note: Own elaboration using Eurostat's HBS 2010 wave.

Table A.3. JRC-GEM-E3 and COICOP-HBS classification and mapping

Code	JRC-GEM-E3 consumption sectors
sec1	Food beverages and tobacco
sec2	Clothing and footwear
sec3	Housing and water charges
sec4	Fuels and power
sec5	Household equipment and operation excluding heating and cooking appliances
sec6	Heating and cooking appliances
sec7	Medical care and health
sec8	Purchase of vehicles
sec9	Operation of personal transport equipment
sec10	Transport services
sec11	Communication
sec12	Recreational services
sec13	Miscellaneous goods and services
sec14	Education

Code	COICOP-HBS products	Mapping
cp011	Food	sec1
cp012	Non-alcoholic beverages	sec1
cp021	Alcoholic beverages	sec1
cp022	Tobacco	sec1
cp031	Clothing	sec2
cp032	Footwear including repair	sec2
cp041	Actual rentals for housing	sec3
cp043	Maintenance and repair of the dwelling	sec3
cp044	Water supply and miscellaneous services relating to the dwelling	sec3
cp0451	Electricity	sec4
cp0452	Gas	sec4
cp0453	Liquid fuels	sec4
cp0454	Solid fuels	sec4
cp0455	Heat energy	sec4
cp051	Furniture and furnishings, carpets and other floor coverings	sec5
cp052	Household textiles	sec5
cp053	Household appliances	sec6
cp054	Glassware, tableware and household utensils	sec5
cp055	Tools and equipment for house and garden	sec5
cp056	Goods and services for routine household maintenance	sec5
cp061	Medical products, appliances and equipment	sec7
cp062	Out-patient services	sec7
cp063	Hospital services	sec7
cp071	Purchase of vehicles	sec8
cp0721	Spare parts and accessories	sec9
cp0722	Fuels and lubricants	sec9
cp0723	Maintenance and repair of personal transport equipment	sec9
cp0724	Other services in respect of personal transport equipment	sec9
cp0731	Passenger transport by railway	sec10
cp0732	Passenger transport by road	sec10
cp0733	Passenger transport by air	sec10
cp0734	Passenger transport by sea and inland waterway	sec10
cp0735	Combined passenger transport	sec10
cp0736	Other purchased transport services	sec10
cp081	Postal services	sec11
cp082	Telephone and telefax equipment	sec11
cp083	Telephone and telefax services	sec11
cp091	Audio-visual, photographic and information processing equipment	sec5
cp092	Other major durables for recreation and culture	sec5
cp093	Other recreational items and equipment, gardens and pets	sec12
cp094	Recreational and cultural services	sec12
cp095	Newspapers, books and stationery	sec13
cp096	Package holidays	sec12
cp10	Education	sec14
cp111	Catering services	sec12
cp112	Accommodation services	sec12
cp121	Personal care	sec13
cp123	Personal effects n.e.c.	sec13
cp124	Social protection	sec13
cp125	Insurance	sec13
cp126	Financial services n.e.c.	sec13
cp127	Other services n.e.c.	sec13

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