Master's Thesis

Examining the Relationship between Household Income and Environmental Footprints in the European Union

Name: Aaron Paris

Study programme: Master of Science Industrial Ecology
Leiden University & Delft University of Technology

Student no. Leiden: s3422747

Student no. Delft: 5890780

First supervisor: Dr. Sebastiaan Deetman
Institute of Environmental Sciences (CML)
Leiden University

Second supervisor: Dr. Enno Schröder
Faculty Technology, Policy and Management (TPM)
Delft University of Technology

Word count: 16843 (without abstract, literature, appendices, tables and captions)

Date: 7th of August 2024

Universiteit Leiden
The Netherlands

TU Delft Delft University of Technology

Abstract

Reducing the environmental impact of household consumption is widely recognised to be essential for achieving sustainable societies. Designing targeted policies requires detailed data on which households contribute how much to environmental footprints.

While many studies look into average environmental footprints of households, assessments across household income remain limited and focused on carbon, energy or material footprints. Furthermore, the existing literature is dominated by Input-Output Analysis despite increasing data availability making it possible to use process-based Life Cycle Assessment (pLCA) as well, with the latter offering potentially much higher levels of detail.

This study addresses this gap by estimating the environmental footprints from the consumption of household goods, appliances and food for 200,000 European households from 24 European countries and the European Union (EU) using a pLCA approach. To do so, pLCAs for the EU covering 16 impact categories are mapped to expenditure data from the EU Household Budget Survey (HBS).

The research question is: *How are the environmental footprints from the consumption of household goods, appliances and food distributed across household income groups in the EU?*

The study focused on carbon, water use, land use and resource use (minerals and metals) footprints, which are considered to be headline indicators. The results show that the carbon, water use and land use footprints at EU-level (without Austria, Italy and Germany), are dominated by the consumption of food and therefore largely independent from household income. The resource use footprint is dominated by appliances. The 10% households with the highest income have, on average, 2.8 times the carbon footprint, 6.4 times the water use footprint, 3.4 times the land use footprint and about 8.2 times the resource footprint of households belonging to the lowest income decile. Income inequality (with about 28.6 times the mean household income for top decile vs bottom decile households at EU-level) is much larger. At the same time, the range of household environmental footprints is large in all impact categories due to factors other than household income. The difference to existing literature, which generally finds a stronger connection between income and impacts, particularly for the carbon footprint, mainly stems from the exclusion of mobility and housing.

The study furthermore discusses the significant limitations of HBS data and outlines what improvements are required to get more robust, comprehensive and detailed estimates of household environmental footprints. Ideally, future HBS would record physical quantities and/or prices along with the expenditures, which would make it possible to consider product quality differences. Using digital tools might make it possible to record consumption all year round or even for multiple years and thus mitigate the bias from infrequent purchases.

Future research should include services, housing and mobility and use regionalised impact data and find mitigation strategies for infrequent purchases and the product quality problem. The pLCA approach should be upheld due to the granularity it offers, for example for the assessment of the distribution of EFs under scenarios.

Abbreviations

B50	Bottom 50%
CC	Climate change
CF	Carbon footprint
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
COICOP	Classification of Individual Consumption by Purpose
D1 to D10	Deciles 1 to 10
DAP	Detailed Average Prices
ECOICOP	European Classification of Individual Consumption by Purpose
EF	Environmental Footprint
EF3.1	Environmental Footprint 3.1
EU	European Union
gSbeq	Kilograms of antimony equivalents
HBS	Household Budget Survey
IE	Industrial Ecology
JRC	Joint Research Centre
km^3 water eq	Cubic kilometres of water equivalents
kPt	Thousand points
LCA	Life Cycle Assessment
LU	Land use
MRD	Resource use, minerals and metals
MRIO	Multi-Regional Input-Output Analysis
No.	Number
ph. unit	Physical units
pLCA	Process-based Life Cycle Assessment
PPP	Purchasing Power Parities
RPI	Representative Product Impacts
RU	Reference unit
T10	Top 10%
WU	Water use

The abbreviations for the countries are the official EU member state country codes (see Appendix 2).

Table of Contents

Abstract I
Abbreviations II
1 Introduction 1
2 Literature review 1
3 Research objective, research question and scope 3
4 Methods and data 4
4.1 Household expenditures 4
4.1.1 Data 4
4.1.2 Pre-processing 7
4.1.2.1 Filtering 7
4.1.2.2 Dealing with negative values 9
4.1.2.3 Harmonising values at ECOICOP levels 10
4.1.2.4 Outlier treatment 11
4.1.2.5 Adding reference quantities and units for physical quantity data 12
4.1.3 Resulting household expenditure dataset 12
4.2 Prices 13
4.2.1 Purchasing Power Parities (PPP) dataset 13
4.2.2 Detailed Average Prices (DAP) dataset 14
4.3 Conversion to physical quantities 15
4.4 Impact intensities 18
4.4.1 Representative product impacts (RPI) 18
4.4.2 Ecoinvent 20
4.5 Conversion to environmental impacts 20
4.6 Aggregation 23
5 Results 24
5.1 Mean decile Environmental Footprints 24
5.2 Household Environmental Footprints 27
5.3 Comparing countries 29
5.4 Sensitivity analysis 31
6 Discussion 32
6.1 Implications 32
6.2 Limitations 33
6.2.1 Limitations regarding household expenditures 33
6.2.2 Limitations regarding prices and conversion to physical quantities 35
6.2.3 Limitations regarding impact intensities and conversion to impacts 35
6.2.4 Other limitations 36
6.3 Future research and improving data 36
7 Conclusions 38
Data availability 39
Code availability 39
Acknowledgements 39
References IV
Appendix X

1 Introduction

Increasing environmental degradation and economic inequality are among the most pressing challenges the world is facing. Socio-economic trends have accelerated in unison with pressures on the Earth's system [1]. The world's material footprint, for example, has more than doubled between 1990 and 2019 [2].

While global economic inequality between countries has declined over the past two decades, it remains at alarming levels with the richest 10% of the world's population owning 76% of all wealth and taking 52% of global income [3]. Furthermore, inequality within countries has increased [3].

In the past decade, the availability of data on and understanding of monetary inequality have improved significantly [3]. However, designing policies to mitigate environmental pressures and reduce economic inequality requires a thorough understanding of their relationship.

Existing studies predominantly look into differences between countries (e.g., [4, 5]) while studies at household-level (e.g., [6, 7]) seldom examine distributional aspects. According to an estimate by Ivanova *et al.* [6], household consumption contributes between 50% and 80% to global resource use and is therefore highly relevant for reducing impacts. While increasing attention is paid to the connection of energy use as well as carbon emissions and income [8], studies looking into the distribution of other environmental footprints (EFs) remain limited.

This study aims to improve the understanding of the relationship between household income and EFs from household consumption.

2 Literature review

Environmental Footprints (EFs) are indicators of human pressures on the environment and the resulting environmental changes and impacts [9]. They are typically based on the principle of consumption-based accounting, attributing direct and indirect impacts of the life cycle of products to the consumer [10]. EFs are not to be confused with the ecological footprint, which seeks to convert impacts from consumption into a measure of biologically productive land and sea required to sustain it [11].

EFs are typically assessed through Life Cycle Assessment (LCA), accounting for impacts during production, distribution, use and disposal of products. The main approaches for calculating EFs are typically based on process-based LCA (pLCA), Multi-Regional Input-Output Analysis (MRIO) or their combination [12].

pLCA is based on the physical descriptions of processes in a product life cycle and thus able to represent specific technologies and conditions, e.g. basic and luxury products [12]. The descriptions of the processes include inputs from and outputs to the economy, i.e. intermediate products, and the environment, i.e. emissions or raw material extraction. The main limitation of pLCA is high data requirements, which make it necessary to exclude parts of the economy [12], e.g. services [13], and cause a generally worse regional disaggregation than MRIO [14].

MRIO builds on links among sectors of the economy derived from national accounts and sector-average environmental impacts [12]. The main limitations include low product-level resolution [14], limited coverage and granularity of elementary flows [13], i.e. material or energy flows from or to the environment [15], as well as the inability to assess other than average environmental impacts [12]. More or less sustainable ways of producing the same product, for example, cannot be distinguished. In contrast to pLCA, MRIO is typically bound to current or past production recipes and not used to assess a reduction of impacts from technological development production processes or products [16]. Furthermore, analysing the contribution of life cycle stages (e.g. the use phase) to impacts is not possible with the MRIO-based approach [17]. While it is possible to say, for example, what share of the environmental impacts is caused by the provision of electricity, it is not possible to distinguish the impacts from electricity used in the production and the use phase of a product. In contrast to pLCA, MRIO provides a framework that is consistent with accounting conventions used by national statistical offices [13]. Note that this does not mean that MRIO databases are fully in line with national statistics. Building MRIO databases requires many steps of harmonising and linking national statistics and data from other sources [18].

pLCA is typically used to evaluate the environmental impacts of specific products while MRIO is applied to product groups or sectors. Recently, however, pLCAs of representative products have been combined and upscaled [13] to assess impacts at macro-level, for example a category of household consumption (e.g. [17]), while MRIO has become detailed enough to look at specific products [14].

A systematic comparison of product-level estimates of carbon footprints from ecoinvent and EXIOBASE, two popular databases for pLCA and MRIO respectively, found a difference by more than a factor of two for half the products considered [14]. Interestingly, the authors found no clear pattern. In about half the cases, the pLCA-based carbon footprint was higher, and in the other half, the MRIO-based footprint was higher. Thus, they could not confirm the general expectation that EFs from pLCA are lower due to neglecting parts of the economy. With regard to macro-level indicators, Castellani *et al.* [13] compare estimates of the average household EFs in the European Union (EU) using pLCA and MRIO. They find that MRIO results are higher in 10 of 14 impact categories, with the largest difference being 9 times the pLCA results. Potential explanations include internal uncertainties of both approaches as well as coverage and level of detail of elementary flows, i.e. the exchanges with the environment. The choice of products to include, that is necessary when using pLCA due to limited data availability, adds further uncertainty [13]. Hybrid approaches can mitigate known issues of both methods but are rarely applied so far [19].

Because combining pLCA data for many representative products is a new development, most studies looking into EFs at household level are based on MRIO. Typically, household EFs based on MRIO are calculated without allocating investment and public consumption, the two other components of the final demand of an economy [10]. Thus, they do not account for the total environmental impacts of an economy. This is also the case for pLCA approaches.

Physical quantities of household consumption are seldom available [10]. Therefore, MRIO-based studies usually derive impact intensities per monetary unit for the consumption categories and map those to household expenditure data as a proxy for physical consumption [20], while pLCA studies convert monetary expenditure to physical quantities using mean prices for the consumption category. A significant limitation of both approaches is that quality and price differences of similar products with similar environmental impacts cannot be taken into account [20]. A sustainably produced bread, for example, likely has lower impacts than a standard one but can have a much higher price. Because both approaches rely on average impacts intensities and/or prices, higher monetary expenditures simply mean higher impacts, although they could just represent the consumption of products with higher prices. This, so-called, product quality problem makes it difficult to model different consumer behaviours, for example paying premiums for reduced environmental impacts, or eco-innovations [10]. Also, it can lead to overestimation of EFs of high-income households [21], which typically buy products with higher prices.

Most research studying the environmental footprint focuses on the average footprints within a geographic boundary like countries (e.g., [6]), neighbourhoods (e.g., [20]) or urban/rural areas (e.g., [22]). Increasingly, however, studies also look into the connection of environmental impacts of households and household characteristics. Most common is the assessment of the relationship of EFs and income. The methods can be divided into bottom-up and top-down [10]. Bottom-up studies estimate the EFs of households using household expenditure data and relate it to income [10]. Top-down methods infer the distributions of EFs from income distributions at country-level assuming a constant and deterministic relationship between income and the EFs, which is typically derived from bottom-up studies [10] (e.g., [8, 23]). This relationship is described using the elasticity of the EF, i.e. the increase of the EF when income respectively expenditure rises by 1% [10]. An elasticity equal to 1 would mean that income or expenditure and EF are proportional, while an elasticity below 1 shows that EF rises less than proportionally with income respectively expenditure. Because top-down studies assume a constant elasticity across the full income distribution, they conceal the variability at a given income level [10, 24] and need to be considered a rough estimation of the real distribution of EFs [25].

Bottom-up estimates are more accurate [8]. However, as income data is not always available, they often assess the relation of EFs and expenditure instead (e.g., [26–28]). Notably, of the studies claiming to examine the distribution of the EFs by income, some use expenditure as proxy and thus actually evaluate the distribution of EFs by household expenditure [10] (e.g., [29–33]). Because households do

not spend all of their income, these arguably do not contribute to the understanding of how income and EFs relate. High-income households will typically spend less of their income [10], meaning that the ratio of expenditure to income is not the same in all income groups and using expenditure as proxy for income is questionable. Therefore, more studies using income data are required.

Bottom-up studies assessing the relationship of EFs and income predominantly look into carbon footprints (e.g., [24, 34–42]. Some focus on energy (e.g., [43]), material (e.g., [35, 44]) or nitrogen (e.g., [45]) footprints. Also, comparably few studies include other household characteristics as control variables in their estimates [10], all of which look into carbon or energy footprints only (e.g., [22, 46–51]). Including control variables is important because of the "horizontal" variability of EFs across income groups [10]. How the EFs change with household income may depend on other variables, that affect both the income and the EFs [10]. The household size, for example, likely has an effect on household income and certainly on the EFs. Two households with different income but the same household size could show similar EF and vice versa two households with the same income but different size might show vastly different EFs. Therefore, estimating the true effect of income on EFs requires the household size (and other variables) as control variable. For the top down studies, where the EFs are derived only from the assumed relation of income and EF, income elasticities estimated without control variables are used [10]. Of the few studies using pLCA, most calculate EFs of one or multiple product groups of average households or per capita at EU- [13, 17], country- [52–55] or city-level [56, 57]. The few studies that combine pLCA with household characteristics look into few impact categories [16, 21, 58] or assess clusters of households without looking into the relationship of footprints and specific variables like income [19, 59]. To the authors' knowledge, no study has yet assessed the relation of multiple EFs and household income for multiple countries using pLCA, despite the advantage of granular results.

3 Research objective, research question and scope

In light of this literature gap the research objective of this study is to understand the distribution of environmental footprints (EFs) from the consumption of household goods, appliances and food across income on household level within the European Union (EU) and its member states. When income is referred to in this study, it always means the total yearly monetary household income after taxes.

The **research question** is: *How are the environmental footprints from the consumption of household goods, appliances and food distributed across household income groups in the EU?*

The EU is chosen as geographic scope for three reasons: (a) data availability, (b) responsibility for significant share of environmental impacts [18] and (c) explicit ambition and efforts to become more sustainable, e.g. circular and carbon neutral [60]. One key pillar of these efforts is promoting sustainable consumption [61], which requires a detailed understanding of how household characteristics, consumption practices and EFs relate. Data was available for all current member states except for Austria, Germany and Italy. For simplicity, the 24 countries included in this study will be referred to as EU.

The study focuses on four environmental impact categories that are often considered headline indicators (carbon, material, water use and land use footprints) [62]. The advantage of this small set of indicators is the reduction of information overload for decision makers. Steinmann *et al.* [62] show that these four indicators are highly representative of the general damage to humans and the environment. Unfortunately, the material footprint, is not covered by the Environmental Footprint 3.1 (EF3.1) impact assessment method that is applied in this study. Instead, the impact category "Resource use, minerals and metals" is used.

The study focuses on household goods, appliances and food to keep the scope manageable and because of (a) their relevance for total environmental impacts, with food and household goods together contributing about 45% to the carbon footprint, 84% to the land use footprint and 55% to the water use footprint of an average European citizen in 2010 [17]; (b) data availability; and (c) their direct connection to household consumption decisions. Consumption patterns in mobility and housing are likely more influenced by long-term decisions and structural factors, such as public infrastructure. Whether a household buys a vehicle and what type of vehicle presumably depends significantly on the

available infrastructure, such as public transport availability, parking spots or charging stations in the case of electric cars. Therefore, while they are critical components of environmental impact, their influence is significantly mediated through structural changes rather than direct consumer choices directly. In contrast, the consumption of food, households goods and appliances mainly depends on preferences and available funds, especially because the required public infrastructure like electricity is already largely present. They are also consumed much more frequently, with food and non-durable household goods being a daily need. Therefore, consumer can much more quickly adjust their consumption patterns and policy interventions targeting sustainable consumption can thus have a more immediate effect.

Previous studies find that the impacts of appliances are negligible for the carbon, land use and water use footprint of European citizens [17]. They are nevertheless included because they make up 41% of the depletion of mineral and metal resources [17], which is going to become more important in the future since the demand for minerals and metals is projected to increase rapidly with the energy transition [63]. Services, living animals and immaterial products, such as software, are excluded from the scope due to missing impact data.

Household goods, appliances and food are referred to as "baskets of consumption" or simply "baskets" in the remainder of the study. The temporal scope is the household consumption in the year 2015.

4 Methods and data

The research flow of this study is shown in Figure 1. It consists of six main steps: acquiring and pre-processing household expenditure data (Section 4.1), acquiring and pre-processing price data (Section 4.2), converting the monetary household expenditure into physical units using the prices (Section 4.3), acquiring and pre-processing impact intensity data (Section 4.4), converting the physical consumption quantities into environmental footprints (EFs) with the impact intensities (Section 4.5) and, finally, aggregating the resulting impacts by households and income decile (Section 4.6). In this Chapter, the data and methods for each step are described in detail.

An overview of all used datasets and their version as well as where to find them can be found in the Section Data availability. The datasets used follow similar classification systems but contain slight differences. Appendix 3 contains a brief discussion of that issue and how compatibility was ensured.

4.1 Household expenditures

The main data needed for the objective of this study are household expenditures on different groups and income of households.

4.1.1 Data

The first main data source is the European Union (EU) Household Budget Survey (HBS) [64], a harmonisation of national HBSs conducted by the member states. It contains yearly expenditures of households for various consumption purposes. The expenditures are provided including non-deductible Value Added Tax and in Euro for all countries [65].

The EU HBS is published by Eurostat in five-year intervals. Because of pending updates to the 2020 version, the HBS from 2015 was chosen for the analysis. It includes data on 272,046 households from 26 countries (all current EU member states without Austria) and their yearly expenditure in 298 consumption categories [65]. These categories correspond to the most granular level, the subclass (denoted in 5-digits), of the European Classification of Individual Consumption by Purpose (ECOICOP) [65], which provide product-level data. The other three levels, from next highest to lowest granularity are class (4-digits), group (3-digits) and division (2-digits), representing increasingly aggregated product groupings. To give an example: The subclasses "Coffee" (01211), "Tea" (01212) and "Cocoa and powdered chocolate" (01213) together comprise the class "Coffee, tea and cocoa" (0121). This class builds, together with "Mineral waters, soft drinks, fruit and vegetable juices" (0122), the group "Non-alcoholic beverages" (012). This group is part of the division "Food and non-alcoholic beverages" (01), which in total contains two groups, eleven classes and 61 subclasses. Appendix 3 contains a brief discussion of the ECOICOP classification.

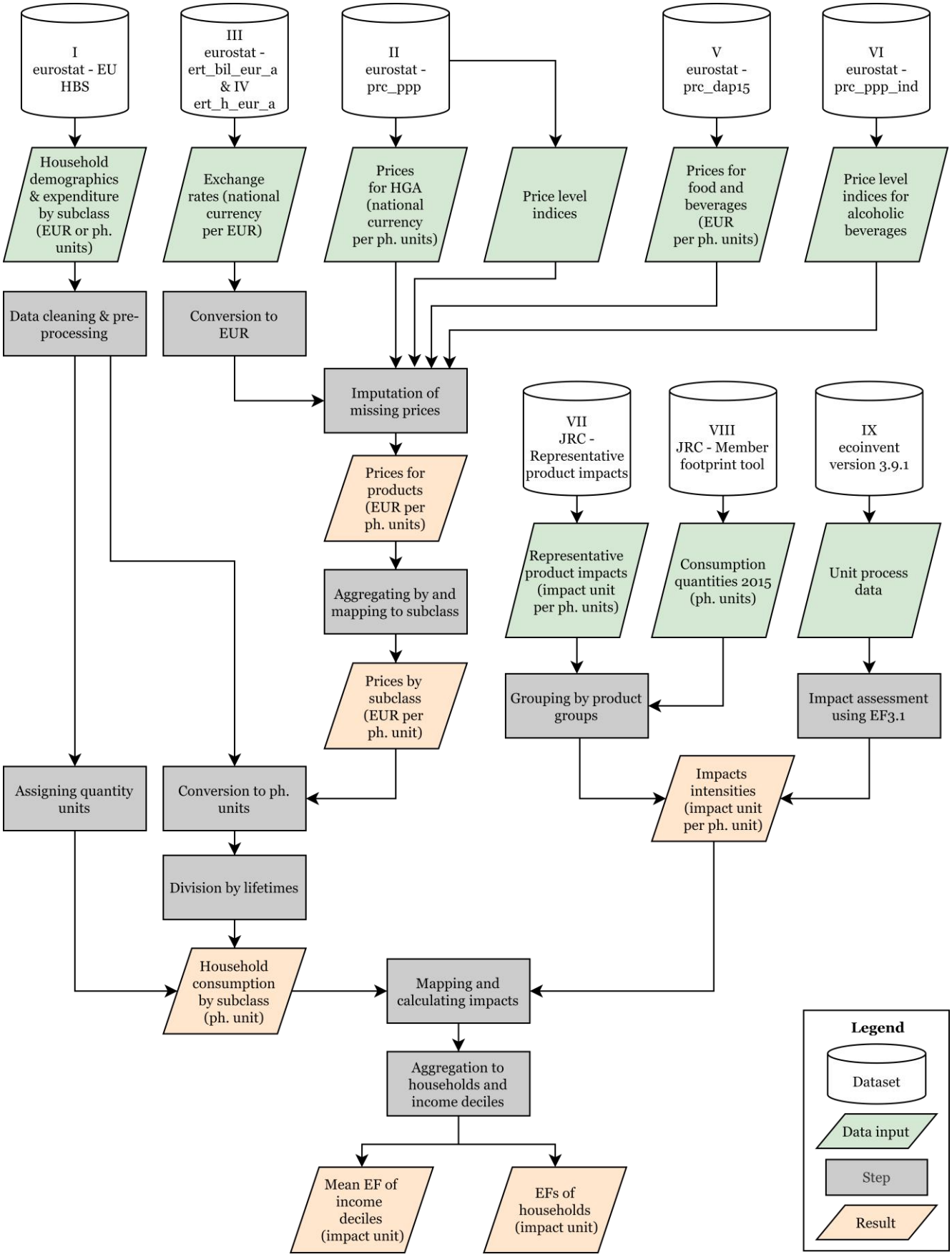

Figure 1: Research flow diagram with the most important steps. Physical units (ph. unit) vary for the different subclasses and are therefore not explicitly disclosed. The Roman numbers refer to the number of the dataset. The same number can be found in the Data availability section and the code for the analysis.

Apart from data on expenditures, the HBS covers multiple variables on household characteristics, like household income, age composition or region. Furthermore, the HBS provides household weights to correct for sampling and response bias [65]. These were applied throughout the study.

Next to monetary expenditure, the EU HBS provides physical consumption quantities for the ECOICOP divisions 01 ("Food and non-alcoholic beverages") and 02 ("Alcoholic beverages, tobacco and narcotics") for 15 of the 26 countries [65]. Variables referring to narcotics are suppressed in the data and tobacco will be excluded later due to missing impact data. The remaining items in divisions 01 and 02 together comprise the basket of consumption food in this study. Of the 11 countries that do not provide physical quantities, 10 include the expenditure values for food. Only Germany does neither provide physical consumption quantities nor expenditures for divisions 01 and 02. This means that it is not possible to calculate EFs from the consumption of food for the German households. The HBS data comes with several limitations, e.g. not fully aligned national methodologies [10]. One other important limitation are infrequent purchases. The expenditure data is collected through short-term diaries with a recording period of one week to one month in the case of the EU HBS [66]. This means that some households may not record certain expenditures despite continued consumption from existing stocks [48]. Conversely, recorded expenditures might exceed actual consumption if purchased stocks last beyond the observation period or items are bought infrequently [48]. If one household bought a washing machine, for example, in the recording period while another bought it at another time that year, the HBS data will only show it for one of the households while the other one displays a false zero. Furthermore, because the expenditures need to be annualised, the purchase of the one washing machine might be scaled up from the recording period, depending on how the data is processed by the responsible national statistics authority. This can lead to an overestimation of the consumption of items that are not bought regularly. This means that the consumption amounts of each household might be wrong. Existing literature deals with this issue mainly by analysing mean consumption of income groups, assuming that the mean expenditure is balanced by using a larger sample of households [67]. However, is it not clear how representative these really are [67]. Although the mean expenditure for the sample is assumed balanced [67], as shown for Belgium for example [68], distributional analysis is challenging due to inflated high and zero values, misrepresenting actual consumption [48].

Some countries correct for this error by using data from questionnaires and interviews, that include retrospective questions for high expenses and fixed costs [66]. However, there is no general overview and/or transparency on how member states process the data. The infrequent purchases problem was partially corrected for by replacing the top 1% expenditure and physical consumption values per subclass (see Section 4.1.2.4), following Büchs *et al.* [48].

While the above discussed issue is important for having the right consumption quantity in the reference year, the incompatibility of the consumption of durable goods and the reference period of one year is another issue. Households that own a durable good but did not buy it during the year in scope will not record its impacts. This is partially balanced by the multiple durable goods included. A household owning a washing machine and a dishwasher might, for example, have bought the former in the reference year but the other not. However, because goods differ in environmental impact intensity, this will not fully even the difference across years. This does not mean that the consumption of a households within that specific year is misrepresented, because the survey would indeed show what the household consumed. But it does mean that the average EF of that household over multiple years might be. It is a normative decision, if the average EFs or the EFs for one specific year is of interest.

If the average EFs are of interest, dividing by the average product lifetime would distribute the impacts the consumption in a particular subclass across the years. However, because the present data only records the consumption within a specific year, i.e. only of the goods bought by that household in that specific year, there is no data on the other durable goods owned by that household. Therefore, dividing by the lifetime would just allocate the impacts for the goods bought in that year without allocating the impacts for goods bought in other years. Thus, this would underestimate the overall impacts.

While the impacts for one household might therefore be misrepresented, the average for an income group should be accurate with a large enough sample size because the infrequency across years for

single households should balance each other out. One household of that year will have bought the dishwasher instead of the washing machine, for example.

4.1.2 Pre-processing

Multiple steps of pre-processing were needed to prepare the consumption data for the analysis.

4.1.2.1 Filtering

First, foreign expenditures had to be excluded from the analysis because they are only provided at the most aggregate ECOICOP level, the division. Also, two countries were excluded from the study entirely: Germany because it does neither provide expenditure nor quantities for food consumption and Italy because it does not disclose the household incomes. The remaining data included 204,620 households.

Also, the data was filtered by the consumption categories. Of the 298 subclasses in total, 55 are out of scope because they belong to housing (division 04) or transport (division 07), living animals (09214 and 09341) or software (09133). Another 79 subclasses are not within scope because they represent services. 22 subclasses, all belonging to the basket household goods, had to be dropped because of missing impacts or price data, leaving a total of 141 subclasses for which the EFs were calculated in the end. Table 1 shows these subclasses and the higher ECOICOP levels they belong to. Appendix 4 includes an overview on the coverage per division and why the specific subclasses had to be excluded, while Appendix 1 contains the details for each subclass and examples of products they include.

Table 1: Included ECOICOP subclasses, the higher ECOICOP levels they belong to [65]. The assigned baskets of consumption are denoted as F for food, HG for household goods and A for appliances.

Division	Group	Class	Subclass	Basket
01 Food and non-alcoholic beverages	011 Food	0111 Bread and cereals	01111 Rice	F
			01112 Flours and other cereals	F
			01113 Bread	F
			01114 Other bakery products	F
			01115 Pizza and quiche	F
			01116 Pasta products and couscous	F
			01117 Breakfast cereals	F
			01118 Other cereal products	F
		0112 Meat	01121 Beef and veal	F
			01122 Pork	F
			01123 Lamb and goat	F
			01124 Poultry	F
			01125 Other meats	F
			01126 Edible offal	F
			01127 Dried, salted or smoked meat	F
			01128 Other meat preparations	F
		0113 Fish and seafood	01131 Fresh or chilled fish	F
			01132 Frozen fish	F
			01133 Fresh or chilled seafood	F
			01134 Frozen seafood	F
			01135 Dried, smoked or salted fish and seafood	F
			01136 Other preserved or processed fish and seafood-based preparations	F
		0114 Milk, cheese and eggs	01141 Milk, whole, fresh	F
			01142 Milk, low fat, fresh	F
			01143 Milk, preserved	F
			01144 Yoghurt	F
			01145 Cheese and curd	F
			01146 Other milk products	F
			01147 Eggs	F
		0115 Oils and fats	01151 Butter	F
			01152 Margarine and other vegetable fats	F
			01153 Olive oil	F
			01154 Other edible oils	F
			01155 Other edible animal fats	F
		0116 Fruit	01161 Fresh or chilled fruit	F
			01162 Frozen fruit	F
			01163 Dried fruit and nuts	F
			01164 Preserved fruit and fruit-based products	F

Table continued on next page.

Division	Group	Class	Subclass	Basket
01 Food and non-alcoholic beverages		0117 Vegetables	01171 Fresh or chilled vegetables other than potatoes and other tubers	F
			01172 Frozen vegetables other than potatoes and other tubers	F
			01173 Dried vegetables, other preserved or processed vegetables	F
			01174 Potatoes	F
			01175 Crisps	F
			01176 Other tubers and products of tuber vegetables	F
		0118 Sugar, jam, honey, chocolate and confectionery	01181 Sugar	F
			01182 Jams, marmalades and honey	F
			01183 Chocolate	F
			01184 Confectionery products	F
			01185 Edible ices and ice cream	F
			01186 Artificial sugar substitutes	F
		0119 Food products NEC	01191 Sauces, condiments	F
			01192 Salt, spices and culinary herbs	F
			01193 Baby food	F
			01194 Ready-made meals	F
			01199 Other food products NEC	F
	012 Non-alcoholic beverages	0121 Coffee, tea and cocoa	01211 Coffee	F
			01212 Tea	F
			01213 Cocoa and powdered chocolate	F
		0122 Mineral waters, soft drinks, fruit and vegetable juices	01221 Mineral or spring waters	F
			01222 Soft drinks	F
			01223 Fruit and vegetable juices	F
02 Alcoholic beverages, tobacco and narcotics	021 Alcoholic beverages	0211 Spirits	02111 Spirits and liqueurs	F
			02112 Alcoholic soft drinks	F
		0212 Wine	02121 Wine from grapes	F
			02122 Wine from other fruits	F
			02123 Fortified wines	F
			02124 Wine-based drinks	F
		0213 Beer	02131 Lager beer	F
			02132 Other alcoholic beer	F
			02133 Low and non-alcoholic beer	F
			02134 Beer-based drinks	F
03 Clothing and footwear	031 Clothing	0311 Clothing materials	03110 Clothing materials	HG
		0312 Garments	03121 Garments for men	HG
			03122 Garments for women	HG
			03123 Garments for infants- 0-to-2-years and children-3- to-13-years	HG
		0313 Other articles of clothing and clothing accessories	03131 Other articles of clothing	HG
			03132 Clothing accessories	HG
	032 Footwear	0321 Shoes and other footwear	03211 Footwear for men	HG
			03212 Footwear for women	HG
			03213 Footwear for infants and children	HG
05 Furnishings, household equipment and routine household maintenance	051 Furniture and furnishings, carpets and other floor coverings	0511 Furniture and furnishings	05111 Household furniture	HG
			05112 Garden furniture	HG
			05113 Lighting equipment	HG
			05119 Other furniture and furnishings	HG
		0512 Carpets and other floor coverings	05121 Carpets and rugs	HG
			05122 Other floor coverings	HG
	052 Household textiles	0520 Household textiles	05201 Furnishing fabrics and curtains	HG
			05202 Bed linen	HG
			05203 Table linen and bathroom linen	HG
			05209 Other household textiles	HG
	053 Household appliances	0531 Major household appliances whether electric or not	05311 Refrigerators, freezers and fridge-freezers	A
			05312 Clothes washing machines, clothes drying machines and dish washing machines	A
			05313 Cookers	A
			05314 Heaters, air conditioners	A
			05315 Cleaning equipment	A
			05319 Other major household appliances	A
		0532 Small electric household appliances	05321 Food processing appliances	A
			05322 Coffee machines, tea makers and similar appliances	A
			05323 Irons	A
			05324 Toasters and grills	A
			05329 Other small electric household appliances	A
	054 Glassware, tableware and household utensils	0540 Glassware, tableware and household utensils	05401 Glassware, crystal ware, ceramic ware and chinaware	HG
			05402 Cutlery, flatware and silverware	HG
			05403 Non-electric kitchen utensils and articles	HG
	055 Tools and equipment for house and garden	0551 Major tools and equipment	05511 Motorized major tools and equipment	A
			05521 Non-motorized small tools	HG
			05522 Miscellaneous small tool accessories	A

Table continued on next page.

Division	Group	Class	Subclass	Basket
	056 Goods and services for routine household maintenance	0561 Non-durable household goods	05611 Cleaning and maintenance products	HG
			05612 Other non-durable small household articles	HG
08 Communication	082 Telephone and telefax equipment	0820 Telephone and telefax equipment	08201 Fixed telephone equipment	A
			08202 Mobile telephone equipment	A
			08203 Other equipment of telephone and telefax equipment	A
09 Recreation and culture	091 Audio-visual, photographic and information processing equipment	0911 Equipment for the reception, recording and reproduction of sound and picture	09111 Equipment for the reception, recording and reproduction of sound	A
			09112 Equipment for the reception, recording and reproduction of sound and vision	A
			09113 Portable sound and vision devices	A
			09119 Other equipment for the reception, recording and reproduction of sound and picture	A
		0912 Photographic and cinematographic equipment and optical instruments	09121 Cameras	A
			09122 Accessories for photographic and cinematographic equipment	A
			09123 Optical instruments	HG
		0913 Information processing equipment	09131 Personal computers	A
			09132 Accessories for information processing equipment	A
		0914 Recording media	09149 Other recording media	HG
	093 Other recreational items and equipment, gardens and pets	0931 Games, toys and hobbies	09311 Games and hobbies	HG
			09312 Toys and celebration articles	HG
		0932 Equipment for sport, camping and open-air recreation	09322 Equipment for camping and open-air recreation	HG
		0933 Gardens, plants and flowers	09331 Garden products	HG
			09332 Plants and flowers	HG
		0934 Pets and related products	09342 Products for pets	HG
	095 Newspapers, books and stationery	0951 Books	09511 Fiction books	HG
			09512 Educational text books	HG
			09513 Other non-fiction books	HG
		0952 Newspapers and periodicals	09521 Newspapers	HG
			09522 Magazines and periodicals	HG
		0953 Miscellaneous printed matter	09530 Miscellaneous printed matter	HG
		0954 Stationery and drawing materials	09541 Paper products	HG
			09549 Other stationery and drawing materials	HG
12 Miscellaneous goods and services	121 Personal care	1212 Electric appliances for personal care	12121 Electric appliances for personal care	A
		1213 Other appliances, articles and products for personal care	12131 Non-electrical appliances	HG
			12132 Articles for personal hygiene and wellness, esoteric products and beauty products	HG
	123 Personal effects NEC	1231 Jewellery, clocks and watches	12312 Clocks and watches	HG
		1232 Other personal effects	12329 Other personal effects NEC	HG

4.1.2.2 Dealing with negative values

The second step was dealing with negative values in the data. 309 households (~0.15 % of the remaining households at this stage) showed negative incomes. The maximum share of households with a negative income was 0.62% for Poland. Because the income in the HBS is not recorded as net income, i.e. the expenses are not deducted, negative incomes are likely due to reporting errors. A household with dept repayments exceeding their salary or other forms of income, for example, would still record a positive income in the HBS data, because the debt repayment is recorded separately as expense. Because negative incomes are thus not realistic and the share is considered negligible, households with negative income were dropped from the data.

Negative expenditures at subclass level were replaced with zeros. This affected 4971 households (2.43 % of the remaining households at this stage). Negative values at higher ECOICOP levels were replaced with the sum of expenditures for the belonging consumption categories at the next lower level of that particular household. Consistency with the respective lower level was given the priority. A negative value at class level, for example, was replaced by the sum of subclass expenses even if the

resulting class level expenditure then mismatched the value at group level (that should be a sum of all belonging expenditures at class level).

4.1.2.3 Harmonising values at ECOICOP levels

Next was harmonising the values of the different ECOICOP levels. This is particularly important because not all countries provide data for all subclasses, for example due to broader questions or categories in the recording diary. The harmonisation was done separately for the quantity data provided directly and the expenditure data.

The remaining quantity data included the physical consumption of 144,908 households in 14 countries per 71 subclasses (food), meaning a total of 10,288,468 observations. For 0.55% of the observations, quantity data was provided at class but not at subclass level. For another 2.96% (304,479 in total), the values at class and subclass level were inconsistent, i.e. the sum of quantities at subclass level is unequal to the sum at class level. Thus, in total 3.51% of the quantity data showed inconsistencies between the two ECOICOP levels it is provided in.

The consumption quantities at subclass and class were harmonised for each household with the following approach: If the quantity reported at class level was higher than the sum of the quantities of all belonging subclass levels, the difference was distributed among the belonging subclasses assuming equal market shares. This might introduce errors because some of the subclass grouped under a class can have different units. However, these are considered negligible as most classes have the same unit throughout and only a small fraction of the data is affected. For the case that the sum of the belonging subclass levels exceeded the reported quantity for the sum, the unchanged subclass level values were taken for the analysis. Redistributing the negative difference (class level value smaller than sum of values for all belonging subclasses), would have meant to reduce the subclass level quantities. As some subclasses contain zero values, this would have, under the assumption of equal market shares, introduced negative consumption quantities.

The harmonisation was more complicated for the monetary expenditures because they are provided at all four ECOICOP levels. As the divisions contain a mix of subclasses that are either within or out of scope, the harmonisation was done for all consumption categories except for those in division 04 (housing) and 07 (transport). In total, the expenditures of 204,310 households in 245 subclasses were harmonised, meaning a total number of 50,055,950 observations. Of these, 28,807,710 (57.6%) refer to the 141 subclasses within scope.

First, the sum of all expenditures at the subclass level was examined to determine how much of the division-level expenditure is covered. This enable the identification of consumption categories that are only provided at more aggregate values. The mean coverage of division expenditure for the countries is 93.7% at subclass level, 95.7% at class and 99.8% at group level. Figure 2 shows how much of the reported division level expenditure is covered by the reported subclass expenditures in the countries (each datapoint refers to one country). Note that the figure includes the expenditures for food (division 01 and 02) of the countries that provide physical quantities and for subclasses that are out of scope as well. This is because, except for divisions 04 and 07, all divisions contain subclasses that are within the 141 filtered subclasses and some that are not. Therefore, excluding subclasses out of scope would bias the comparison with the reported expenditures at division level, which is a sum of all belonging subclasses (also those that are out of scope).

As can be seen, most divisions have a high coverage in many countries, with some countries and divisions being strong outliers though. Divisions 12 (Miscellaneous Goods and Services) and 02 have the generally poorest coverage. Appendix 5 shows the coverage for the divisions for each country specifically. Looking at the details for division 12 and 02, it becomes apparent that the low coverages mainly stem from a few countries (for example Spain with 34.1% for division 02 or France with 62.4% for division 12). This indicates that the different methodologies, e.g. how granular the expenditures are recorded, are the main cause for the issue. If, for example, the French HBS only asks for the expenditures on wine, spirits and beer (class level) and not for the different types of each, that make up the subclass level, then there will be no expenses at subclass level for these, reducing the coverage of division 02.

In total, 1,428,668 observations (2.85%) contain inconsistencies between the levels. Of those, 658,595 (46%) belong to the case that expenditures for certain consumption categories are only provided at more aggregate levels and 770,073 (53.9%) are because of contradictions between the levels. The missing granularity case affects only certain countries because of methodological differences in the HBS, while the contradictions are likely noise and errors. Of the observations with inconsistencies 672,805 (47.1%) concern the 141 subclasses within scope.

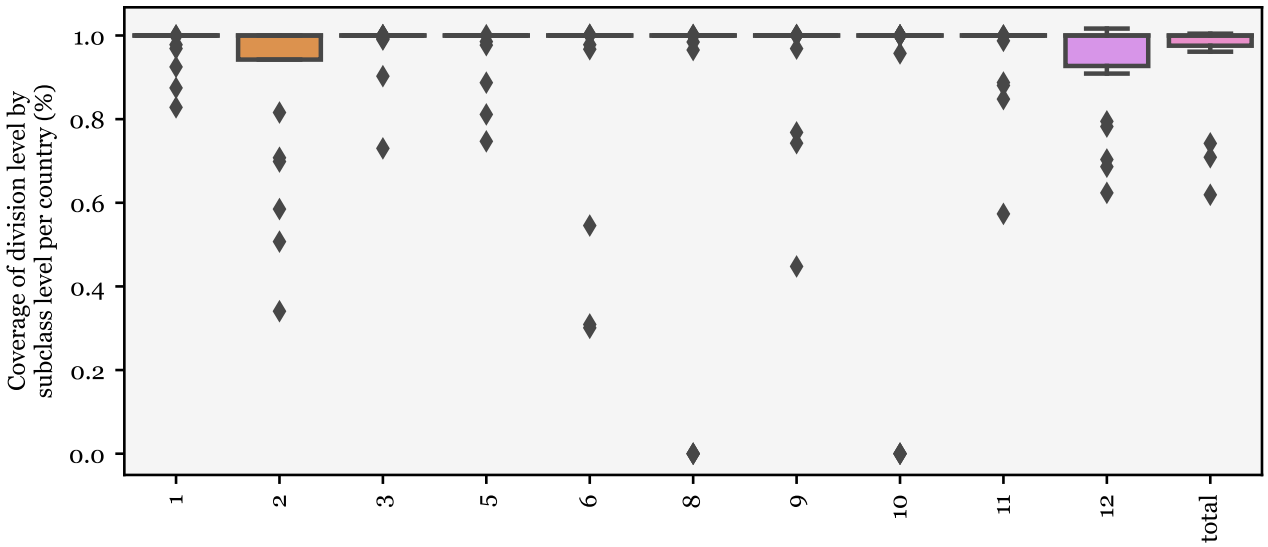

Figure 2: Coverage of total division level expenditure by the sum of all subclass level expenditures per country. ”Total” refers to the sum of all divisions. The datapoint represent the coverage in a specific country.

The levels were harmonised using the same approach as for the quantities, just for all four ECOICOP levels instead of only two: For the case that higher level categories show a higher value than the sum of the belonging lower level categories, the difference was distributed among all lower level categories assuming equal shares. This was done going from high to low aggregation, i.e. first division to group, then group to class and finally class to subclass. For negative differences, meaning that the sum of the lower belonging categories is higher than of the reported one, the lower category reporting was assumed to be correct and the higher category value adjusted accordingly. This also means that there is no full consistency with the original higher-level expenditures for these cases anymore.

4.1.2.4 Outlier treatment

After the levels were harmonised, outlier households for income and total expenditure were removed. This was done by removing all households with an income or total expenditure of more than 250,000 Euro, translating into dropping 0.08 % of the remaining households at this stage. 204,149 households were left in the data after this step. Appendix 6 shows the distribution of households by income and total expenditure and after removing the outliers.

To partially correct for the infrequent purchases problem, the top 1% of expenditure and quantity values per subclass for each country were replaced with the mean expenditure respectively quantity for the specific subclass in the income deciles in the country of the specific household (see Section 4.6 for details on how the deciles were assigned). This implicitly assumes a relationship of income and consumption, which might bias the results. However, it is more realistic than using the overall mean without considering income differences. This was done per country because doing it for the whole dataset would have meant that the 1% likely just consisted of high-income countries, failing to get the inflated expenditure values in low-income countries as well. Also, as not all countries provide quantities, it would have led to the 1% being a different number of values for the quantities directly acquired from the HBS and those from expenditure values. A similar approach is taken by Büchs *et al.* [48], who instead of replacing the top 1% per subclass exclude the top 1% expenditure values of the whole dataset from their analysis entirely.

Appendix 7 and Appendix 8 show the distribution of quantities and expenditures before and after converting the outliers. Both expenditures and quantities show strong outliers with unrealistic values. One household, for example, reported to have consumed more than 15 tonnes of bread in a year. For the expenditure, some subclasses stand out, such as "Household furniture" (05111), for which a few households report a yearly expenditure of more than 100,000 Euros. After replacing the top 1%, the distributions have a much smaller spread for each subclass. However, for some subclasses, especially for the expenditures, the boxes of the boxplots are barely visible, which illustrated the remaining strong outliers. Because it is not possible to perfectly determine which values represent true consumption, no further outliers are replaced. A sensitivity variant with replacing the 5% top values was conducted as well (see Section 5.4).

4.1.2.5 Adding reference quantities and units for physical quantity data

The last step in pre-processing was to add the reference quantities and reference units for the physical quantity data. Metadata specifying the reference quantities and units is missing in the HBS data and the user manual [65]. The only HBS document addressing this issue is the description of the data transmission requirements for the member states [69]. It states that they should provide quantity data in the following units [69, p. 12]: kg for 'solids', litre for 'liquids/non-solids' and 'Unit' for eggs. 'Unit' is assumed to be equivalent to pieces here. Exact definitions as well as a description of which food subclasses are considered solids and liquids is missing. Furthermore, no information is given on how member state transmissions were harmonised after receiving them. Therefore, the assigning of food subclasses to solids and non-solids was done manually, with the exception of eggs that are in pieces. As services were excluded, the food subclasses describe only goods that are bought for use at home. "Coffee" (01211), for example, is thus assumed to be a solid, as liquid coffee will mostly be bought outside of the household. Some subclasses remain edge cases. "Yoghurt" (01144), for example, can be considered an edge case with properties of a solid and a liquid at the same time.

These reference units and quantities are important because of a potential mismatch with the reference unit and quantity of the impact intensities. The impact intensity for yoghurt, for example, is given per one kg (see Section 4.4.2). If the consumption quantity for yoghurt in the HBS were given per one litre, a conversion to kg would be required by assuming an average density of yoghurt, changing the consumption quantity that is multiplied with the impact intensity. If the quantity were given per one kg, no conversion would be needed. Therefore, the assumed reference quantities and units for physical quantities given in the HBS affect the calculated impact from the consumption of food items. This error would be consistent across all households and countries, but nevertheless matters for the distributional analysis. If households at a higher income level consumed, for example, on average more yoghurt and yoghurt had a very high impact intensity, the conversion of the quantities to match the impact intensity units could cause higher or lower differences of EFs between high- and low-income households.

The assigned units for affected subclasses can be found in Appendix 1. The reference quantity is assumed to be one for all subclasses.

4.1.3 Resulting household expenditure dataset

The result of the pre-processing was data on the yearly expenditures for 141 ECOICOP subclasses of 204,149 households in 24 countries and yearly physical consumption quantities for 71 ECOICOP subclasses of 144,882 households in 14 countries for the year 2015. Table 2 shows how many households were in the raw data and how many remain for the analysis for each country.

Table 2: Number of households in the HBS data before and after cleaning. If the number of dropped households is below 50, they are reported as <50 due to data confidentiality requirements. The country abbreviations are Eurostat standard for the EU member states [70]. They are applied throughout this study.

Country abbreviation	Country name	No. of households left	Households dropped	Households dropped (%)
BE	Belgium	6127	<50	<0.8
BG	Bulgaria	2966	0	0
CY	Czechia	2875	<50	<1.7
CZ	Cyprus	2929	0	0
DE	Germany	0	52413	100
DK	Denmark	2193	<50	<2.3
EE	Estonia	3395	0	0
EL	Greece	6147	<50	<0.8
ES	Spain	22130	0	0
FI	Finland	3662	<50	<1.4
FR	France	16941	<50	<0.3
HR	Croatia	2028	<50	<2.5
HU	Hungary	7163	<50	<0.7
IE	Ireland	6825	<50	<0.7
IT	Italy	0	15013	100
LT	Lithuania	3443	0	0
LU	Luxembourg	3139	<50	<1.6
LV	Latvia	3844	0	0
MT	Malta	3690	<50	<1.4
NL	Netherlands	14337	71	<0.3
PL	Poland	36913	235	<0.1
PT	Portugal	11394	<50	<0.4
RO	Romania	30615	<50	<0.2
SE	Sweden	2858	<50	<1.7
SI	Slovenia	3750	0	0
SK	Slovakia	4785	0	0
Total	**Total**	**204,149**	**67,897**	**24.96**

4.2 Prices

To convert the monetary expenditures into physical units, two price datasets were used.

4.2.1 Purchasing Power Parities (PPP) dataset

The first is the Eurostat Purchasing Power Parities (PPP) dataset [71], for which the underlying prices used to calculate the PPP are available on request. They are provided as purchaser's prices in national currency for individual products assigned to a ECOICOP subclass (e.g. 05.3.1.1.01.da with ".01" representing a specific product and ".da" a version of that product) while the household expenditure data is at ECOICOP subclass level (e.g. 05311). Note that this does not mean that the PPP themselves were applied. The prices that are part of the PPP dataset are country specific. Thus, the different purchasing power per Euro across the EU member states is represented by the prices themselves and they can be used to convert the expenditure into physical quantities directly.

The prices are given for different years, depending on when the respective consumption purpose group was surveyed. For the group "Personal appearance" a survey from 2015 was available while for "Furniture and health" the year 2014 and for "House and garden" the year 2016 were used, assuming the price differences from one year negligible. Interpolating the prices was not possible because of a changing composition of the included products between the surveys. In total, prices for 1179 items were available for the chosen years.

The next step was to convert the national currency prices into Euro, which is the unit of expenditures in the HBS. This was done using year-specific exchange rates from Eurostat [72]. The exchange rates were chosen based on the actual survey year, i.e. 2016 for “House and garden”, 2014 for “Furniture and health” and 2015 for “Personal appearance” to exclude bias from fluctuating exchange rates. For Lithuania and Croatia the above dataset did not provide exchange rates. Therefore, it was supplemented with another Eurostat dataset containing exchange rates for countries that are today part of the Euro-Zone [73]. Because Lithuania adopted the Euro in 2015, the prices for it were only converted for the “Furniture and health” group, which is based on a 2014 survey.

To ensure consistent calculation of subclass-level prices across all countries, missing prices for items were imputed, i.e. filled, using country-specific price level indices for 2015. These indices refer to the same subclasses that the price items are assigned to and are provided by Eurostat with the PPP dataset. Missing prices were replaced using cross-multiplication with an available item price for a country and the price level index of the subclass in both the country with price and the one where it was missing.

Next, the subclasses in the PPP dataset were compared to the ones in the HBS. This made clear that the PPP dataset does not allocate all individual products to a certain subclass, but some also to the class level (one-step higher). The HBS ECOICOP subclasses "Other articles of clothing" (03131) and "Clothing accessories" (03132), for example, are not in the PPP price data. However, it does include the subclass "Other articles of clothing and clothing accessories" (03130). Looking closely, this subclass matches the class "Other articles of clothing and clothing accessories" (no. 0313), which is the overarching category for the subclasses 03131 and 03132 in the HBS. Thus, the price dataset includes prices for subclasses and classes, but denotes the latter with 5-digits instead of the intended 4-digits. Because the specific items could easily be distinguished by their actual subclass, i.e. there were none that did not fit the subclass-level distinctions, they were assigned to the correct subclass manually. The item “Baseball cap” (original notation A.03.1.3.0.01.ba), for example, had the class 0313, denoted as 03130, assigned in the dataset, but actually belongs to the ECOICOP subclass "Other articles of clothing" (03131), to which it was assigned manually. This was necessary for 158 items (see Appendix 1 for details).

To get to the prices at subclass level, the mean of the prices of all belonging items was calculated assuming equal market shares. For the subclass "Other articles of clothing" (03131), for example, the mean of the price for the baseball cap and all other items assigned to it was calculated without applying any weights to the items. The same approach is taken by Eurostat for the calculation of PPP because weights for the prices, for example in form of consumption quantities, are not available [74]. Before the grouping, 5 items were dropped that were duplicates in a different unit in the respective subclass. Also, 373 items that were not relevant to the 141 subclasses in scope were dropped. The product “'National flag, polyester, BNR” was excluded from the aggregation because no country provided any prices for them, leaving 799 items for the grouping.

Some subclasses contained individual products with varying reference units and reference quantities that had to be harmonised before aggregation. For products with a unit that is essentially a different version of pieces the unit and reference quantity were changed to 1 piece without regarding the specific reference quantity. “100 filters”, for example, was treated as 1 piece without converting the respective price. Prices for items with a reference unit describing a mass, but not 1 kg, were changed to the reference of 1 kg by using conversion factors. Details on which products are included for the mean at each subclass and the conversion factors for the harmonisation of reference units and quantities can be found in Appendix 1.

The grouping resulted in prices for 60 subclasses for the 24 countries in scope.

4.2.2 Detailed Average Prices (DAP) dataset

Because the PPP price dataset does not contain any prices on food items, it was complemented with the latest version of the Eurostat Detailed Average Prices (DAP) dataset [75], which provides prices in Euro for up to 190 commodities for many European countries [76]. The coverage in the publicly available dataset is quite low for other consumption baskets than food and beverages, which is why it was only used for food expenditures. Prices for food items were only needed for the 10 countries that do not provide quantity data for divisions 01 and 02 directly.

The DAP prices are provided as specific products assigned to Classification of Individual Consumption by Purpose (COICOP) subclasses (note: not **E**COICOP, see Appendix 3), similar to the PPP price dataset. For example, prices for the COICOP subclass "Flour and other cereals" (01112) are provided for "Wheat flour" (01112A) and "Cornflakes" (01112B). Similar to for the PPP dataset above, missing product prices were imputed using the price level indices from the PPP dataset and prices from other countries. Mixing the price level indices of the PPP dataset, which is denoted in ECOICOP, and the DAP dataset, which is in COICOP, is possible because divisions 01 and 02 (see Appendix 3) do not show any differences in the two classifications.

For the subclasses belonging to alcoholic beverages (02111, 02121 and 02131), no price level indices were provided in the PPP dataset. Therefore, these were taken from another PPP related Eurostat dataset [77]. This shows that Eurostat does not disclose all data used to calculate the PPPs, even when requesting the detailed data for research [71].

The prices for Denmark, France, Ireland, Sweden and Luxembourg had to be imputed for all food items.

Before aggregating the prices to subclass level, the reference units and quantities had to be harmonised. This mostly meant changing the reference quantity and scale of a mass unit, for example from 500 g to 1 kg. Details on the conversion factors for the harmonisation of reference units and quantities can be found in Appendix 1.

With harmonised units, the prices were grouped to country-specific prices at subclass level (42 in total). Together with the PPP dataset, prices for 102 ECOICOP subclasses were obtained.

4.3 Conversion to physical quantities

With pre-processed expenditure and price data available, the monetary expenditure from the HBS was converted to physical units by dividing the expenditures by the country-specific price. The physical quantities in divisions 01 and 02 that were provided by 14 of the 24 the countries, were left unchanged. The prices derived from the PPP dataset were used for household goods and appliances while food was covered using the prices from the DAP dataset.

For 99 subclasses, prices were directly available, while the remaining 42 were covered using other subclasses as proxies (see Appendix 1 for details). The subclass "Garden furniture" (05112), for example, was converted using the price for the subclass "Household furniture" (05111).

Table 3 shows the resulting average consumption per subclass for the included households in monetary and physical units. It was calculated by weighting the consumption of each household with the sample weights provided by the HBS. The same information can be found per income decile for all countries in Appendix 1. Appendix 9 shows the distribution of physical consumption for each ECOICOP subclass for all households in the dataset, i.e. on EU level, for the lowest and highest income decile differentiated by durable and non-durable goods as well as the unit of measurement (kg, litres or pieces).

Table 3: Mean expenditure and physical consumption per ECOICOP subclass for all included households, i.e. on European level, rounded to three decimal places. The reference unit (RU) differs per subclass. The reference quantity is 1 for all subclasses. The unrounded average consumption quantities per income decile for all countries are provided in Appendix 1.

Subclass	Mean expenditure in EUR	Mean physical consumption in RU	RU
01111 Rice	18.747	10.948	kg
01112 Flours and other cereals	179.978	168.422	kg
01113 Bread	127.367	89.875	kg
01114 Other bakery products	143.917	57.046	kg
01115 Pizza and quiche	10.343	1.154	kg
01116 Pasta products and couscous	36.719	14.611	kg
01117 Breakfast cereals	10.938	4.731	kg
01118 Other cereal products	6.110	2.762	kg
01121 Beef and veal	126.923	12.309	kg
01122 Pork	96.321	18.528	kg
01123 Lamb and goat	15.132	1.424	kg
01124 Poultry	130.227	28.878	kg
01125 Other meats	145.291	15.618	kg
01126 Edible offal	45.493	6.576	kg
01127 Dried, salted or smoked meat	104.953	17.329	kg
01128 Other meat preparations	49.366	7.332	kg
01131 Fresh or chilled fish	91.012	8.738	kg
01132 Frozen fish	33.800	3.577	kg
01133 Fresh or chilled seafood	11.603	0.747	kg
01134 Frozen seafood	43.757	3.308	kg
01135 Dried, smoked or salted fish and seafood	8.930	0.922	kg
01136 Other preserved or processed fish and seafood-based preparations	15.474	1.526	kg
01141 Milk, whole, fresh	33.444	39.626	litre
01142 Milk, low fat, fresh	52.293	60.064	litre
01143 Milk, preserved	2.857	1.726	litre
01144 Yoghurt	73.151	33.658	kg
01145 Cheese and curd	183.372	25.248	kg
01146 Other milk products	56.291	12.584	kg
01147 Eggs	44.644	267.909	piece
01151 Butter	26.285	4.728	kg
01152 Margarine and other vegetable fats	14.437	4.679	kg
01153 Olive oil	25.773	5.859	litre
01154 Other edible oils	17.277	12.172	litre
01155 Other edible animal fats	2.491	0.564	kg
01161 Fresh or chilled fruit	147.851	99.174	kg
01162 Frozen fruit	39.666	18.852	kg
01163 Dried fruit and nuts	55.475	25.332	kg
01164 Preserved fruit and fruit-based products	32.941	10.977	kg
01171 Fresh or chilled vegetables other than potatoes and other tubers	132.749	95.992	kg
01172 Frozen vegetables other than potatoes and other tubers	20.092	12.986	kg
01173 Dried vegetables, other preserved or processed vegetables	80.405	34.756	kg
01174 Potatoes	66.337	78.015	kg
01175 Crisps	23.758	5.427	kg
01176 Other tubers and products of tuber vegetables	49.608	41.305	kg
01181 Sugar	13.973	15.945	kg
01182 Jams, marmalades and honey	25.337	6.133	kg
01183 Chocolate	59.189	6.097	kg
01184 Confectionery products	44.603	5.424	kg
01185 Edible ices and ice cream	25.589	8.094	kg
01186 Artificial sugar substitutes	3.753	2.719	kg
01191 Sauces, condiments	38.036	9.463	kg
01192 Salt, spices and culinary herbs	16.456	9.754	kg
01193 Baby food	30.909	3.566	kg
01194 Ready-made meals	23.320	5.762	kg
01199 Other food products NEC	21.338	2.980	kg
01211 Coffee	66.343	7.133	kg

Table continued on next page.

Subclass	Mean expenditure in EUR	Mean physical consumption in RU	RU
01212 Tea	12.606	0.629	kg
01213 Cocoa and powdered chocolate	4.538	0.805	kg
01221 Mineral or spring waters	42.120	123.383	litre
01222 Soft drinks	65.792	83.150	litre
01223 Fruit and vegetable juices	53.952	41.992	litre
02111 Spirits and liqueurs	43.236	2.943	litre
02112 Alcoholic soft drinks	0.648	0.359	litre
02121 Wine from grapes	91.408	29.893	litre
02122 Wine from other fruits	6.823	2.694	litre
02123 Fortified wines	1.546	0.278	litre
02124 Wine-based drinks	0.156	0.044	litre
02131 Lager beer	50.734	28.333	litre
02132 Other alcoholic beer	5.703	3.805	litre
02133 Low and non-alcoholic beer	1.519	2.102	litre
02134 Beer-based drinks	1.453	2.068	litre
03110 Clothing materials	0.609	0.090	piece
03121 Garments for men	216.795	2.973	piece
03122 Garments for women	319.862	7.148	piece
03123 Garments for infants- 0-to-2-years and children-3- to-13-years	105.511	6.928	piece
03131 Other articles of clothing	16.143	0.819	piece
03132 Clothing accessories	2.597	0.117	piece
03211 Footwear for men	70.140	0.906	piece
03212 Footwear for women	95.825	1.442	piece
03213 Footwear for infants and children	32.391	1.017	piece
05111 Household furniture	178.720	0.441	piece
05112 Garden furniture	1.326	0.003	piece
05113 Lighting equipment	3.586	0.068	piece
05119 Other furniture and furnishings	7.902	0.054	piece
05121 Carpets and rugs	2.436	0.016	piece
05122 Other floor coverings	0.192	0.008	piece
05201 Furnishing fabrics and curtains	7.145	0.365	piece
05202 Bed linen	15.428	0.411	piece
05203 Table linen and bathroom linen	7.940	0.780	piece
05209 Other household textiles	7.941	0.633	piece
05311 Refrigerators, freezers and fridge-freezers	18.056	0.032	piece
05312 Clothes washing machines, clothes drying machines and dish washing machines	27.214	0.057	piece
05313 Cookers	11.766	0.108	piece
05314 Heaters, air conditioners	6.918	0.063	piece
05315 Cleaning equipment	4.481	0.018	piece
05319 Other major household appliances	0.834	0.003	piece
05321 Food processing appliances	7.559	0.133	piece
05322 Coffee machines, tea makers and similar appliances	0.595	0.010	piece
05323 Irons	0.190	0.003	piece
05324 Toasters and grills	0.122	0.002	piece
05329 Other small electric household appliances	2.377	0.042	piece
05401 Glassware, crystal ware, ceramic ware and chinaware	10.880	2.209	piece
05402 Cutlery, flatware and silverware	6.378	0.091	piece
05403 Non-electric kitchen utensils and articles	23.659	1.035	piece
05511 Motorized major tools and equipment	12.725	0.145	piece
05521 Non-motorized small tools	32.456	2.350	piece
05522 Miscellaneous small tool accessories	15.642	3.874	piece
05611 Cleaning and maintenance products	244.966	42.640	kg
05612 Other non-durable small household articles	65.107	50.671	piece
08201 Fixed telephone equipment	8.139	0.273	piece
08202 Mobile telephone equipment	22.644	0.053	piece
08203 Other equipment of telephone and telefax equipment	8.482	0.280	piece
09111 Equipment for the reception, recording and reproduction of sound	3.752	0.008	piece
09112 Equipment for the reception, recording and reproduction of sound and vision	32.096	0.067	piece
09113 Portable sound and vision devices	0.525	0.005	piece
09119 Other equipment for the reception, recording and reproduction of sound and picture	0.642	0.005	piece

Table continued on next page.

Subclass	Mean expenditure in EUR	Mean physical consumption in RU	RU
09121 Cameras	3.682	0.009	piece
09122 Accessories for photographic and cinematographic equipment	1.324	0.009	piece
09123 Optical instruments	1.215	0.003	piece
09131 Personal computers	51.482	0.074	piece
09132 Accessories for information processing equipment	5.071	0.035	piece
09149 Other recording media	0.897	0.038	piece
09311 Games and hobbies	87.492	0.814	piece
09312 Toys and celebration articles	25.597	1.080	piece
09322 Equipment for camping and open-air recreation	1.480	0.037	piece
09331 Garden products	34.280	4.570	kg
09332 Plants and flowers	33.567	6.304	piece
09342 Products for pets	35.744	1.471	piece
09511 Fiction books	50.051	3.637	piece
09512 Educational text books	7.844	0.380	piece
09513 Other non-fiction books	2.214	0.107	piece
09521 Newspapers	58.829	41.663	piece
09522 Magazines and periodicals	13.097	3.985	piece
09530 Miscellaneous printed matter	9.519	1.890	piece
09541 Paper products	21.692	7.810	piece
09549 Other stationery and drawing materials	8.497	0.877	piece
12121 Electric appliances for personal care	48.000	0.947	piece
12131 Non-electrical appliances	164.404	25.472	piece
12132 Articles for personal hygiene and wellness, esoteric products and beauty products	139.978	1.418	kg
12312 Clocks and watches	1.507	0.008	piece
12329 Other personal effects NEC	8.291	0.247	piece

4.4 Impact intensities

To assess the environmental impacts of the households, life cycle impact intensities from process-based Life Cycle Assessment (pLCA) models were mapped to the physical consumption quantities. The impact intensities were taken from two data sources. Note that regionalised impact intensities were not available. Therefore, a constant impact vector was used for all countries.

4.4.1 Representative product impacts (RPI)

Preference was given to the representative product impacts (RPI) dataset [78], developed by the Joint Research Centre (JRC) of the EU for the Consumption footprint indicator [17, 79, 80]. It includes impact intensities for 165 representative products from five areas of consumption [52]: housing [81], mobility [82], food [83], appliances [84] and household goods [85]. 101 of the 165 products correspond to food, appliances and household goods and are thus relevant for this study.

Limitations include missing data on services [13] and limited coverage of products [80]. The data for household goods does, for example, not include toys or pharmaceuticals [79]. Impacts from the use phase of appliances are included in the RPI models with the European average. The household expenditures on electricity and heat are not differentiated by its use and can thus not be used to represent the use phase impacts of appliances.

The JRC modelled the impact intensities using the system model “Allocation at the Point of Substitution”, which means the responsibility for wastes (burdens) is divided between waste producers and users of the products resulting from waste treatment, e.g. recycled materials [86]. Furthermore, the JRC applied Environmental Footprint 3.1 (EF3.1) [87] as life cycle impact assessment method [80] for their models. Impact assessment means the phase of pLCA in which the inflows from and outflows to the environment that occur during the products life cycle are translated into environmental impact indicators [88]. Each impact category, like global warming for example, has a measurable impact indicator assigned [88]. They are calculated by multiplying all environmental inflows and outflows assigned to it with specific characterisation factors included in the respective impact assessment methods, for example EF3.1 [88]. Greenhouse gas emissions, for example, are multiplied with their global warming potential over 100 years to get to the common unit of CO_2 equivalents (CO_2eq), which is used to represent the impact category climate change.

Table 4 shows the impact categories included in the EF3.1 method and the abbreviations used in this study and the RPI data. For details regarding this particular impact assessment method see Andreasi Bassi *et al.* [87].

Table 4: Impact categories, indicators, characterisation factors and units for the EF3.1 impact assessment method [87]. Note that the units were partially adapted to this study with respect to their dimension (e.g. kg changed to g) and notation. The units presented here refer to the converted ones and not the original units of the impact intensity data as provided in the RPI dataset.

Abbreviation	Impact category	Indicator	Indicator unit
AC	Acidification	Accumulated Exceedance	molc H+ eq
CC	Climate change	Radiative forcing	tCO_2eq
ECOTOX	Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe
FEU	Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment	kgPeq
MEU	Eutrophication, marine	Fraction of nutrients reaching marine end compartment	kgNeq
TEU	Eutrophication, terrestrial	Accumulated Exceedance (AE)	molc N eq
HTOX_c	Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh
HTOX_nc	Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh
IR	Ionising radiation	Human exposure efficiency relative to U^{235}	kBq U235 eq
LU	Land use	Soil quality index	Dimensionless (kPt)
ODP	Ozone depletion	Ozone Depletion	kg CFC11 eq
PM	Particulate matter	Human health effects associated with exposure to PM2.5	Disease inc
POF	Photochemical ozone formation	Tropospheric ozone concentration increase	kg NMVOC eq
FRD	Resource use, fossils	Abiotic resource depletion – fossil fuels	MJ
MRD	Resource use, minerals and metals	Abiotic resource depletion	gSbeq
WU	Water use	User deprivation potential (deprivation weighted water consumption)	km^3 water eq

For simplicity, the “impact indicator results”, which would be the technically correct term, will be referred to as “impacts” in the rest of this study. The RPI representative products come classified in product groups [80], which will also be used for the impacts of some subclasses. Impact intensities for these product groups are not included in the raw data set provided by the JRC. Thus, they were based on the specifications in the technical report of the dataset [80] (see Appendix 1 for details). The JRC’s classification was adjusted to mirror the consumption categories more accurately with respect to two things: “Sandals” were assigned to the product group "Footwear" instead of "Plastic products" and “Plastic furniture” was assigned to "Furniture" instead of "Plastic products". Before calculating the mean impact intensities per product group, the reference units of the products within each group had to be harmonised. This was required for “Toys” and “Sleeping bag”, both of which were converted from per piece to per kg, assuming a mean mass of 0.5 kg for toys and 1.5 kg for sleeping bags. Then, the mean impact intensities of each group were calculated by weighing the included products with EU consumption quantities from 2015. These were acquired from the member states tool of the consumption footprint platform [89, 90].

In the end, impacts for 16 impact categories for 101 products and 35 product groups were acquired from the RPI dataset.

4.4.2 Ecoinvent

The RPI data was supplemented with the database Life Cycle Inventory database ecoinvent, version 3.9.1, which contains data on environmental flows of more than 20,000 products and processes. Appendix 1 includes a list of the exact datasets taken from ecoinvent. To convert these environmental flows to impact intensities consistent with the RPI dataset, the same system model and impacts assessment method were used. The impacts intensities were calculated using the pLCA software openLCA [91]. In contrast to the RPI data, the ecoinvent impact intensities only include the impacts from raw material extraction to the customer, neglecting use phase and end of life impacts.

All impact intensities from the RPI aim to represent the EU average while the data taken from Ecoinvent has varying geographic references, depending on the availability of data. In general, the following order of preference for the geographic reference was used for choosing Ecoinvent datasets: Europe, Europe without Switzerland, specific countries within Europe, Global, Rest of the World.

Impact intensities for another 40 products were acquired from ecoinvent. Together with the RPI dataset, impact intensities of 141 products and 35 product groups were available for matching the subclass consumption quantities.

4.5 Conversion to environmental impacts

The impact data and ECOICOP subclasses were mapped manually. Due to data constraints and the heterogeneity of products that are subsumed under ECOICOP subclasses, a variety of approaches was used to represent their impact intensities. Each subclass is represented either by a product, an RPI product group or a combination of products. For the combinations, the mean impact intensity was taken, assuming equal market shares. The RPI dataset and ecoinvent were not mixed, meaning that each subclass has its impact intensity either represented by RPI data or ecoinvent data.

Before calculating the impact intensity per subclass, the units of all impact intensities used to represent that subclass were converted to match the physical consumption units of that subclass. For that conversion factors, mostly assumed weights for the representative products, were used. These can be found in Appendix 1. This was required for 27 of the 141 subclasses.

Table 5 shows the distribution of mapping types and an example for each.

Table 5: Type of mapping of representative products with impacts to ECOICOP subclasses.

Type	No. of subclasses	Share (%)	Example
RPI product	69	49	RPI product “Fridge” mapped to subclass “05311 Refrigerators, freezers and fridge-freezers”
RPI product group	27	19	RPI product group “Meat” mapped to subclass “01125 Other meats”
RPI combination	9	6	RPI product group “Dairy” and product “Sugar” mapped to subclass “01185 Edible ices and ice cream”
Ecoinvent product	31	22	Ecoinvent dataset “steel, chromium steel 18/8” mapped to subclass “05402 Cutlery, flatware and silverware”
Ecoinvent combination	5	4	Ecoinvent datasets “salt”, “coriander”, “chilli” and “mint” mapped to subclass “01192 Salt, spices and culinary herbs”

Table 6 shows the resulting impact intensities for the four impact categories for each ECOICOP subclass.

Table 6: Impact intensities per ECOICOP subclass for climate change (CC), water use (WU), land use (LU) and resource use of minerals and metals (MRD), rounded to four decimal places. The reference unit (RU) refers to the unit of the physical quantity as calculated in Section 4.3. The unrounded impact intensities for all impact categories are provided in Appendix 1.

Subclass	RU	CC (tCO_2eq per RU)	WU (km^3 water eq per RU)	LU (kPt per RU)	MRD (gSbeq per RU)
01111 Rice	kg	0.0039	0.1036	0.0015	0.0283
01112 Flours and other cereals	kg	0.0008	0.0845	0.0051	0.0076
01113 Bread	kg	0.0010	0.0457	0.0014	0.0003
01114 Other bakery products	kg	0.0017	0.0440	0.0021	0.0013
01115 Pizza and quiche	kg	0.0043	0.1429	0.0086	0.0060
01116 Pasta products and couscous	kg	0.0014	0.1919	0.0047	0.0015
01117 Breakfast cereals	kg	0.0007	0.1598	0.0031	0.0010
01118 Other cereal products	kg	0.0016	0.0973	0.0170	0.0135
01121 Beef and veal	kg	0.0495	1.8886	0.0064	0.0138
01122 Pork	kg	0.0112	0.4857	0.0023	0.0045
01123 Lamb and goat	kg	0.0087	1.0234	0.0158	0.0069
01124 Poultry	kg	0.0092	0.3312	0.0017	0.0038
01125 Other meats	kg	0.0133	0.5160	0.0024	0.0048
01126 Edible offal	kg	0.0133	0.5160	0.0024	0.0048
01127 Dried, salted or smoked meat	kg	0.0133	0.5160	0.0024	0.0048
01128 Other meat preparations	kg	0.0133	0.5160	0.0024	0.0048
01131 Fresh or chilled fish	kg	0.0066	0.0825	0.0291	0.0076
01132 Frozen fish	kg	0.0035	0.0456	0.0051	0.0021
01133 Fresh or chilled seafood	kg	0.0085	0.1596	0.0179	0.0022
01134 Frozen seafood	kg	0.0085	0.1596	0.0179	0.0022
01135 Dried, smoked or salted fish and seafood	kg	0.0055	0.0627	0.0141	0.0121
01136 Other preserved or processed fish and seafood-based preparations	kg	0.0055	0.0627	0.0141	0.0121
01141 Milk, whole, fresh	l	0.0019	0.0482	0.0101	0.0007
01142 Milk, low fat, fresh	l	0.0019	0.0482	0.0101	0.0007
01143 Milk, preserved	l	0.0019	0.0482	0.0101	0.0007
01144 Yoghurt	kg	0.0019	0.7200	0.0115	0.0028
01145 Cheese and curd	kg	0.0177	0.4059	0.0054	0.0036
01146 Other milk products	kg	0.0025	0.9953	0.0156	0.0039
01147 Eggs	piece	0.0002	0.0111	0.0001	0.0002
01151 Butter	kg	0.0360	0.9863	0.0073	0.0075
01152 Margarine and other vegetable fats	kg	0.0050	0.5835	0.0236	0.0050
01153 Olive oil	l	0.0036	0.6021	0.0423	0.0107
01154 Other edible oils	l	0.0069	0.3947	0.0120	0.0019
01155 Other edible animal fats	kg	0.0360	0.9863	0.0073	0.0075
01161 Fresh or chilled fruit	kg	0.0011	0.0195	0.0029	0.0070
01162 Frozen fruit	kg	0.0011	0.0195	0.0029	0.0070
01163 Dried fruit and nuts	kg	0.0037	0.2924	0.0263	0.0715
01164 Preserved fruit and fruit-based products	kg	0.0011	0.0195	0.0029	0.0070
01171 Fresh or chilled vegetables other than potatoes and other tubers	kg	0.0006	0.0083	0.0039	0.0016
01172 Frozen vegetables other than potatoes and other tubers	kg	0.0006	0.0083	0.0039	0.0016
01173 Dried vegetables, other preserved or processed vegetables	kg	0.0006	0.0083	0.0039	0.0016
01174 Potatoes	kg	0.0005	0.0159	0.0030	0.0001
01175 Crisps	kg	0.0005	0.0159	0.0030	0.0001
01176 Other tubers and products of tuber vegetables	kg	0.0005	0.0159	0.0030	0.0001
01181 Sugar	kg	0.0007	0.0413	0.0004	0.0004
01182 Jams, marmalades and honey	kg	0.0007	0.0413	0.0004	0.0004
01183 Chocolate	kg	0.0151	1.0642	0.0360	0.0761
01184 Confectionery products	kg	0.0085	0.5594	0.0192	0.0391
01185 Edible ices and ice cream	kg	0.0035	0.0990	0.0048	0.0010
01186 Artificial sugar substitutes	kg	0.0007	0.0413	0.0004	0.0004
01191 Sauces, condiments	kg	0.0013	0.2814	0.0057	0.0022
01192 Salt, spices and culinary herbs	kg	0.0003	0.0180	0.0012	0.0032
01193 Baby food	kg	0.0043	0.1429	0.0086	0.0060
01194 Ready-made meals	kg	0.0043	0.1429	0.0086	0.0060
01199 Other food products NEC	kg	0.0043	0.1429	0.0086	0.0060
01211 Coffee	kg	0.0129	0.6133	0.1047	0.0060
01212 Tea	kg	0.0112	0.4109	0.0805	0.1003

Table continued on next page.

Subclass	RU	CC (tCO_2eq per RU)	WU (km^3 water eq per RU)	LU (kPt per RU)	MRD (gSbeq per RU)
01213 Cocoa and powdered chocolate	kg	0.0191	1.2292	0.0703	0.0368
01221 Mineral or spring waters	l	0.0002	0.0016	0.0060	0.0001
01222 Soft drinks	l	0.0007	0.0216	0.0033	0.0035
01223 Fruit and vegetable juices	l	0.0006	0.0118	0.0048	0.0051
02111 Spirits and liqueurs	l	0.0020	0.0924	0.0163	0.0700
02112 Alcoholic soft drinks	l	0.0002	0.0016	0.0060	0.0001
02121 Wine from grapes	l	0.0020	0.0924	0.0163	0.0700
02122 Wine from other fruits	l	0.0020	0.0924	0.0163	0.0700
02123 Fortified wines	l	0.0020	0.0924	0.0163	0.0700
02124 Wine-based drinks	l	0.0020	0.0924	0.0163	0.0700
02131 Lager beer	l	0.0013	0.0257	0.0061	0.0008
02132 Other alcoholic beer	l	0.0013	0.0257	0.0061	0.0008
02133 Low and non-alcoholic beer	l	0.0013	0.0257	0.0061	0.0008
02134 Beer-based drinks	l	0.0013	0.0257	0.0061	0.0008
03110 Clothing materials	piece	0.0048	0.0524	0.0173	0.0055
03121 Garments for men	piece	0.0048	0.0524	0.0173	0.0055
03122 Garments for women	piece	0.0048	0.0524	0.0173	0.0055
03123 Garments for infants- 0-to-2-years and children-3- to-13-years	piece	0.0048	0.0524	0.0173	0.0055
03131 Other articles of clothing	piece	0.0048	0.0524	0.0173	0.0055
03132 Clothing accessories	piece	0.0017	0.0749	0.0087	0.0454
03211 Footwear for men	piece	0.0096	0.1152	0.1088	0.0068
03212 Footwear for women	piece	0.0096	0.1152	0.1088	0.0068
03213 Footwear for infants and children	piece	0.0096	0.1152	0.1088	0.0068
05111 Household furniture	piece	0.2292	6.5147	0.5103	0.2479
05112 Garden furniture	piece	0.0619	3.5395	0.1052	0.0133
05113 Lighting equipment	piece	0.0045	0.0162	1.0818	0.0011
05119 Other furniture and furnishings	piece	0.1877	6.6289	0.6766	0.1565
05121 Carpets and rugs	piece	0.0588	2.0022	0.2550	1.1892
05122 Other floor coverings	piece	0.0079	0.0211	0.0885	0.0036
05201 Furnishing fabrics and curtains	piece	0.0176	0.6007	0.0765	0.3568
05202 Bed linen	piece	0.0118	0.4004	0.0510	0.2378
05203 Table linen and bathroom linen	piece	0.0059	0.2002	0.0255	0.1189
05209 Other household textiles	piece	0.0059	0.2002	0.0255	0.1189
05311 Refrigerators, freezers and fridge-freezers	piece	0.3751	2.2867	29.9705	0.1662
05312 Clothes washing machines, clothes drying machines and dish washing machines	piece	0.5384	3.5608	76.0684	0.2049
05313 Cookers	piece	0.1838	1.4824	25.1374	0.0566
05314 Heaters, air conditioners	piece	1.5138	4.9440	108.2201	0.2250
05315 Cleaning equipment	piece	0.0323	0.0753	0.2549	0.0096
05319 Other major household appliances	piece	0.0614	0.3564	6.0900	0.0199
05321 Food processing appliances	piece	0.0066	0.0318	0.4000	0.0073
05322 Coffee machines, tea makers and similar appliances	piece	0.0413	0.1179	0.4047	0.0077
05323 Irons	piece	0.0066	0.0318	0.4000	0.0073
05324 Toasters and grills	piece	0.0066	0.0318	0.4000	0.0073
05329 Other small electric household appliances	piece	0.0066	0.0318	0.4000	0.0073
05401 Glassware, crystal ware, ceramic ware and chinaware	piece	0.0010	0.0040	0.0074	0.0002
05402 Cutlery, flatware and silverware	piece	0.0005	0.0028	0.0130	0.0001
05403 Non-electric kitchen utensils and articles	piece	0.0015	0.0084	0.0390	0.0004
05511 Motorized major tools and equipment	piece	0.0051	0.0279	0.1300	0.0014
05521 Non-motorized small tools	piece	0.0051	0.0279	0.1300	0.0014
05522 Miscellaneous small tool accessories	piece	0.0045	0.0162	1.0818	0.0011
05611 Cleaning and maintenance products	kg	0.0016	0.2134	0.0528	0.0011
05612 Other non-durable small household articles	piece	0.0051	0.0601	0.0083	0.0008
08201 Fixed telephone equipment	piece	0.0265	0.1320	7.2688	0.0065
08202 Mobile telephone equipment	piece	0.0265	0.1320	7.2688	0.0065
08203 Other equipment of telephone and telefax equipment	piece	0.0265	0.1320	7.2688	0.0065
09111 Equipment for the reception, recording and reproduction of sound	piece	0.1082	0.5561	43.5400	0.0404
09112 Equipment for the reception, recording and reproduction of sound and vision	piece	0.5298	2.3403	132.0653	0.1261
09113 Portable sound and vision devices	piece	0.0265	0.1320	7.2688	0.0065
09119 Other equipment for the reception, recording and reproduction of sound and picture	piece	0.0265	0.1320	7.2688	0.0065

Table continued on next page.

Subclass	RU	CC (tCO_2eq per RU)	WU (km^3 water eq per RU)	LU (kPt per RU)	MRD (gSbeq per RU)
09121 Cameras	piece	0.0265	0.1320	7.2688	0.0065
09122 Accessories for photographic and cinematographic equipment	piece	0.0009	0.0146	0.0160	0.0009
09123 Optical instruments	piece	0.0013	0.0220	0.0240	0.0014
09131 Personal computers	piece	0.1356	0.6465	36.5541	0.0325
09132 Accessories for information processing equipment	piece	0.0605	0.5537	2.3500	0.0228
09149 Other recording media	piece	0.0044	0.0220	0.6600	0.0014
09311 Games and hobbies	piece	0.0030	0.0058	0.0056	0.0012
09312 Toys and celebration articles	piece	0.0030	0.0058	0.0056	0.0012
09322 Equipment for camping and open-air recreation	piece	0.0058	0.0007	0.0175	0.0021
09331 Garden products	kg	0.0000	0.0001	0.0001	0.0000
09332 Plants and flowers	piece	0.0000	0.0004	0.0000	0.0002
09342 Products for pets	piece	0.0127	0.1503	0.0208	0.0020
09511 Fiction books	piece	0.0019	0.0149	0.0041	0.0012
09512 Educational text books	piece	0.0019	0.0149	0.0041	0.0012
09513 Other non-fiction books	piece	0.0019	0.0149	0.0041	0.0012
09521 Newspapers	piece	0.0017	0.0353	0.0044	0.0013
09522 Magazines and periodicals	piece	0.0017	0.0353	0.0044	0.0013
09530 Miscellaneous printed matter	piece	0.0017	0.0353	0.0044	0.0013
09541 Paper products	piece	0.0018	0.0251	0.0043	0.0013
09549 Other stationery and drawing materials	piece	0.0001	0.0097	0.0006	0.0001
12121 Electric appliances for personal care	piece	0.0070	0.0117	0.1045	0.0025
12131 Non-electrical appliances	piece	0.0380	0.4509	0.0623	0.0059
12132 Articles for personal hygiene and wellness, esoteric products and beauty products	kg	0.0018	0.0447	0.0049	0.0011
12312 Clocks and watches	piece	0.0014	0.0017	0.0076	0.0006
12329 Other personal effects NEC	piece	0.0051	0.0601	0.0083	0.0008

The quality of the mapping varies across the subclasses. To summarise the general mapping quality, a self-defined classification system was used. Table 7 shows that classification and how many of the subclasses fall into each quality class. The complete mapping, including an evaluation of the mapping quality for each subclass, can be found in Appendix 1.

Table 7: Quality of mapping of representative products with impacts to ECOICOP subclasses. The accuracy was determined with a self-created scale from "exact product covering all or most of subclass" to "Far proxy".

Accuracy	No. of subclasses	Share (%)	Example
Exact product covering all or most of subclass	55	39	RPI product "Rice" mapped to subclass "01111 Rice"
Exact product covering part of subclass	32	23	RPI product "Sleeping bag" mapped to subclass "09322 Equipment for camping and open-air recreation"
Close proxy	35	25	RPI product "Sugar" mapped to subclass "01182 Jams, marmalades and honey"
Far proxy	19	13	Ecoinvent dataset "electric kettle" mapped to subclass "05324 Toasters and grills"

The impacts for each household and subclass were calculated by multiplying the physical consumption per subclass (see Table 3) with the impacts intensities shown in Table 6. This resulted in impacts for each subclass per household in the dataset.

4.6 Aggregation

The last step was to aggregate the results by households and income deciles. First, the environmental impacts from all subclasses were summed up to the total and by basket of consumption for each household and impact category.

Then, the households were assigned to income deciles separately on EU, i.e. including all households, and member state level because one household can be part of different deciles in each.

The deciles, denoted as D1 to D10, are usually constructed by sorting the households by their income and cutting the total number into ten equally sized chunks, with each chunk containing the same number of households. The decile D1 then represents the lowest 10% of households by income, decile D2 the next 10% and so forth up to D10, which includes the highest 10% by income. However, to ensure representativeness for the total population, the grouping was not based on the number of households, but the total sample weight they represent. After sorting the households by income at both the EU and member state levels, not the first 10% of households were grouped in D1, but the first group of households that together represent 10% of the total sample weight at the EU-level or for the respective member state, as provided by the HBS data. The households representing the next 10% of sample weight form D2 and so forth. Table 13 in Appendix 10 shows selected descriptive statistics for the income deciles. After all households were assigned, the mean EFs for each decile, on member state and EU-level were calculated.

5 Results

This Chapter presents the results with a focus on the European Union (EU) (without Austria, Italy and Germany). It is important to note again that the scope of this study is the three consumption baskets food, appliances and household goods, meaning that mobility, housing and services are excluded. Thus, when referring to the total environmental footprints (EFs) of a household, the sum of the EFs from the consumption of food, appliances and household goods is implied.

As described in Chapter 3, all results are reported for four impact categories of the Environmental Footprint 3.1 (EF3.1) method: climate change (carbon footprint), land use (land use footprint), water use (water use footprint) and resource use, minerals and metals (resource use footprint).

5.1 Mean decile Environmental Footprints

Starting with the results on income decile level for the EU, Figure 3 shows the mean size of EFs for EU income deciles by basket of consumption. Keep in mind that the income deciles include households from countries with vastly different socio-economic preconditions. Thus, the lowest income decile consists mostly of households from low-income member states, like Bulgaria, while the higher income deciles mostly include households from high-income countries, such as Luxembourg. The footprints vary strongly between the income deciles. The 10% of households with the highest income in the EU (D10) have, on average, 2.8 times the carbon footprint, 6.4 times the water use footprint, 3.4 times the land use footprint and about 8.2 times the resource footprint than households belonging to the lowest income decile (D1). Income inequality with D10 households having 28.6 times the mean and 24.6 times the median income of D1, is much higher. For all impact categories, the highest changes relative to the lower decile mean can be observed from D1 to D3 and the highest absolute changes are found from D7 to D10. While the rates of change between D3 and D9 remain relatively constant for the water (plot (b)) and resource footprint (plot (d)), they decrease for the carbon and land use footprints (plots (a) and (c)) from D3 to D6, almost resulting in a plateau. All mean footprints show a strong absolute increase between D9 and D10.

Food dominates the total impacts (i.e. aggregated across all households), for all impact categories, contributing 69% to the total carbon, 87% to the total land use and 90% to the total water use footprint. Only the resource use is dominated by the 70% contribution of appliances, which have a negligible influence on all other impact categories. Household goods contribute 27% to the overall carbon, 13% to the land use, 9% to the water use and 12% to the resource use footprint. This dominance of food with the exception of resource use footprints holds for all income deciles individually. Appendix 1 contains the percentage contribution values of each.Due to the granularity of the analysis the contributions can be traced down to the ECOICOP subclass level. Appendix 1 includes an analysis of the relative differences between the deciles and the contribution of the subclasses to those. For the carbon footprint, animal products are particularly relevant, explaining between 21% (D2 to D3) and 50% (D1 to D2) of the differences between the deciles and contributing 35% (D9 and D10) to 55% (D2) to the mean footprints. Apart from food, “Non-electrical appliances” (12131) are important, contributing between 4% (D1 and D2) and 20% (D8) to the mean footprints and explaining between 4% (D1 to D2) and 33% (D5 to D6) of the decile differences.

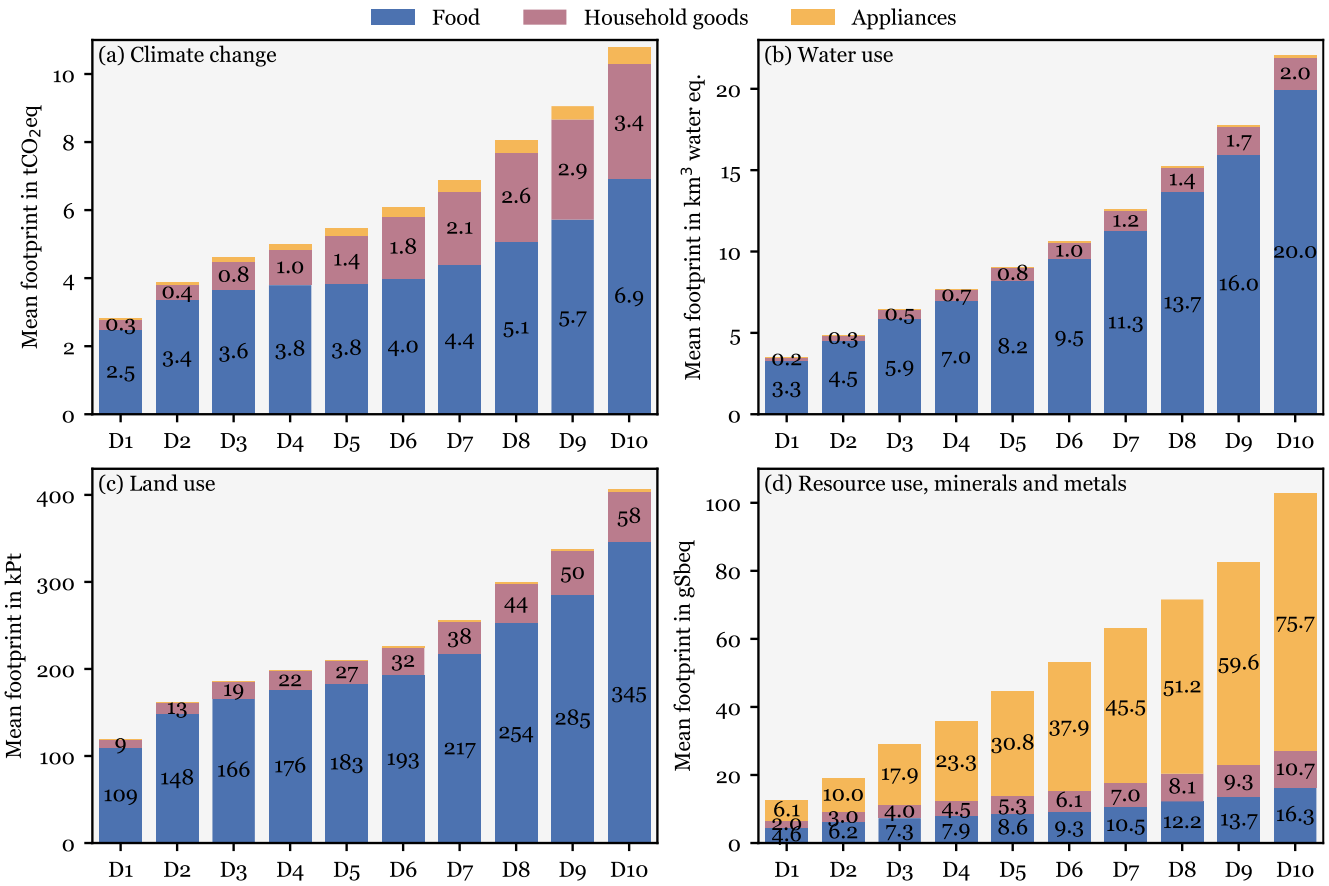

Figure 3: Mean EFs for EU household income deciles (not including Germany, Italy and Austria) for the year 2015 by basket of consumption. The same graphs for the member states can be found in Appendix 11. Data labels for appliances are hidden in (a), (b) and (c).

For water use, only food subclasses contribute more than 5% to any decile difference. Three subclasses stand out: “Flours and other cereals” (01112), “Dried fruits and nuts” (01163) and “Wine from grapes” (02121) together comprise between 26% (D1 and D2) and 45% (D10) of the mean footprints, showing a stark increase for the higher income deciles. They also explain between 25% (D1 to D2) and 64% (D5 to D6) of the decile differences. The land use footprints and its changes between deciles are again dominated by animal-based products, which contribute 46% (D9 and D10) to 58% (D2) to the mean footprints and explain between 33% (D8 top D9) and 61% (D1 to D2) of the decile differences. Of non-food subclasses, only “Non-electrical appliances” (12131) and “Cleaning and maintenance products” (05611) explain significant parts of the land use footprints.

Because appliances dominate the overall resource use footprint, they also explain the differences between the deciles. Particularly relevant are “Heaters and air conditioners” (05314), “Washing and dish-washing machines” (05312), “Miscellaneous small tool accessories” (05522), which includes goods such as light bulbs or curtain rails, and “Equipment for the reception, recording and reproduction of sound” (subclass 09112), which is mainly comprised of televisions and belonging equipment. Together, they contribute between 56% (D1) and 68% (D10) to the mean resource use footprint and 66% (D8 to D9) and 71% (D1 to D2) of the decile differences.

Figure 4 and Figure 5 show the results for the income deciles in Sweden and Hungary to illustrate how different the results can be on a country-level. The two countries were chosen because of their strong differences, such as country income, economic structure and location. As can be seen, the EFs in Hungary are lower for all deciles and impact categories. Sweden shows larger differences between the deciles for all impact categories except for resource use, for which a similar inequality can be observed. Interestingly, the Swedish D7 and D8 do not follow the general pattern of rising impacts with income for resource use. Unlike for the EU, the plateau from D3 to D6 cannot be observed for climate change and land use. Hungary shows a plateau for all categories except for resource use between D6 and D8 instead. The results for all other member states can be found in Appendix 11.

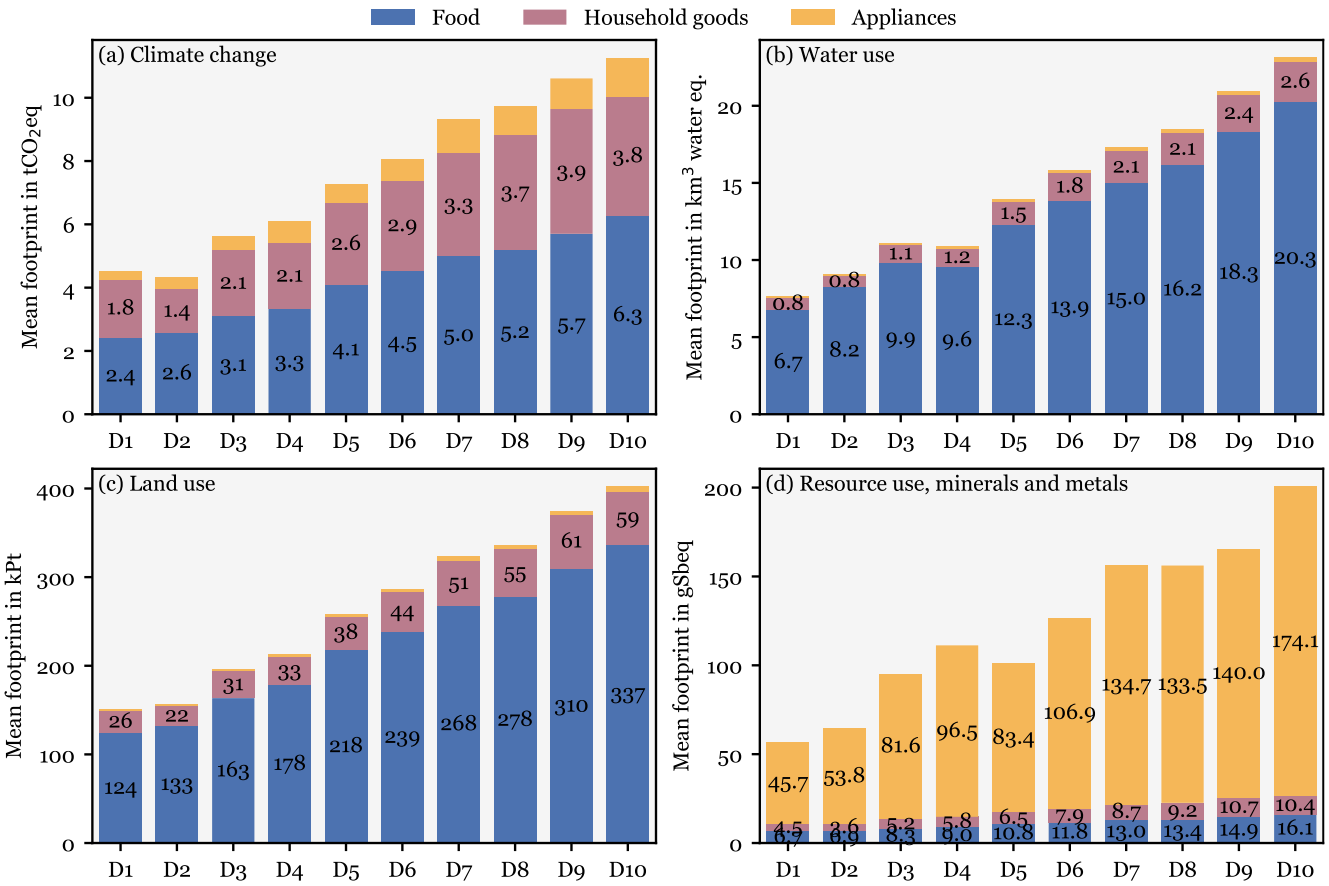

Figure 4: Mean EFs of household income deciles for the year 2015 by basket of consumption for Sweden. Note that the y-axis scale is different from that for the EU (above) to highlight relative differences between the deciles.

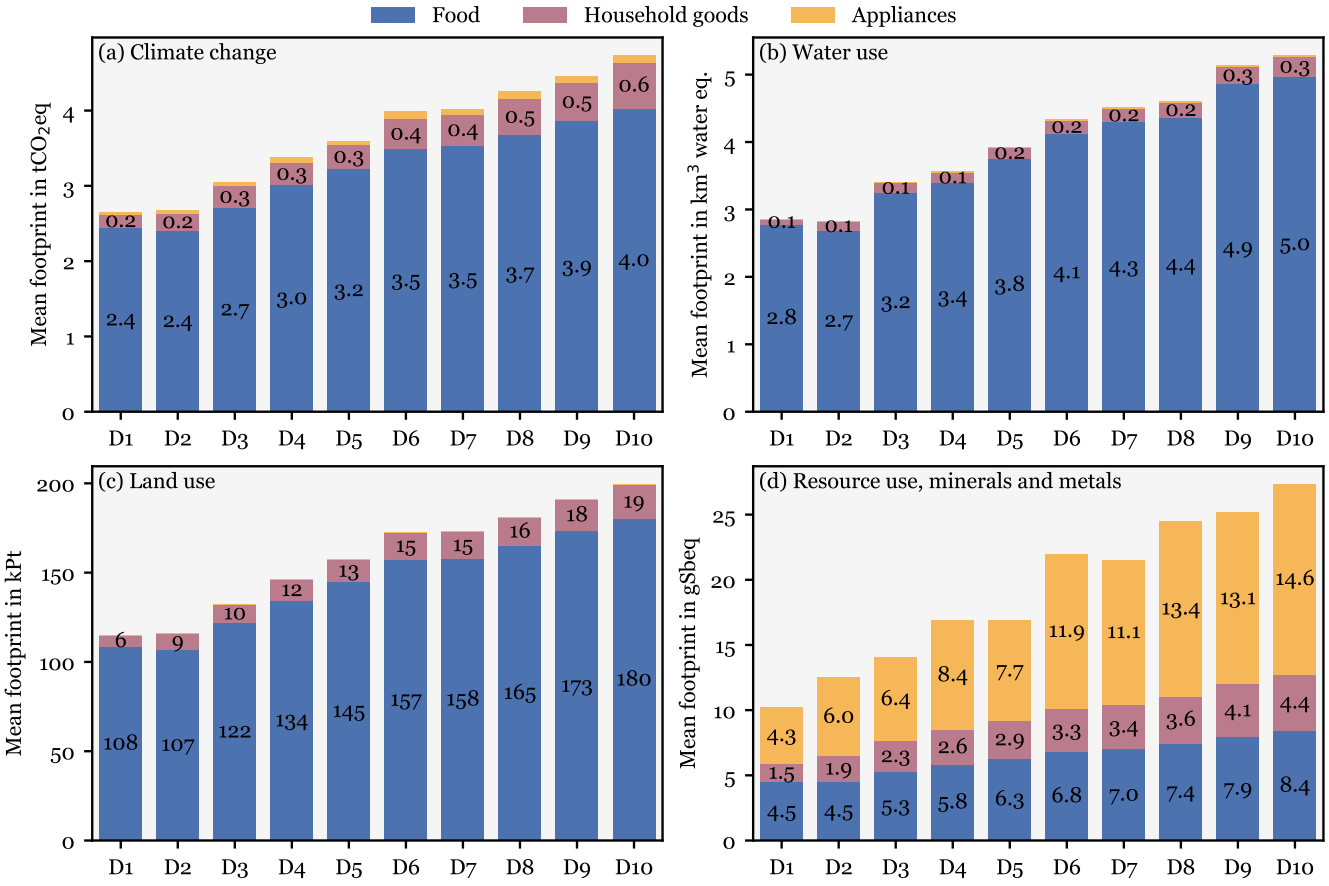

Figure 5: Mean EFs of household income deciles for the year 2015 by basket of consumption for Hungary. Note that the y-axis scale is different from that for the EU (above) to highlight relative differences between the deciles.

5.2 Household Environmental Footprints

To get a more detailed look into the relationship of income and EFs, two common visualisations of inequality are used [10]. EFs are distributed across household income. Figure 6 shows Lorenz curves (plots on the left) and Concentration curves (plots on the right) for the total footprints and each basket of consumption for the EU. The results for all countries individually can be found in Appendix 12.

The Lorenz curves show the cumulative population (i.e. number of households) ranked by increasing EF against its cumulative share of the EF, illustrating how EFs are distributed independently of household income. The Concentration curves show the cumulative population (i.e. number of households) ranked by increasing household income against its cumulative share of the EF. They illustrate how the EFs are distributed across household income. Because households with the same income can have significantly different EFs, for example due to their size, the sustainability of their lifestyle or their location [10] the two curves are not expected to be the same.

Instead of simply sorting the households in the data, however, sample weights were applied to ensure that the curves are representative of the total population. This was done by adjusting the x-axis position of each household according to its sample weight. This means, that each household "occupies" as much of the x-axis as it represents of the population. A point with a larger sample size is further away from the household directly left and right of it, while household with small sample weights are closer together. The y-axis positions were adjusted accordingly by calculating the cumulative share of the weighted impacts (household impacts times household sample weight).

The Lorenz curve can be used to answer questions such as “How much of the total carbon footprint are the 10% of the households emitting the most responsible for?” while the concentration curve is applicable to questions such as “How much of the total carbon footprint are the 10% of the households with the highest income responsible for?”.

These questions can be answered by drawing ordinal lines between the axes and the respective curve. Take the example of the carbon footprint for all baskets together: Drawing an ordinal line to the Lorenz curve for the carbon footprint (plot (a)) and from there horizontally to the y-axis shows that the 50% households emitting the least greenhouse gases account for about 23% of the total carbon footprint in the EU, meaning that about 80% are caused by the other half. Doing the same for the Concentration curve (plot (b)) shows that the 50% households with the lowest income cause about 35% of the total carbon footprint. The general interpretation of both curves is that the stronger they are bent, the higher the inequality of the underlying distribution. The line of equality shows a distribution where every household has the exact same impact.

The curves for all baskets together, plots (a) and (b), are closely aligned with the curves of the food basket, plots (c) and (d), and with each other. This is due to the fact that the consumption within the food basket is the largest contributor to these footprints (see Figure 3) and thus also has the most influence on how the curves across all baskets look like. The only exception is the curve for resource use, which differs more from the food curves than the other impacts, because of the strong influence of appliances in particular (see Figure 3, plot (d)).

The visually small differences of the curves for the impact categories can mean comparably large deviations for the mean EFs per decile. As shown in Section 5.1, the decile difference for the mean water use EF (about 6.4 times larger for D10 compared to D1) is more than double that of the carbon footprint (about 2.8 times larger for D10 compared to D1), despite the visually close alignment of the curves.

Looking more closely at the curves for the food baskets (plot (c) and (d)), the Lorenz curves are bent much more strongly, meaning that there is a strong concentration of total environmental impacts among high EF households, while the Concentration curves are much closer to the line of equality. This shows that the impacts from food are unequally distributed across households, but not much affected by the income. This is also found by Multi-Regional Input-Output Analysis (MRIO) based studies (see, for example, [35, 37, 92]). Only the water use footprint shows a closer relation to the income with the bottom 50% of households by income causing only about 30% of the total impact. These differences likely represent the different products consumed at different income levels.

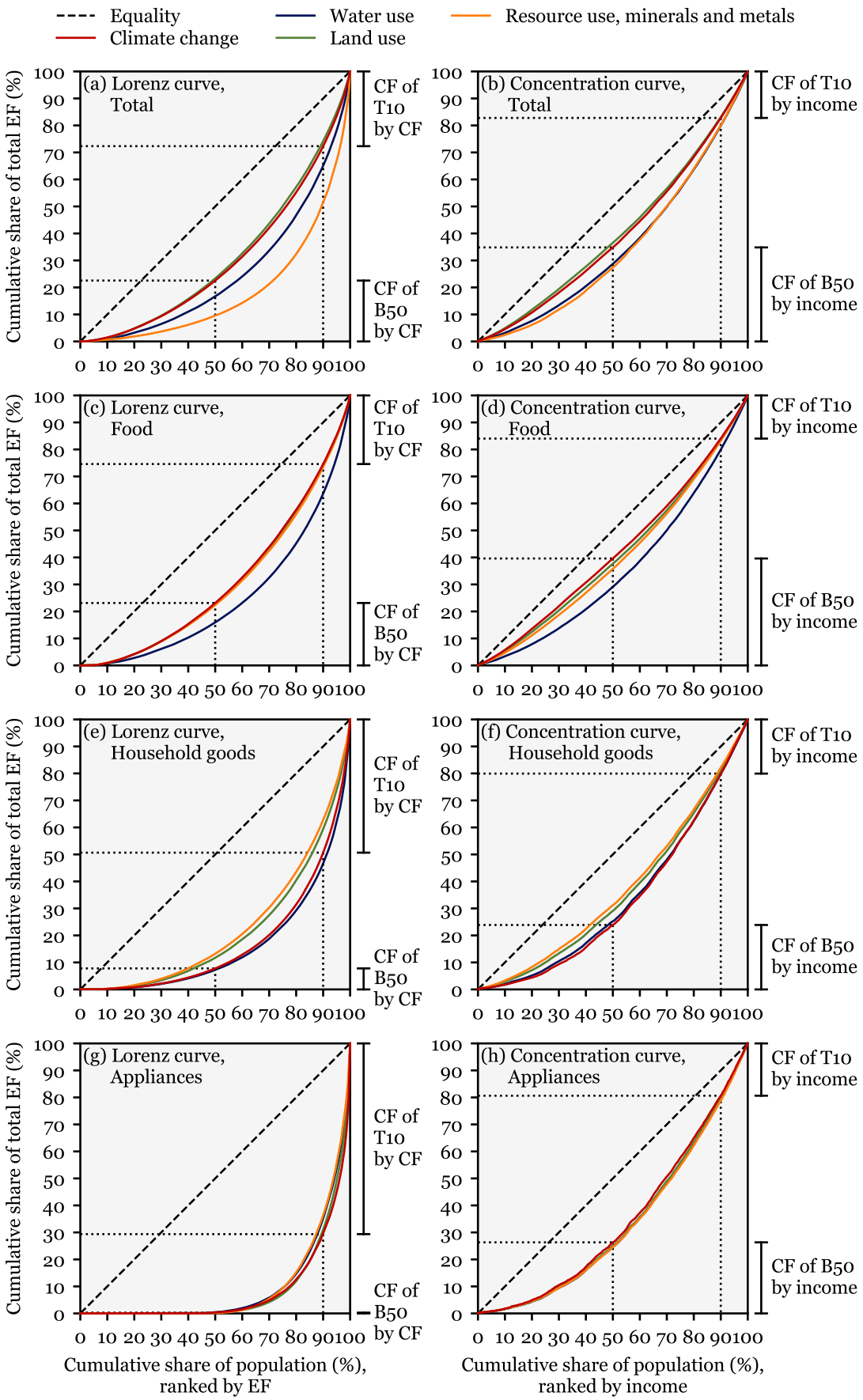

Figure 6: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in the EU (without Germany, Italy and Austria) in 2015. The annotations show examples for how to read the curves for the carbon footprint (CF). The upper guiding brackets show the share of the cumulative impact that the top 10% (T10) of the households sorted by impact (Lorenz curve) or income (Concentration curve) are responsible for. The bottom guiding brackets shows the same for the bottom 50% (B50).

The EFs from household goods, plots (e) and (f), show a strong concentration of impacts among high EFs households with the top 10% households by EF having between 50% and 60% of the impact. The Concentration curve again shows more equal distributions. The 50% of households with the lowest income have about 25% of the total water use and carbon footprint and 30% of the total land use and resource use footprint for household goods. The impact curves align closer at the higher income levels with the top 10% of the population having 20% of the total impacts for all categories.

The appliances basket shows the strongest bent Concentration curves. However, particularly remarkable are the very strongly bent Lorenz curve for all impact categories (plot (g)), with the 10% of highest impact households having more than 70% of the cumulative footprint of all categories while the bottom half of the households have no impacts at all. It also shows the strongest dependence on income with the bottom 50% of the population by income having only about 27% of the impacts.

The inequality exhibited by the appliances and also partially the household goods basket in the Lorenz curves is likely due to the infrequency of purchase problem [48]. The appliances basket contains only durable goods, which are bought infrequently, while the household goods basket contains many such goods. Households that bought a durable good within the period of the survey diary therefore have large EFs, while the ones that did not have an EF at or close to 0 in the appliances basket. Households that did not buy an appliance in the survey period do not have any impact, despite the correction (false zeros). This effect is stronger for appliances than household goods as the latter contain also short-lived products likely not affected by this problem. Appendix 13 shows the household goods curves differentiated by durable and non-durable goods. Durable household goods are much more similar to the appliances Lorenz curve than non-durable ones, further indicating that the false zero values are partially responsible for the observed inequality of consumption. As mentioned in Section 4.1.1 it is unclear whether these infrequent purchases also have an effect on the income deciles' mean EFs and the concentration curves. This depends on whether there is a connection between household income and whether it is affected by this bias. This is further discussed in Chapter 6 below.

Of all baskets, appliances show the most aligned curves for the different impacts, indicating that differences mostly stem from the amount of consumption and not so much the composition. If households, that have on average larger impacts from appliances or larger income would buy different types of appliances, the impacts would differ more as different appliances have different impact intensities. However, this is also due to a limitation of this study, as many appliance subclasses were covered using similar proxies for the impacts. Therefore, even if the consumption would differ strongly between the subclasses, the impacts would not reflect this. Generally, the Lorenz curves show a much larger bent than the concentration curves for all baskets, reflecting the differences of footprints that come from other factors than income, such as lifestyle, household size or location [10]. Furthermore, as shown in Figure 72 in Appendix 14, the Lorenz curve for household income is consistently bent more strongly than the concentration curves. This means that the EFs rise less than proportionally with household income (income elasticity of the EFs below 1) [10].

5.3 Comparing countries

The EFs and their distribution across income groups also vary significantly between member states. Figure 7 shows the range of mean footprints between the lowest and highest income decile for the countries included in this study. It is important to note that the differences between the countries stem from the amount and composition of consumption only because EU-average impact intensities were used (see Section 4.4).

Carbon footprint (plot (a)): Generally, high-income member states like France, Luxembourg and Belgium show a wider spread while Eastern European countries like Slovenia, Hungary and Czechia show lower levels of footprints and a smaller range between the deciles. However, there are some exceptions, such as Greece and Croatia showing comparably high impacts and range as well as Romania and Bulgaria, which show a wide spread in the low impact segment. The EU- total also shows a wide range. A similar picture emerges for the land use footprint (plot (c)): Czechia again has the lowest spread. High-income countries like Denmark, Malta and Ireland show a wide range and higher impact levels, while Eastern European countries show lower impacts and smaller ranges.

The water use footprint (plot (b)) and resource use footprint (plot (d)) show a similar overall pattern but stronger differences between the countries. High-income countries, particularly Denmark, Luxembourg and France for the water use footprint and Sweden for the resource use footprint, show vast differences between D10 and D1. Below the EU, there are mostly low-income Eastern European countries with very small ranges compared to the high-income countries. However, some exceptions like the water use footprint of Finish households can be found.

Overall, the data across all four environmental footprints demonstrate a relatively consistent pattern of high-income countries having larger impact and countries with larger impacts having a bigger range between D1 and D10.

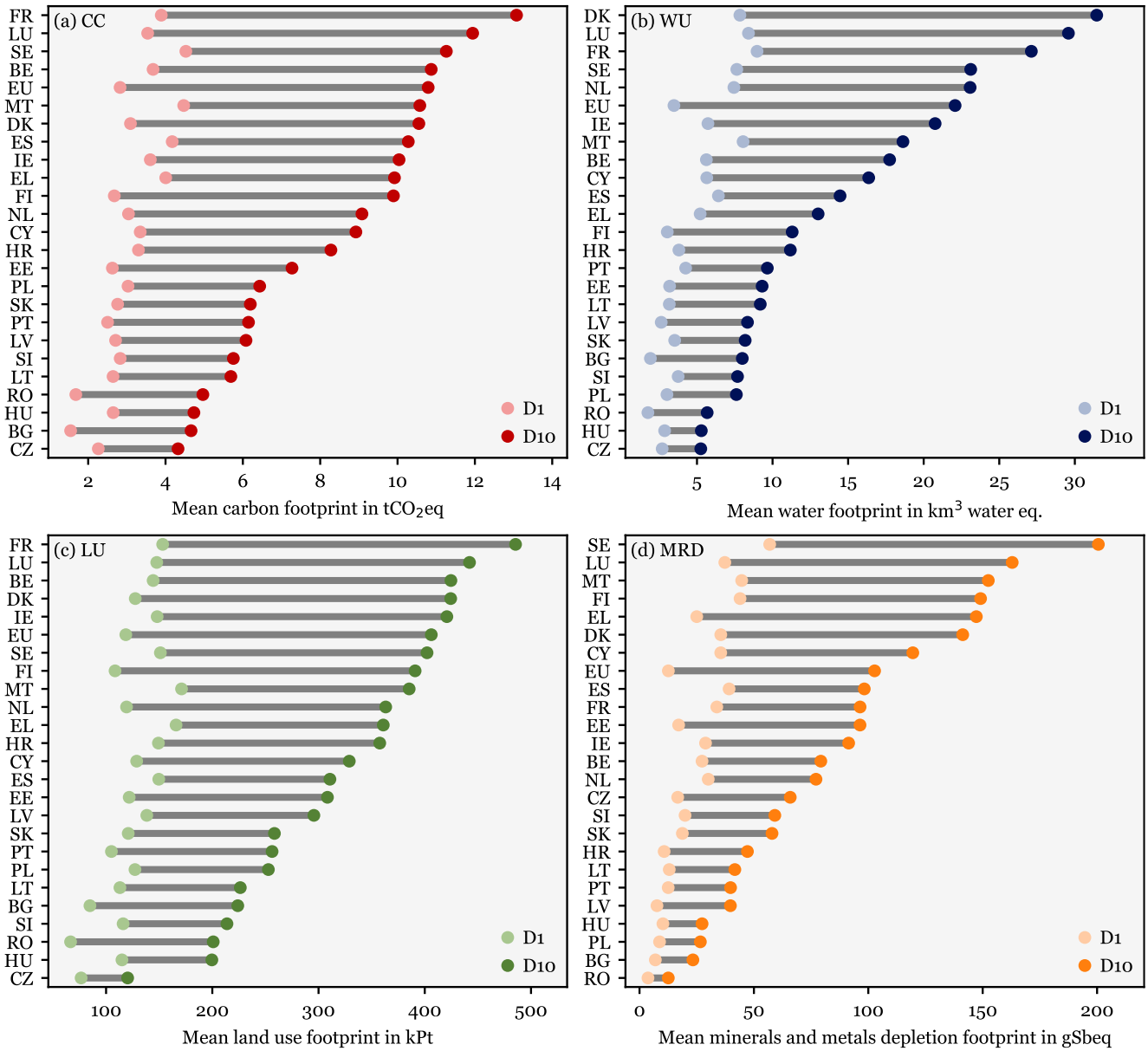

Figure 7: Range of mean footprints of the lowest and highest income decile in 2015 for each country included in this study. The countries are sorted by the D10 mean of the respective environmental footprint. EU without Austria, Italy and Germany. (a) Climate change (CC), (b) Water use (WU), (c) Land use (LU), (d) Resource use, minerals and metals (MRD). Note that the order of the countries changes between the subplots. Also note that the differences between the countries stem only from the consumption, because EU-average impact intensities per product were used. The same plot with the countries sorted alphabetically can be found in Appendix 15.

The last indicator evaluated is the ratio between the mean footprints of households in the top 10% of the population (T10) and the bottom 50% (B50), following Chancel *et al.* [93]. It allows for a straightforward interpretation of EFs from high-income compared to low-income groups. Figure 8

shows that the T10/B50 ratios differ significantly between the countries. The largest differences are observed for Denmark and Finland. Generally, the ratio does not differ much between the different EFs, confirming the observation from the concentration curves in Figure 6. For some countries, the water use and/or resource use footprint stand out, for example Greece, Latvia and Czechia. This is also the case on EU-level.

The ratios for each basket of consumption separately, provided in Appendix 16, show large differences. Appliances show generally larger differences between T10 and B50 than household food and much larger ratios than those for food. This fits the findings from the Lorenz and concentration curves.

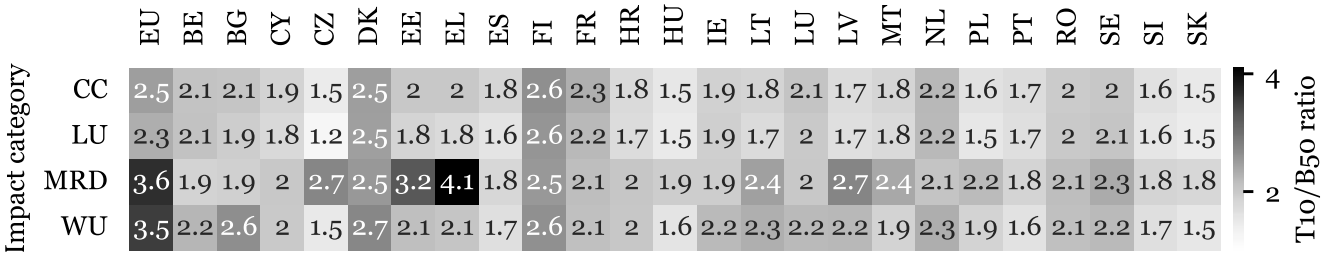

Figure 8: Ratio between mean EF of the top 10% households (T10) and the bottom 50% (B50) by income for the countries included in this study. Higher ratios, meaning that the T10 has a higher EF compared to the B50, are shown in a darker shading. Note that the shading is scaled to the highest ratio (4.1). EU without Austria, Italy and Germany. Appendix 16 contains the same figure including all baskets of consumption separately.

5.4 Sensitivity analysis

As described in Section 4.1.2.4, a sensitivity analysis for the outlier replacement was conducted. In the sensitivity variant, the top 5% of expenditure and consumption quantity values were replaced with the decile mean for the respective household and country, instead of the top 1%. Appendix 1 includes an analysis of the differences in the decile mean EFs for both variants.

Appendix 17 shows the resulting mean decile EFs, Lorenz curves and Concentration curves for the EU. Because more consumption quantity outliers are replaced, the decile means for the 5% threshold are much lower than those for the base variant for all baskets of consumption, impact categories and deciles. The results for the 1% threshold show between 1.15 and 1.48 times the carbon footprint, 1.14 to 1.40 times the land use footprint, 1.22 to 1.52 times the water use footprint and 1.58 to 2.09 times the resource use footprint compared to the 5% threshold, depending on the decile. This indicates a strong sensitivity of the total impacts to the choice of the threshold.

The results for the 5% threshold show a slightly lower contribution of household goods and appliances to carbon, water use and land use footprints. For the resource use footprint, of which the total EF is also stronger reduced by applying the 5% threshold than for the other categories, shows a strong reduction of the contribution of appliances of between 10% and 22% less compared to the 1% threshold, depending on the decile. This is likely due to its overall dependence on appliances, which are more sensitive to inflated consumption quantities from infrequent purchases.

The Lorenz curves for all baskets and impact categories show more equal distributions for the 5% threshold (see Appendix 17). This outcome is expected by definition, as households are sorted by their environmental footprints (EFs) in the Lorenz curves.

More interesting is the effect on the Concentration curves. Household goods and food show similarly pronounced shifts to more equal distributions. The contribution of lower income deciles to the overall impacts, i.e. sum of all baskets, are increased by up to 0.7% and the one of higher income deciles reduced by up to 1.8% (see Appendix 1 for the numerical changes).

In contrast to the other baskets, the Concentration curve of appliances shows a more unequal distribution for the 5% threshold. This indicates that for appliances, more outliers are removed in lower income groups for the 5% threshold compared to the 1% threshold. The effect size is low with changes of -1% to 2% in the decile contributions to the overall impacts from appliances.

To conclude, the absolute impacts, measured as income decile mean EFs, the Lorenz curves and the contribution of appliances to the resource use footprints show a strong sensitivity to the choice of the

threshold. However, the relative responsibility of income groups, i.e. the inequality of the EFs, is rather robust against changed in the threshold. That food and household goods show more equal distributions with a higher threshold while for appliances less equal distributions are the consequence, argues against assumption that higher income households are more affected by outliers from infrequent purchases.

6 Discussion

For the discussion of the findings, the implications are explored first (Section 6.1), followed by the limitations of the methods and data (Section 6.2) and suggested directions for future research and necessary improvements of data (Section 6.3).

6.1 Implications

Existing studies show that income redistribution likely increases the environmental impacts of households, at least under the paradigm of consumption-based accounting paradigm, because of saving rates increasing with income [10, 94].

The results from this study suggest that the horizontal variability of the environmental footprints (EFs) from households goods, appliances and food, meaning differences at the same income level [10], might be more important. This can be seen from the fact that responsibility for the total EFs differs much more between households with low EFs and high EFs (Lorenz curves) than between households with high and low income (Concentration curves). This heterogeneity in expenditure patterns within income groups is also found by other studies, for example for Belgium [25]. The ratio of the mean EF for the highest (D10) to the lowest income decile (D1) is largest for the resource use EF (8.2 times). Although it first seems large, comparing it to the ratio of the mean household income (with about 28.6 times the mean household income for top decile vs bottom decile households) shows that it is much smaller. Despite the fact that both are aggregate values at EU level, including heterogeneous countries such as Bulgaria and Luxembourg, they offer an insight for EU-wide policies. These should target responsible consumption patterns directly rather than an intermediate target like income equality, despite good reasons to reduce economic inequality like the potential to reduce status consumption [95].

It is important to consider that this finding only applies for the limited set of consumption categories considered. Especially housing and mobility have been shown, in Multi-Regional Input-Output Analysis (MRIO) based studies (e.g. [37]), to be closer connected to household incomes.

The reason for the comparatively low connection between EFs and household income in this study is the dominance of food consumption across three of the four impact categories. Food is typically consumed similarly across income groups [21, 35]. For the impact categories land use and water use, other studies (e.g. [92, 96]) also find the dominance of food. For the carbon footprint, however, the results of this study differ from previous work. Ivanova and Wood [37], who use a MRIO-based approach, find a similar importance of food for lower EU income deciles, but clothing and manufactured products, which would fall into households goods and appliances, to have double the carbon footprint than food for the D10. They also find food consumption to have a much lower carbon footprint with 2.1 tCO_2eq for D10 compared to the 6.9 tCO_2eq found here. For Austria, which was not included here because it does not participate in the EU HBS, Theine *et al.* [39] also find food to have a smaller contribution to the household carbon footprint than "goods" across all income deciles. Although they do not specify what is included under "goods", it is likely close to what is considered here as household goods and appliances because they explicitly include services, mobility, energy and housing as separate categories. Many other MRIO-based studies (e.g. [6] or [40]) report EFs for aggregated total household consumption, including housing and mobility, or classify consumption categories differently (e.g. [36]). Because not all household consumption was included here, this makes a comparison impossible.

The different importance with respect to the contribution of household goods might be explained by the ones that were excluded because of missing price and/or impact data. Especially items of status consumption with likely high impact intensities and strong connection to income, like boats (09213), aeroplanes (09212) and jewellery (12311), are not covered here. The absolute difference for food might

come from the differences between the process-based Life Cycle Assessment (pLCA) approach employed here and MRIO methods (see [14]). Comparing MRIO- and pLCA-based mean European EFs, Castellani *et al.* [13] find food to contribute systematically less to overall impacts in the MRIO based approach.

Sala and Castellani [17] use a pLCA based approach with the Representative product impacts (RPI) dataset, the same impact assessment method and the same consumption baskets as here to estimate average European EFs. Because they do not conduct a distributional analysis, only the contribution of baskets to the total EFs, meaning aggregated across all income categories, can be compared. For that, they have very similar results with a dominance of food for climate change, water use and land use and appliances being most important for resource use. Because they do not calculate EFs for households and the absolute EFs they report include all EU countries, while Austria, Italy and Germany had to be excluded here, a direct comparison of absolute impacts is not possible. A recent methodology report by the Joint Research Centre (JRC) of the European Union (EU), building on the work of Sala and Castellani [17], but instead of them also using the EU Household Budget Survey (HBS), finds food to make up more of half the impacts despite including mobility and housing [97]. The results are so far reported only as single-weighted score and not per impact category, but show the same overall contributions for the consumption baskets considered here.

Apart from the relation to income, the results clearly show that policies targeting the food system could have significant impact on reducing household EFs. Policies should promote more sustainable diets [98], for example through higher taxes on meat [99]. At the same time, appliances and household goods must not be neglected, with the former being especially important for reducing the depletion of minerals and metals, which are important resources for the energy transition [63]. Therefore, policies facilitating the efficient use of appliances and prolonging their lifetime are also important. An overview of possible interventions can be found in Hischier *et al.* [7].

Generally, it must be considered that economic instruments will affect poorer households disproportionally in relation to their income. Furthermore, high-income households can switch more easily to less environmentally harmful consumption [99, 100]. By providing universally accessible public services with lower environmental impacts [99, 101], such as public canteens with a focus on sustainability [102, 103], all households, regardless of their income, could be enabled to shift to more sustainable lifestyles.

Because of the granularity of the approach, the results also showed that single ECOICOP subclasses are highly relevant for the overall footprints and the differences between the mean decile EFs. These were predominantly subclasses including animal-based food, but also nuts, wine and non-electrical appliances. The latter it includes many different small items such as brushes, hairpins, scales or razors, which shows that small items also need to be considered for environmental policies.

The variation in environmental footprints across EU member states indicates that national contexts significantly influence consumption patterns and their environmental impacts. High-income countries such as Malta, Belgium, and Denmark exhibit higher footprints and greater disparities between income deciles, while Eastern European countries like Slovenia, Hungary, and Czechia show lower levels of footprints and smaller ranges between deciles. These differences underscore the need for tailored policy approaches that consider the specific socio-economic and cultural contexts of each country.

6.2 Limitations

There are several methodological and data-specific limitations to consider.

6.2.1 Limitations regarding household expenditures

First, the EU HBS is based on HBSs from all member states with differences in timing, frequency, sample design, structure and content [10, 104]. They even differ in how they define what constitutes a household [66]. An overview of the differences can be found in the quality report for the 2015 HBS [66]. Thus, comparisons between countries are possible only to a limited extent.

Second, the surveys rely on short survey periods ranging from one week to a month [66]. As described above, this leads to a misrepresentation of goods that are not bought on a weekly basis, mainly durable goods such as appliances, for some households. This was partially corrected for by replacing the top 1%

of expenditure values per country with the mean of the income decile in the respective country and changing negative expenditure values to zero, following Büchs *et al.* [48]. Because it is not possible to distinguish genuine from artificially inflated values, the share replaced (i.e. the 1%) is somewhat arbitrary. False zeros, i.e. households that did not buy a certain good in the survey period but another time in that year, are not mitigated by that approach. A sensitivity analysis with a 5% boundary was conducted, showing a high sensitivity of the absolute results but a relatively low sensitivity of the relative differences between the deciles, i.e. the inequality. Interestingly, appliances, that should be more affected by outliers due to them being more infrequently purchases, show a less equal distribution across income groups for removing more outliers.

The importance of this limitation has to be differentiated for the different results. Infrequent purchases are undoubtedly an issue for deriving the Lorenz curves. The Lorenz curve for appliances, in particular, showed very unequal impacts with 50% of households having none at all. This is surely not entirely due to real consumption patterns but rather to false zeros and inflated values.

With regard to the Concentration curves and the income decile mean EFs, infrequent purchases would only have an effect if higher or lower income households are systematically more affected. As stressed by Bardsley *et al.* [67], it is unclear whether the decile mean EFs are representative or biased by higher income deciles being more affected by inflated values from infrequent purchases, because they buy more affected products like appliances. The low sensitivity of the relationships between the deciles in the sensitivity analysis suggests that low- and high-income households are similarly affected by extreme outliers, i.e. inflated values. However, this might also be due to the choice of replacing the values with income averages. This stabilises the mean EF of the deciles. Furthermore, at least for the overall impacts, it might be due to the large contribution of food. The consumption of food can be affected by infrequent purchases as well, but mainly in countries with subsistence farming where consumption patterns are thus more dependent on the local agricultural cycle and the inherent infrequency of harvest [105]. For the resource use of metals and minerals footprint, the bias might be significant. To conclude, the influence of infrequent purchases on findings from the distributional analysis remains uncertain. Because how statistical authorities deal with infrequent purchases is difficult if not impossible to understand from the outside, collaborating with statistical authorities responsible for the HBSs, which was beyond the scope of this thesis, might help clarify the importance of the issue and potential mitigation strategies.

HBSs are also subject to factors such as recall bias, changes in survey design, faulty sampling, poor supervision or nonresponse [66, 106]. Furthermore, there is underreporting for socially undesirable goods such as alcohol or sweets [10, 66].

Fourth, the response rate varies with socio-economic status, with richer people tending to participate less [10]. Ultra-rich households typically to not participate in HBSs at all [37], resulting in a selection bias. This results an underestimation of inequality because their extremely high EFs [24, 100, 107] cannot be included.

Finally, because the HBS does not record other differences within subclasses (e.g. the price segment of goods), all subclasses were represented using an average price and impact intensity, which was referred to as product quality problem in the literature review (see Chapter 2). Environmental impact intensities of products can differ for various reasons. Ikeda [108] shows for furniture in the USA that, apart from price differences, products in different quality segments also differ strongly with respect to material composition. The same issue also means that effects of green consumerism (i.e. explicitly consuming less environmentally harmful products or buying second-hand) cannot be considered.

Using one price per subclass for all households within a country also means that the physical consumption might be under- or overestimated for any particular household. Take the hypothetical example of shoes: Let us assume an average price of 80€ per pair for the relevant subclass (03211 for men, 03212 for women). A low-income household buying shoes for 40€ a pair and recording an expenditure of 80€ in the HBS would have a consumption of one pair in that year despite having bought two pairs. A high-income household buying shoes for 480€ per pair and with an expenditure in the HBS of 960€, would have a consumption of twelve pairs recorded despite actually consuming two pairs only. Therefore, two vastly different amounts of consumption are recorded, twelve for the high-income and one for the low-income household, despite having consumed the same physical number of shoes.

From the side of the price data, different price segments could roughly be differentiated for some goods, because the Purchasing Power Parities (PPP) price dataset [71] differentiates several product types by labels such as “Well known brand – higher segment” or “Well known brand – lower segment”.

Girod and Haan [21] conducted the only study so far that adjusts EF estimates by considering the quality of goods [24]. They derive physical consumption units for COICOP classes from the 2005 Swiss HBS and then calculate the average prices at which households consumed for each COICOP class. This is possible because, in contrast to the EU HBS, the Swiss HBS includes not only the physical consumption quantities for food and beverages but also the number of purchases made by each household in the COICOP class. Girod and Haan [21] multiplied the latter with assumptions about the weight of the goods to obtain physical consumption quantities for household goods and appliances. They find significant price increases for consumed goods at both higher and lower household income for food, household goods and appliances. However, it was decided not to use their estimates to correct prices here for three reasons: (a) they are provided at aggregate consumption categories, such as furnishings or clothes, and thus miss the necessary granularity; (b) they only refer to Switzerland and price difference between income groups might be very different in other countries; and (c) they only differentiate two income groups, above and below the median income.

This issue of not getting the physical consumption right affects only part of the food and beverage consumption in this study because physical quantities were available for 14 of the 24 covered countries, representing 71% of the households. However, this limits the comparability of EFs from food between these 14 and the remaining 10 countries, for which prices had to be used. Girod and Haan [21] find for Switzerland that the differences in food consumption between income groups are almost exclusively due to price differences, indicating that the inequality for EFs from food found here might be an overestimation for the 10 countries not providing physical quantities directly. A potential improvement would be to derive income-decile level average food prices from the 14 countries providing quantities and expenditure and then adapt those for 10 countries without data to obtain more accurate prices.

6.2.2 Limitations regarding prices and conversion to physical quantities

Apart from the uncertainties inherent to the PPP and Detailed Average Prices (DAP) datasets and the currency conversion rates used for the PPP prices as well as the above described product quality problem, four main limitations pf the price data and the conversion to physical quantities need to be considered.

First, the prices are grouped to subclass level assuming equal market shares for all assigned items. This is common practice by Eurostat [74]. However, this might introduce errors, especially for heterogeneous subclasses with items that vary strongly in price. The subclass “Games and hobbies” (09311), for example, includes traditional card games as well as game consoles. If the market shares of the items in the subclass are not truly equal, the price used for subclass might deviate strongly from the true average.

Second, prices for many countries and subclasses had to be imputed using price level indices from the PPP dataset, introducing further uncertainty. Interestingly, the price level indices are calculated by Eurostat based on the same items used here from the PPP dataset, despite many types of items, like food for example, missing from the provided data. It could be that Eurostat simply does not provide these to researchers.

Third, units of 85 of the 899 items, for which prices where provided and which were used for the grouping to subclass, had to be converted, mostly by assuming a mass to change the unit from kg to piece or vice versa.

Finally, a direct mapping was only possible for 99 of the 141 HBS subclasses, while 42 subclasses were represented by using the price for another subclass as a proxy.

6.2.3 Limitations regarding impact intensities and conversion to impacts

The impact intensities derived from Ecoinvent as well as the JRC’s RPI dataset come with inherent uncertainties from the modelling they are based on. Beyond that and the product quality problem discussed in Section 6.2.1), there are two main limitations to consider.

First, because there are no impact intensities available for ECOICOP subclasses specifically, the subclasses had to be represented using 141 products and 35 product groups and combinations of both. Only for 87 rather homogeneous subclasses, a good mapping was achieved because the impact intensity for a very similar or the exact products in that subclass was available. For the other 54 subclasses, proxies had to be used. Often, this meant only covering parts of the cycle of products in a subclass. For the subclass "Crisps" (01175), for example, the impact intensities of potatoes were taken as a proxy, missing impacts from processing steps and end of life. Furthermore, the market shares of products included in the subclasses is unknown, equal market shares were assumed, causing the same problem for heterogeneous subclasses as described for the prices above.

Second, the used impact intensities refer to the European average product, limiting the accuracy of country level results. For example, a fridge produced and used in France, with a largely decarbonised electricity grid, will have a much lower carbon footprint than its counterpart in Bulgaria [109]. This is less important for the results at EU-level. However, because Austria, Italy and Germany had to be excluded, the EU average in the consumption data refers to other countries than in the impacts data, for which all EU countries were considered [80]. The JRCs RPI dataset includes regionalisation of impact intensities [80], which are not publicly available. Using regionalised impact intensities, however, would conceal differences in consumption patterns as differences in EFs would also stem from difference impact intensities. Therefore, depending on the question it might not make sense to use them even if available.

6.2.4 Other limitations

A general limitation is that only environmental impacts directly associated with a certain household's behaviour were considered, without redistributing governmental consumption to households. This especially limits the comparability between countries because depending on the type of provisioning system, households might not need to make the same expenses [10]. A country with a privatised healthcare system, for example, would see those expenses in households while a state-funded and organised healthcare system would not require households to make those expenses at all. However, this general limitation likely has a negligible effect on the results of this study. The goods included in the scope are all strongly household related and usually not provided by the government directly. Indirect provisioning through social security payments does not introduce any bias because the expenses made with it are recorded in the HBS in the same way as all other expenditures.

6.3 Future research and improving data

Mainly, more accurate and robust results require better data. National statistical offices need to harmonise the HBS methodologies to improve the comparability of countries. Fortunately, a new EU framework regulation will require the harmonisation of data collections from 2025 onwards [66]. Furthermore, the scope of the surveys should be extended to include prices for consumed products to enable researchers to consider product quality differences. While this would not help differentiate more or less sustainable products, the consumption rates would be much more accurate. Furthermore, the more accurate consumption rates could help identify inflated values from infrequent purchases.

Increasing the frequency of surveys as done in Japan, where a monthly HBS is conducted, might mitigate issues with infrequency of purchase and enrich analyses [50]. Another option is to integrate novel data sources, like personal budgeting apps or electronic banking, to have more complete account of consumption for the entire year. A few countries already consider or have implemented similar new approaches [66]. The main problem with these demands is that additional requirements might result in falling response rates [68].

Eurostat should also ensure consistency of applied data classifications (see Appendix 3), denote missing values in the HBS as such and not as false zeros and make more datasets available for outside researchers. The DAP dataset, for example, which was last published for the year 2015, is available for later years and for more subclasses for research within the European Commission [97].

Until better data are available, there are several potential directions for future research.

First, all ECOICOP subclasses need to be included as a next step, especially since mobility and housing show much stronger connection to household income in other, MRIO-based, studies [37],. To increase

completeness while maintaining a high level of detail, a hybrid approach of MRIO and process-based Life Cycle Assessment (pLCA) might be promising [19].

Second, future research should include other household characteristics besides income, for example using a clustering approach as done by Froemelt *et al.* [19]. The observed "horizontal" heterogeneity [10] from factors such as household size or location underlines the importance of this. While this is out of scope of this study, including more household characteristics is possible with the EU HBS data, which covers many such variables [65]. Future studies should also explore the connection of wealth and EFs as well, as recently done by Büchs *et al.* [110] for carbon footprints in the United Kingdom and Belgium.

Third, sustainability research should examine the importance of infrequent purchases, for which, as discussed above, the influence on distributional analyses remains unclear. Future research could explore methods to mitigate the problem of infrequent purchases, for example, by looking into the field of econometrics [67, 111]. However, econometric models of infrequent purchases require many assumptions and a priori model specifications [67]. Gibson and Kim [105] compare infrequent purchase models with directly measured hidden consumption for food and find significant differences, with the fundamental issue still being that distinguishing genuine consumption from false zeros and inflated values remains difficult. Bardsley *et al.* [67], for example, show how propensity score matching might be used in this context. However, their method required knowing whether a unit records a zero value because of the survey window or for some other reason.

If one came to the conclusion that the results of the distributional analysis, e.g. the mean consumption rates for income deciles, are not biased by infrequent purchases, they could help identify inflated consumption values of households or false zeros and thus estimate more accurate Lorenz curves.

Fourth, researchers need to address the product quality problem as much as possible without better data. As described above, so far only Girod and Haan [21] were able to do so because of additional data in the Swiss HBS. Researchers could survey product prices and map the price and income deciles one to one, as done by previous master's theses for furniture [108, 112]. However, while low-income households are restrained in their ability to buy high-prices products, neglecting consumer loans, high-income households that prefer cheaper products are not hindered in buying them. Price might not be the decisive criterion for all products consumed by households. Therefore, it is unclear how well the mapping would be backed empirically.

Fifth, researchers could use the detailed pLCA models to examine potential future developments. It could be interesting, for example, to assess how EFs and income might be related in a largely decarbonised energy system. Because the JRC does not provide access to the models as such, this was not possible here.

Finally, for Industrial Ecology (IE) in particular, the HBS and similar datasets are well established in MRIO analysis. Typically, impact intensities per unit of currency for different consumption categories, derived from MRIO tables, are multiplied with the monetary expenditure to estimate EFs of household consumption and their distribution (see, for example, [33, 37, 43, 48]). Also, as described in Chapter 2, household expenditure data is increasingly used with impact intensities from combined pLCA models (see, for example, [19, 52, 59]). However, the use of HBS data for other fields of IE research, for example estimating product stocks in households, is underexplored. The main limitation for estimating household stocks using HBS data is the inability to differentiate product prices, which causes errors in estimating consumption rates. The importance of infrequent purchases and missing longitudinal data on single households, because each HBS surveys different households, depend on the level of aggregation that data is needed for. Differences over the years, for example, should balance for the income decile, assuming that the sample weights provided by the HBS ensure representativity.

Generally, it might be worth exploring selected countries first in future research. Spain, for example, provides HBS data on a yearly basis since 2006 and freely accessible anonymised files [113]. The Belgian HBS includes expenditure at an even more granular level than the ECOICOP subclass [68]. This does not only provide additional detail but also mitigates some of the uncertainties here, as it might be possible to avoid the grouping step for prices. An overview of what the survey diaries included for the 2015 version of the HBS and each country can be found in the EU HBS quality report [66].

7 Conclusions

In this study the environmental footprints (EFs) from the consumption of household goods, appliances and food for 200,000 European households from 24 European countries and the European Union (EU) (without Austria, Italy and Germany) were estimated using a process-based Life Cycle Assessment (pLCA) approach. To do this, pLCAs for the EU covering four impact categories were be mapped to expenditure data from the EU Household Budget Survey.

The research question was: *How are the environmental footprints from the consumption of household goods, appliances and food distributed across household income groups in the EU?*

The results show that the carbon, water use and land use footprint, three of the four headline indicators considered in this study, are dominated by the consumption of food at EU-level and therefore largely independent from household income. The fourth indicator, the resource use (minerals and metals) footprint, consists mostly of impacts from the consumption of appliances.

For the product groups within the scope of this study, the 10% households with the highest income have, on average, 2.8 times the carbon footprint, 6.4 times the water use footprint, 3.4 times the land use footprint and about 8.2 times the resource footprint than households belonging to the lowest income decile. Income inequality is much larger, with about 28.6 times the mean household income for top decile vs bottom decile households. At the same time, the range of household EFs, independent of income, is large for all impacts categories. Therefore, policies aiming at a reduction of EFs should target the consumption behaviour directly and not the mediator of income inequality, despite good reasons to reduce economic inequality for its own sake. The results also show that differences between the EU member states are large, indicating that policies need to consider local circumstances.

It is important to consider, however, that due to the limitations of the available data and methodology, a significant share of household consumption, particularly housing, mobility, status consumption and services, were not included in this study. This likely also explains the difference from results in existing literature, which generally finds a stronger connection to income, particularly for the carbon footprint. Therefore, the results should not be generalised to the total EFs of households.

Future research could expand the analysis presented here to include services, housing and mobility and by using regionalised impact data to obtain more accurate results. The pLCA approach should be upheld due to the granularity it offers, for example for the assessment of the distribution of EFs under scenarios.

Statistical authorities need to improve the quality of household expenditure data. Ideally, physical quantities and/or prices would be recorded along with the expenditures, which would make it possible to consider product quality differences. Using digital tools might make it possible to record consumption all year round or even for multiple years and thus mitigate the bias from infrequent purchases. Also, national Household Budget Survey methodologies need to be harmonised to improve the comparability between countries.

Data availability

The following datasets were used in the study. They are numbered using Roman numbers. These numbers are also included in the code and the research flow chart (Figure 1).

- **Dataset I:** Eurostat (2023). EU Household Budget Survey, reference year 2015. Version last modified 07.06.2024. Accessed 13.06.2024. Available on request from Eurostat (see https://ec.europa.eu/eurostat/web/microdata/household-budget-survey). [114]
- **Dataset II:** Eurostat (2024). Purchasing power parities - Average prices of individual products. Received 27.03.2024. Available on request from Eurostat (see https://ec.europa.eu/eurostat/web/purchasing-power-parities/information-data#Access%20to%20detailed%20data). [71]
- **Dataset III:** Eurostat (2024). Euro/ECU exchange rates - annual data. Eurostat online data code ert_bil_eur_a. Version last modified 22.03.2024. Accessed 02.04.2024. Available from https://doi.org/10.2908/ERT_BIL_EUR_A. [72]
- **Dataset IV:** Eurostat (2024). Former euro area national currencies vs. euro/ECU - annual data. Eurostat online data code ert_h_eur_a. Version last modified 22.03.2024. Accessed 02.04.2024. Available from https://doi.org/10.2908/ERT_H_EUR_A. Eurostat online data code *ert_h_eur_a*. [73]
- **Dataset V:** Eurostat (2024). Detailed average prices – 2015. Eurostat online data code prc_dap15. Version last modified 30.08.2016. Accessed 18.06.2024. Available from https://doi.org/10.2908/PRC_DAP15. [75]
- **Dataset VI:** Eurostat (2024). Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates. Eurostat online data code prc_ppp_ind. Version last modified 19.06.2024. Accessed 25.06.2024. Available from https://doi.org/10.2908/PRC_PPP_IND. [77]
- **Dataset VII:** European Commission, Joint Research Centre (2023). Consumption Footprint: impact per product for EU average representative products, by impact category. Version last modified 26.07.2023. Accessed 26.02.2024. Available from https://data.jrc.ec.europa.eu/dataset/59ed26ba-66be-407f-9408-874a91dbbbe5. [78]
- **Dataset VIII:** European Commission, Joint Research Centre (2023). Member States – Consumption footprint Tool. Accessed 17.04.2024. Available from https://eplca.jrc.ec.europa.eu/MSConsumptionFootprint.html. [90]
- **Dataset IX:** ecoinvent (2023). ecoinvent version 3.9.1. Accessed 08.05.2024 from the openLCA Nexus [115]. [116]

Please note that I have no permission to share raw data.

Code availability

The code is available on request _____

Acknowledgements

This study is based on data from Eurostat, Household Budget Survey, 2015, 21.05.2021, version from 07.06.2024. The responsibility for all conclusions drawn from the data lies entirely with the author.

References

[1] W. Steffen, W. Broadgate, L. Deutsch, O. Gaffney, and C. Ludwig, "The trajectory of the Anthropocene: The Great Acceleration," *The Anthropocene Review*, vol. 2, no. 1, pp. 81–98, 2015, doi: 10.1177/2053019614564785.

[2] UN Environment Programme, *Global Material Flows Database: Supporting evidence-based decision-making by policy and business communities*. [Online]. Available: https://www.resourcepanel.org/global-material-flows-database (accessed: Oct. 9 2023).

[3] L. Chancel, T. Piketty, E. Saez, and G. Zucman, "World inequality report 2022," World Inequality Lab, 2022. Accessed: Oct. 9 2023.

[4] J. K. Steinberger, F. Krausmann, and N. Eisenmenger, "Global patterns of materials use: A socioeconomic and geophysical analysis," *Ecological Economics*, vol. 69, no. 5, pp. 1148–1158, 2010, doi: 10.1016/j.ecolecon.2009.12.009.

[5] J. Teixidó-Figueras *et al.,* "International inequality of environmental pressures: Decomposition and comparative analysis," *Ecological Indicators*, vol. 62, pp. 163–173, 2016, doi: 10.1016/j.ecolind.2015.11.041.

[6] D. Ivanova *et al.,* "Environmental Impact Assessment of Household Consumption," *J of Industrial Ecology*, vol. 20, no. 3, pp. 526–536, 2016, doi: 10.1111/jiec.12371.

[7] R. Hischier, F. Reale, V. Castellani, and S. Sala, "Environmental impacts of household appliances in Europe and scenarios for their impact reduction," *Journal of Cleaner Production*, vol. 267, p. 121952, 2020, doi: 10.1016/j.jclepro.2020.121952.

[8] L. Chancel, "Global carbon inequality over 1990–2019," *Nat Sustain*, vol. 5, no. 11, pp. 931–938, 2022, doi: 10.1038/s41893-022-00955-z.

[9] A. Y. Hoekstra and T. O. Wiedmann, "Humanity's unsustainable environmental footprint," *Science (New York, N.Y.)*, vol. 344, no. 6188, pp. 1114–1117, 2014, doi: 10.1126/science.1248365.

[10] A. Pottier, "Expenditure elasticity and income elasticity of GHG emissions: A survey of literature on household carbon footprint," *Ecological Economics*, vol. 192, p. 107251, 2022, doi: 10.1016/j.ecolecon.2021.107251.

[11] Global Footprint Network, *Data and Methodology*. [Online]. Available: https://www.footprintnetwork.org/resources/data/ (accessed: Jan. 17 2024).

[12] E. G. Hertwich, "Life cycle approaches to sustainable consumption: a critical review," *Environmental science & technology*, vol. 39, no. 13, pp. 4673–4684, 2005, doi: 10.1021/es0497375.

[13] V. Castellani, A. Beylot, and S. Sala, "Environmental impacts of household consumption in Europe: Comparing process-based LCA and environmentally extended input-output analysis," *Journal of Cleaner Production*, vol. 240, p. 117966, 2019, doi: 10.1016/j.jclepro.2019.117966.

[14] B. Steubing, A. de Koning, S. Merciai, and A. Tukker, "How do carbon footprints from LCA and EEIOA databases compare? A comparison of ecoinvent and EXIOBASE," *J of Industrial Ecology*, vol. 26, no. 4, pp. 1406–1422, 2022, doi: 10.1111/jiec.13271.

[15] *Environmental management - Life cycle assessment - Principles and framework*, ISO 14040:2006, International Organization for Standardization, Jul. 2006.

[16] J. Teubler, J. Buhl, M. Lettenmeier, K. Greiff, and C. Liedtke, "A Household's Burden – The Embodied Resource Use of Household Equipment in Germany," *Ecological Economics*, vol. 146, pp. 96–105, 2018, doi: 10.1016/j.ecolecon.2017.10.004.

[17] S. Sala and V. Castellani, "The consumer footprint: Monitoring sustainable development goal 12 with process-based life cycle assessment," *Journal of Cleaner Production*, vol. 240, p. 118050, 2019, doi: 10.1016/j.jclepro.2019.118050.

[18] A. Tukker *et al.,* "Environmental and resource footprints in a global context: Europe's structural deficit in resource endowments," *Global Environmental Change*, vol. 40, pp. 171–181, 2016, doi: 10.1016/j.gloenvcha.2016.07.002.

[19] A. Froemelt, D. J. Dürrenmatt, and S. Hellweg, "Using Data Mining To Assess Environmental Impacts of Household Consumption Behaviors," *Environmental science & technology*, vol. 52, no. 15, pp. 8467–8478, 2018, doi: 10.1021/acs.est.8b01452.

[20] L. Kilian, A. Owen, A. Newing, and D. Ivanova, "Microdata selection for estimating household consumption-based emissions," *Economic Systems Research*, vol. 35, no. 3, pp. 325–353, 2023, doi: 10.1080/09535314.2022.2034139.

[21] B. Girod and P. de Haan, "More or Better? A Model for Changes in Household Greenhouse Gas Emissions due to Higher Income," *J of Industrial Ecology*, vol. 14, no. 1, pp. 31–49, 2010, doi: 10.1111/j.1530-9290.2009.00202.x.

[22] B. Gill and S. Moeller, "GHG Emissions and the Rural-Urban Divide. A Carbon Footprint Analysis Based on the German Official Income and Expenditure Survey," *Ecological Economics*, vol. 145, pp. 160–169, 2018, doi: 10.1016/j.ecolecon.2017.09.004.
[23] G. Semieniuk and V. M. Yakovenko, "Historical evolution of global inequality in carbon emissions and footprints versus redistributive scenarios," *Journal of Cleaner Production*, vol. 264, p. 121420, 2020, doi: 10.1016/j.jclepro.2020.121420.
[24] J. Starr, C. Nicolson, M. Ash, E. M. Markowitz, and D. Moran, "Assessing U.S. consumers' carbon footprints reveals outsized impact of the top 1%," *Ecological Economics*, vol. 205, p. 107698, 2023, doi: 10.1016/j.ecolecon.2022.107698.
[25] P. Z. Lévay, T. Goedemé, and G. Verbist, "Income and expenditure elasticity of household carbon footprints. Some methodological considerations," *Ecological Economics*, vol. 212, p. 107893, 2023, doi: 10.1016/j.ecolecon.2023.107893.
[26] F. Pothen and M. A. Tovar Reaños, "The Distribution of Material Footprints in Germany," *Ecological Economics*, vol. 153, pp. 237–251, 2018, doi: 10.1016/j.ecolecon.2018.06.001.
[27] B. Bruckner, K. Hubacek, Y. Shan, H. Zhong, and K. Feng, "Impacts of poverty alleviation on national and global carbon emissions," *Nat Sustain*, vol. 5, no. 4, pp. 311–320, 2022, doi: 10.1038/s41893-021-00842-z.
[28] A. C. Kerkhof, S. Nonhebel, and H. C. Moll, "Relating the environmental impact of consumption to household expenditures: An input–output analysis," *Ecological Economics*, vol. 68, no. 4, pp. 1160–1170, 2009, doi: 10.1016/j.ecolecon.2008.08.004.
[29] K. Hubacek, G. Baiocchi, K. Feng, R. Muñoz Castillo, L. Sun, and J. Xue, "Global carbon inequality," *Energ. Ecol. Environ.*, vol. 2, no. 6, pp. 361–369, 2017, doi: 10.1007/s40974-017-0072-9.
[30] J. Min and N. D. Rao, "Estimating Uncertainty in Household Energy Footprints," *J of Industrial Ecology*, vol. 22, no. 6, pp. 1307–1317, 2018, doi: 10.1111/jiec.12670.
[31] Y. Oswald, J. Millward-Hopkins, J. K. Steinberger, A. Owen, and D. Ivanova, "Luxury-focused carbon taxation improves fairness of climate policy," *One Earth*, vol. 6, no. 7, pp. 884–898, 2023, doi: 10.1016/j.oneear.2023.05.027.
[32] Y. Oswald, A. Owen, and J. K. Steinberger, "Large inequality in international and intranational energy footprints between income groups and across consumption categories," *Nat Energy*, vol. 5, no. 3, pp. 231–239, 2020, doi: 10.1038/s41560-020-0579-8.
[33] J. C. Steckel *et al.,* "Distributional impacts of carbon pricing in developing Asia," *Nat Sustain*, vol. 4, no. 11, pp. 1005–1014, 2021, doi: 10.1038/s41893-021-00758-8.
[34] E. L. Bjelle *et al.,* "Future changes in consumption: The income effect on greenhouse gas emissions," *Energy Economics*, vol. 95, p. 105114, 2021, doi: 10.1016/j.eneco.2021.105114.
[35] G. Hardadi, A. Buchholz, and S. Pauliuk, "Implications of the distribution of German household environmental footprints across income groups for integrating environmental and social policy design," *J of Industrial Ecology*, vol. 25, no. 1, pp. 95–113, 2021, doi: 10.1111/jiec.13045.
[36] R. Duarte, S. Miranda-Buetas, and C. Sarasa, "Household consumption patterns and income inequality in EU countries: Scenario analysis for a fair transition towards low-carbon economies," *Energy Economics*, vol. 104, p. 105614, 2021, doi: 10.1016/j.eneco.2021.105614.
[37] D. Ivanova and R. Wood, "The unequal distribution of household carbon footprints in Europe and its link to sustainability," *Glob. Sustain.*, vol. 3, 2020, doi: 10.1017/sus.2020.12.
[38] K. Song, S. Qu, M. Taiebat, S. Liang, and M. Xu, "Scale, distribution and variations of global greenhouse gas emissions driven by U.S. households," *Environment international*, vol. 133, Pt A, p. 105137, 2019, doi: 10.1016/j.envint.2019.105137.
[39] H. Theine, S. Humer, M. Moser, and M. Schnetzer, "Emissions inequality: Disparities in income, expenditure, and the carbon footprint in Austria," *Ecological Economics*, vol. 197, p. 107435, 2022, doi: 10.1016/j.ecolecon.2022.107435.
[40] M. Sommer and K. Kratena, "The Carbon Footprint of European Households and Income Distribution," *Ecological Economics*, vol. 136, pp. 62–72, 2017, doi: 10.1016/j.ecolecon.2016.12.008.
[41] L. Sager, "Income inequality and carbon consumption: Evidence from Environmental Engel curves," *Energy Economics*, vol. 84, p. 104507, 2019, doi: 10.1016/j.eneco.2019.104507.
[42] A. Jacksohn, M. A. Tovar Reaños, F. Pothen, and K. Rehdanz, "Trends in household demand and greenhouse gas footprints in Germany: Evidence from microdata of the last 20 years," *Ecological Economics*, vol. 208, p. 107757, 2023, doi: 10.1016/j.ecolecon.2023.107757.
[43] M. Baltruszewicz, J. K. Steinberger, J. Paavola, D. Ivanova, L. I. Brand-Correa, and A. Owen, "Social outcomes of energy use in the United Kingdom: Household energy footprints and their links to well-being," *Ecological Economics*, vol. 205, p. 107686, 2023, doi: 10.1016/j.ecolecon.2022.107686.

[44] L. A. López, G. Arce, M. Morenate, and J. E. Zafrilla, "How does income redistribution affect households' material footprint?," *Journal of Cleaner Production*, vol. 153, pp. 515–527, 2017, doi: 10.1016/j.jclepro.2017.01.142.
[45] C. Johne, E. Schröder, and H. Ward, "The distributional effects of a nitrogen tax: Evidence from Germany," *Ecological Economics*, vol. 208, p. 107815, 2023, doi: 10.1016/j.ecolecon.2023.107815.
[46] C. L. Weber and H. S. Matthews, "Quantifying the global and distributional aspects of American household carbon footprint," *Ecological Economics*, vol. 66, 2-3, pp. 379–391, 2008, doi: 10.1016/j.ecolecon.2007.09.021.
[47] M. Christis, K. Breemersch, an Vercalsteren, and E. Dils, "A detailed household carbon footprint analysis using expenditure accounts – Case of Flanders (Belgium)," *Journal of Cleaner Production*, vol. 228, pp. 1167–1175, 2019, doi: 10.1016/j.jclepro.2019.04.160.
[48] M. Büchs, N. Cass, C. Mullen, K. Lucas, and D. Ivanova, "Emissions savings from equitable energy demand reduction," *Nat Energy*, vol. 8, no. 7, pp. 758–769, 2023a, doi: 10.1038/s41560-023-01283-y.
[49] D. Wiedenhofer, D. Guan, Z. Liu, J. Meng, N. Zhang, and Y.-M. Wei, "Unequal household carbon footprints in China," *Nature Clim Change*, vol. 7, no. 1, pp. 75–80, 2017, doi: 10.1038/nclimate3165.
[50] L. Huang *et al.,* "Extension and update of multiscale monthly household carbon footprint in Japan from 2011 to 2022," *Scientific data*, vol. 10, no. 1, p. 439, 2023, doi: 10.1038/s41597-023-02329-2.
[51] M. Büchs and S. V. Schnepf, "Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO2 emissions," *Ecological Economics*, vol. 90, pp. 114–123, 2013, doi: 10.1016/j.ecolecon.2013.03.007.
[52] P. Nuss, E. Sanyé-Mengual, and S. Sala, "Monitoring the consumption footprint of countries to support policy-making: An assessment of data availability in Germany," *J of Industrial Ecology*, vol. 27, no. 5, pp. 1354–1369, 2023, doi: 10.1111/jiec.13412.
[53] U. Eberle and J. Fels, "Environmental impacts of German food consumption and food losses," *Int J Life Cycle Assess*, vol. 21, no. 5, pp. 759–772, 2016, doi: 10.1007/s11367-015-0983-7.
[54] P. P. Kalbar, M. Birkved, S. Kabins, and S. E. Nygaard, "Personal Metabolism (PM) coupled with Life Cycle Assessment (LCA) model: Danish Case Study," *Environment international*, vol. 91, pp. 168–179, 2016, doi: 10.1016/j.envint.2016.02.032.
[55] E. Kotakorpi, S. Lähteenoja, and M. Lettenmeier, "Household MIPS: Natural resource consumption of Finnish households and its reduction," Helsinki, 2008. Accessed: Oct. 7 2023. [Online]. Available: www.environment.fi/publications
[56] C. Genta, E. Sanyé-Mengual, S. Sala, and P. Lombardi, "The Consumption Footprint as possible indicator for environmental impact evaluation at city level. The case study of Turin (Italy)," *Sustainable Cities and Society*, vol. 79, p. 103679, 2022, doi: 10.1016/j.scs.2022.103679.
[57] A. Lavers, Y. Kalmykova, L. Rosado, F. Oliveira, and R. Laurenti, "Selecting representative products for quantifying environmental impacts of consumption in urban areas," *Journal of Cleaner Production*, vol. 162, pp. 34–44, 2017, doi: 10.1016/j.jclepro.2017.06.030.
[58] D. A. Notter, R. Meyer, and H.-J. Althaus, "The Western lifestyle and its long way to sustainability," *Environmental science & technology*, vol. 47, no. 9, pp. 4014–4021, 2013, doi: 10.1021/es3037548.
[59] D. Saner, N. Heeren, B. Jäggi, R. A. Waraich, and S. Hellweg, "Housing and mobility demands of individual households and their life cycle assessment," *Environmental science & technology*, vol. 47, no. 11, pp. 5988–5997, 2013, doi: 10.1021/es304084p.
[60] European Commission, Ed., "The European Green Deal: Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions," Dec. 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52019DC0640
[61] European Commission, *Sustainable consumption: Policy-relevant insights on the consumers' engagement in the circular economy*. [Online]. Available: https://commission.europa.eu/live-work-travel-eu/consumer-rights-and-complaints/sustainable-consumption_en (accessed: Feb. 7 2024).
[62] Z. J. Steinmann *et al.,* "Headline Environmental Indicators Revisited with the Global Multi-Regional Input-Output Database EXIOBASE," *J of Industrial Ecology*, vol. 22, no. 3, pp. 565–573, 2018, doi: 10.1111/jiec.12694.
[63] IEA, "The Role of Critical Minerals in Clean Energy Transitions," World Energy Outlook Special Report, 2022. Accessed: Feb. 20 2023. [Online]. Available: https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf
[64] European Commission, Ed., "Household Budget Survey 2020: Scientific-use files. User Manual," Version 1, Jul. 2023. Accessed: Oct. 26 2023. [Online]. Available: https://ec.europa.eu/eurostat/web/microdata/household-budget-survey

[65] European Commission, Ed., "Household Budget Survey 2015: Scientific-use files. User Manual," Version 1.3, Jan. 2022. Accessed: Apr. 18 2024. [Online]. Available: https://ec.europa.eu/eurostat/web/microdata/household-budget-survey
[66] European Commission and eurostat, Eds., "Household Budget Survey: 2015 Wave EU Quality Report (Version 1)," 2020. Accessed: Jun. 30 2024. [Online]. Available: https://ec.europa.eu/eurostat/documents/54431/1966394/HBS_EU_QualityReport_2015.pdf
[67] N. Bardsley, M. Büchs, and S. V. Schnepf, "Something from nothing: Estimating consumption rates using propensity scores, with application to emissions reduction policies," *PloS one*, vol. 12, no. 10, e0185538, 2017, doi: 10.1371/journal.pone.0185538.
[68] K. Sabbe, T. Delclite, and G. Geenens, "Change in the duration of the household budget survey: Analysis of a transition to 15 days," Analyse 15, 2021. Accessed: Jun. 30 2024. [Online]. Available: https://statbel.fgov.be/sites/default/files/files/documents/Analyse/EN/Analyse_15_Household%20budget%20survey_STATBEL_v2.pdf
[69] European Commission, Ed., "Description of the data transmission for the Household Budget Survey (HBS) for the Reference Year 2015," Version 3, 2016. Accessed: Apr. 18 2024. [Online]. Available: https://ec.europa.eu/eurostat/web/microdata/household-budget-survey
[70] eurostat, *Glossary:Country codes*. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Country_codes (accessed: Jun. 30 2024).
[71] eurostat, *Purchasing Power Parities: Information on data*. [Online]. Available: https://ec.europa.eu/eurostat/web/purchasing-power-parities/information-data#Access%20to%20detailed%20data (accessed: May 12 2024).
[72] eurostat, "Euro/ECU exchange rates - annual data," Mar. 2024. Accessed: Apr. 2 2024. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/product/page/ERT_BIL_EUR_A
[73] eurostat, "Former euro area national currencies vs. euro/ECU - annual data," Aug. 2023. Accessed: Apr. 2 2024. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/product/page/ERT_H_EUR_A
[74] eurostat, *Purchasing power parities (prc_ppp): Reference Metadata in Euro SDMX Metadata Structure (ESMS)*. [Online]. Available: https://ec.europa.eu/eurostat/cache/metadata/en/prc_ppp_esms.htm (accessed: May 21 2024).
[75] eurostat, "Detailed average prices - 2015," Aug. 2016. Accessed: Jun. 25 2024. [Online]. Available: https://doi.org/10.2908/PRC_DAP15
[76] eurostat, *Detailed average prices (prc_dap): Reference Metadata in Euro SDMX Metadata Structure (ESMS)*. [Online]. Available: https://ec.europa.eu/eurostat/cache/metadata/en/prc_dap_esms.htm (accessed: May 21 2024).
[77] eurostat, "Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates," Jun. 2024. Accessed: Jun. 25 2024. [Online]. Available: https://doi.org/10.2908/PRC_PPP_IND
[78] E. S. Mengual, T. Sinkko, A. Amadei, V. Castellani, and S. Sala, *Consumption Footprint: impact per product for EU average representative products, by impact category*. [Online]. Available: http://data.europa.eu/89h/59ed26ba-66be-407f-9408-874a91dbbbe5 (accessed: Feb. 25 2024).
[79] V. Castellani, E. Sanyé-Mengual, and S. Sala, "Environmental impacts of household goods in Europe: a process-based life cycle assessment model to assess consumption footprint," *Int J Life Cycle Assess*, vol. 26, no. 10, pp. 2040–2055, 2021, doi: 10.1007/s11367-021-01987-x.
[80] E. Sanyé Mengual, J. Foschi, V. Orza, T. Sinkko, P. Wierzgala, and S. Sala, *Consumption Footprint: methodological overview: A life cycle assessment-based model to assess environmental impacts of consumption*. Luxembourg: Publications Office of the European Union, 2023. Accessed: Apr. 15 2024. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/handle/JRC132734
[81] C. Baldassarri, K. Allacker, F. Reale, V. Castellani, and S. Sala, "Consumer Footprint: Basket of Products indicator on Housing," Luxembourg, JRC technical reports 107958, 2017. Accessed: Oct. 26 2023. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/
[82] V. Castellani, M. Fantoni, J. Cristòbal, L. Zampori, and S. Sala, "Consumer Footprint: Basket of Products indicator on Mobility," Luxembourg, JRC technical reports 107954, 2017. Accessed: Oct. 26 2023. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/
[83] V. Castellani, A. Fusi, and S. Sala, "Consumer footprint: Basket of products indicator on food," Luxembourg, JRC technical reports 107959, 2017. Accessed: Oct. 26 2023. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/
[84] F. Reale, V. Castellani, R. Hischier, S. Corrado, and S. Sala, "Consumer footprint: Basket of products indicators on household appliances," Europäische Gemeinschaften, Luxembourg, JRC technical reports JRC116704, 2019.

[85] V. Castellani *et al.,* "Consumer Footprint: Basket of Products indicator on Household goods," Luxembourg, JRC technical reports 116120, 2019. Accessed: Oct. 26 2023. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/
[86] ecoinvent, *System Models*. [Online]. Available: https://support.ecoinvent.org/system-models#Allocation_Substitution (accessed: May 12 2024).
[87] S. Andreasi Bassi *et al.,* "Updated characterisation and normalisation factors for the Environmental Footprint 3.1 method," Luxembourg JRC130796, 2023. Accessed: May 8 2024. [Online]. Available: doi://10.2760/798894
[88] J. B. Guinée, *Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards*. Dordrecht: Springer Netherlands, 2002. [Online]. Available: https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=6350862
[89] E. Sanyé Mengual, F. Biganzoli, and S. Sala, "User guide for the "Member States - Consumption footprint Tool"," Luxembourg JRC132621, 2023. Accessed: Apr. 17 2024. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/handle/JRC132621
[90] European Commission and Joint Research Centre, *Member States – Consumption footprint Tool*. [Online]. Available: https://eplca.jrc.ec.europa.eu/MSConsumptionFootprint.html (accessed: May 22 2024).
[91] A. Ciroth, "ICT for environment in life cycle applications openLCA — A new open source software for life cycle assessment," *Int J Life Cycle Assess*, vol. 12, no. 4, pp. 209–210, 2007, doi: 10.1065/lca2007.06.337.
[92] I. I. Dorband, M. Jakob, M. Kalkuhl, and J. C. Steckel, "Poverty and distributional effects of carbon pricing in low- and middle-income countries – A global comparative analysis," *World Development*, vol. 115, pp. 246–257, 2019, doi: 10.1016/j.worlddev.2018.11.015.
[93] L. Chancel, P. Bothe, and T. Voituriez, "Climate Inequality Report," World Inequality Lab Study, 2023. Accessed: Oct. 15 2023. [Online]. Available: https://wid.world/wp-content/uploads/2023/01/CBV2023-ClimateInequalityReport1.pdf
[94] A. Pottier, E. Combet, J.-M. Cayla, S. de Lauretis, and F. Nadaud, "Who emits CO2? Landscape of ecological inequalities in France from a critical perspective," 2021. Accessed: Sep. 22 2023. [Online]. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3853896
[95] R. G. Wilkinson and K. E. Pickett, "Why the world cannot afford the rich," *Nature*, vol. 627, no. 8003, pp. 268–270, 2024, doi: 10.1038/d41586-024-00723-3.
[96] K. Steen-Olsen, R. Wood, and E. G. Hertwich, "The Carbon Footprint of Norwegian Household Consumption 1999–2012," *J of Industrial Ecology*, vol. 20, no. 3, pp. 582–592, 2016, doi: 10.1111/jiec.12405.
[97] European Commission *et al.,* "Carbon and environmental footprint inequality of household consumption in the EU: A new methodology," Luxembourg, 2024. Accessed: Jun. 28 2024. [Online]. Available: https://data.europa.eu/doi/10.2760/841471, JRC137520.
[98] W. Willett *et al.,* "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems," *The Lancet*, vol. 393, no. 10170, pp. 447–492, 2019, doi: 10.1016/S0140-6736(18)31788-4.
[99] C. A. Kukowski and E. E. Garnett, "Tackling inequality is essential for behaviour change for net zero," *Nat. Clim. Chang.*, vol. 14, no. 1, pp. 2–4, 2024, doi: 10.1038/s41558-023-01900-4.
[100] I. M. Otto, K. M. Kim, N. Dubrovsky, and W. Lucht, "Shift the focus from the super-poor to the super-rich," *Nature Clim Change*, vol. 9, no. 2, pp. 82–84, 2019, doi: 10.1038/s41558-019-0402-3.
[101] J. Vogel, J. K. Steinberger, D. W. O'Neill, W. F. Lamb, and J. Krishnakumar, "Socio-economic conditions for satisfying human needs at low energy use: An international analysis of social provisioning," *Global Environmental Change*, vol. 69, p. 102287, 2021, doi: 10.1016/j.gloenvcha.2021.102287.
[102] M. Speck, L. Wagner, F. Buchborn, F. Steinmeier, S. Friedrich, and N. Langen, "How public catering accelerates sustainability: a German case study," *Sustainability science*, vol. 17, no. 6, pp. 2287–2299, 2022, doi: 10.1007/s11625-022-01183-2.
[103] V. Lopez, J. Teufel, and C.-O. Gensch, "How a Transformation towards Sustainable Community Catering Can Succeed," *Sustainability*, vol. 12, no. 1, p. 101, 2020, doi: 10.3390/su12010101.
[104] European Commission, *Household budget surveys: Information on data*. [Online]. Available: https://ec.europa.eu/eurostat/web/household-budget-surveys/information-data (accessed: Jan. 5 2024).
[105] J. Gibson and B. Kim, "Testing the Infrequent Purchases Model Using Direct Measurement of Hidden Consumption from Food Stocks," *American J Agri Economics*, vol. 94, no. 1, pp. 257–270, 2012, doi: 10.1093/ajae/aar135.
[106] A. Deaton, "Measuring Poverty in a Growing World (or Measuring Growth in a Poor World)," *The Review of Economics and Statistics*, vol. 87, no. 1, pp. 1–19, 2005, doi: 10.1162/0034653053327612.

[107] B. Barros and R. Wilk, "The outsized carbon footprints of the super-rich," *Sustainability: Science, Practice and Policy*, vol. 17, no. 1, pp. 316–322, 2021, doi: 10.1080/15487733.2021.1949847.
[108] Y. Ikeda, "Quantifying materials in household furniture: A case study of dynamic furniture stock in American homes," Delft University of Technology; Leiden University, 2023. Accessed: Jul. 26 2024. [Online]. Available: http://resolver.tudelft.nl/uuid:fec8d24f-f856-43a4-8673-570cc6de9d01
[109] European Environment Agency, *Greenhouse gas emission intensity of electricity generation in Europe*. [Online]. Available: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emission-intensity-of-1?activeAccordion=309c5ef9-de09-4759-bc02-802370dfa366 (accessed: Jul. 16 2024).
[110] M. Büchs, T. Goedemé, S. Kuypers, and G. Verbist, "Emission inequality: Comparing the roles of income and wealth in Belgium and the United Kingdom," *Journal of Cleaner Production*, vol. 467, p. 142818, 2024b, doi: 10.1016/j.jclepro.2024.142818.
[111] H. Hasegawa, K. Ueda, and K. Mori, "Estimation of Engel Curves from Survey Data with Zero Expenditures*," *Oxf Bull Econ Stat*, vol. 70, no. 4, pp. 535–558, 2008, doi: 10.1111/j.1468-0084.2008.00507.x.
[112] B. van Beijnum, "The cost of comfort: waking up to furniture waste: Researching material use in European household furniture using dynamic stock analysis," Delft University of Technology; Leiden University, 2021.
[113] Instituto Nacional de Estadística, *Household Budger Suvey - Microdata*. [Online]. Available: https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736176806&menu=resultados&secc=1254736195147&idp=1254735976608#_tabs-1254736195147 (accessed: Jun. 28 2024).
[114] eurostat, *Household budget survey: Microdata*. [Online]. Available: https://ec.europa.eu/eurostat/web/microdata/household-budget-survey (accessed: Jan. 4 2024).
[115] GreenDelta, *ecoinvent*. [Online]. Available: https://nexus.openlca.org/database/ecoinvent (accessed: May 8 2024).
[116] ecoinvent, *ecoinvent Version 3.9.1*. [Online]. Available: https://support.ecoinvent.org/ecoinvent-version-3.9.1 (accessed: May 21 2024).
[117] eurostat, *European Classification of Individual Consumption according to Purpose (ECOICOP)*. [Online]. Available: https://op.europa.eu/s/zLKP (accessed: Jun. 25 2024).
[118] eurostat, "Classification of individual consumption by purpose (COICOP)," May. 2023. Accessed: Jun. 18 2024. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/bulk?lang=en&selectedTab=codeList
[119] eurostat, *276 Basic Headings and_61 Analytical Categories for Metadata*. [Online]. Available: https://circabc.europa.eu/d/a/workspace/SpacesStore/6535e71e-454f-4c60-ac3a-01c8b660b3a3/2015_%20276_Basic%20Headings_and_61_Analytical_Categories_for_Metadata (accessed: Jun. 25 2024).

Appendix

Appendix 1: Additional details on mapping and price grouping

Appendix 1 can be found in the supporting Excel file. It contains additional information on the mapping decisions for each subclass, the grouping of the prices and the impact intensities, including which ecoinvent processes were used. Furthermore, the full results for the mean EFs of the deciles are included.

Appendix 2: EU country codes

Table 8: EU member state country codes [70].

Code	Country
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia

Appendix 3: A note on data classification systems

The main data classification system applied in this study it the European Classification of Individual Consumption according to Purpose (ECOICOP), which is used in various economic statistics and analyses related to consumption, such as HBS or PPP [117]. It is based on COICOP (Classification of Individual Consumption according to Purpose), which is a classification of the United Nations Statistics Division [118]. ECOICOP has only been published in one version from 2015 so far, while COICOP has been updated in 2018. The objective of both classifications is to have a framework of homogeneous categories of goods and services.

ECOICOP is structured in four levels, which are denoted using 5 digits. Each level has one or more subcategories assigned to it, resulting in a tree-like structure. The first, most aggregated level, consists of 12 "divisions" that have the codes 01 to 12. Example of such divisions include "Clothing and footwear" (number 03) or "Recreation and culture" (number 09). The divisions consist of different numbers of "groups" with 3 digits, 47 in total. These in turn consist of 117 "classes", denoted with 4 digits. Finally, the most granular level entails 303 subclasses with a 5-digit code. The code of each more granular level always included the code of the parent level. The subclass for "Fiction books" (09511), for example, includes the code for the class "Books" (0951), the group "Newspapers, books and stationery" (095) and the division "Recreation and culture (09).

The EU HBS is, according to the manual for the scientific use files [65], following the ECOICOP 2013 classification. After consulting Eurostat, it became clear that this is the same as the 2015 version mentioned above. However, the HBS only contains 298 subclasses because "Narcotics" (02300), "Games of chance" (09430), "Prostitution" (12200), "Life insurance" (12510) and "FISIM" (12610), which stands for "financial intermediation services indirectly measured", are suppressed. For this study, all metadata for the HBS, like variables labels, were taken from the HBS 2015 scientific-use manual [65]. Table 9 shows an overview of the divisions and the numbers of subunits they contain, following the HBS manual [65].

Table 9: ECOICOP divisions and associated sublevels [65].

Division	Groups	Classes	Sub-classes
01 Food and non-alcoholic beverages	2	11	61
02 Alcoholic beverages, tobacco and narcotics	2	4	13
03 Clothing and footwear	2	6	12
04 Housing, water, electricity, gas and other fuels	5	15	25
05 Furnishings, household equipment and routine household maintenance	6	12	40
06 Health	3	7	14
07 Transport	3	14	28
08 Communication	3	3	11
09 Recreation and culture	5	20	52
10 Education	5	5	6
11 Restaurants and hotels	2	3	6
12 Miscellaneous goods and services	6	12	30
Total	**44**	**112**	**298**

For the PPP prices [71], the classification scheme is only mentioned as "basic heading level" [74], but follows the same format as ECOICOP / COICOP. To ensure that the PPP dataset is also provided in ECOICOP, not COICOP, the accompanying Excel file [119], accessible through a link in the metadata [74], with labels for the basic headings (5-digits) were compared to the ECOICOP labels from the HBS. For the prices, which are given per subclass level (see Section 4.2), they align fully. Thus, it was concluded that the PPP dataset is also given in ECOICOP codes and no additional harmonisation step is needed.

The DAP price data [75] comes in five-digit sub-classes of COICOP [76]. Because the latest version of the data was published in 2016, meaning before the COICOP revision in 2018, data labels from the original COICOP version [118] were taken for it. The DAP dataset does not contain prices for all subclasses. Those, that were included in the data, were compared to their corresponding ECOICOP data labels for food and beverages (division 01 and 02) to ensure consistency before the matching. Details on both comparisons for both price datasets can be found in Appendix 1. The impact data from ecoinvent and the JRC do not follow a classification scheme and was aligned manually as described in Section 4.5.

Appendix 4: Coverage of subclasses in the HBS

This appendix provides an overview of how many of the HBS subclasses are covered by this study. Table 10 shows how many of the subclasses for each are included in this study. As can be seen it varies a lot with divisions 04 and 07 not being included at all due to the scope not including mobility and housing while food and non-alcoholic beverages are fully included. The other missing subclasses are mostly explained by the exclusion of services, which is also why division 10 and 11, that consist entirely of services, are not covered at all.

Table 10: Coverage of subclasses per ECOICOP division. "No. of subclasses" shows the count of the originally includes subclasses while "No. of remaining subclasses" counts the one covered by this study.

Division	No. of subclasses	No. of remaining subclasses	Coverage (%)
01 Food and non-alcoholic beverages	61	61	100
02 Alcoholic beverages, tobacco and narcotics	13	10	77
03 Clothing and footwear	12	9	75
04 Housing, water, electricity, gas and other fuels	25	0	0
05 Furnishings, household equipment and routine household maintenance	40	29	73
06 Health	14	0	0
07 Transport	28	0	0
08 Communication	11	3	27
09 Recreation and culture	52	24	46
10 Education	6	0	0
11 Restaurants and hotels	6	0	0
12 Miscellaneous goods and services	30	5	17
Total	**298**	**141**	**47**

Table 11 shows the 22 subclasses that had to be excluded due to missing prices or missing impact data, despite being within scope. All of these subclasses refer to household goods.

Table 11: Overview of within scope excluded ECOICOP subclasses and the reason for excluding them.

Division	Group	Class	Subclass	Reason for dropping
02 Alcoholic beverages, tobacco and narcotics	022 Tobacco	0220 Tobacco	02201 Cigarettes 02202 Cigars 02203 Other tobacco products	No impact data
06 Health	061 Medical products, appliances and equipment	0611 Pharmaceutical products	06110 Pharmaceutical products	No impact data
06 Health	061 Medical products, appliances and equipment	0612 Other medical products	06121 Pregnancy tests and mechanical contraceptive devices 06129 Other medical products NEC	No impact data
06 Health	061 Medical products, appliances and equipment	0613 Therapeutic appliances and equipment	06131 Corrective eyeglasses and contact lenses 06132 Hearing aids 06139 Other therapeutic appliances and equipment	No impact data
09 Recreation and culture	091 Audio-visual, photographic and information processing equipment	0913 Information processing equipment	09134 Calculators and other information processing equipment	No impact data
09 Recreation and culture	091 Audio-visual, photographic and information processing equipment	0914 Recording media	09141 Pre-recorded recording media 09142 Unrecorded recording media	No impact data
09 Recreation and culture	092 Other major durables for recreation and culture	0921 Major durables for outdoor recreation	09211 Camper vans, caravans and trailers 09212 Aeroplanes, microlight aircraft, gliders, hang-gliders and hot-air balloons 09213 Boats, outboard motors and fitting out of boats 09215 Major items for games and sport	No price and no impact data
09 Recreation and culture	092 Other major durables for recreation and culture	0922 Musical instruments and major durables for indoor recreation	09211 Musical instruments 09222 Major durables for indoor recreation	No price and no impact data
09 Recreation and culture	093 Other recreational items and equipment, gardens and pets	0932 Equipment for sport, camping and open-air recreation	09231 Equipment for sport	No impact data
12 Miscellaneous goods and services	123 Personal effects NEC	1231 Jewellery, clocks and watches	12311 Jewellery	No impact data
12 Miscellaneous goods and services	123 Personal effects NEC	1232 Other personal effects	12321 Travel goods 12322 Articles for babies	No impact data

Appendix 5: Coverage of division level expenditure by lower levels

Table 12: Coverage of total division level expenditure for all households by lower-level expenditure totals for each country and all countries together per division and in total.

Country	Division no.	Share of division expenditure covered at group level (%)	Share of division expenditure covered at class level (%)	Share of division expenditure covered at subclass level (%)
BE	1	100.00	100.00	100.00
BE	2	100.00	100.00	100.00
BE	3	100.00	100.00	100.00
BE	5	100.00	100.00	100.00
BE	6	100.00	100.00	100.00
BE	8	100.00	100.00	100.00
BE	9	100.00	100.00	100.00
BE	10	100.00	100.00	100.00
BE	11	100.00	100.00	100.00
BE	12	100.00	93.32	93.32
BE	total	100.00	98.76	98.76
BG	1	100.00	100.00	100.00
BG	2	100.00	100.00	100.00
BG	3	100.00	100.00	100.00
BG	5	100.00	100.00	100.00
BG	6	100.00	100.00	100.00
BG	8	100.00	100.00	100.00
BG	9	100.00	100.00	100.00
BG	10	100.00	100.00	100.00
BG	11	100.00	100.00	100.00
BG	12	100.00	100.00	100.00
BG	total	100.00	100.00	100.00
CY	1	97.80	97.80	97.80
CY	2	100.00	100.00	100.00
CY	3	100.00	100.00	100.00
CY	5	100.00	100.00	100.00
CY	6	100.00	100.00	100.00
CY	8	100.00	100.00	100.00
CY	9	100.00	100.00	100.00
CY	10	100.00	100.00	100.00
CY	11	100.00	100.00	84.79
CY	12	99.68	99.68	99.68
CY	total	99.39	99.39	97.32
CZ	1	100.00	100.00	100.00
CZ	2	100.00	100.00	100.00
CZ	3	100.00	100.00	100.00
CZ	5	100.00	100.00	100.00
CZ	6	100.00	100.00	100.00
CZ	8	100.00	100.00	100.00
CZ	9	100.00	100.00	100.00
CZ	10	100.00	100.00	100.00
CZ	11	100.00	100.00	100.00

Table continued on the next page.

Country	Division no.	Share of division expenditure covered at group level (%)	Share of division expenditure covered at class level (%)	Share of division expenditure covered at subclass level (%)
CZ	12	100.00	100.00	100.00
CZ	total	100.00	100.00	100.00
DK	1	100.00	100.00	100.00
DK	2	100.00	100.00	100.00
DK	3	100.00	100.00	100.00
DK	5	100.01	100.01	100.01
DK	6	100.00	100.00	100.00
DK	8	100.01	100.01	100.16
DK	9	100.06	100.08	100.08
DK	10	100.00	100.00	100.00
DK	11	100.00	100.00	100.00
DK	12	100.00	100.00	100.00
DK	total	100.01	100.02	100.02
EE	1	98.52	97.85	96.88
EE	2	99.84	99.35	98.46
EE	3	98.51	97.93	90.27
EE	5	99.85	98.76	97.69
EE	6	99.77	96.95	96.72
EE	8	96.66	96.66	96.53
EE	9	99.97	98.51	96.87
EE	10	95.75	95.75	95.72
EE	11	100.00	99.84	98.73
EE	12	99.97	93.19	90.89
EE	total	99.02	97.71	96.12
EL	1	100.00	100.00	100.00
EL	2	100.00	100.00	100.00
EL	3	100.00	100.00	100.00
EL	5	100.00	100.00	100.00
EL	6	100.00	100.00	100.00
EL	8	100.00	100.00	100.00
EL	9	100.00	100.00	100.00
EL	10	100.00	100.00	100.00
EL	11	100.00	100.00	100.00
EL	12	103.36	100.00	99.83
EL	total	100.31	100.00	99.98
ES	1	100.00	100.00	92.49
ES	2	100.00	34.07	34.07
ES	3	100.00	100.00	99.03
ES	5	100.00	85.55	81.13
ES	6	100.00	97.25	30.90
ES	8	100.00	0.00	0.00
ES	9	100.00	75.38	74.25
ES	10	100.00	0.00	0.00
ES	11	100.00	92.29	88.75
ES	12	97.99	86.53	70.34

Table continued on the next page.

Country	Division no.	Share of division expenditure covered at group level (%)	Share of division expenditure covered at class level (%)	Share of division expenditure covered at subclass level (%)
ES	total	99.74	83.73	74.20
FI	1	100.00	100.00	100.00
FI	2	100.00	100.00	70.76
FI	3	100.00	100.00	100.00
FI	5	100.00	100.00	100.00
FI	6	100.00	100.00	100.17
FI	8	100.00	100.00	100.00
FI	9	100.00	100.00	100.00
FI	10	100.00	100.00	100.00
FI	11	100.00	100.00	100.00
FI	12	100.00	100.00	100.00
FI	total	100.00	100.00	98.87
FR	1	100.00	100.01	87.47
FR	2	100.00	51.43	50.71
FR	3	100.00	100.01	99.28
FR	5	100.01	89.43	88.72
FR	6	100.00	95.12	54.56
FR	8	100.00	0.00	0.00
FR	9	84.84	84.84	76.83
FR	10	100.00	0.00	0.00
FR	11	100.00	81.06	57.35
FR	12	100.00	82.60	62.37
FR	total	98.13	83.40	70.88
HR	1	100.00	100.00	100.00
HR	2	100.00	100.00	100.00
HR	3	100.00	100.00	100.00
HR	5	100.00	100.00	100.00
HR	6	100.00	100.00	100.00
HR	8	100.00	100.00	100.00
HR	9	100.00	100.00	100.00
HR	10	100.00	100.00	100.00
HR	11	100.00	100.00	100.00
HR	12	100.00	100.00	100.00
HR	total	100.00	100.00	100.00
HU	1	100.00	100.00	100.00
HU	2	99.44	99.44	99.44
HU	3	99.74	100.00	100.00
HU	5	100.00	100.00	100.00
HU	6	100.00	100.00	100.00
HU	8	100.00	100.00	100.00
HU	9	100.00	100.00	100.00
HU	10	100.00	100.00	100.00
HU	11	100.00	100.00	100.00
HU	12	100.00	100.00	100.00
HU	total	99.96	99.97	99.97

Table continued on the next page.

Country	Division no.	Share of division expenditure covered at group level (%)	Share of division expenditure covered at class level (%)	Share of division expenditure covered at subclass level (%)
IE	1	100.00	100.00	100.00
IE	2	100.00	100.00	100.00
IE	3	100.00	100.00	100.00
IE	5	100.00	100.00	100.00
IE	6	100.00	100.00	100.00
IE	8	100.00	100.00	100.00
IE	9	100.00	100.00	100.00
IE	10	100.00	100.00	100.00
IE	11	100.00	100.00	100.00
IE	12	100.00	100.00	100.00
IE	total	100.00	100.00	100.00
LT	1	100.00	100.00	100.00
LT	2	100.00	100.00	81.58
LT	3	100.00	100.00	100.00
LT	5	100.00	100.00	98.54
LT	6	100.00	100.00	97.80
LT	8	100.00	100.00	98.45
LT	9	100.00	100.00	100.00
LT	10	100.00	100.00	100.00
LT	11	100.00	100.00	100.00
LT	12	100.00	100.00	79.46
LT	total	100.00	100.00	97.09
LU	1	100.00	100.00	100.00
LU	2	100.00	100.00	100.00
LU	3	100.00	100.00	100.00
LU	5	100.00	100.00	100.00
LU	6	100.00	100.00	100.00
LU	8	100.00	100.00	100.00
LU	9	100.00	100.00	100.00
LU	10	100.00	100.00	100.00
LU	11	100.00	100.00	100.00
LU	12	100.00	100.00	100.00
LU	total	100.00	100.00	100.00
LV	1	100.00	100.00	100.00
LV	2	100.00	100.00	69.86
LV	3	100.00	100.00	100.00
LV	5	100.00	100.00	100.00
LV	6	100.00	100.00	100.00
LV	8	100.00	100.00	100.00
LV	9	100.00	100.00	100.00
LV	10	100.00	100.00	100.00
LV	11	100.00	100.00	100.00
LV	12	100.00	100.00	100.00
LV	total	100.00	100.00	98.67
MT	1	100.00	100.00	99.97

Table continued on the next page.

Country	Division no.	Share of division expenditure covered at group level (%)	Share of division expenditure covered at class level (%)	Share of division expenditure covered at subclass level (%)
MT	2	100.00	99.99	99.99
MT	3	100.00	100.00	99.99
MT	5	100.00	100.00	99.99
MT	6	100.00	100.00	100.00
MT	8	100.00	100.00	100.00
MT	9	100.00	99.99	99.98
MT	10	100.00	100.00	100.00
MT	11	100.00	100.00	100.00
MT	12	100.00	100.00	99.89
MT	total	100.00	100.00	99.97
NL	1	100.01	100.02	100.03
NL	2	100.00	100.00	100.01
NL	3	100.04	100.05	100.10
NL	5	100.07	100.07	100.07
NL	6	100.05	100.18	100.18
NL	8	100.01	100.01	100.01
NL	9	100.06	100.09	100.14
NL	10	100.00	100.00	100.00
NL	11	100.00	100.00	100.01
NL	12	100.02	100.03	101.66
NL	total	100.03	100.04	100.44
PL	1	100.00	100.00	100.00
PL	2	100.00	100.00	100.00
PL	3	100.00	100.00	100.00
PL	5	100.00	100.00	100.00
PL	6	100.00	100.00	100.00
PL	8	100.00	100.00	100.00
PL	9	100.00	100.00	100.00
PL	10	100.00	100.00	100.00
PL	11	100.00	100.00	100.00
PL	12	78.22	78.22	78.22
PL	total	97.64	97.64	97.64
PT	1	100.00	100.00	100.00
PT	2	100.00	100.00	100.00
PT	3	100.00	100.00	100.00
PT	5	100.00	100.00	100.00
PT	6	100.00	100.00	100.00
PT	8	100.00	100.00	100.00
PT	9	100.00	100.00	100.00
PT	10	100.00	100.00	100.00
PT	11	100.00	100.00	100.00
PT	12	100.00	100.00	100.00
PT	total	100.00	100.00	100.00
RO	1	100.00	100.00	100.00
RO	2	100.00	100.00	100.00

Table continued on the next page.

Country	Division no.	Share of division expenditure covered at group level (%)	Share of division expenditure covered at class level (%)	Share of division expenditure covered at subclass level (%)
RO	3	100.00	100.00	100.00
RO	5	100.00	100.00	100.00
RO	6	100.00	100.00	100.00
RO	8	100.00	100.00	100.01
RO	9	100.00	100.00	100.00
RO	10	100.00	100.00	100.00
RO	11	100.00	100.00	100.00
RO	12	100.00	100.00	100.00
RO	total	100.00	100.00	100.00
SE	1	100.00	89.47	82.82
SE	2	100.00	58.49	58.49
SE	3	99.65	99.65	73.01
SE	5	100.16	85.79	74.69
SE	6	100.00	99.69	30.10
SE	8	100.01	0.00	0.00
SE	9	100.41	66.22	44.78
SE	10	100.00	0.00	0.00
SE	11	100.00	88.74	88.05
SE	12	100.04	85.16	68.63
SE	total	100.10	76.92	61.91
SI	1	100.00	100.00	100.00
SI	2	100.00	100.00	100.00
SI	3	100.00	100.00	100.00
SI	5	99.99	99.99	99.98
SI	6	100.00	100.00	100.00
SI	8	100.00	100.00	100.00
SI	9	100.00	99.99	99.99
SI	10	100.00	100.00	100.00
SI	11	100.00	100.00	100.00
SI	12	100.00	100.00	100.00
SI	total	100.00	100.00	100.00
SK	1	100.00	100.00	100.01
SK	2	100.00	100.00	100.00
SK	3	100.00	100.00	100.00
SK	5	100.00	100.00	100.00
SK	6	100.00	100.00	100.00
SK	8	100.00	100.00	100.00
SK	9	100.00	100.00	100.00
SK	10	100.00	100.00	100.00
SK	11	100.00	100.00	100.00
SK	12	100.00	100.00	100.00
SK	total	100.00	100.00	100.00
All	1	99.93	99.72	97.02
All	2	99.99	85.67	84.18
All	3	99.98	99.98	99.07

Table continued on the next page.

Country	Division no.	Share of division expenditure covered at group level (%)	Share of division expenditure covered at class level (%)	Share of division expenditure covered at subclass level (%)
All	5	100.02	96.42	95.41
All	6	100.00	99.25	85.03
All	8	99.96	74.95	74.94
All	9	98.16	93.54	91.33
All	10	99.96	75.13	75.13
All	11	100.00	96.23	92.65
All	12	98.58	93.33	87.76
All	total	99.53	94.79	91.46

Appendix 6: Distribution of household income and total expenditure before and after removing outliers

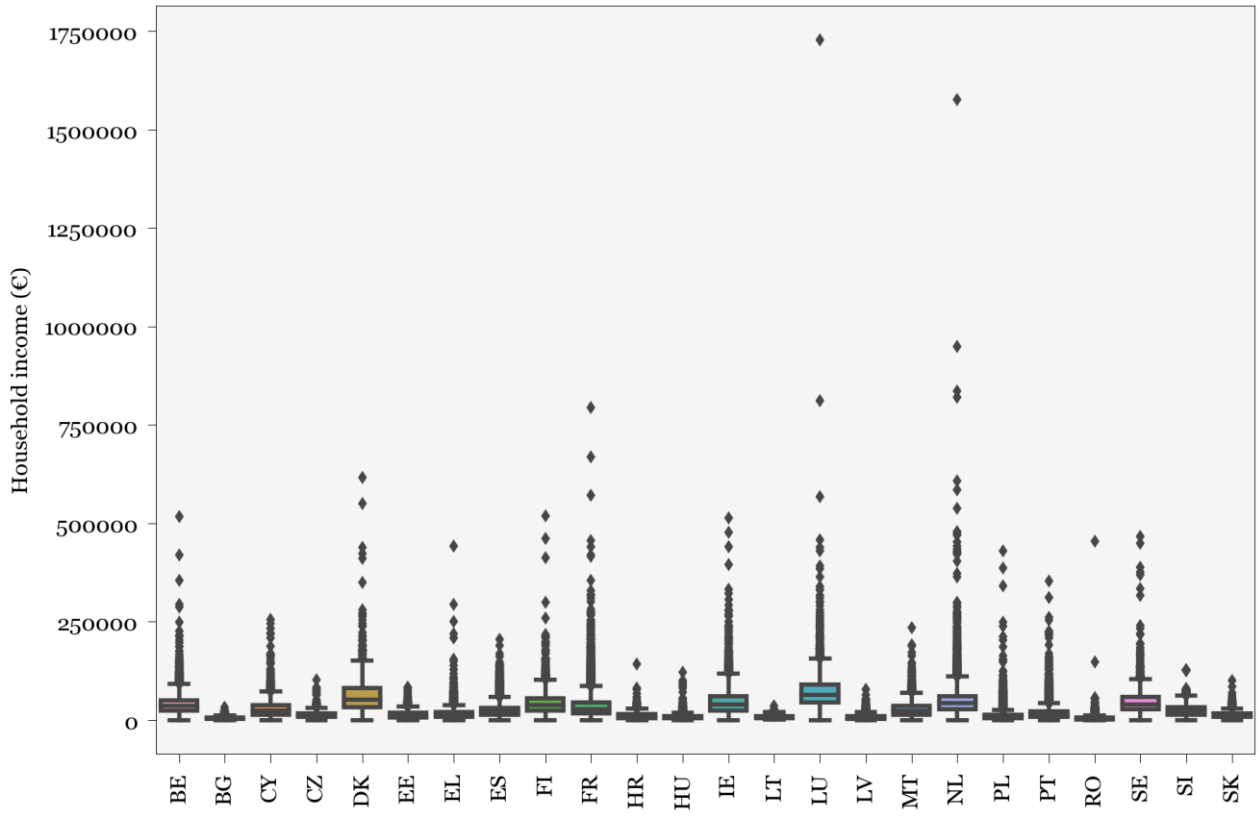

Figure 9: Distribution of yearly income per household in the sample for each country before removing outliers. Note that this is the distribution before removing outliers for total household expenditure.

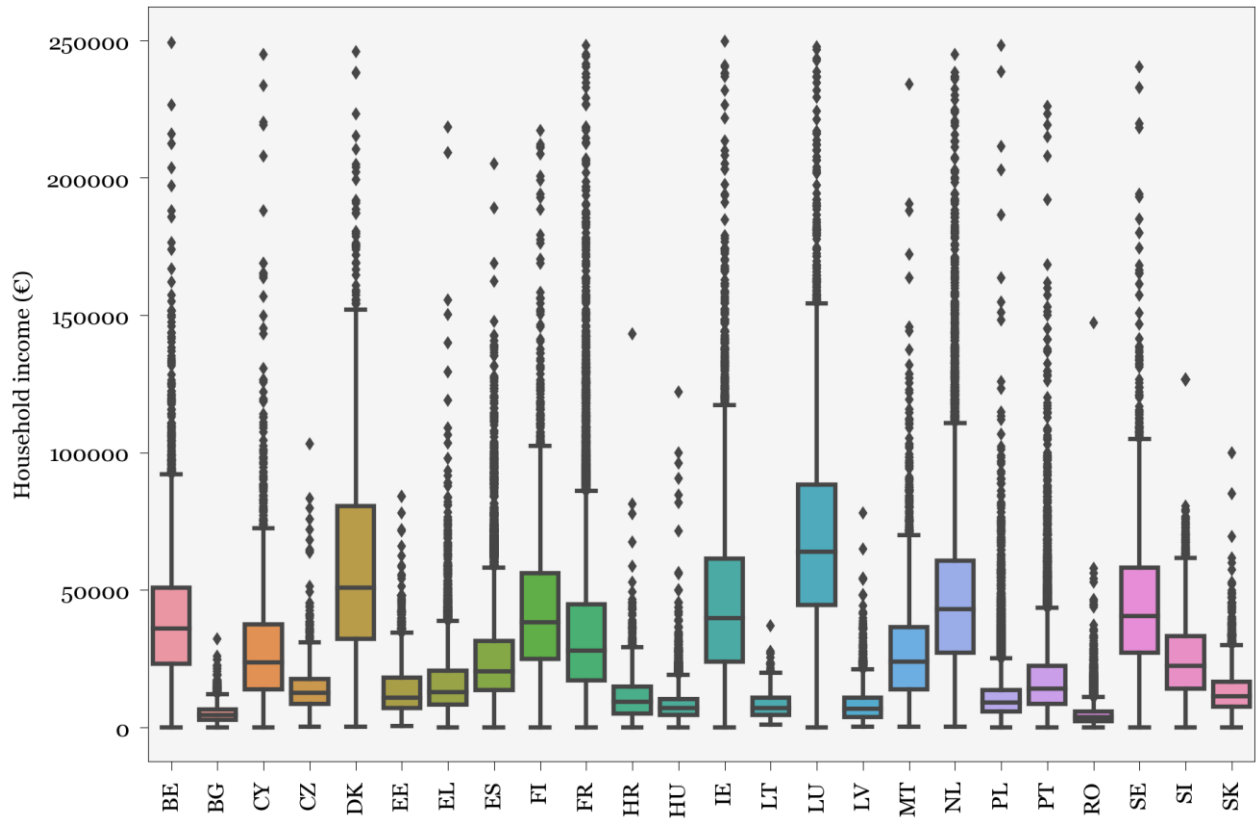

Figure 10: Distribution of yearly income per household in the sample for each country after removing outliers with a cut-off threshold of 250.000€. Note that this is the distribution before removing outliers for total household expenditure.

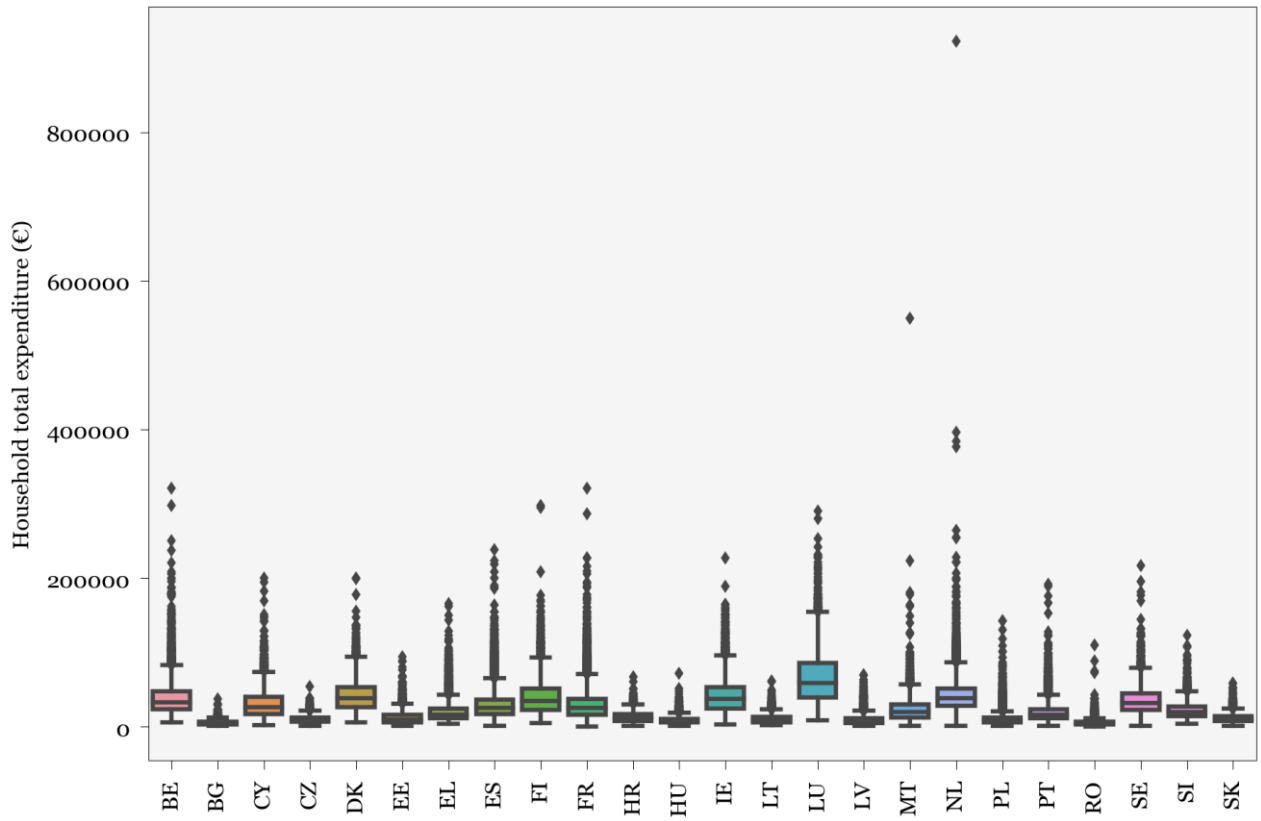

Figure 11: Distribution of total yearly expenditure per household in the sample for each country before removing outliers. Note that this is the distribution after removing outliers for household income.

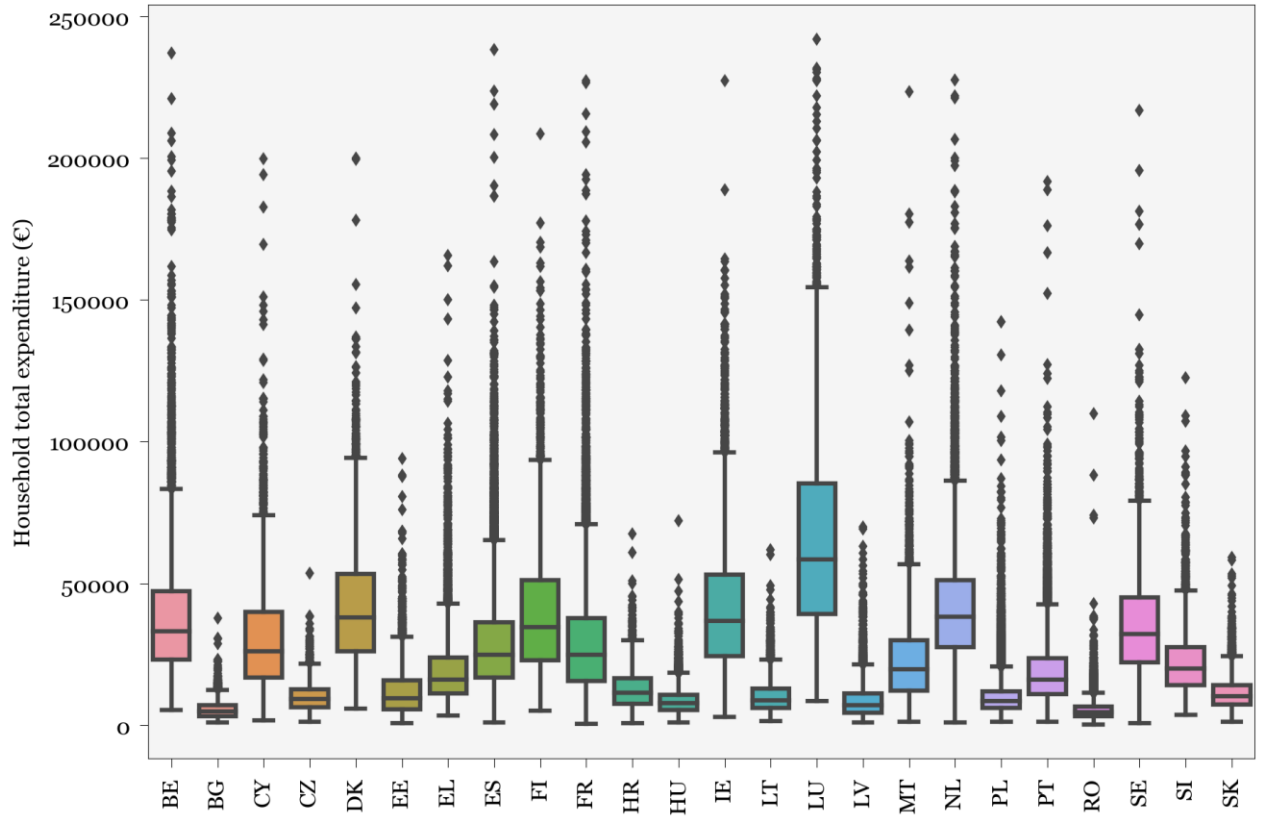

Figure 12: Distribution of total yearly expenditure per household in the sample for each country after removing outliers with a cut-off threshold of 250.000€. Note that this is the distribution after removing outliers for household income.

Appendix 7: HBS physical quantity outliers at subclass level

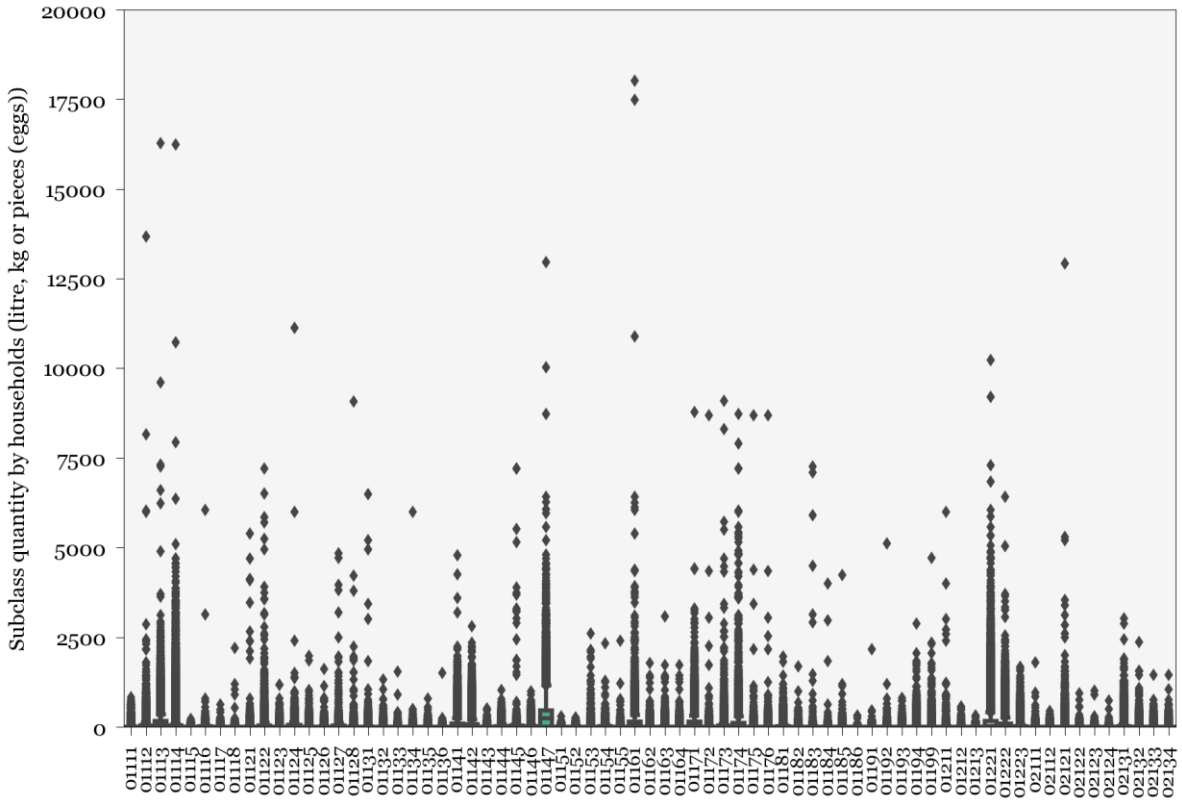

Figure 13: Distribution of physical consumption quantities per ECOICOP subclass of households before replacing outliers. The units differ based on the subclass. Only the households in countries, which provide quantities (i.e. BE, CZ, EE, EL, ES, FI, HR, HU, LV, PL, PT, RO, SI, SK), are shown.

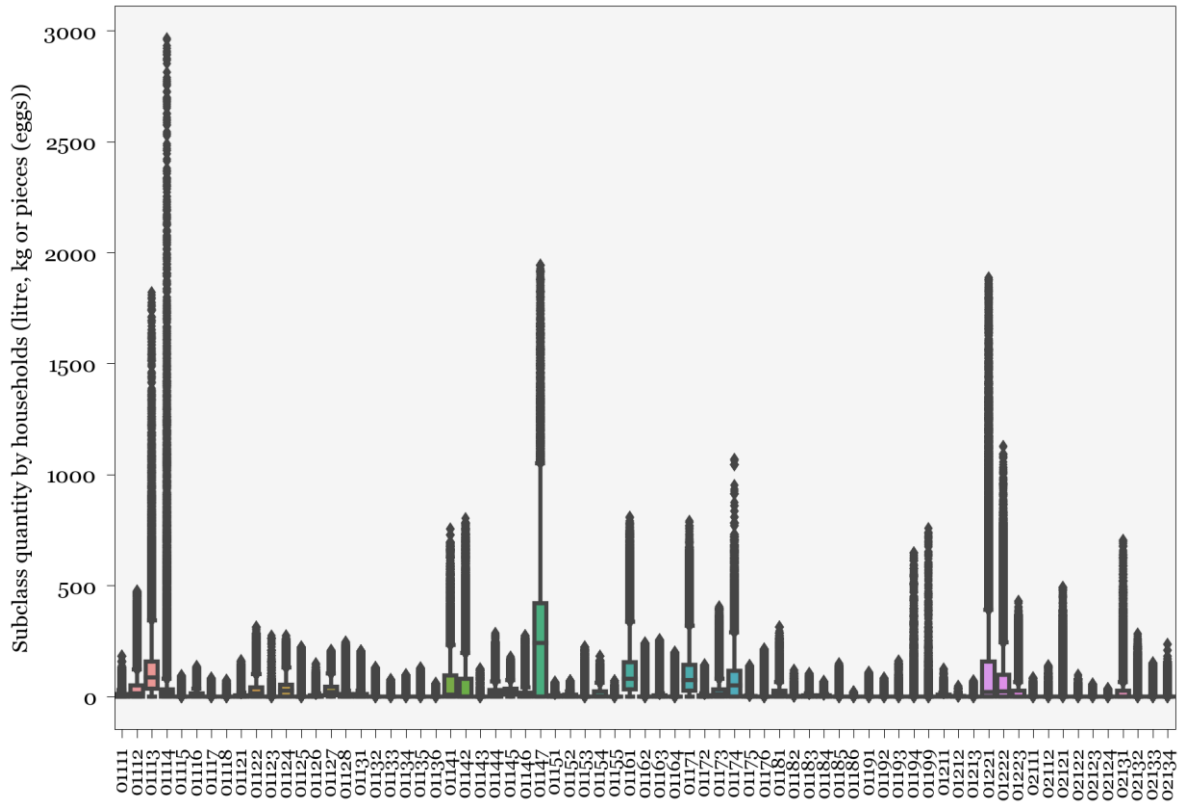

Figure 14: Distribution of physical consumption quantities per ECOICOP subclass of households after replacing outliers by changing the top 1% values per subclass to country mean. The units differ based on the subclass. Only the households in countries, which provide quantities (i.e. BE, CZ, EE, EL, ES, FI, HR, HU, LV, PL, PT, RO, SI, SK), are shown.

Appendix 8: HBS expenditure outliers at subclass level

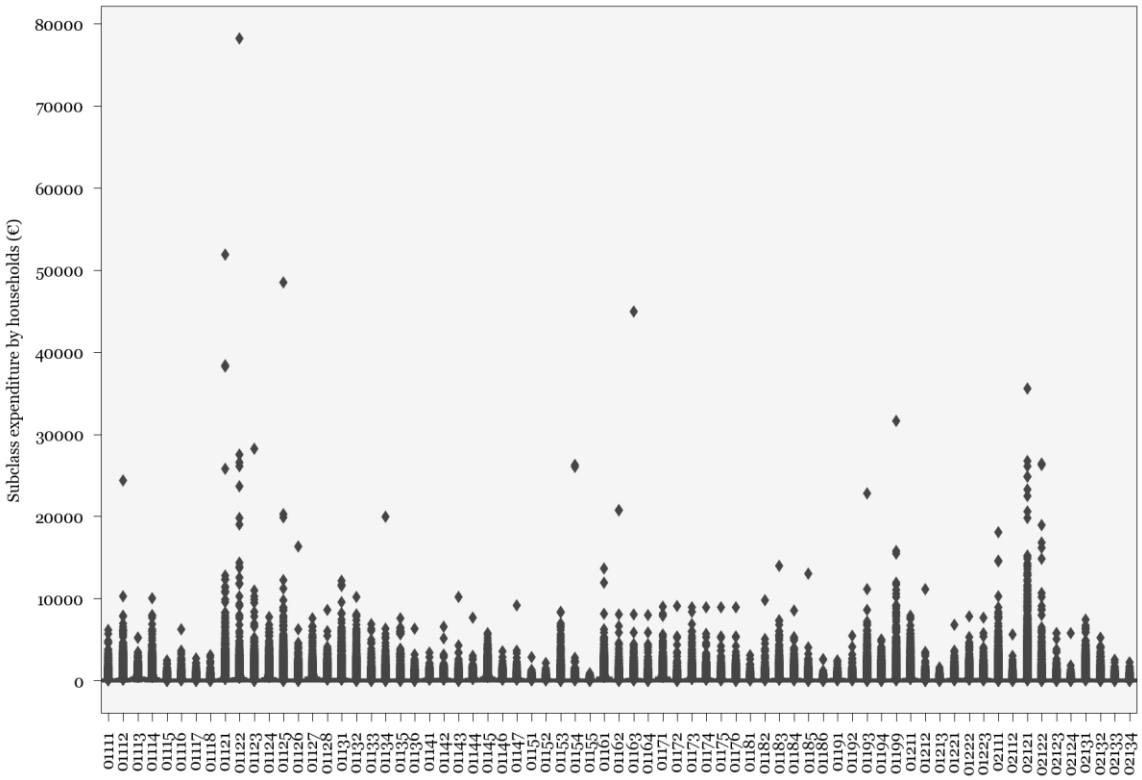

Figure 15: Distribution of expenditure per ECOICOP subclass of all households before replacing outliers. This figure only shows the subclasses 01111 to 02134. The y-axis is scaled to the highest expenditure in all subclasses.

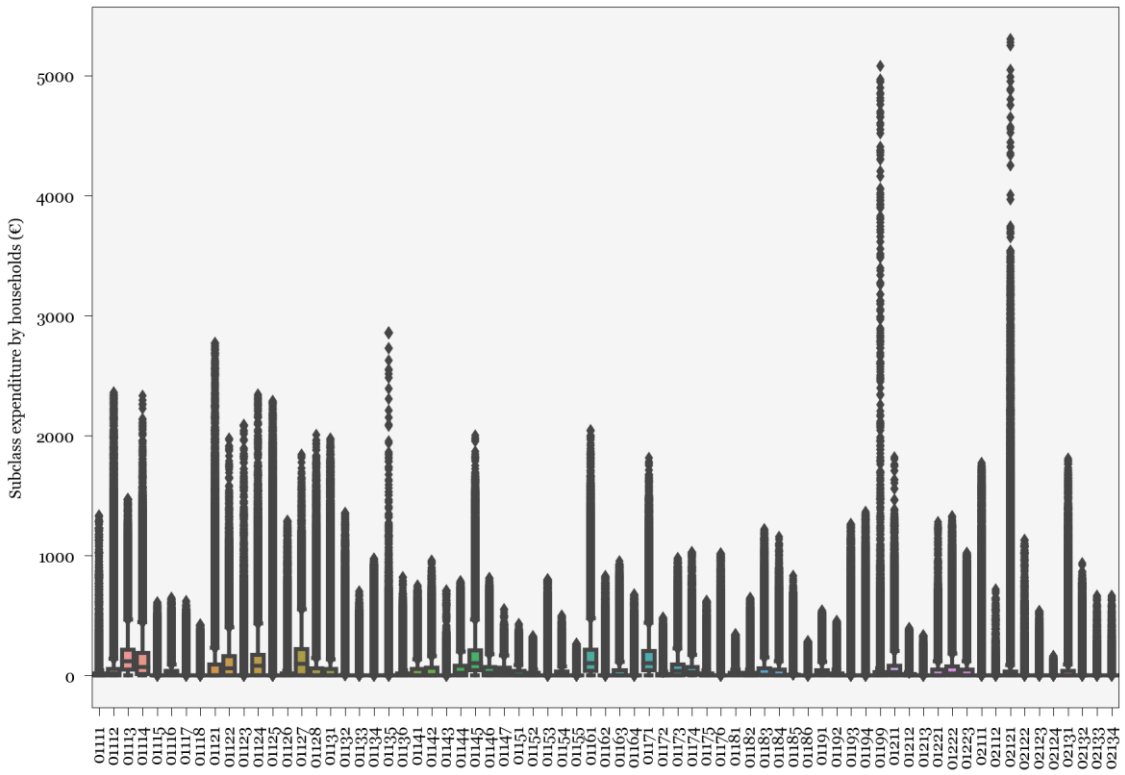

Figure 16: Distribution of expenditure per ECOICOP subclass of all households after replacing outliers by changing the top 1% per subclass to country mean. This figure only shows the subclasses 01111 to 02134. The y-axis is scaled to the highest expenditure in all subclasses.

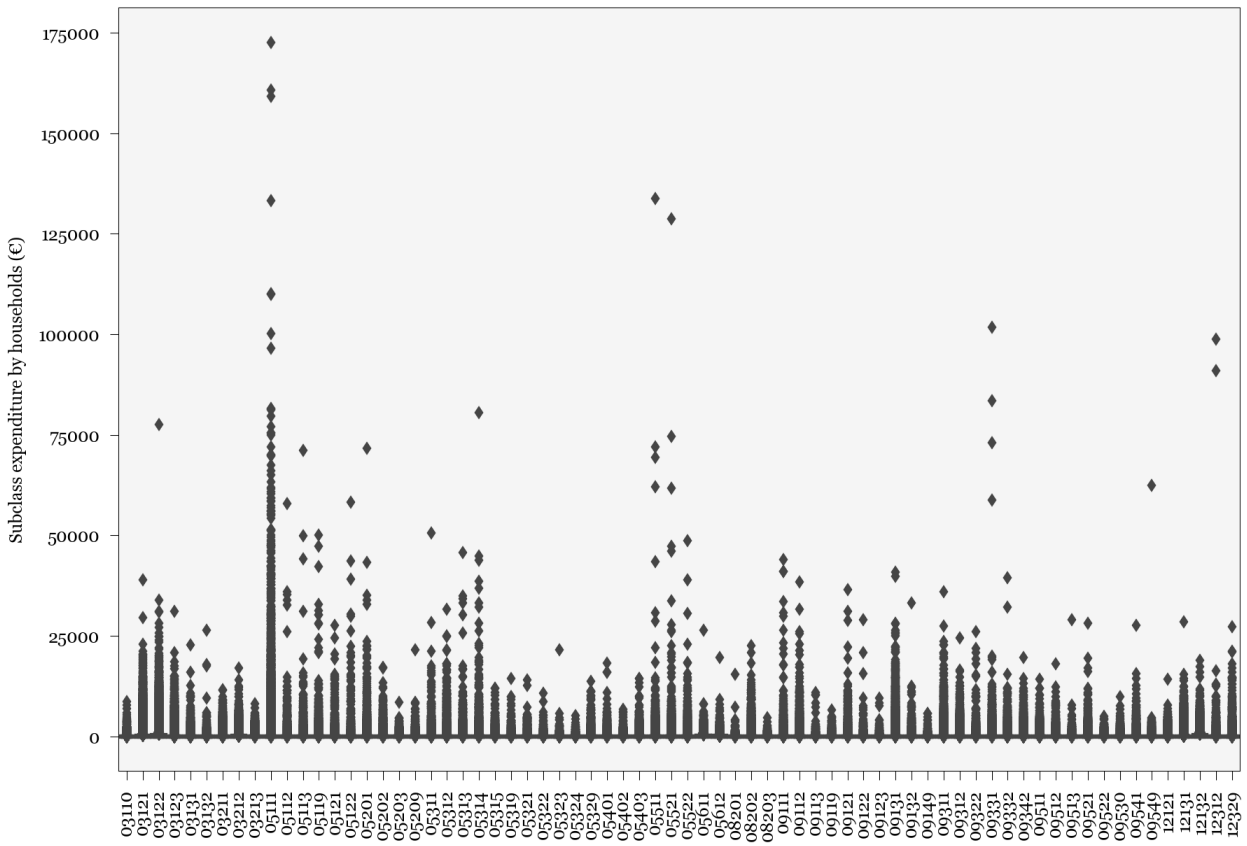

Figure 17: Distribution of expenditure per ECOICOP subclass of all households before removing outliers. This figure only shows the subclasses 03110 to 12329. The y-axis is scaled to the highest expenditure in all subclasses.

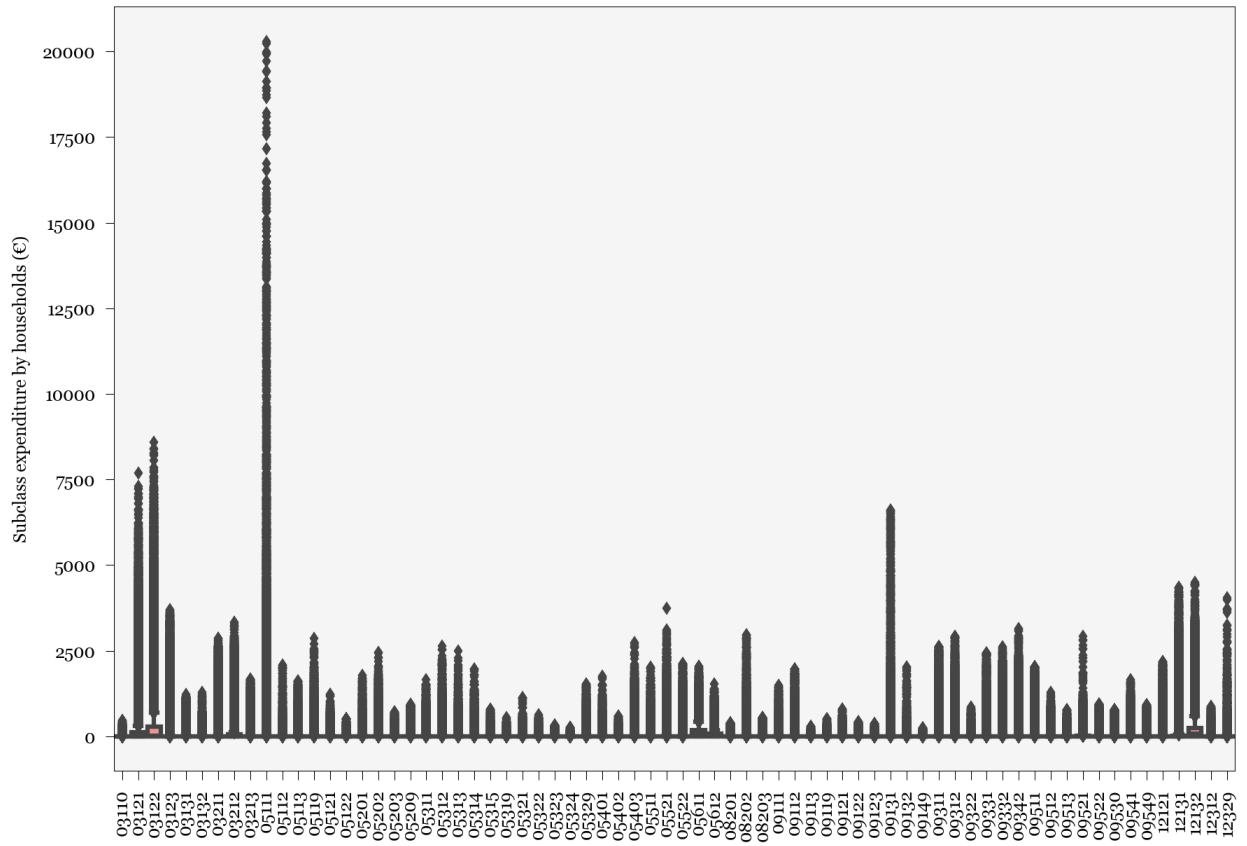

Figure 18: Distribution of expenditure per ECOICOP subclass of all households after replacing outliers by changing the top 1% per subclass to country mean. This figure only shows the subclasses 03110 to 12329. The y-axis is scaled to the highest expenditure in all subclasses.

Appendix 9: Distribution of physical consumption values per subclass

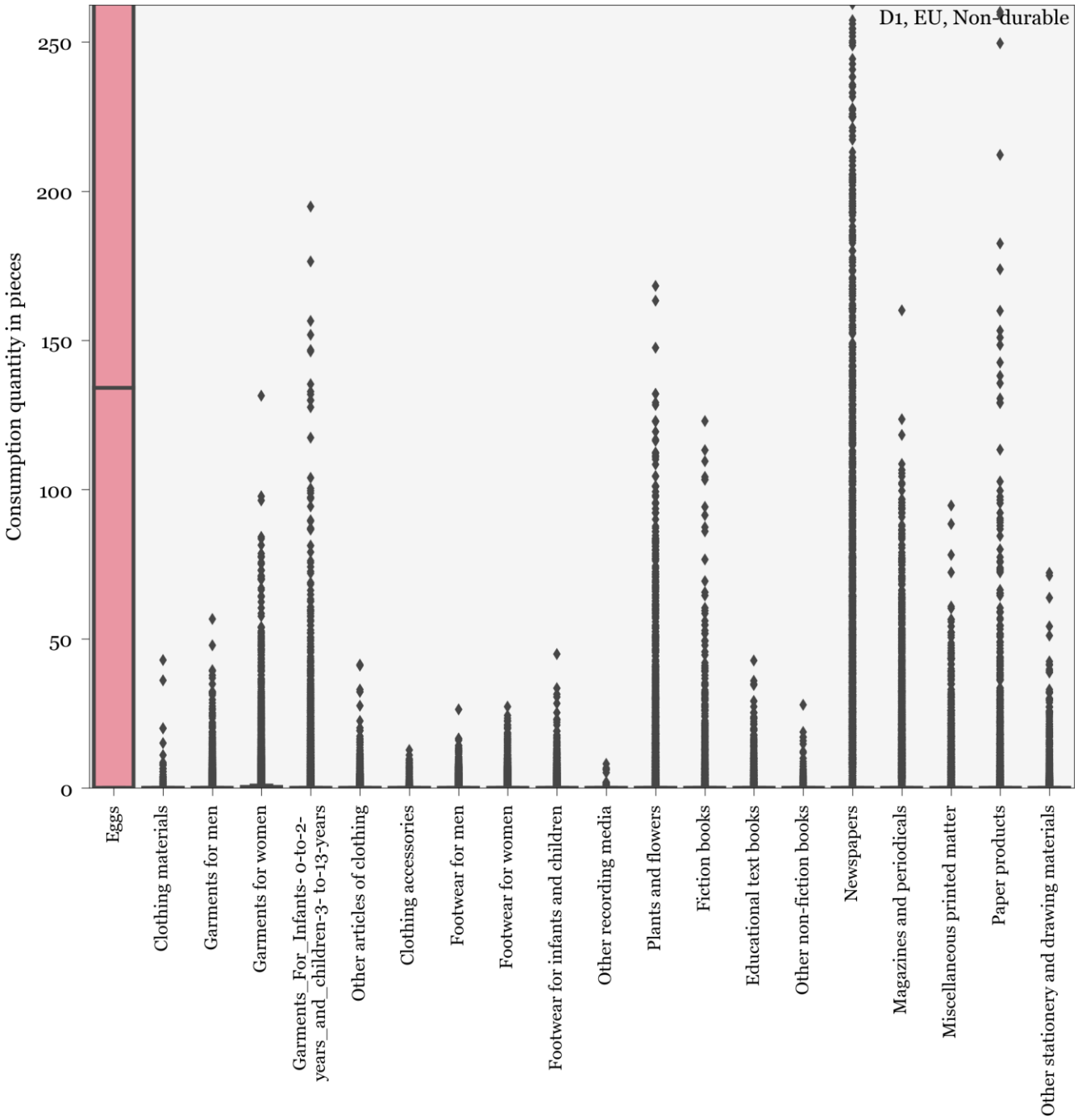

Figure 19: Distribution of physical consumption quantities of non-durable goods per ECOICOP subclasses of households in EU income decile D1. Only subclasses measured in pieces are shown. Note that the y-axis is cut off to highlight differences for subclasses with lower consumption quantities.

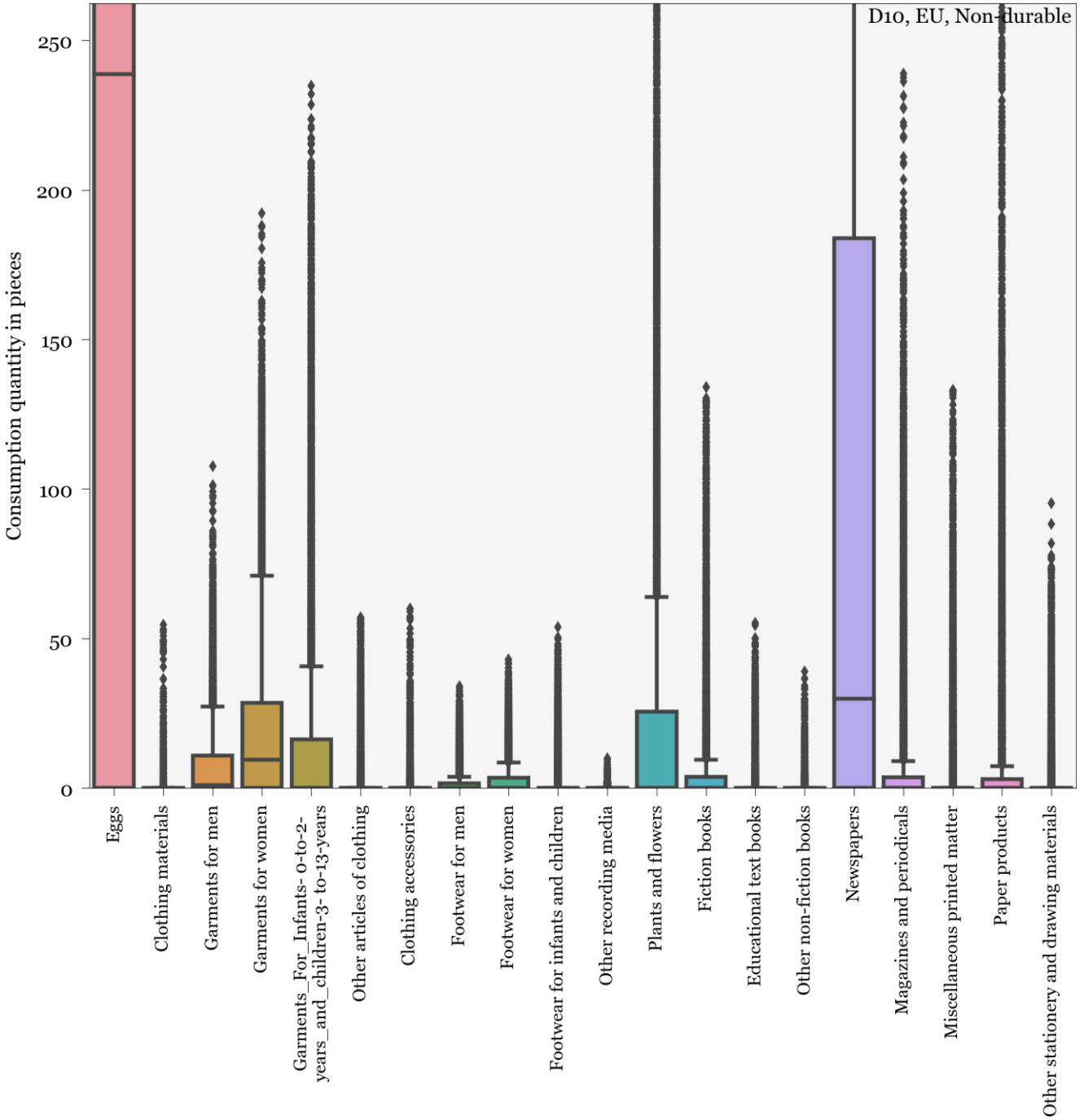

Figure 20: Distribution of physical consumption quantities of non-durable goods per ECOICOP subclasses of households in EU income decile D10. Only subclasses measured in pieces are shown. Note that the y-axis is cut off to highlight differences for subclasses with lower consumption quantities.

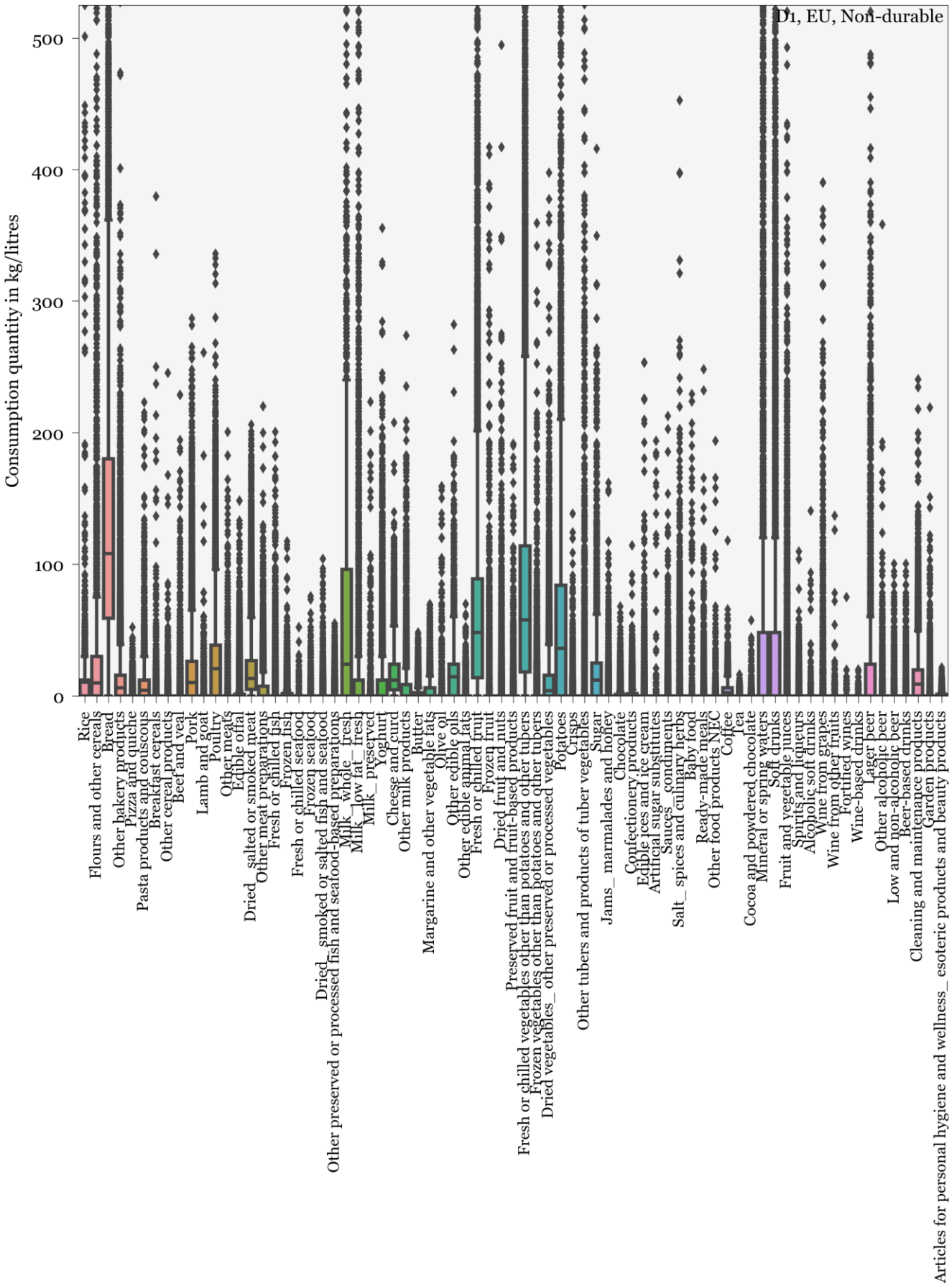

Figure 21: Distribution of physical consumption quantities of non-durable goods per ECOICOP subclasses of households in EU income decile D1. Only subclasses measured in kg or litres are shown. Note that the y-axis is cut off to highlight differences for subclasses with lower consumption quantities.

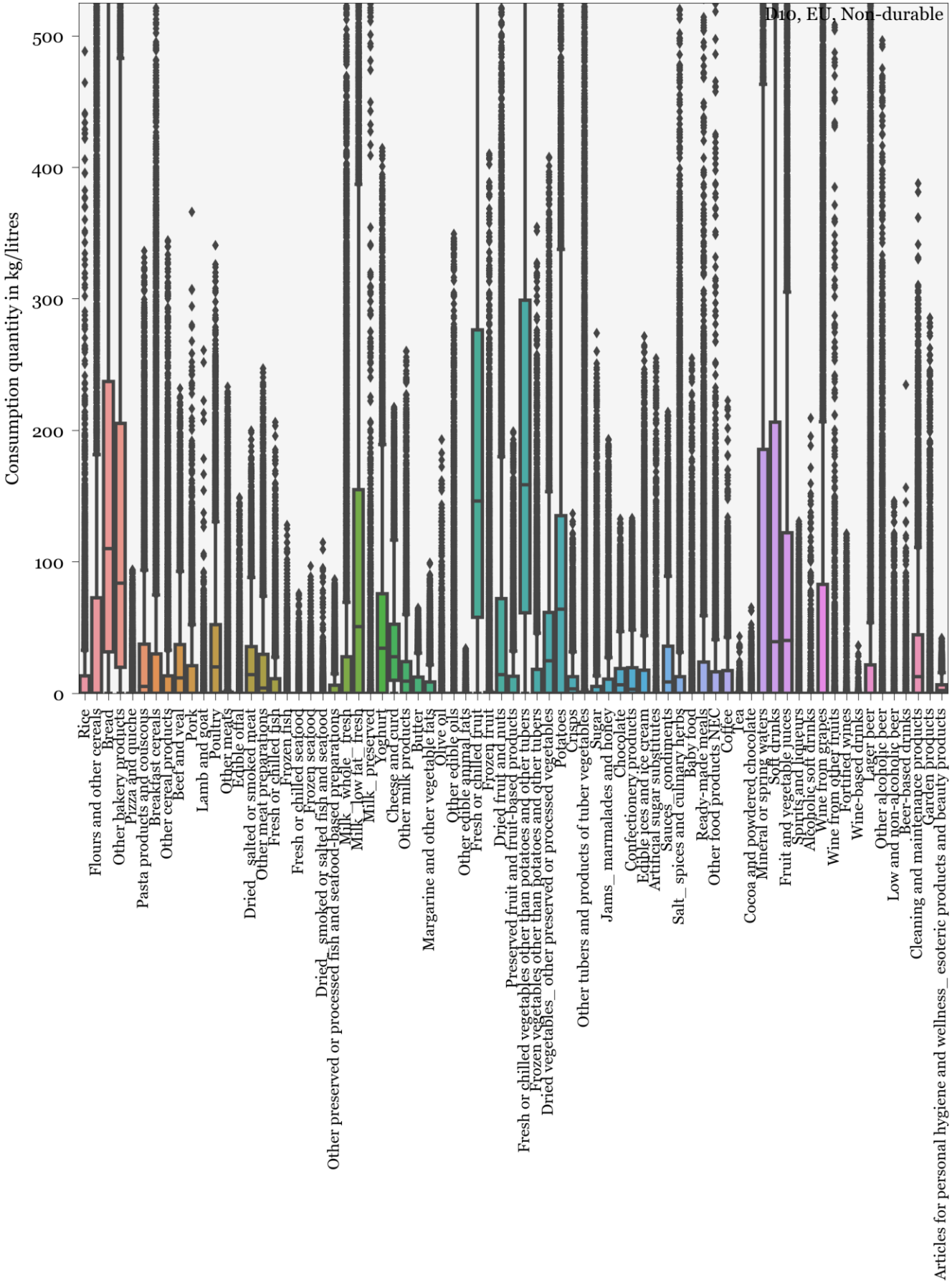

Figure 22: Distribution of physical consumption quantities of non-durable goods per ECOICOP subclasses of households in EU income decile D10. Only subclasses measured in kg or litres are shown. Note that the y-axis is cut off to highlight differences for subclasses with lower consumption quantities.

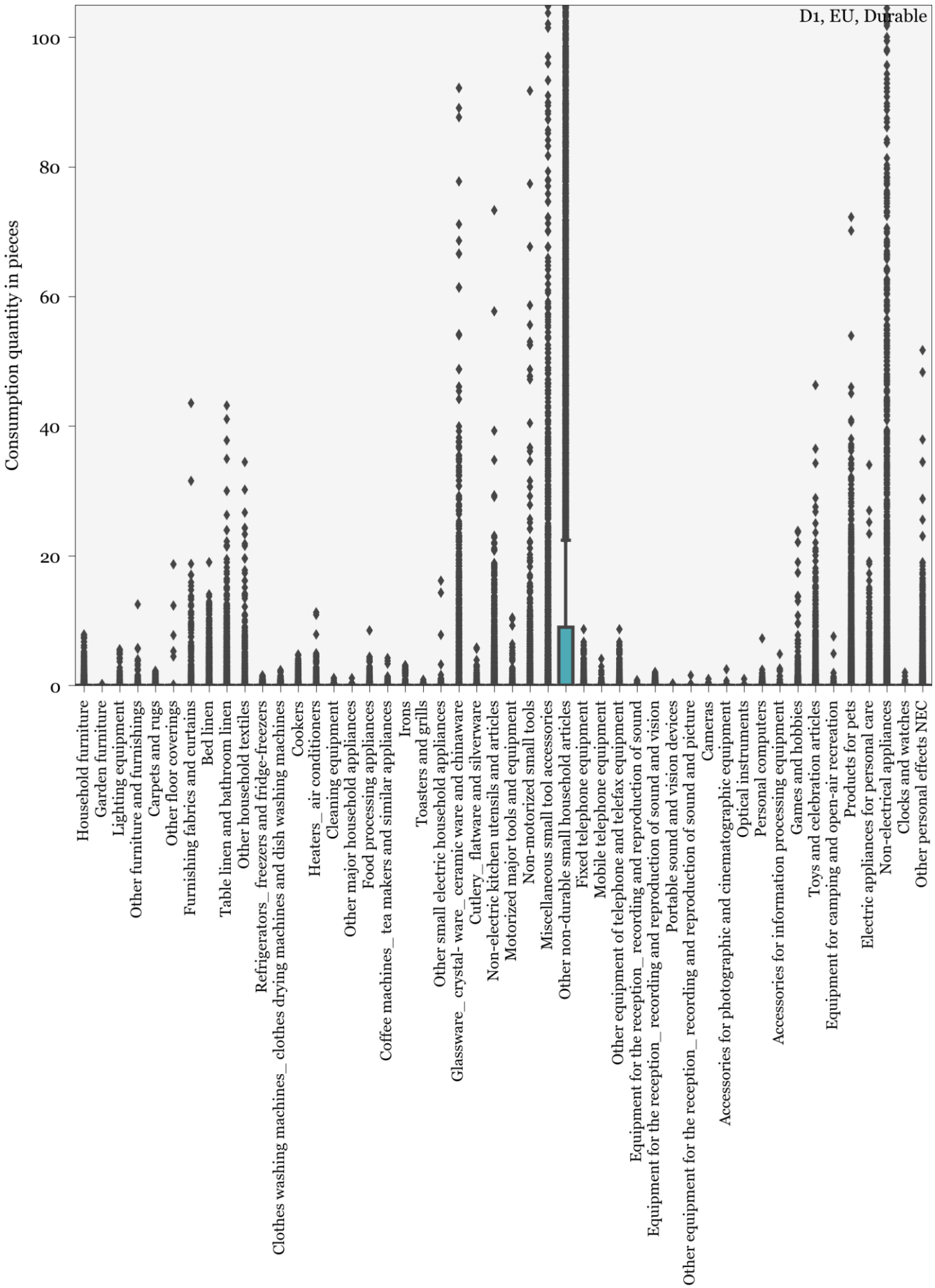

Figure 23: Distribution of physical consumption quantities of durable goods per ECOICOP subclasses of households in EU income decile D1. Unlike non-durable goods, all durable goods are measured in pieces. Note that the y-axis is cut off to highlight differences for subclasses with lower consumption quantities.

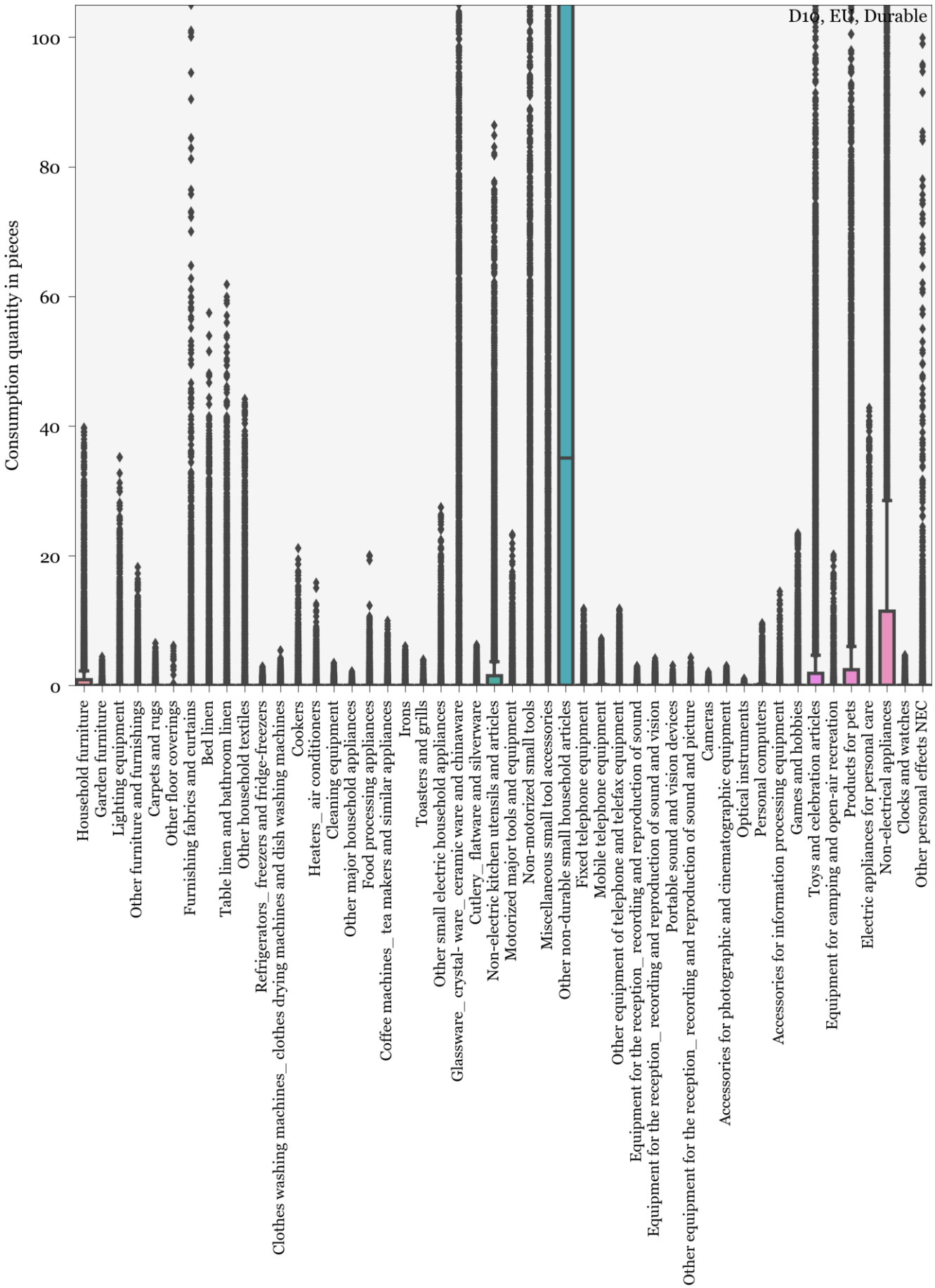

Figure 24: Distribution of physical consumption quantities of durable goods per ECOICOP subclasses of households in EU income decile D10. Unlike non-durable goods, all durable goods are measured in pieces. Note that the y-axis is cut off to highlight differences for subclasses with lower consumption quantities.

Appendix 10: Descriptive statistics for the income deciles

Table 13: Descriptive statistics for the income deciles in all countries, including sample size, the lowest and highest income a household in the respective decile can have and the mean and median income of that decile.

Country	Decile	No. of households	Lowest income (€)	Highest income (€)	Mean income (€)	Median income (€)
EU	D1	34016	0	4500	2766	2867
EU	D2	29474	4500	7687	6004	5963
EU	D3	24360	7687	10824	9217	9200
EU	D4	20863	10824	14521	12652	12608
EU	D5	17214	14521	18642	16344	16200
EU	D6	15480	18642	23566	20897	20772
EU	D7	14834	23566	30005	26577	26473
EU	D8	14898	30008	39437	34356	33953
EU	D9	15223	39437	54456	46237	45921
EU	D10	17787	54456	249745	79020	70587
BE	D1	430	0	14599	11949	12679
BE	D2	465	14619	18381	16571	16663
BE	D3	539	18402	22169	20333	20401
BE	D4	559	22194	26565	24475	24372
BE	D5	587	26565	31395	29093	29113
BE	D6	643	31395	37088	34348	34343
BE	D7	693	37094	43409	40223	40221
BE	D8	730	43409	51439	47218	47207
BE	D9	771	51451	64232	57265	56910
BE	D10	710	64286	249266	83747	76327
BG	D1	316	0	1882	1517	1584
BG	D2	315	1882	2470	2152	2140
BG	D3	309	2471	3096	2788	2789
BG	D4	311	3096	3796	3460	3468
BG	D5	299	3798	4540	4172	4181
BG	D6	295	4543	5303	4920	4928
BG	D7	296	5304	6254	5771	5744
BG	D8	294	6254	7342	6720	6660
BG	D9	284	7342	9390	8325	8294
BG	D10	247	9404	32204	12519	11556
CY	D1	241	0	8530	6218	6500
CY	D2	281	8564	11888	10396	10518
CY	D3	323	11910	15095	13529	13472
CY	D4	291	15100	19084	17023	16950
CY	D5	293	19112	23484	21216	21082
CY	D6	270	23488	27489	25468	25410
CY	D7	283	27545	33280	30287	30196
CY	D8	270	33280	40056	36501	36416
CY	D9	299	40165	52874	45929	45761
CY	D10	324	52875	244932	74815	65300
CZ	D1	233	81	5126	4109	4445
CZ	D2	227	5129	6552	5774	5696
CZ	D3	297	6585	8793	7689	7693
CZ	D4	258	8793	10091	9459	9456
CZ	D5	252	10095	11453	10773	10738
CZ	D6	304	11462	13280	12314	12290
CZ	D7	332	13289	15585	14406	14399

Table continued on the next page.

Country	Decile	No. of households	Lowest income (€)	Highest income (€)	Mean income (€)	Median income (€)
CZ	D8	340	15587	17979	16747	16728
CZ	D9	343	17982	21171	19507	19441
CZ	D10	343	21200	103208	27246	24191
DK	D1	152	218	20182	14957	16054
DK	D2	150	20195	24927	22573	22541
DK	D3	180	24947	30644	27925	27763
DK	D4	211	30683	36708	33582	33503
DK	D5	224	36736	44173	40561	40892
DK	D6	254	44194	53925	48882	48951
DK	D7	255	53968	67361	60963	61302
DK	D8	273	67414	83441	75216	74751
DK	D9	252	83446	103122	92603	92462
DK	D10	242	103219	245969	129916	119634
EE	D1	274	432	4080	3243	3600
EE	D2	216	4092	4680	4373	4368
EE	D3	289	4680	6360	5393	5400
EE	D4	400	6360	8400	7576	7560
EE	D5	378	8400	10200	9217	9291
EE	D6	350	10200	12000	11284	11217
EE	D7	362	12000	15360	13670	13800
EE	D8	372	15366	19200	17194	17866
EE	D9	378	19200	26400	22699	23526
EE	D10	376	26400	84000	34159	31374
EL	D1	616	0	4920	2711	3230
EL	D2	642	4920	7420	6322	6400
EL	D3	656	7440	9390	8400	8400
EL	D4	632	9391	11200	10277	10220
EL	D5	637	11200	13200	12198	12180
EL	D6	622	13200	15551	14323	14280
EL	D7	629	15600	19280	17258	17160
EL	D8	573	19300	23780	21402	21260
EL	D9	576	23796	31680	27163	26840
EL	D10	564	31680	218435	45025	39515
ES	D1	1873	0	8616	5331	5112
ES	D2	2073	8616	10020	9371	9396
ES	D3	2047	10020	14124	11985	12000
ES	D4	2157	14124	15288	14710	14700
ES	D5	2156	15288	19872	17189	16800
ES	D6	2246	19872	21600	20698	20676
ES	D7	2220	21600	26556	24821	25500
ES	D8	2322	26556	32280	28939	28200
ES	D9	2478	32280	40800	35321	33948
ES	D10	2558	40800	205200	55452	49578
FI	D1	246	0	13750	10849	11688
FI	D2	242	13767	17331	15513	15528
FI	D3	280	17369	21973	19718	19865
FI	D4	323	21982	27230	24855	24987
FI	D5	357	27234	32215	29708	29658
FI	D6	407	32225	38410	35461	35545
FI	D7	423	38434	45955	42133	41976
FI	D8	436	45995	55231	50199	49972

Table continued on the next page.

Country	Decile	No. of households	Lowest income (€)	Highest income (€)	Mean income (€)	Median income (€)
FI	D9	475	55301	69720	61669	61154
FI	D10	473	69727	217244	91771	82601
FR	D1	2562	0	12799	7114	8653
FR	D2	1740	12800	17302	15040	14997
FR	D3	1581	17306	21099	19212	19139
FR	D4	1643	21100	25160	23111	23130
FR	D5	1607	25160	30098	27574	27569
FR	D6	1595	30103	35700	32863	32857
FR	D7	1562	35703	42598	39058	38987
FR	D8	1523	42603	51042	46600	46525
FR	D9	1533	51053	65940	57568	56871
FR	D10	1595	65949	248125	92851	82972
HR	D1	218	0	3157	2264	2355
HR	D2	208	3160	4450	3798	3814
HR	D3	204	4467	5997	5242	5269
HR	D4	211	5997	7899	6996	7034
HR	D5	202	7899	9647	8773	8768
HR	D6	212	9647	11678	10676	10714
HR	D7	191	11685	13866	12733	12678
HR	D8	194	13878	16842	15272	15177
HR	D9	196	16856	21759	18862	18665
HR	D10	192	21786	143229	29562	26110
HU	D1	682	0	3202	2379	2576
HU	D2	797	3203	4111	3678	3696
HU	D3	784	4112	5061	4600	4609
HU	D4	788	5063	6165	5640	5668
HU	D5	788	6166	7341	6757	6754
HU	D6	732	7344	8555	7912	7906
HU	D7	741	8557	10188	9358	9352
HU	D8	666	10190	12242	11141	11101
HU	D9	645	12242	15809	13866	13754
HU	D10	540	15821	122141	21820	19097
IE	D1	670	0	13143	10345	11051
IE	D2	721	13143	21003	16777	16707
IE	D3	713	21014	27148	24145	24059
IE	D4	711	27150	33862	30511	30593
IE	D5	691	33863	40733	37307	37237
IE	D6	692	40743	48524	44436	44230
IE	D7	666	48588	57452	53097	53097
IE	D8	645	57481	68669	62708	62455
IE	D9	659	68684	85653	76298	75748
IE	D10	657	85699	249745	110616	101336
LT	D1	240	996	2492	2318	2492
LT	D2	229	2492	3185	2636	2507
LT	D3	265	3187	3848	3641	3596
LT	D4	311	3848	5077	4414	4576
LT	D5	372	5077	6240	5574	5442
LT	D6	469	6240	7385	6743	6773
LT	D7	405	7385	8770	8106	8124
LT	D8	386	8770	10847	9782	9777
LT	D9	407	10847	17450	13229	12693

Table continued on the next page.

Country	Decile	No. of households	Lowest income (€)	Highest income (€)	Mean income (€)	Median income (€)
LT	D10	359	17450	36925	18796	18836
LU	D1	146	0	24000	19517	20448
LU	D2	205	24221	33000	29257	29718
LU	D3	238	33000	39991	36585	36484
LU	D4	272	40000	46056	43043	43158
LU	D5	316	46092	54000	49945	49769
LU	D6	345	54000	62520	58371	58314
LU	D7	371	62532	72775	67795	67464
LU	D8	398	72775	85380	78052	78000
LU	D9	415	85424	108060	95713	95520
LU	D10	433	108072	247617	140321	132360
LV	D1	442	208	2952	2363	2570
LV	D2	432	2952	3600	3211	3180
LV	D3	424	3600	4800	4202	4200
LV	D4	428	4800	6060	5498	5448
LV	D5	387	6060	7200	6681	6648
LV	D6	385	7200	8760	7934	7849
LV	D7	366	8760	10690	9646	9600
LV	D8	352	10692	13200	11635	11653
LV	D9	337	13200	18026	15157	14460
LV	D10	291	18060	78000	24191	22500
MT	D1	277	92	8732	7043	7399
MT	D2	307	8736	11319	10127	10106
MT	D3	351	11334	13797	12495	12501
MT	D4	352	13797	17469	15493	15404
MT	D5	381	17483	21963	19702	19589
MT	D6	413	21992	26503	24253	24241
MT	D7	411	26514	32157	29340	29399
MT	D8	399	32160	39248	35396	35130
MT	D9	395	39266	49601	43954	43712
MT	D10	404	49610	234002	68231	61374
NL	D1	784	249	14144	9638	11067
NL	D2	692	14149	18184	16168	16107
NL	D3	798	18186	22031	20105	20131
NL	D4	1047	22031	26180	24180	24144
NL	D5	1237	26193	31196	28654	28629
NL	D6	1392	31196	37429	34392	34530
NL	D7	1673	37443	45162	41235	41340
NL	D8	1926	45169	54063	49499	49420
NL	D9	2308	54074	67724	60513	60330
NL	D10	2480	67729	244928	89415	80552
PL	D1	3568	0	3728	2606	2868
PL	D2	3577	3728	5026	4381	4352
PL	D3	3827	5028	6310	5681	5736
PL	D4	3930	6310	7744	7082	7148
PL	D5	3925	7744	9178	8491	8572
PL	D6	3825	9178	10784	9965	10038
PL	D7	3725	10784	12619	11657	11575
PL	D8	3637	12619	15193	13830	13766
PL	D9	3496	15194	19231	17002	16924
PL	D10	3403	19233	248248	27964	23713

Table continued on the next page.

Country	Decile	No. of households	Lowest income (€)	Highest income (€)	Mean income (€)	Median income (€)
PT	D1	1192	52	5357	3647	3900
PT	D2	1207	5362	7500	6518	6500
PT	D3	1234	7500	9800	8642	8544
PT	D4	1156	9800	12060	10894	10889
PT	D5	1168	12066	14728	13373	13373
PT	D6	1100	14728	17264	15978	16000
PT	D7	1078	17265	20893	19012	19037
PT	D8	1028	20897	25350	22935	22821
PT	D9	1125	25351	34675	29352	29100
PT	D10	1106	34698	226000	52430	44735
RO	D1	4088	0	1701	1221	1269
RO	D2	3966	1701	2340	2019	1995
RO	D3	3567	2340	2923	2618	2610
RO	D4	3392	2925	3612	3262	3253
RO	D5	3193	3612	4341	3970	3968
RO	D6	2931	4341	5183	4763	4762
RO	D7	2773	5183	6122	5633	5626
RO	D8	2479	6122	7367	6700	6686
RO	D9	2235	7367	9456	8286	8214
RO	D10	1991	9456	147118	13032	11513
SE	D1	178	0	14514	10015	11348
SE	D2	179	14521	19258	16699	16526
SE	D3	240	19306	24999	22584	22791
SE	D4	282	25002	29578	27322	27290
SE	D5	324	29610	35343	32513	32617
SE	D6	329	35344	42617	39051	39171
SE	D7	322	42619	50385	46468	46381
SE	D8	331	50412	59199	54750	54665
SE	D9	336	59201	72411	65156	64794
SE	D10	337	72503	240446	94786	86613
SI	D1	241	0	6690	4986	5470
SI	D2	254	6700	9680	8141	8060
SI	D3	296	9690	12660	11272	11300
SI	D4	354	12670	15720	14258	14280
SI	D5	376	15720	18830	17163	17100
SI	D6	384	18830	22490	20758	20805
SI	D7	421	22490	27020	24661	24560
SI	D8	443	27020	32670	29696	29640
SI	D9	468	32690	40620	36075	35795
SI	D10	513	40650	126460	53416	47840
SK	D1	848	0	6121	4790	5004
SK	D2	625	6125	8623	7365	7403
SK	D3	570	8628	10255	9428	9432
SK	D4	483	10255	11779	10985	10984
SK	D5	465	11780	13630	12635	12588
SK	D6	379	13630	15484	14528	14527
SK	D7	379	15484	17535	16454	16384
SK	D8	363	17536	20183	18766	18755
SK	D9	351	20184	24766	22151	21946
SK	D10	322	24778	99872	31373	28922

Appendix 11: Mean decile EFs for all member states

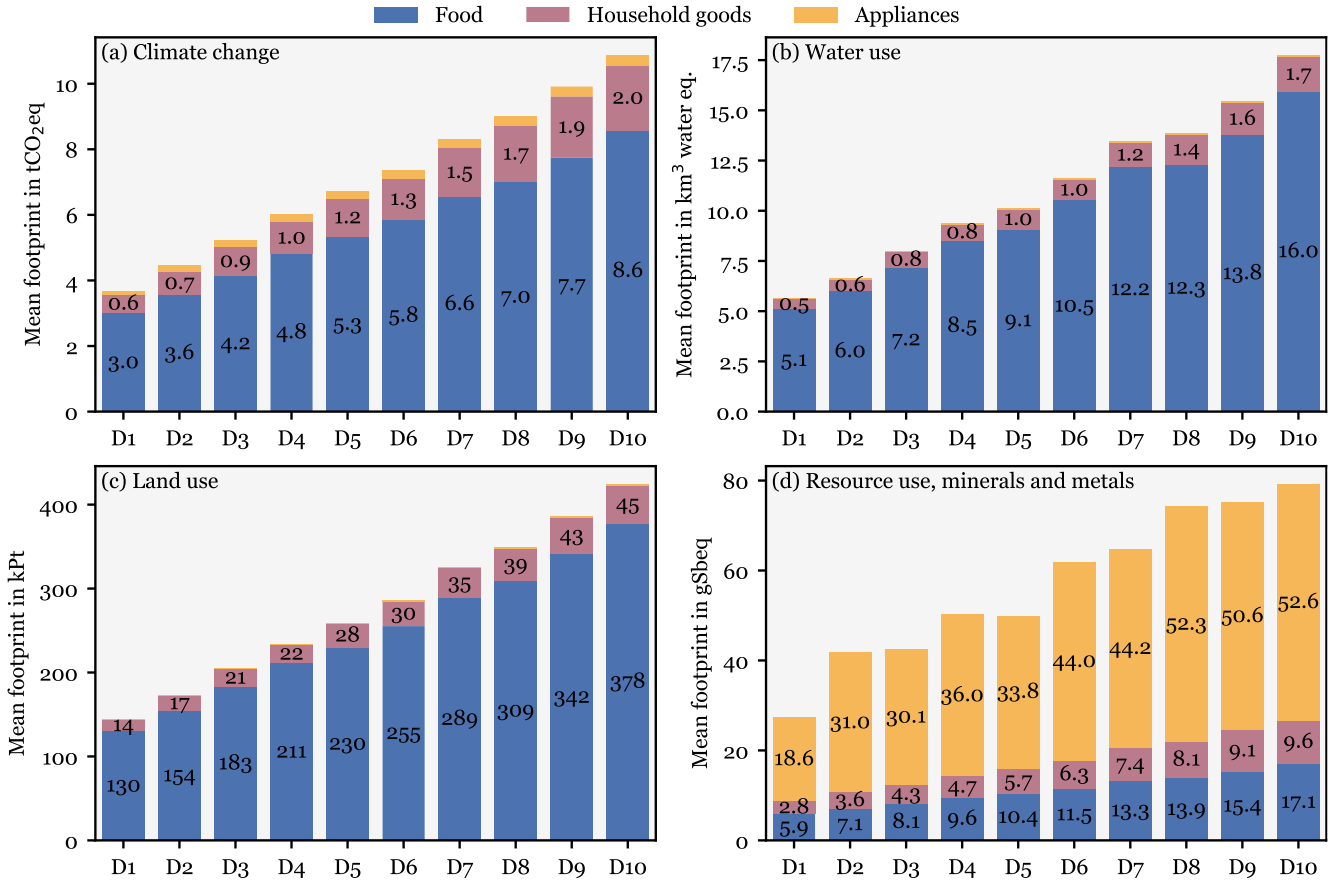

Figure 25: Mean EFs of household income deciles for the year 2015 by basket of consumption for Belgium. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

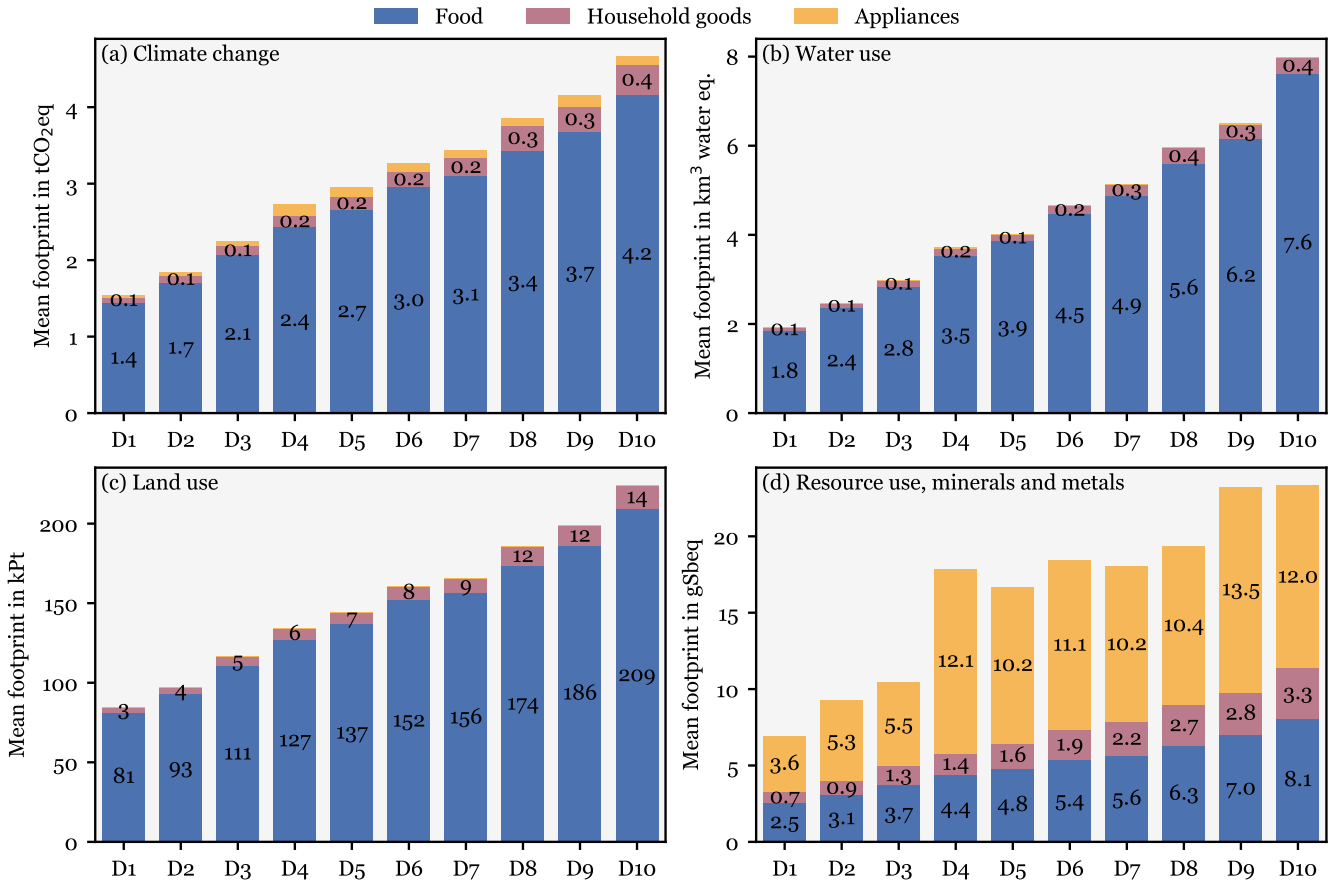

Figure 26: Mean EFs of household income deciles for the year 2015 by basket of consumption for Bulgaria. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

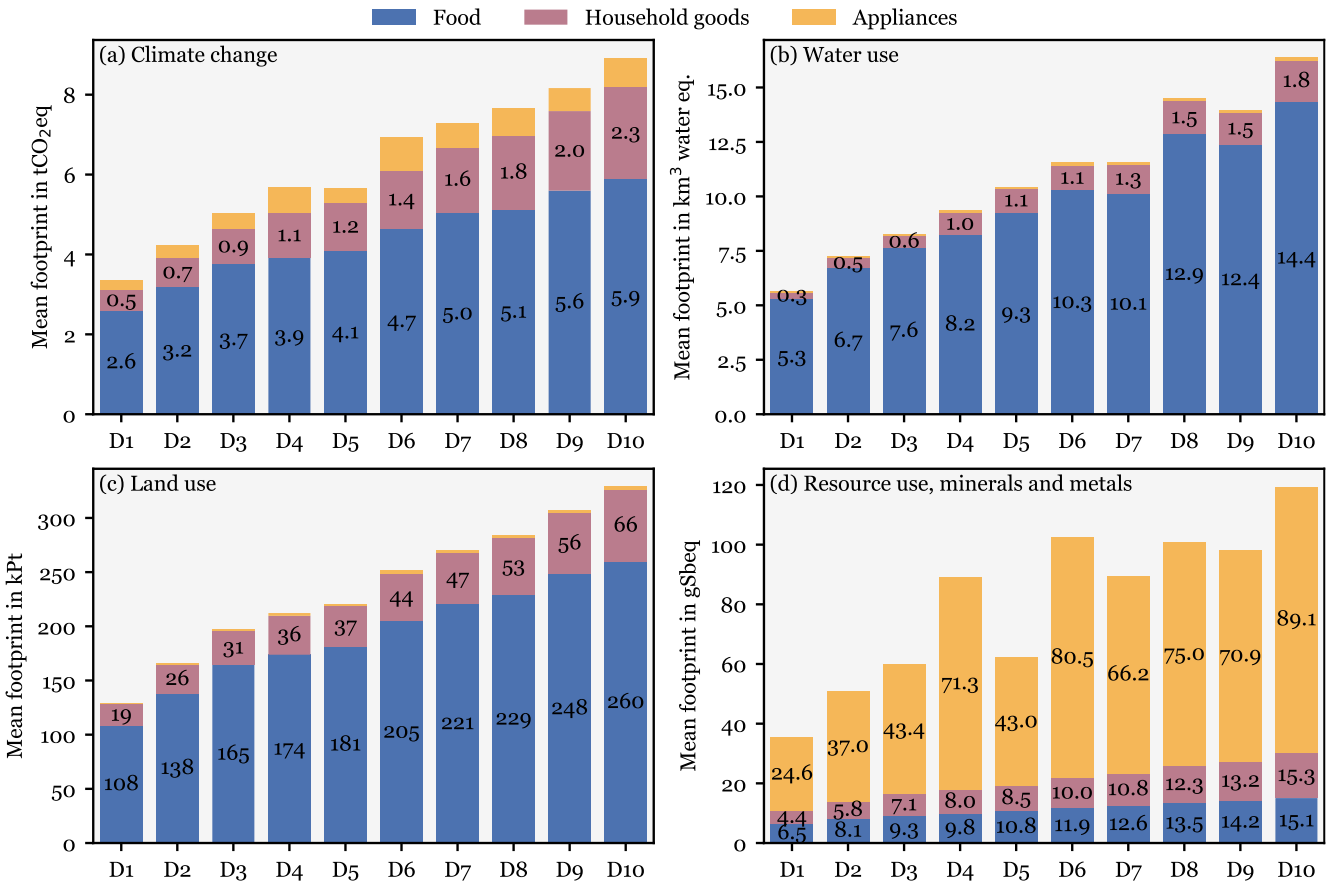

Figure 27: Mean EFs of household income deciles for the year 2015 by basket of consumption for Cyprus. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

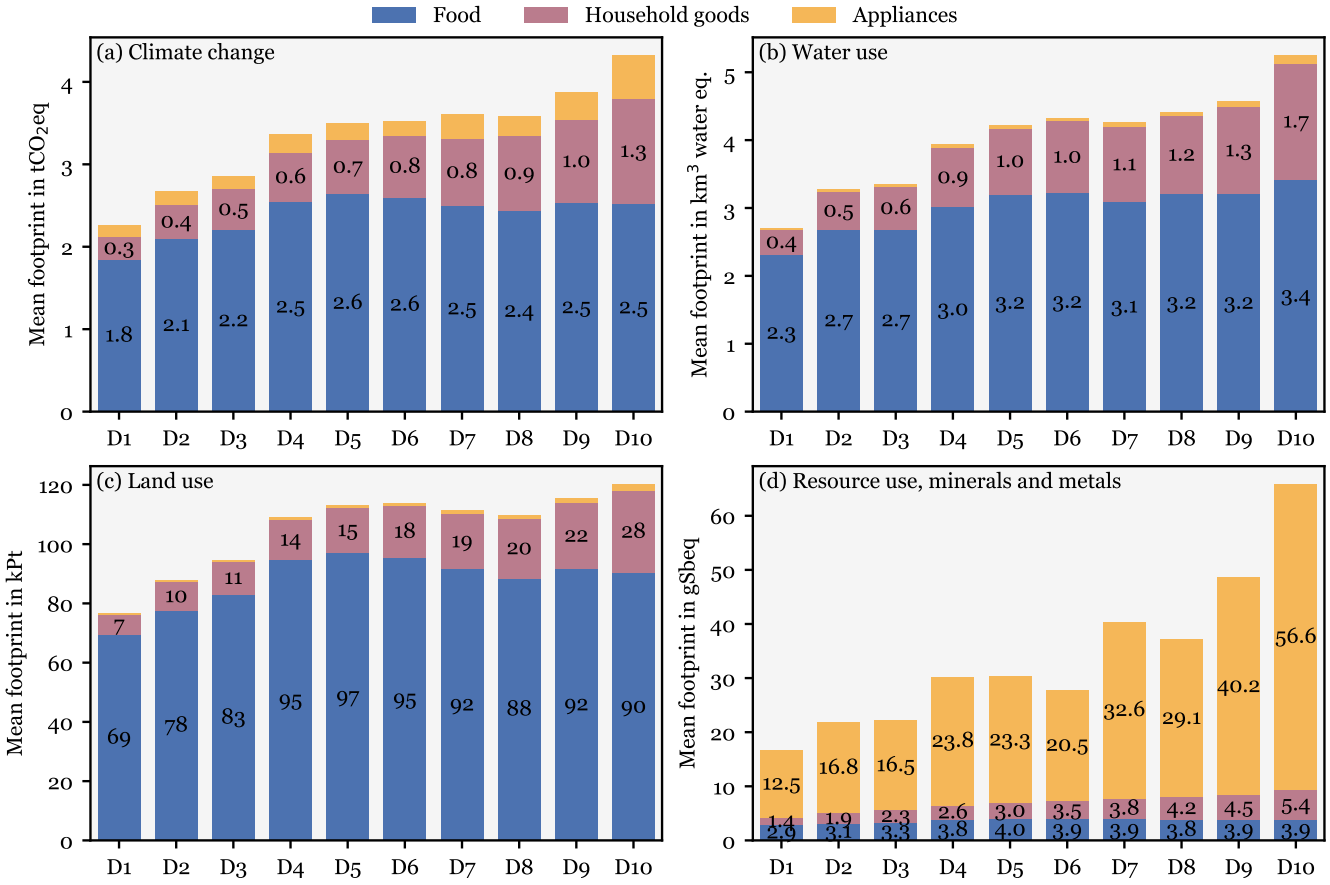

Figure 28: Mean EFs of household income deciles for the year 2015 by basket of consumption for Czechia. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

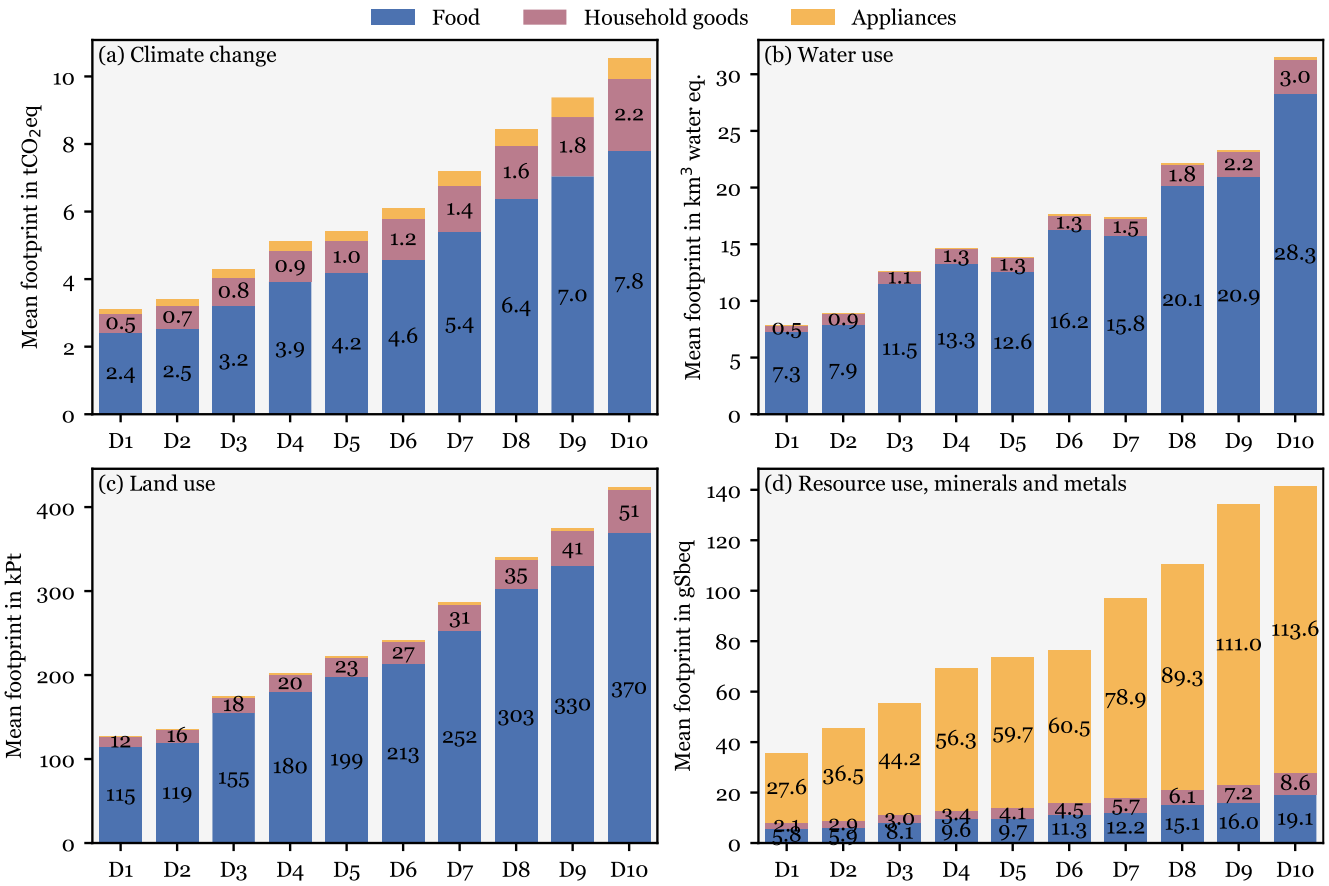

Figure 29: Mean EFs of household income deciles for the year 2015 by basket of consumption for Denmark. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

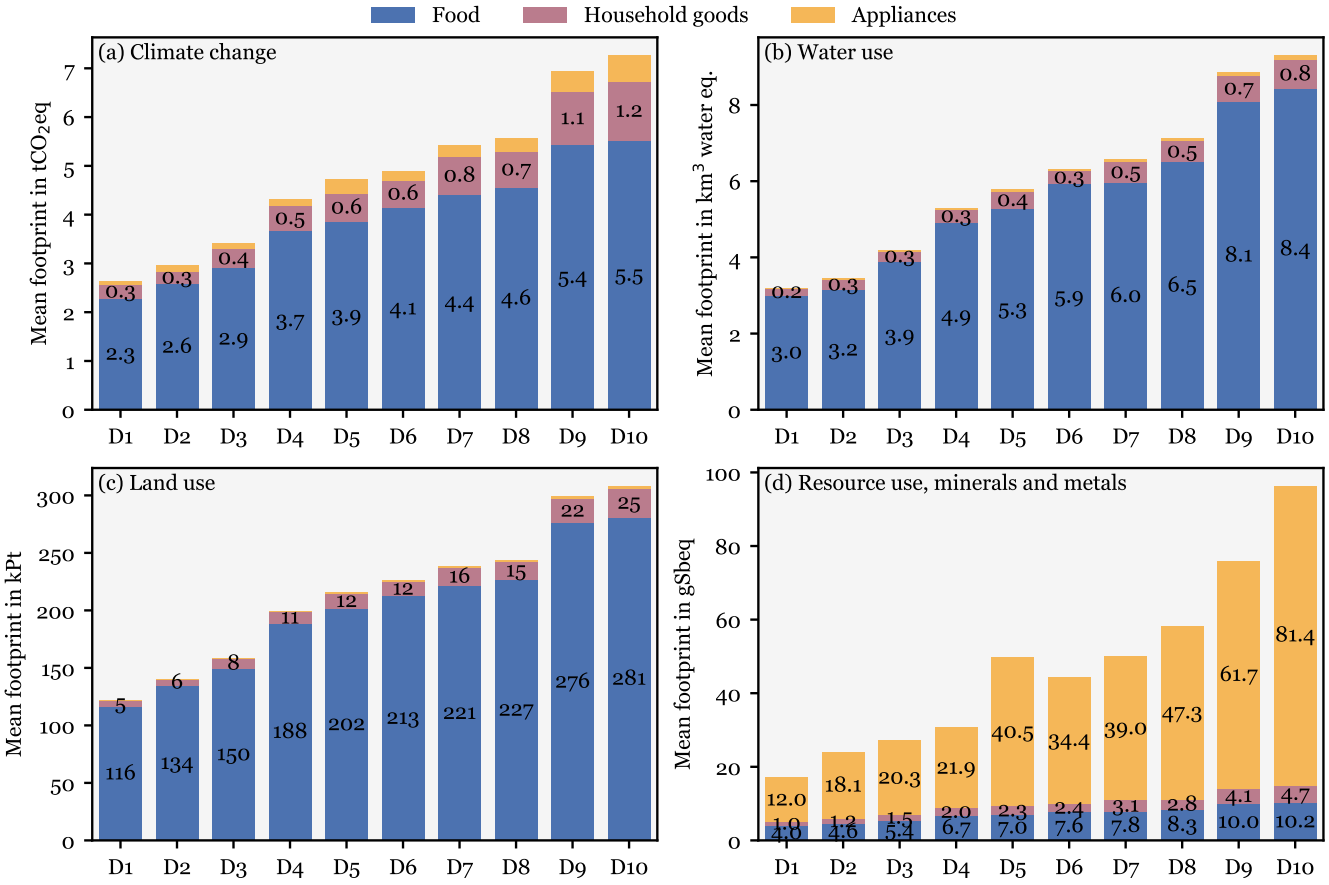

Figure 30: Mean EFs of household income deciles for the year 2015 by basket of consumption for Estonia. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

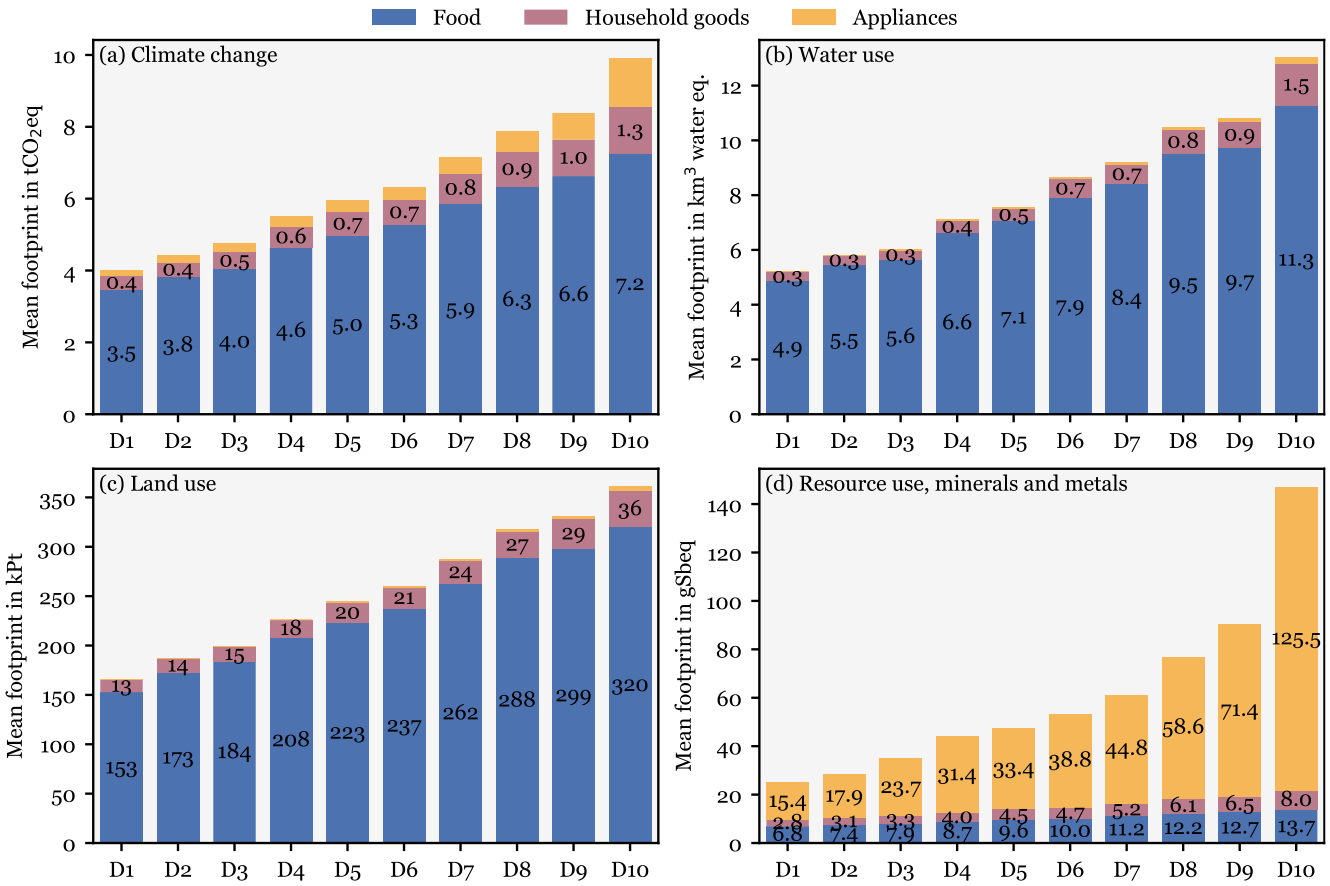

Figure 31: Mean EFs of household income deciles for the year 2015 by basket of consumption for Greece. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

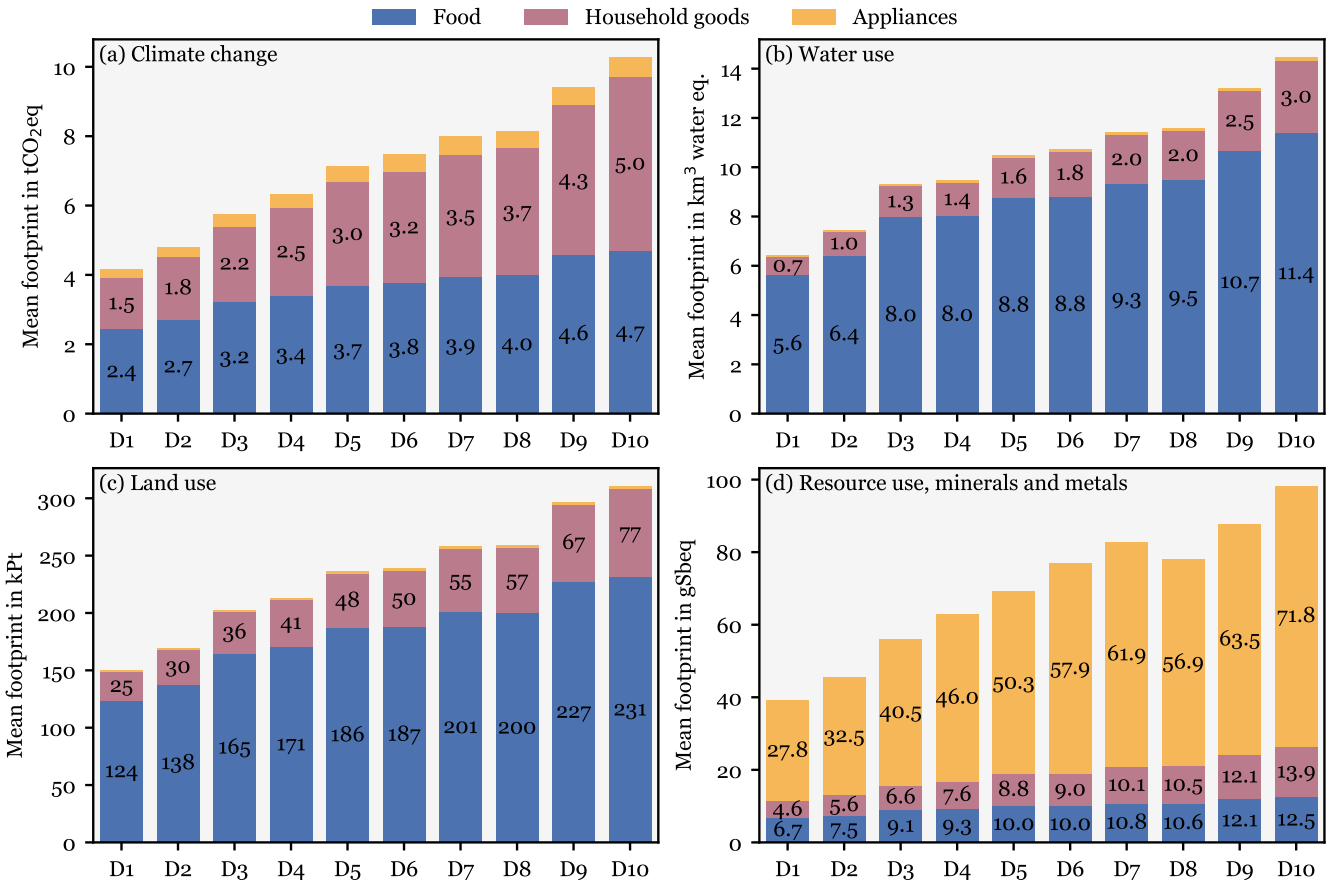

Figure 32: Mean EFs of household income deciles for the year 2015 by basket of consumption for Spain. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

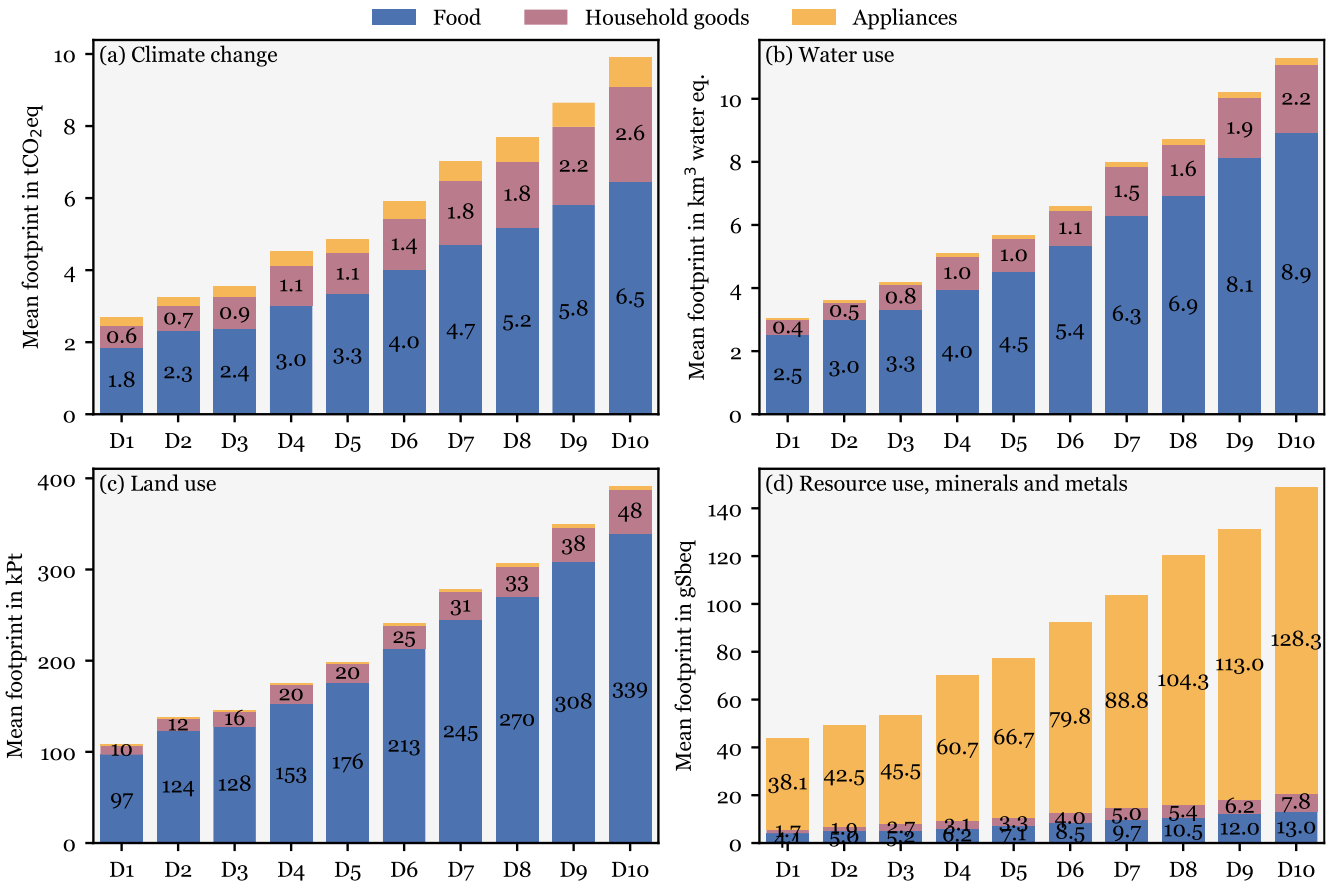

Figure 33: Mean EFs of household income deciles for the year 2015 by basket of consumption for Finland. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

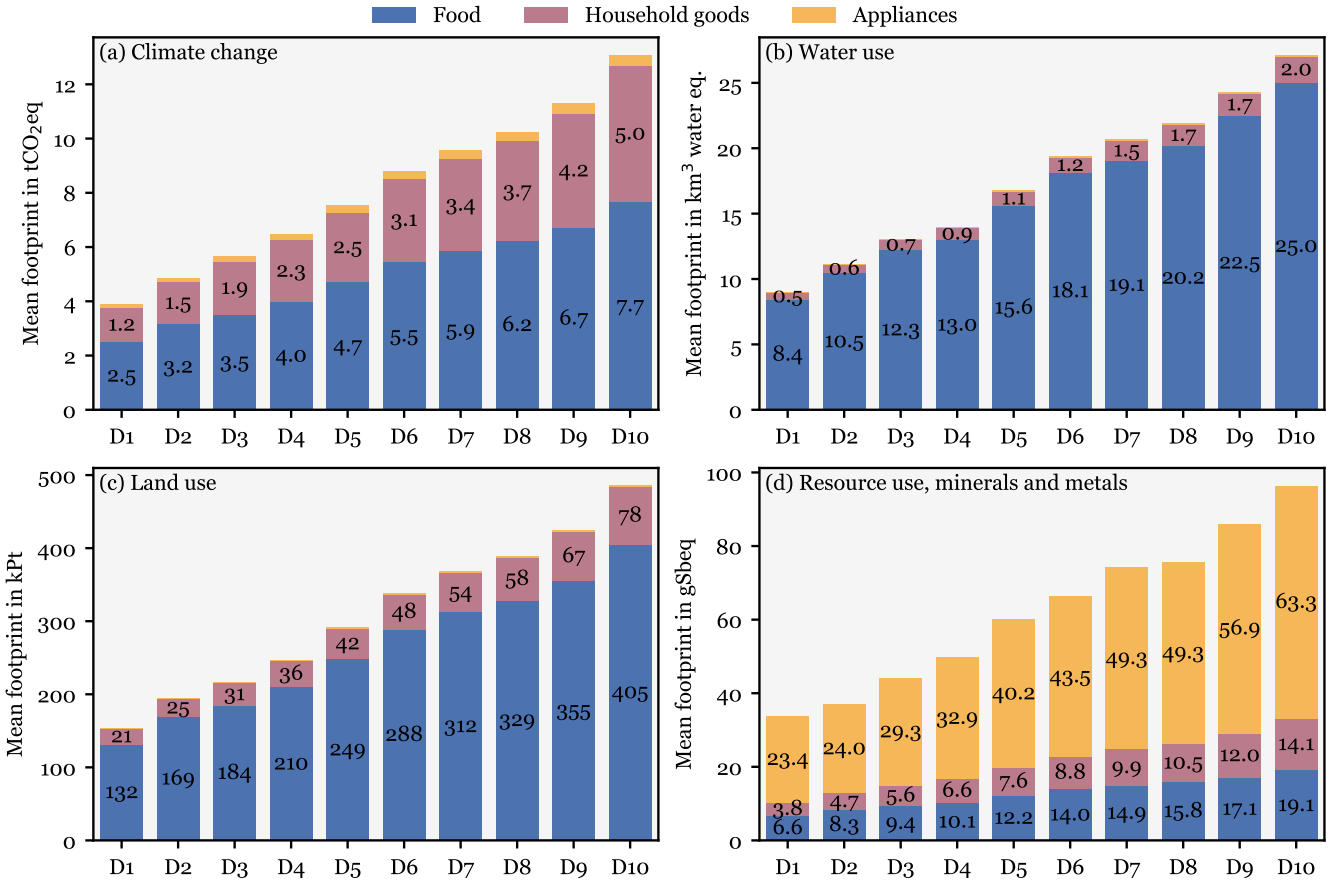

Figure 34: Mean EFs of household income deciles for the year 2015 by basket of consumption for France. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

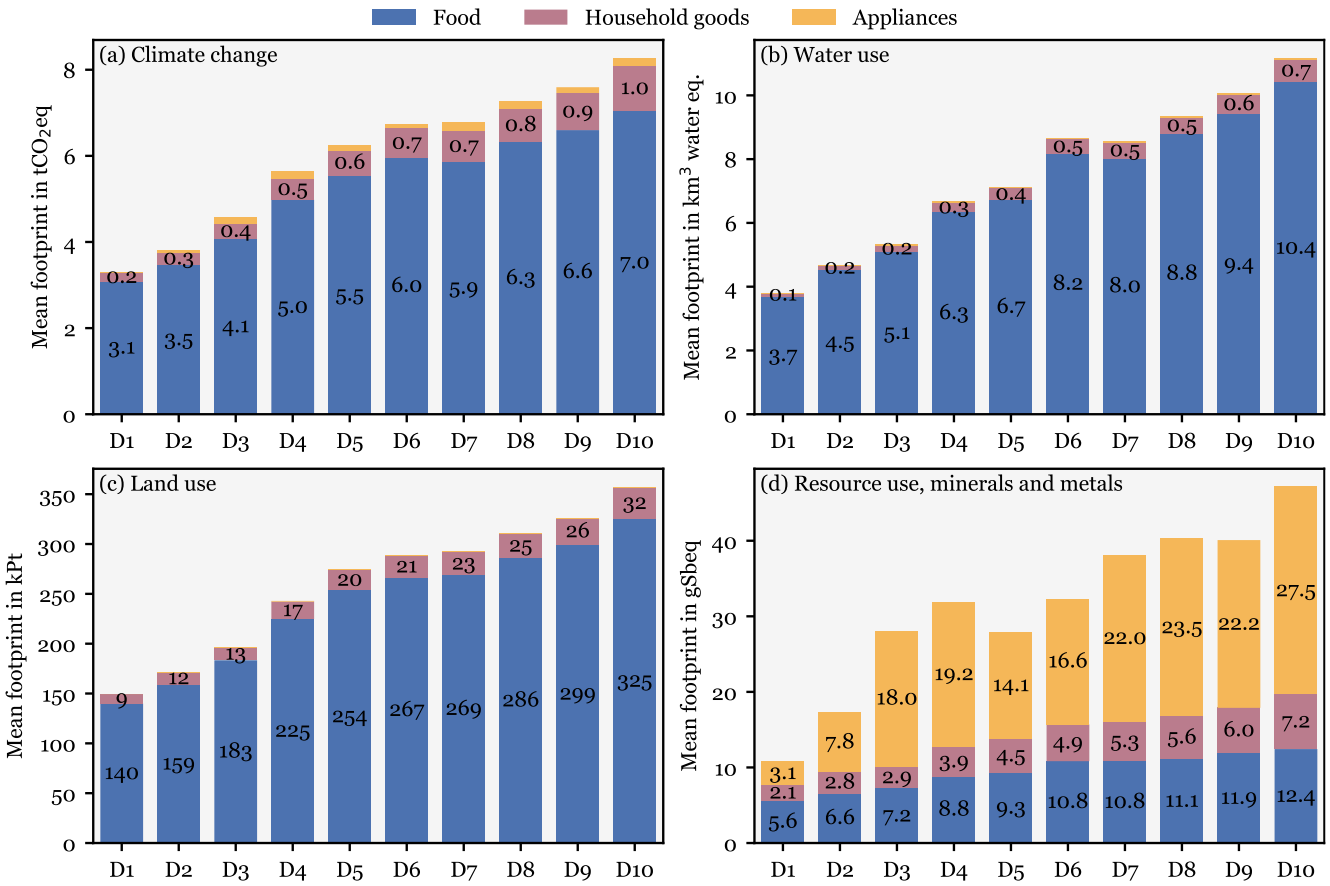

Figure 35: Mean EFs of household income deciles for the year 2015 by basket of consumption for Croatia. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

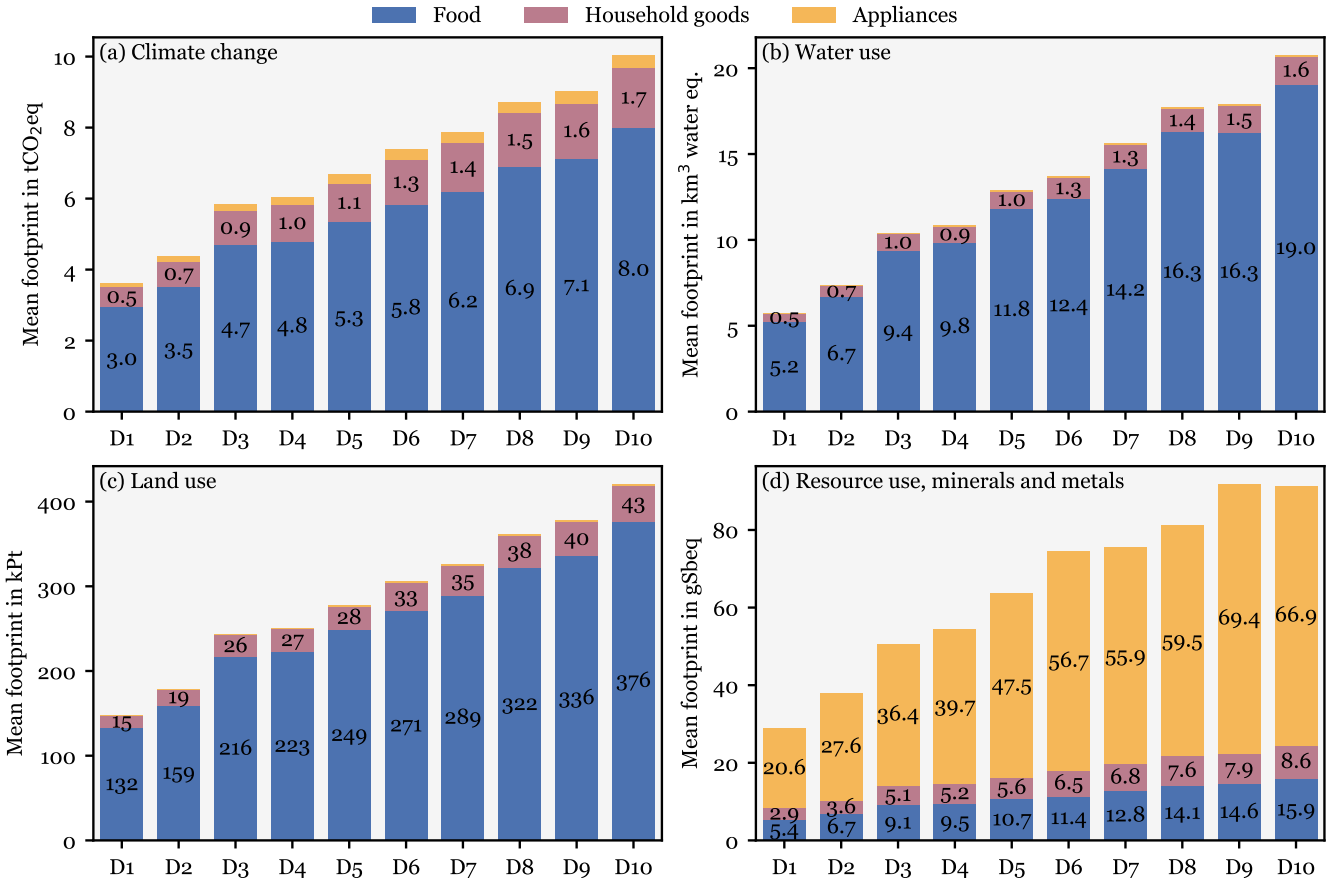

Figure 36: Mean EFs of household income deciles for the year 2015 by basket of consumption for Ireland. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

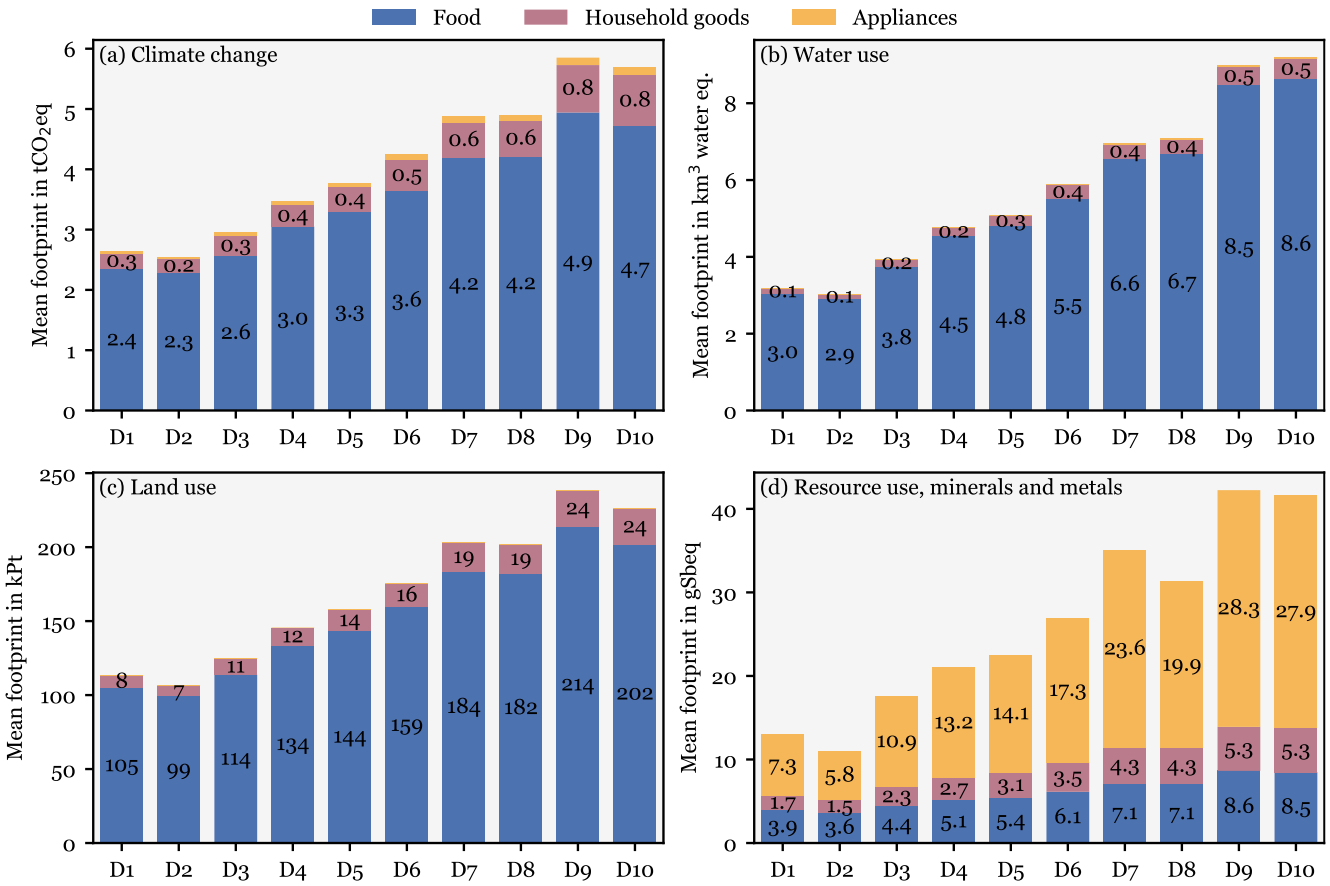

Figure 37: Mean EFs of household income deciles for the year 2015 by basket of consumption for Lithuania. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

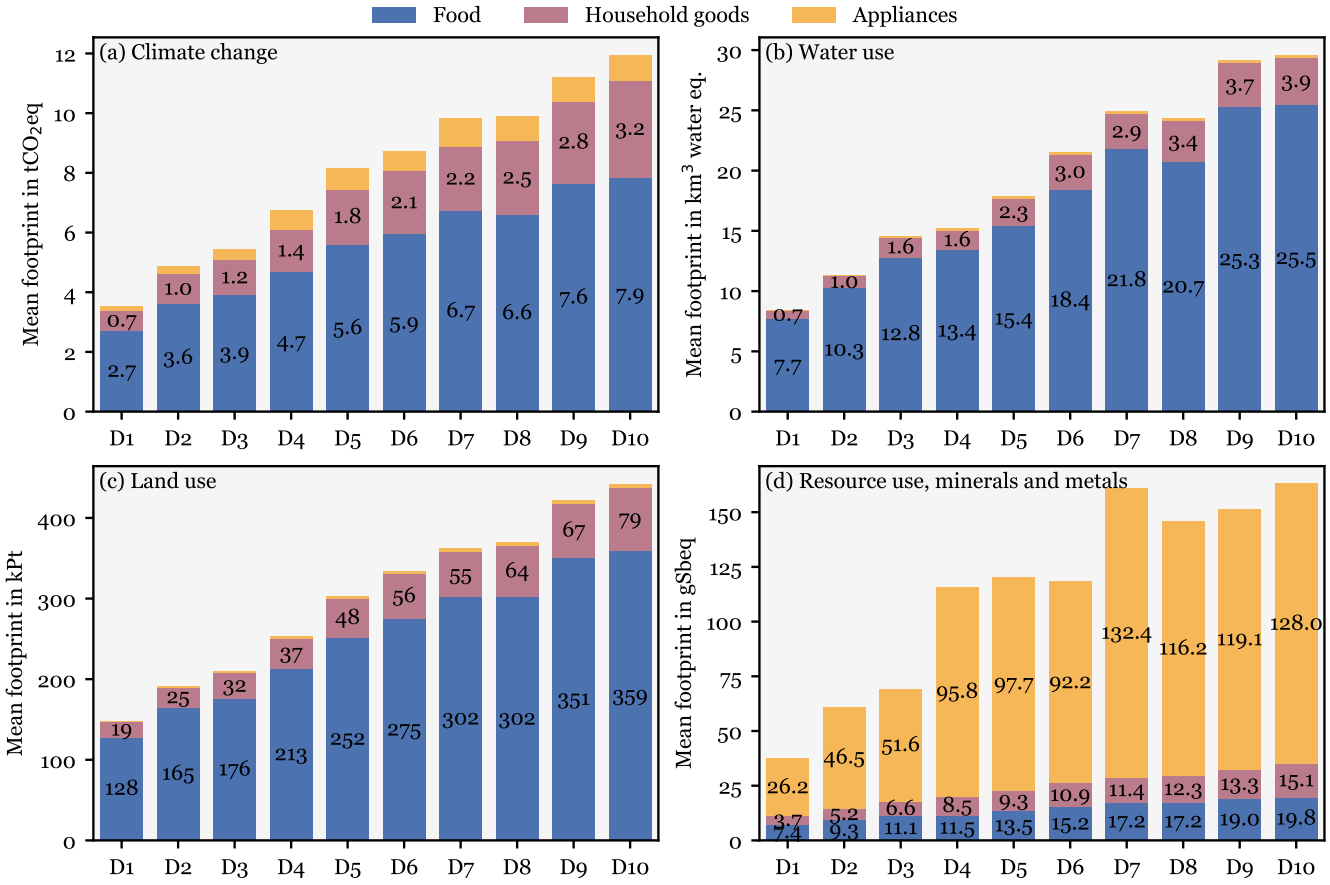

Figure 38: Mean EFs of household income deciles for the year 2015 by basket of consumption for Luxembourg. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

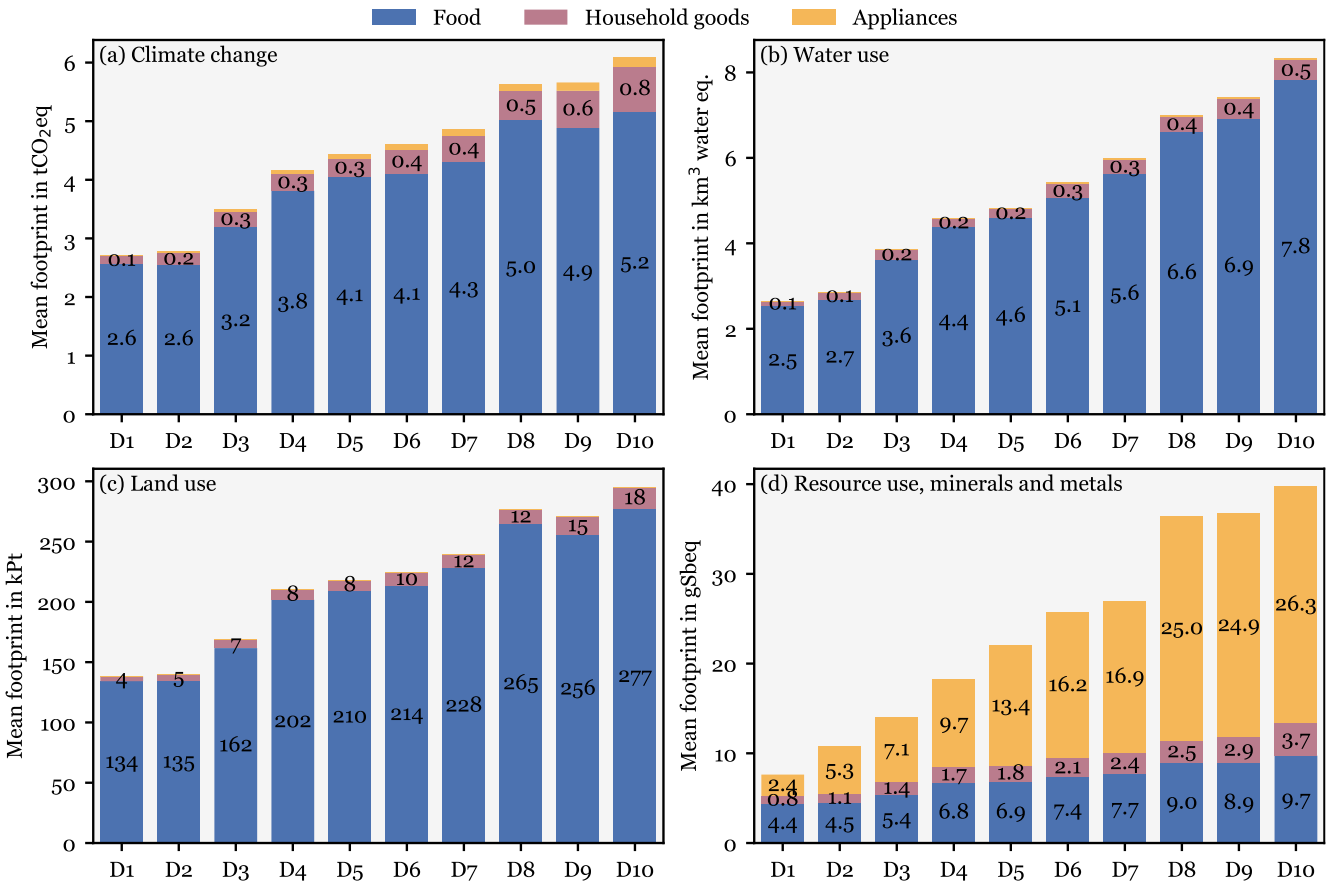

Figure 39: Mean EFs of household income deciles for the year 2015 by basket of consumption for Latvia. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

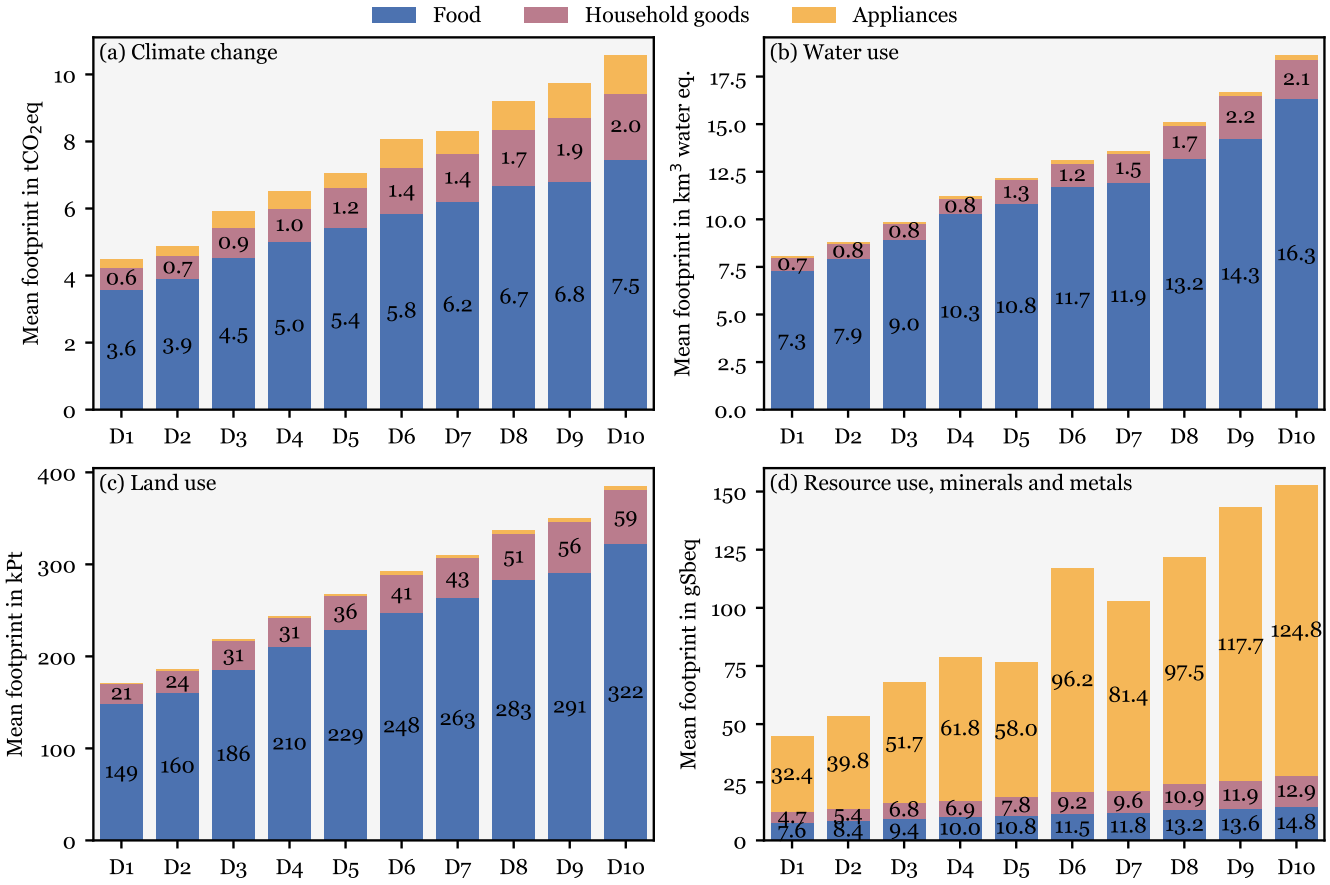

Figure 40: Mean EFs of household income deciles for the year 2015 by basket of consumption for Malta. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

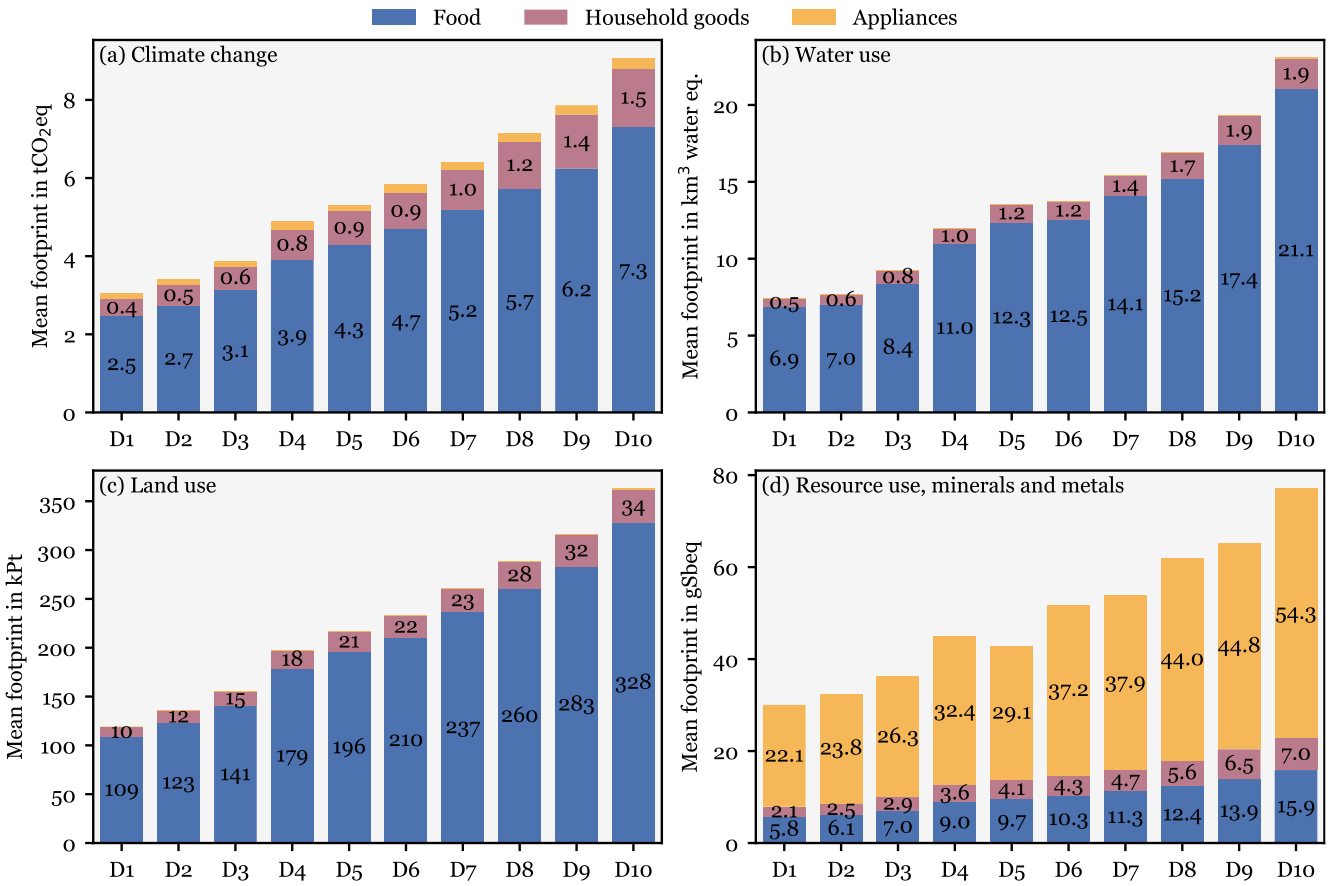

Figure 41: Mean EFs of household income deciles for the year 2015 by basket of consumption for the Netherlands. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

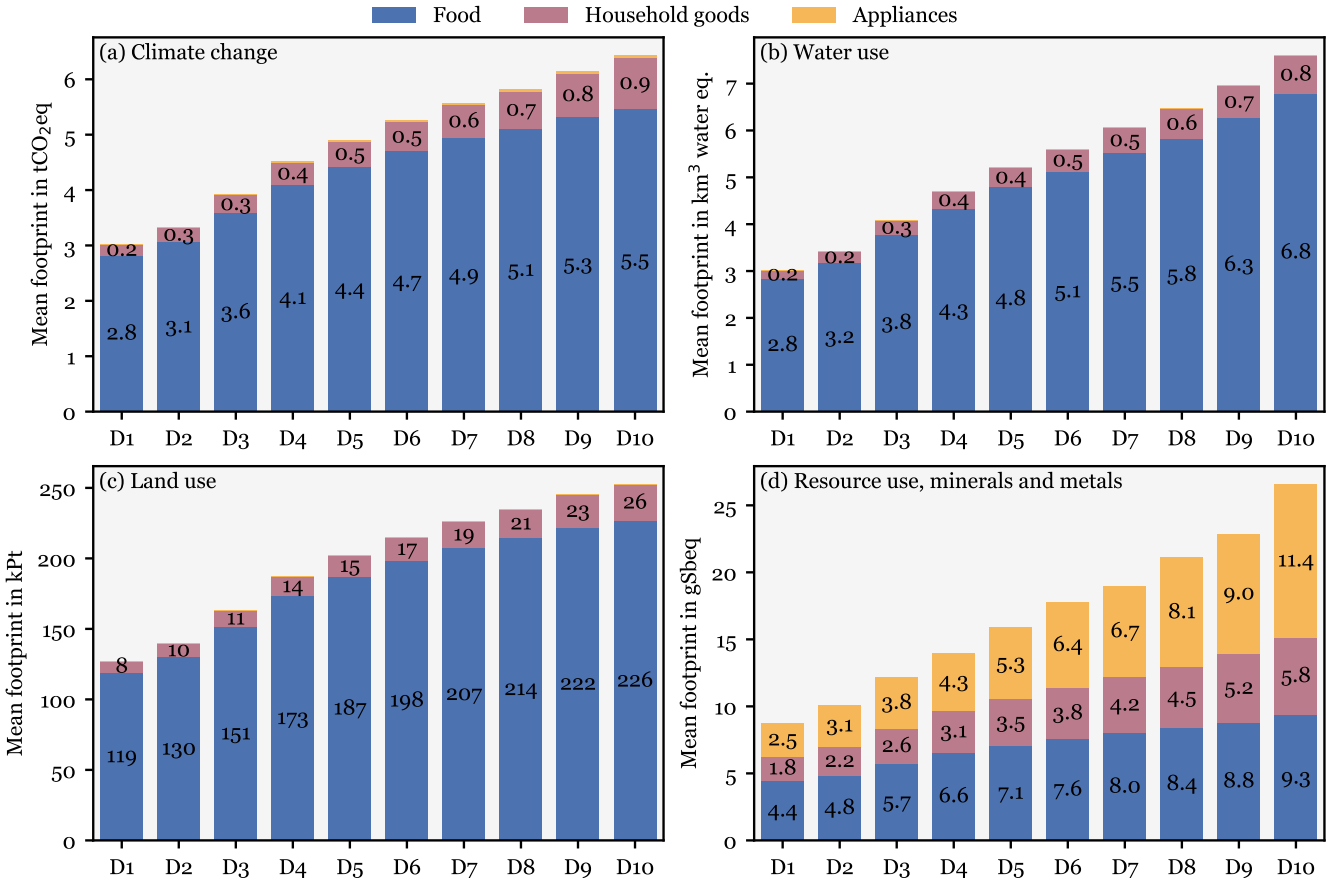

Figure 42: Mean EFs of household income deciles for the year 2015 by basket of consumption for Poland. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

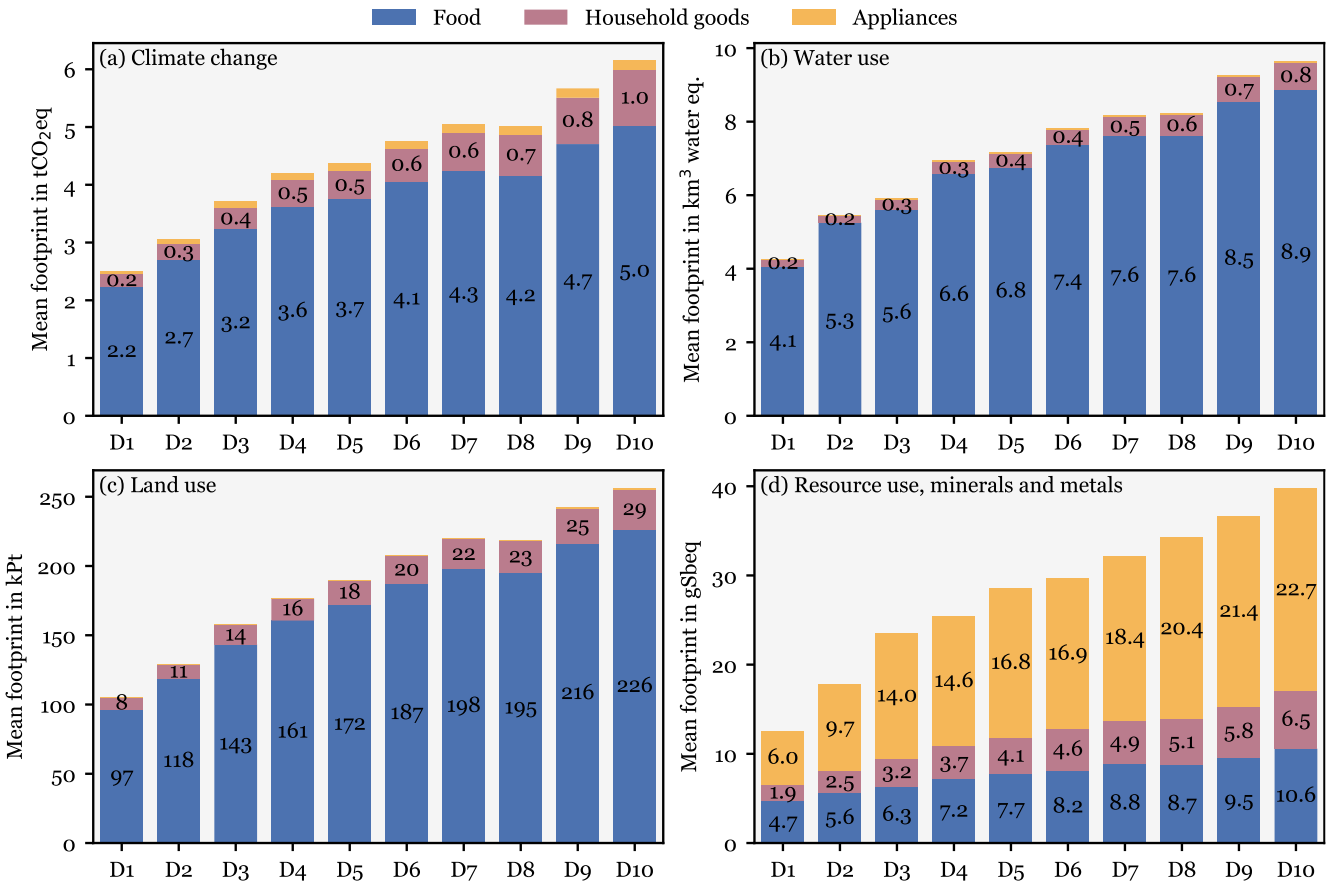

Figure 43: Mean EFs of household income deciles for the year 2015 by basket of consumption for Portugal. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

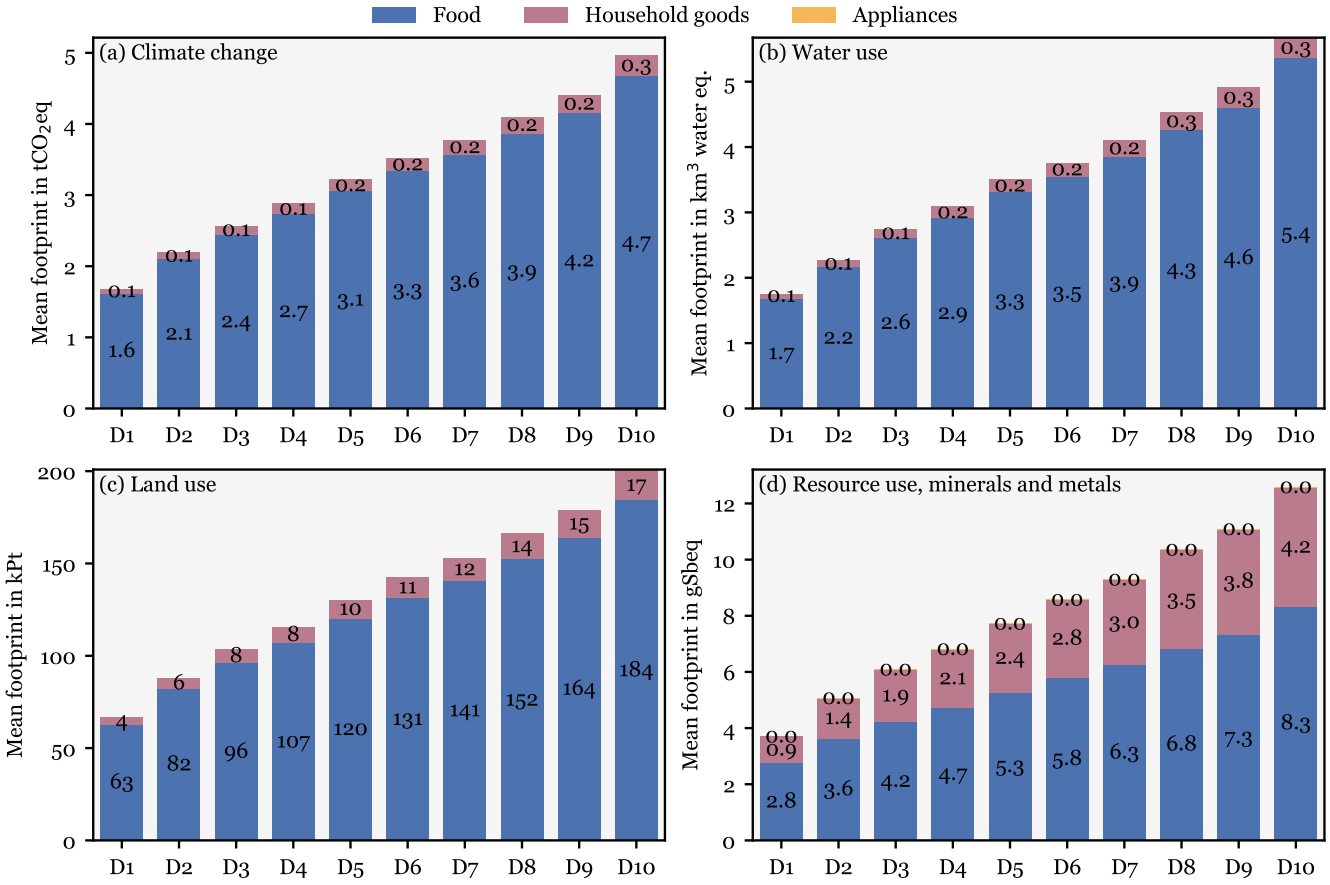

Figure 44: Mean EFs of household income deciles for the year 2015 by basket of consumption for Romania. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

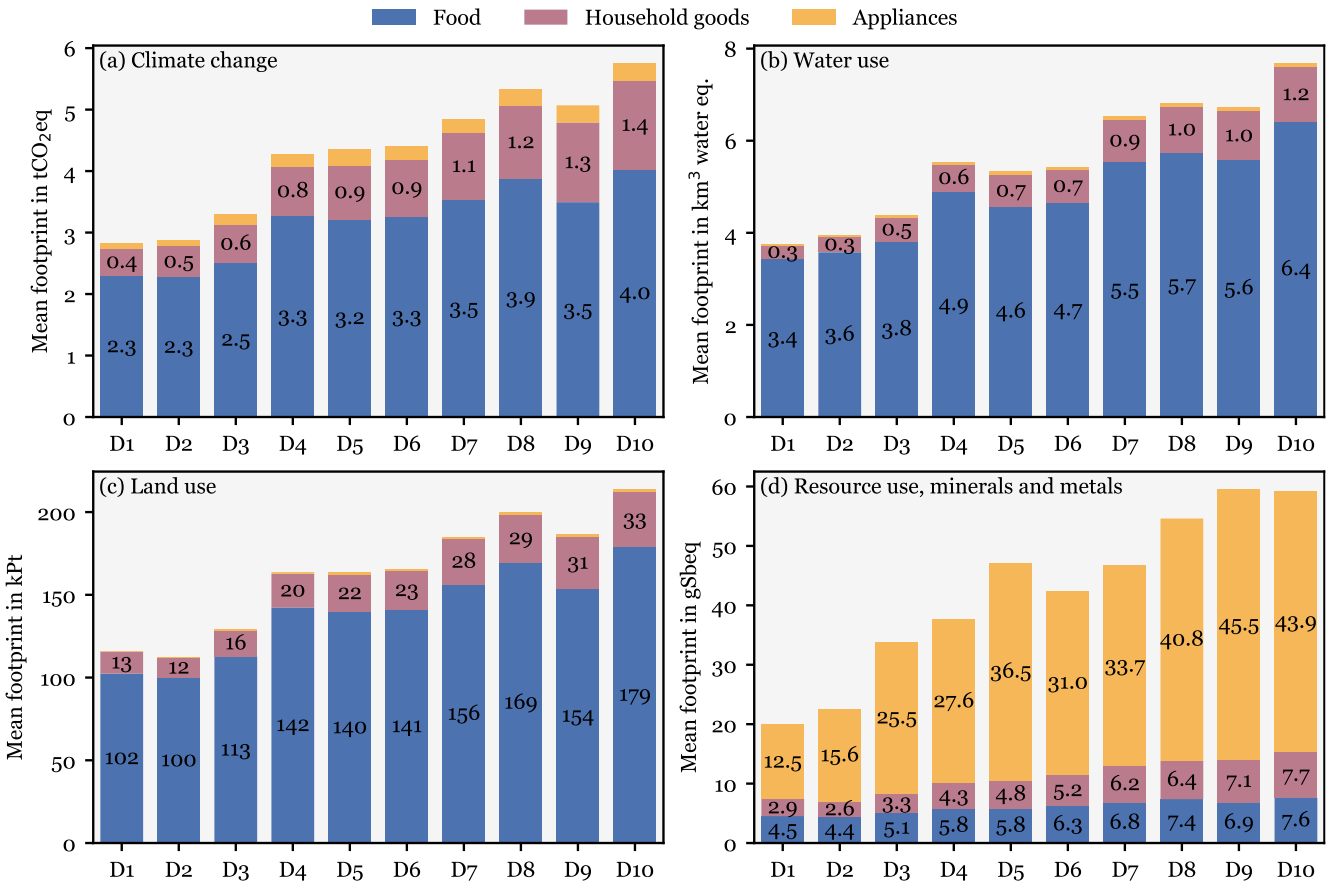

Figure 45: Mean EFs of household income deciles for the year 2015 by basket of consumption for Slovenia. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

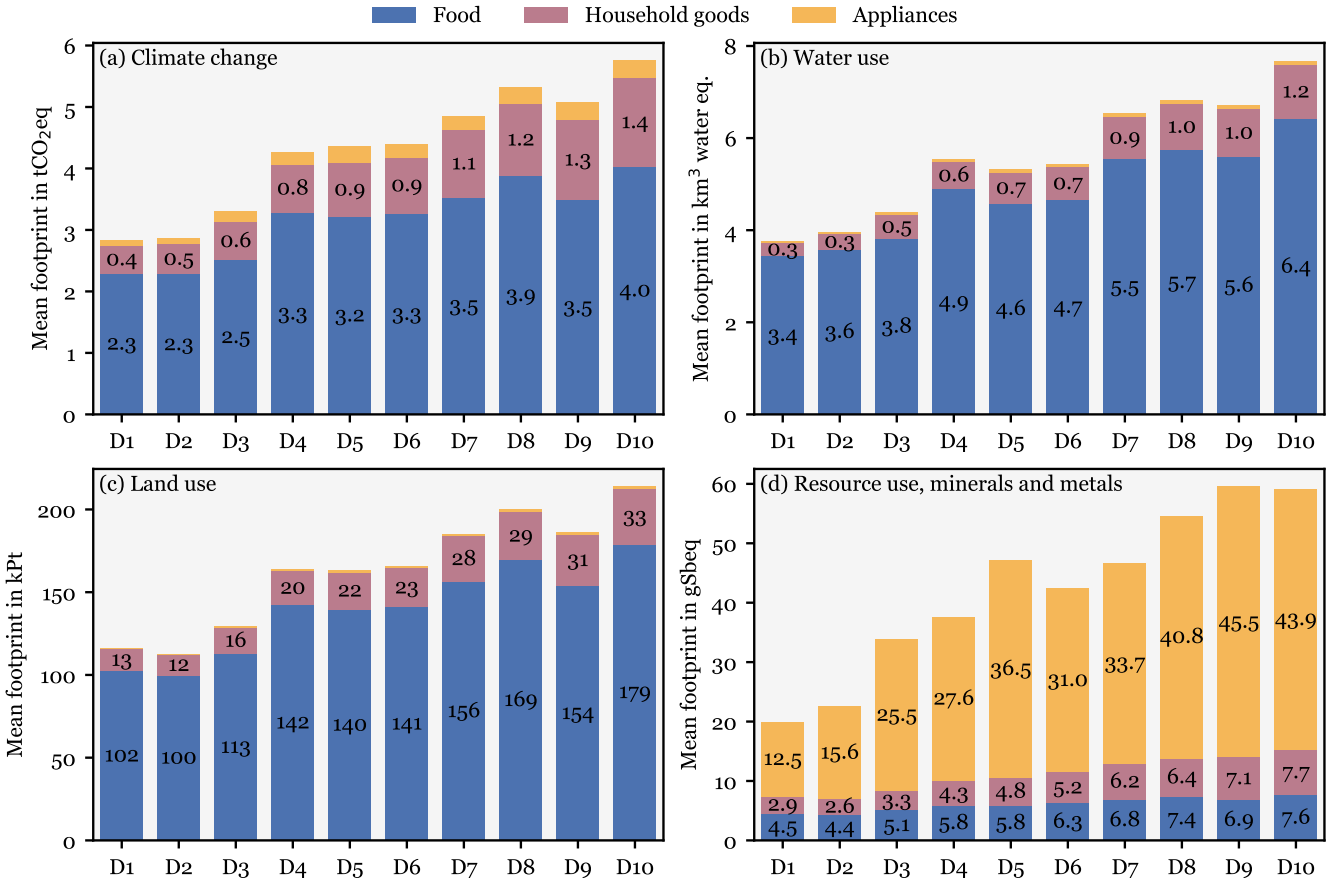

Figure 46: Mean EFs of household income deciles for the year 2015 by basket of consumption for Slovakia. Note that the y-axis scale is different for every country to highlight relative differences between the deciles.

Appendix 12: Household EFs for all member states

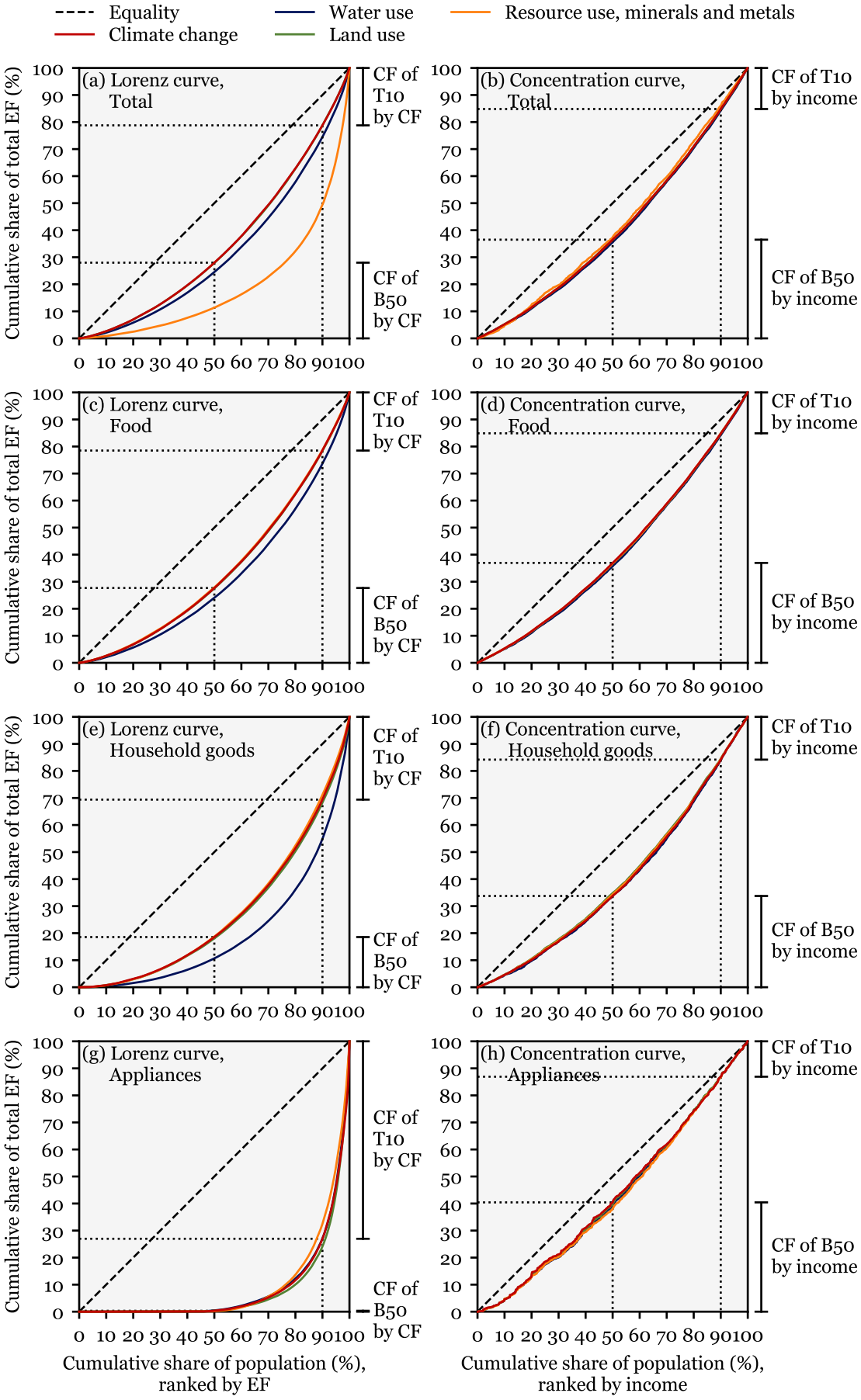

Figure 47: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Belgium in 2015.

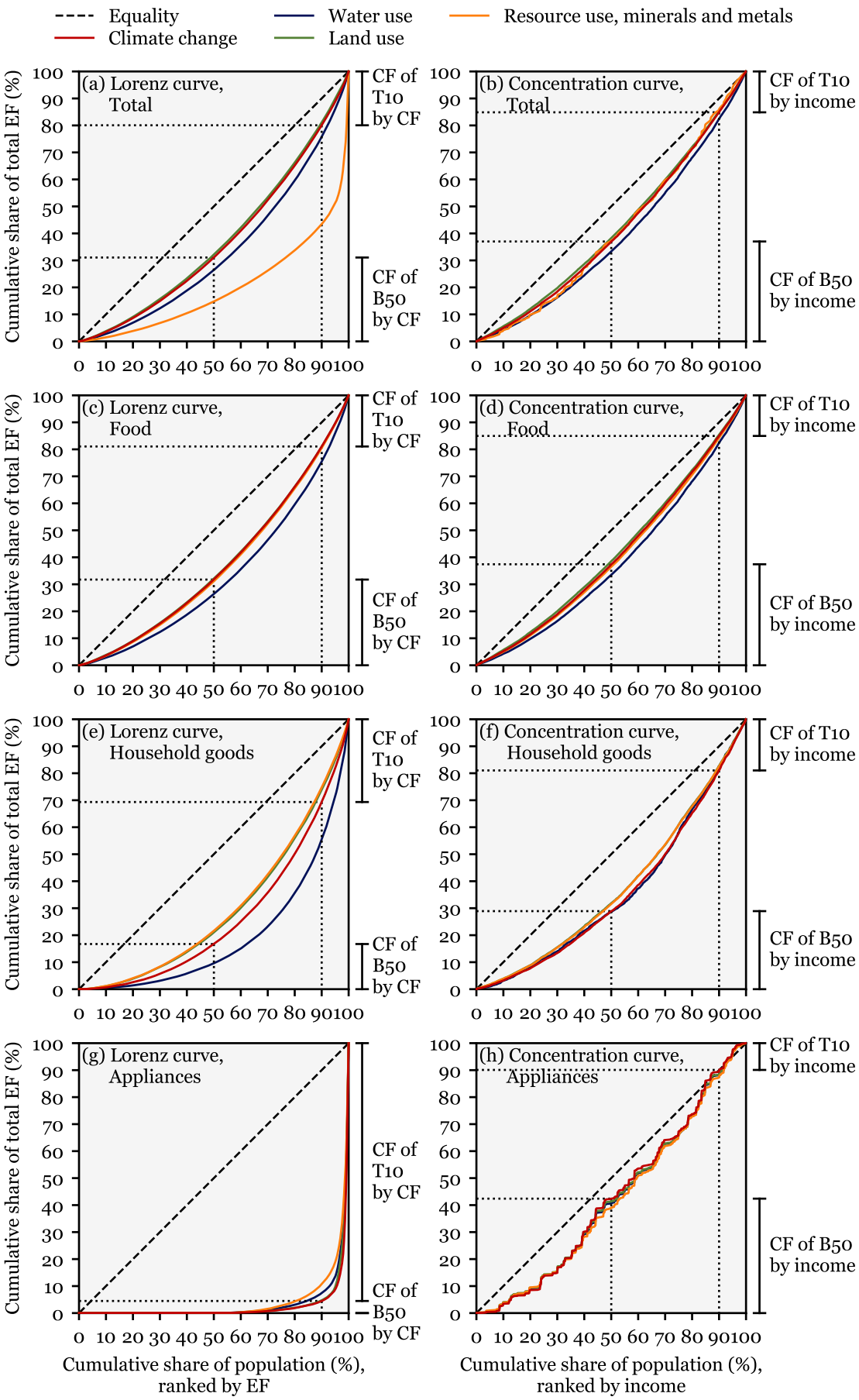

Figure 48: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Bulgaria in 2015.

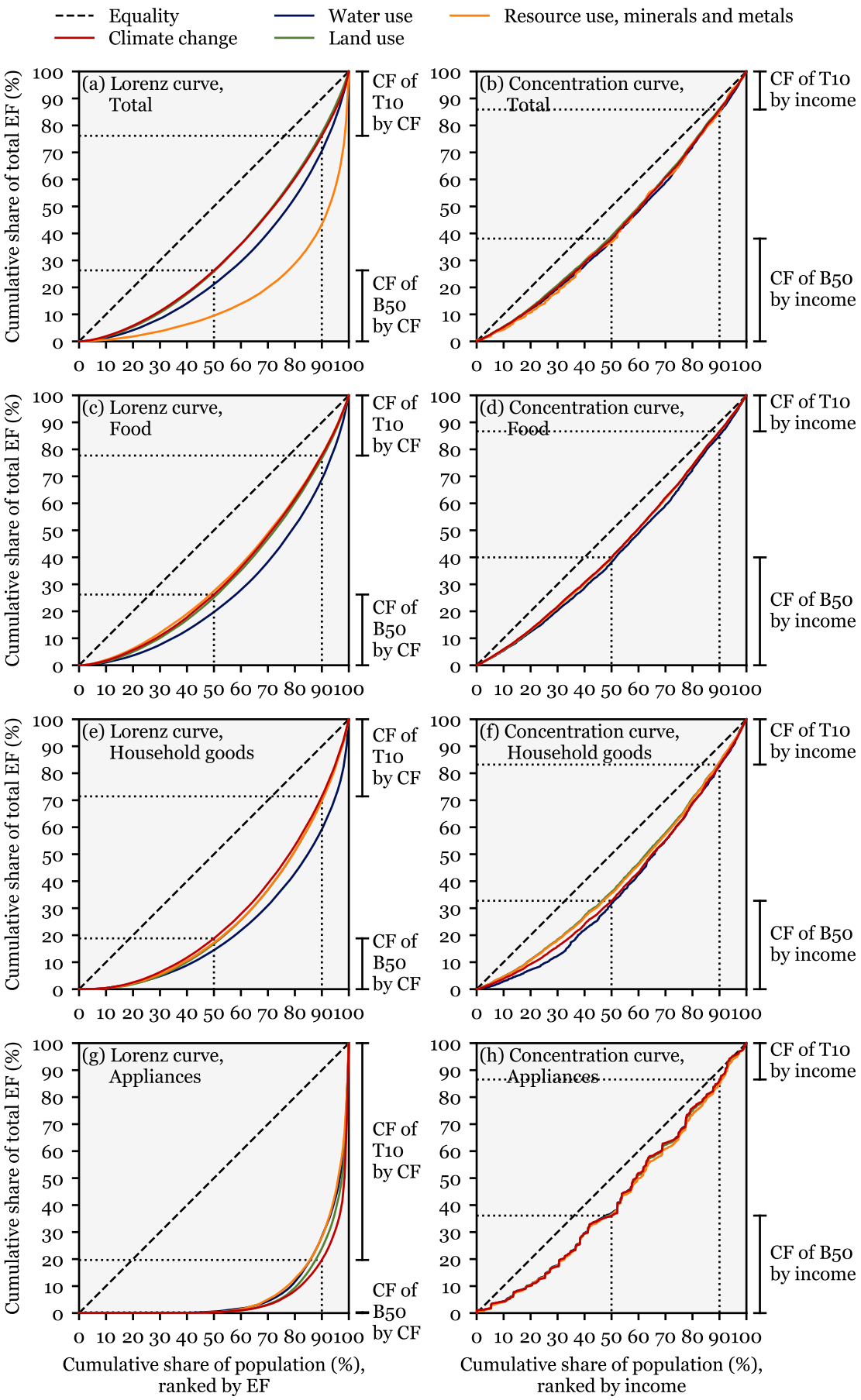

Figure 49: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Cyprus in 2015.

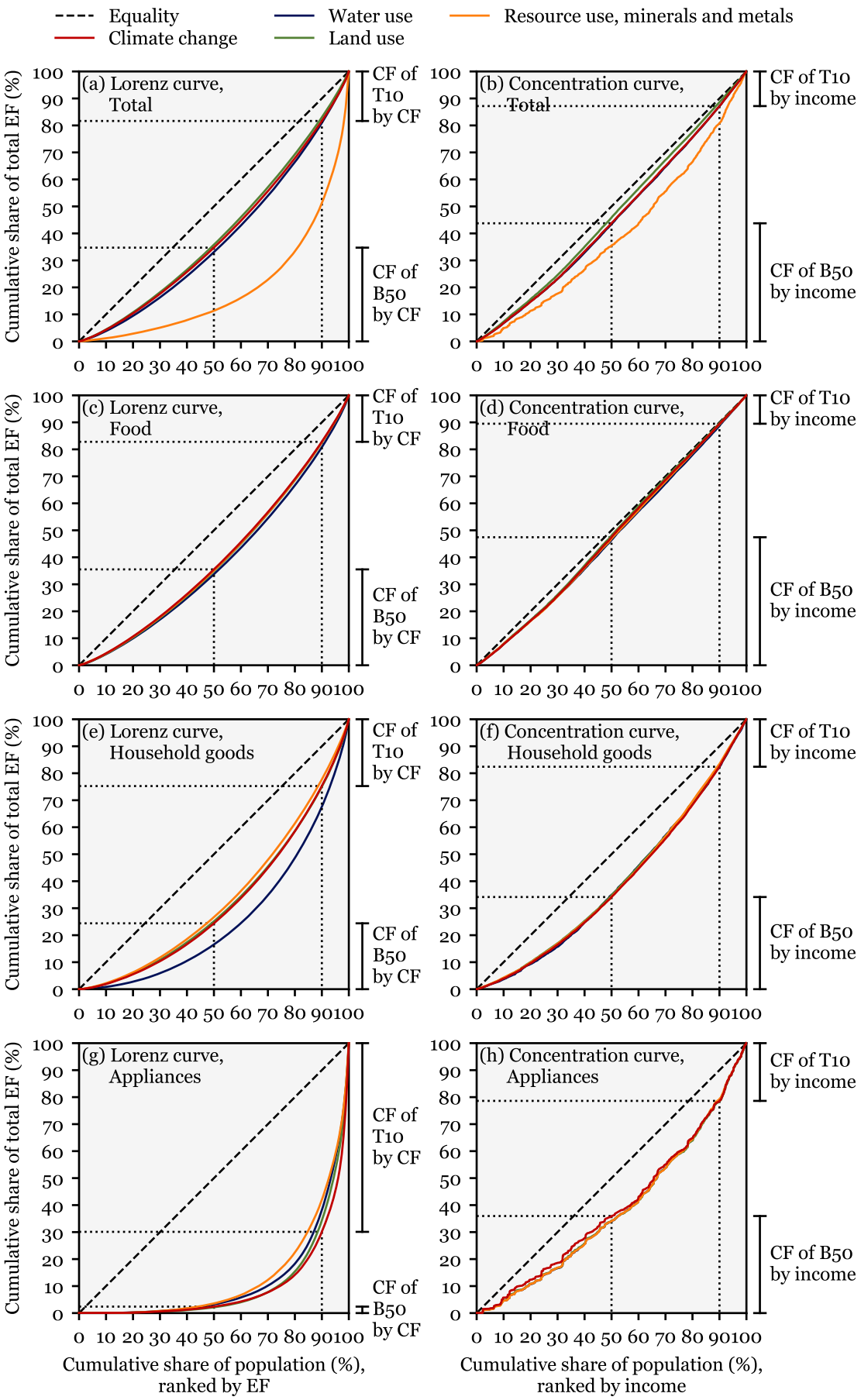

Figure 50: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Czechia in 2015.

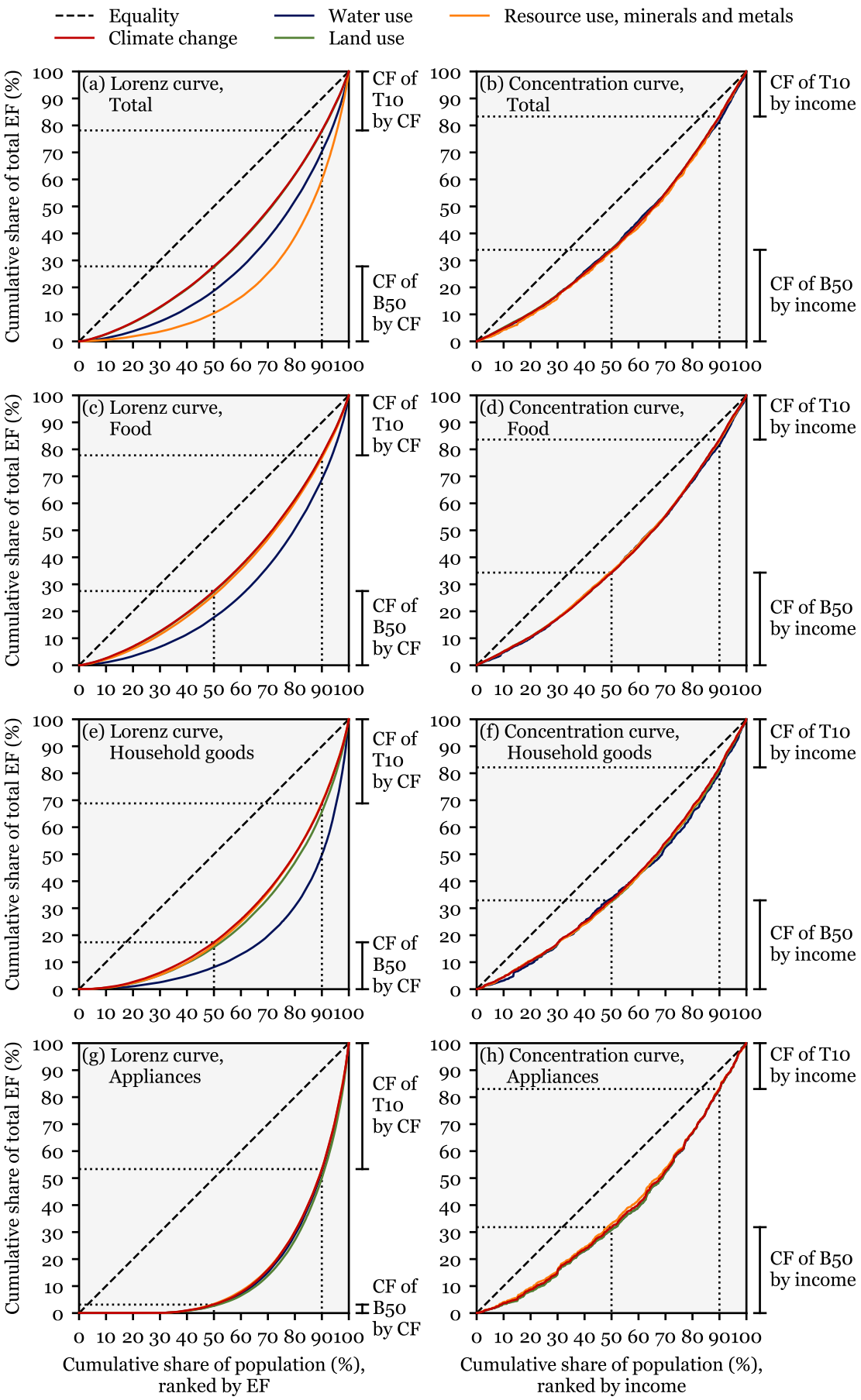

Figure 51: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Denmark in 2015.

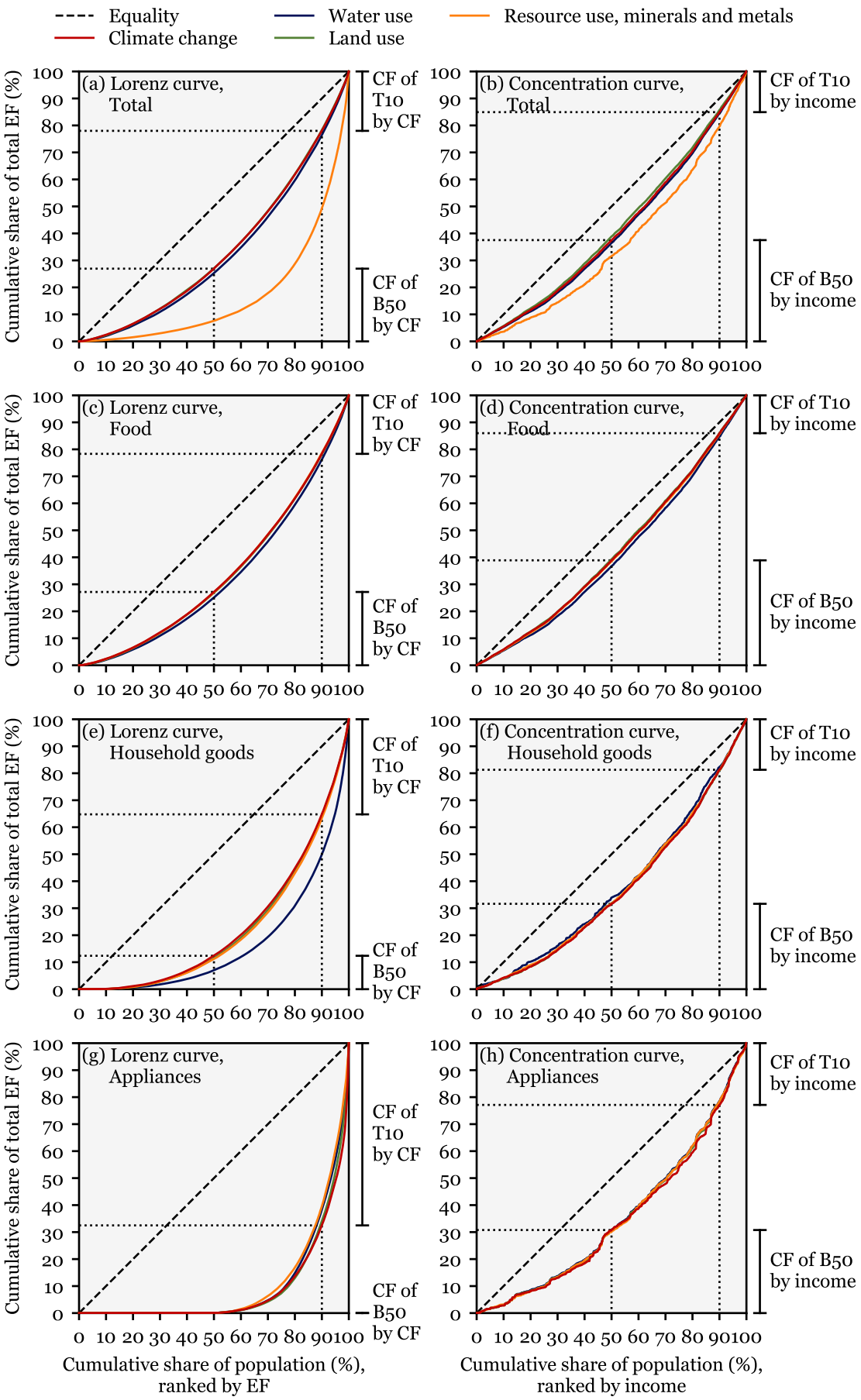

Figure 52: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Estonia in 2015.

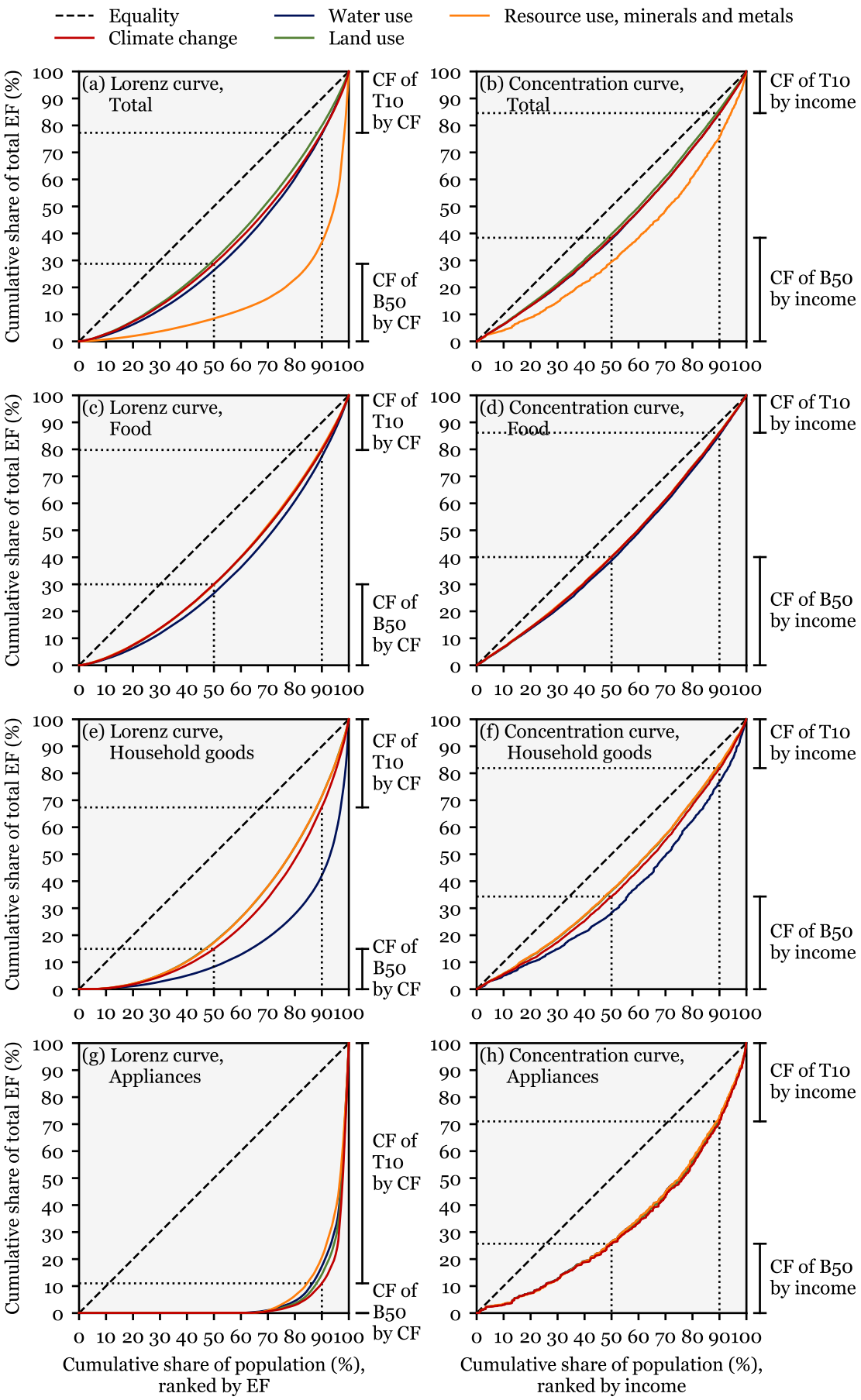

Figure 53: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Greece in 2015.

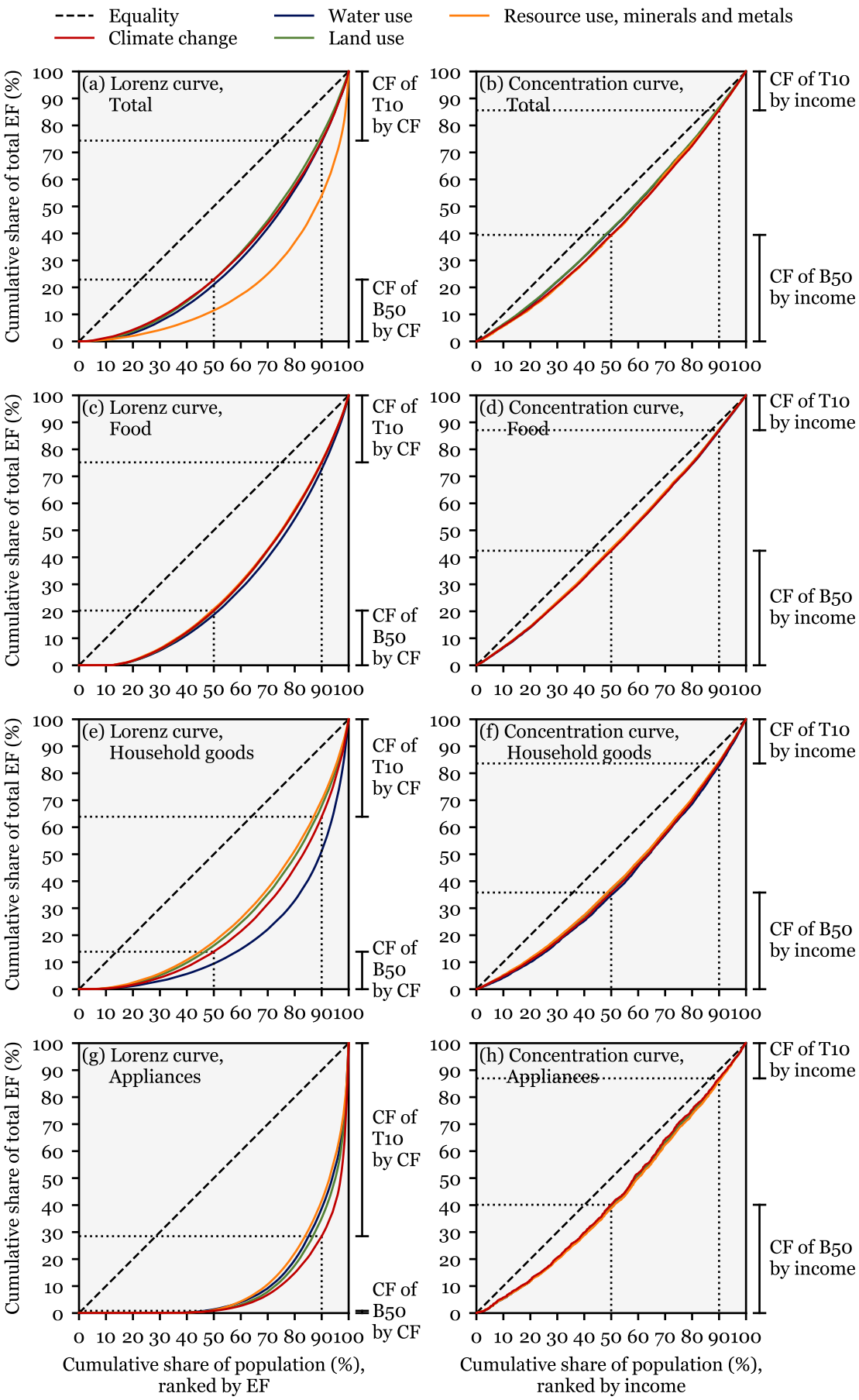

Figure 54: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Spain in 2015.

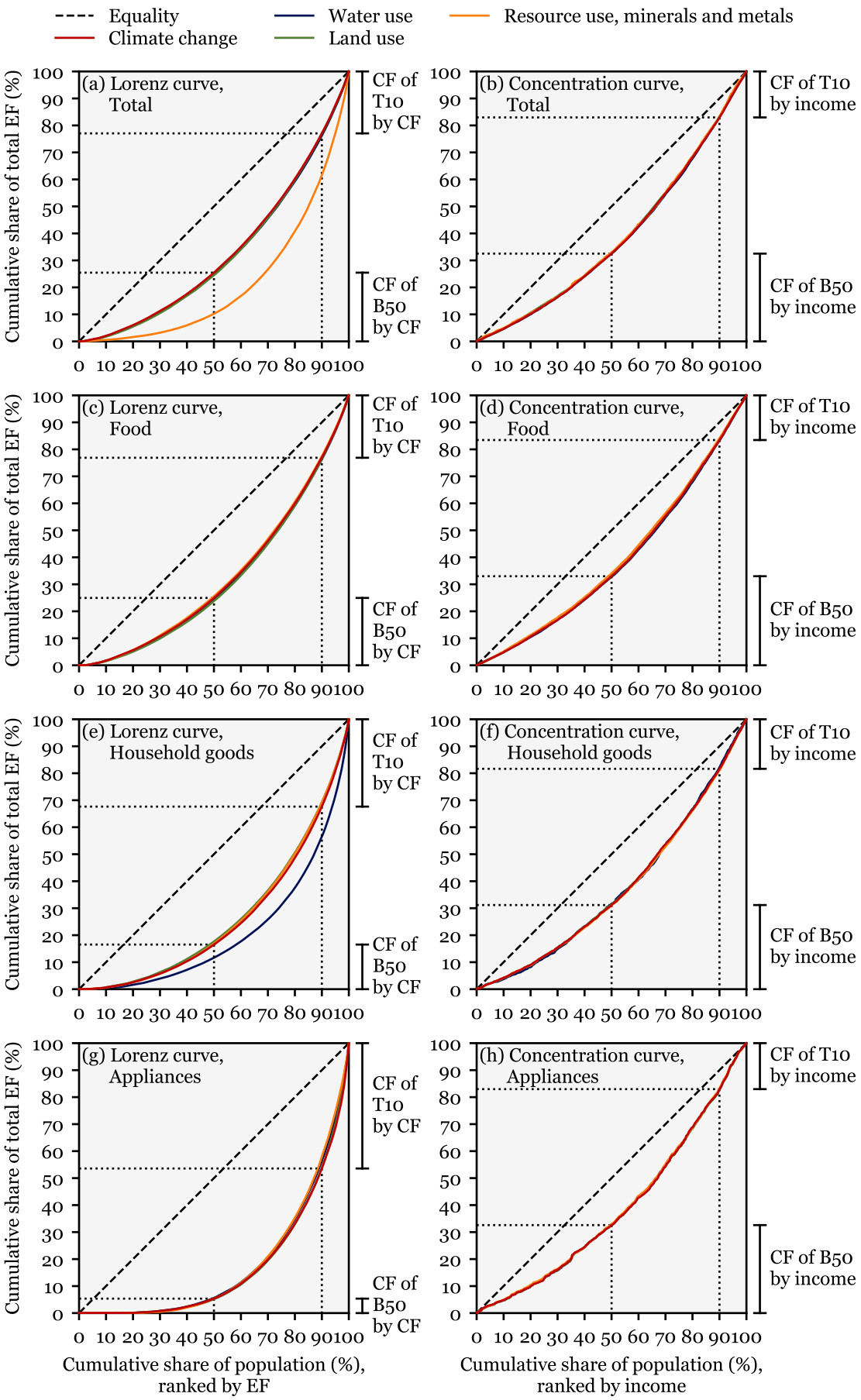

Figure 55: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Finland in 2015.

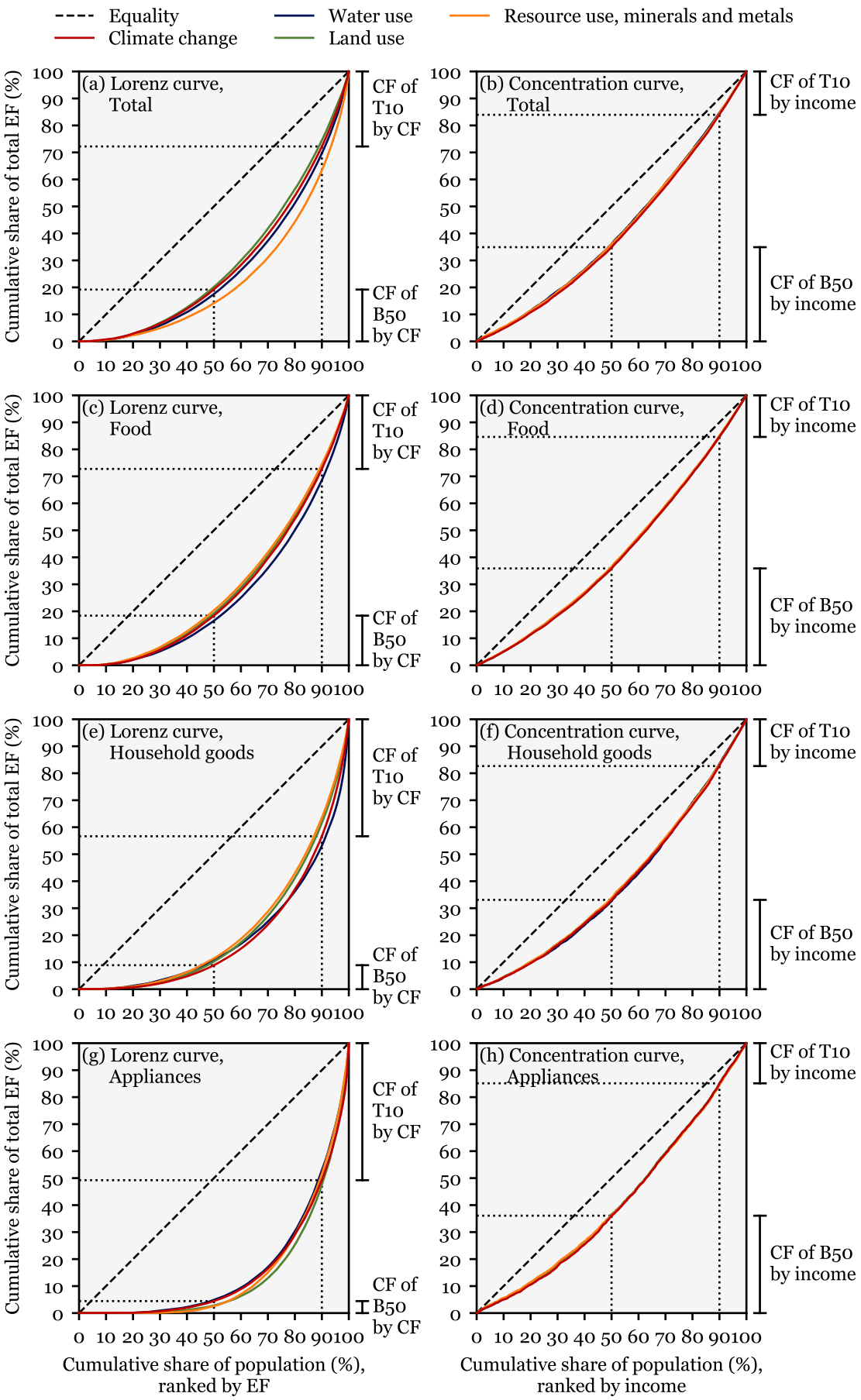

Figure 56: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in France in 2015.

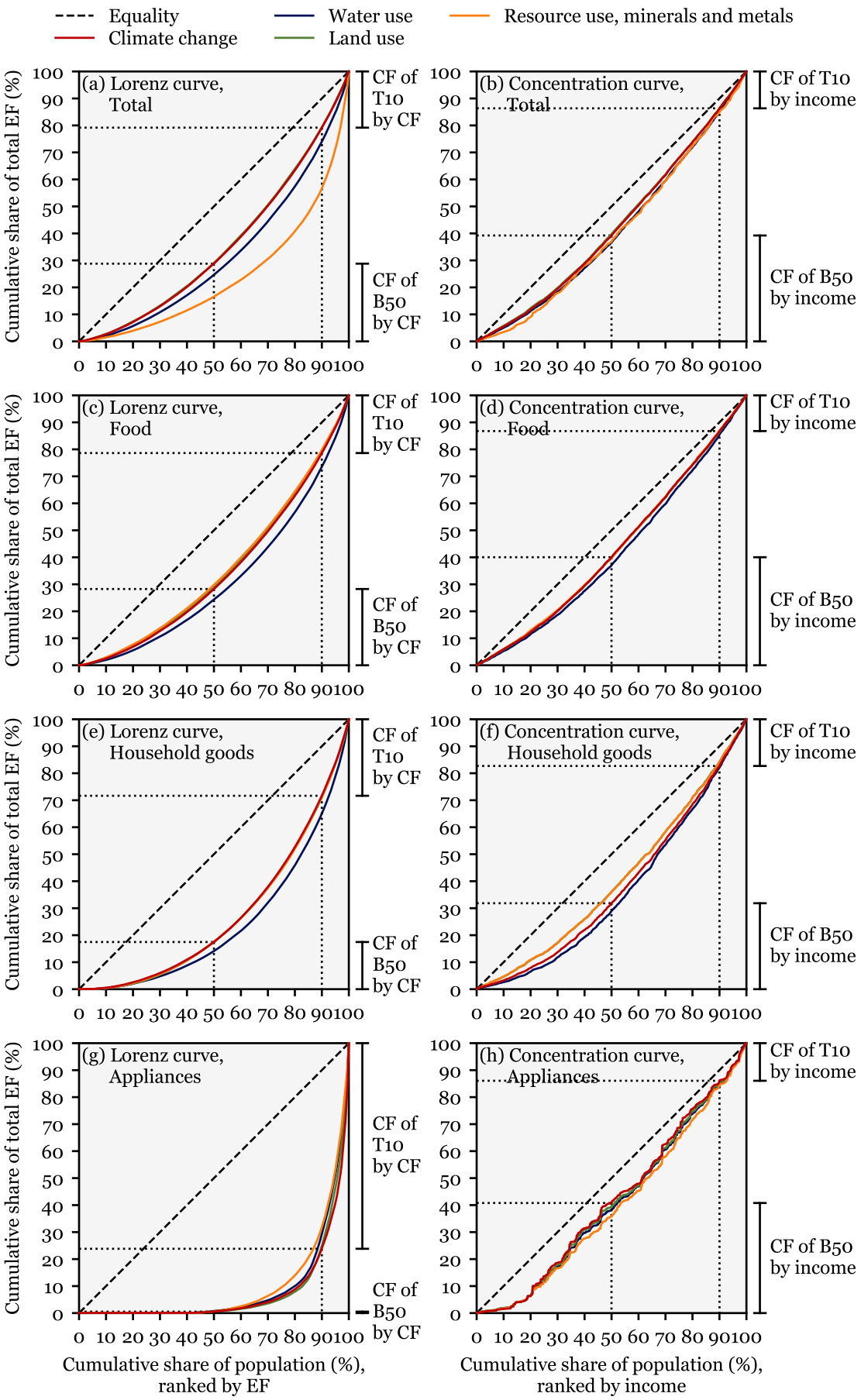

Figure 57: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Croatia in 2015.

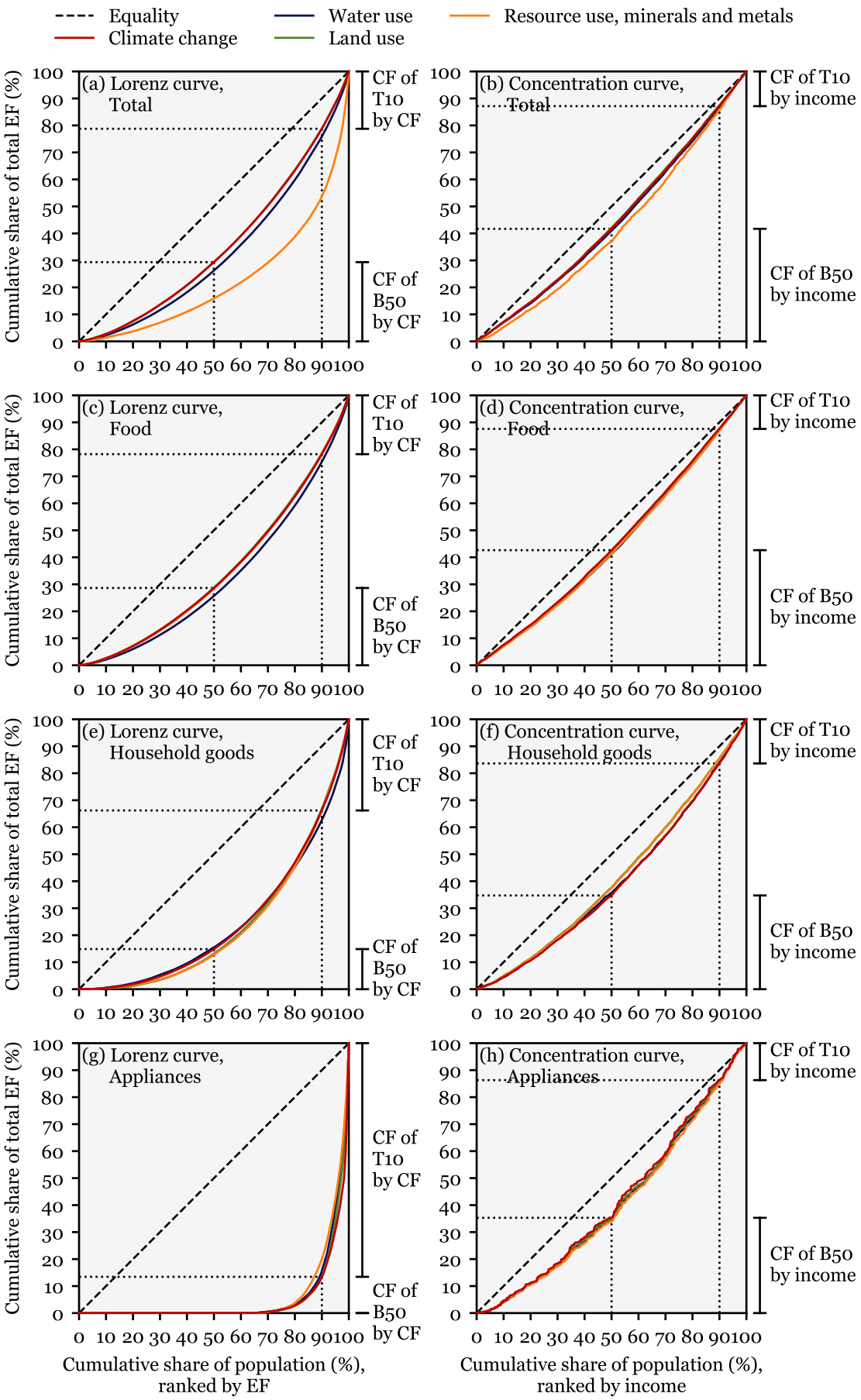

Figure 58: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Hungary in 2015.

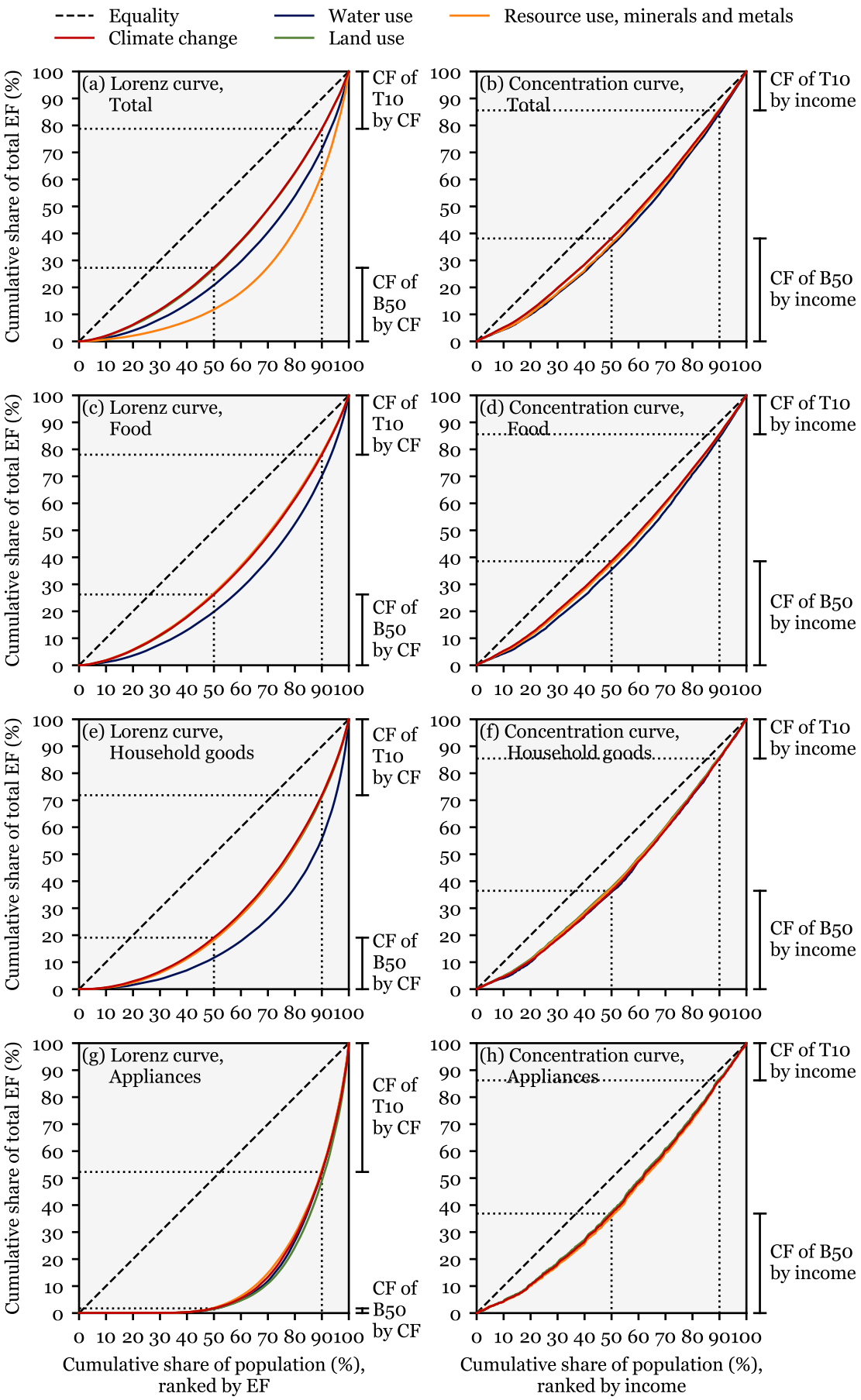

Figure 59: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Ireland in 2015.

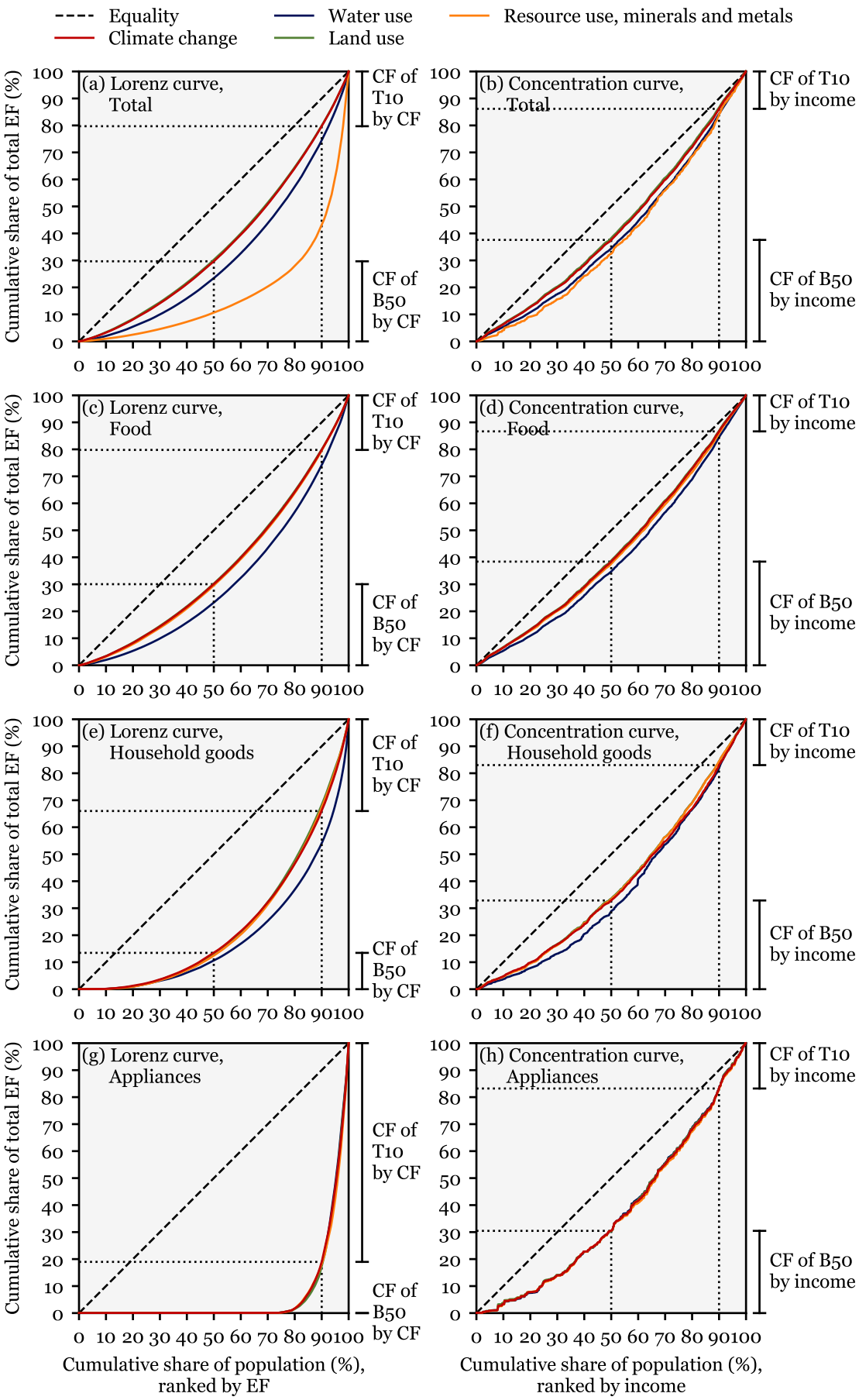

Figure 60: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Lithuania in 2015.

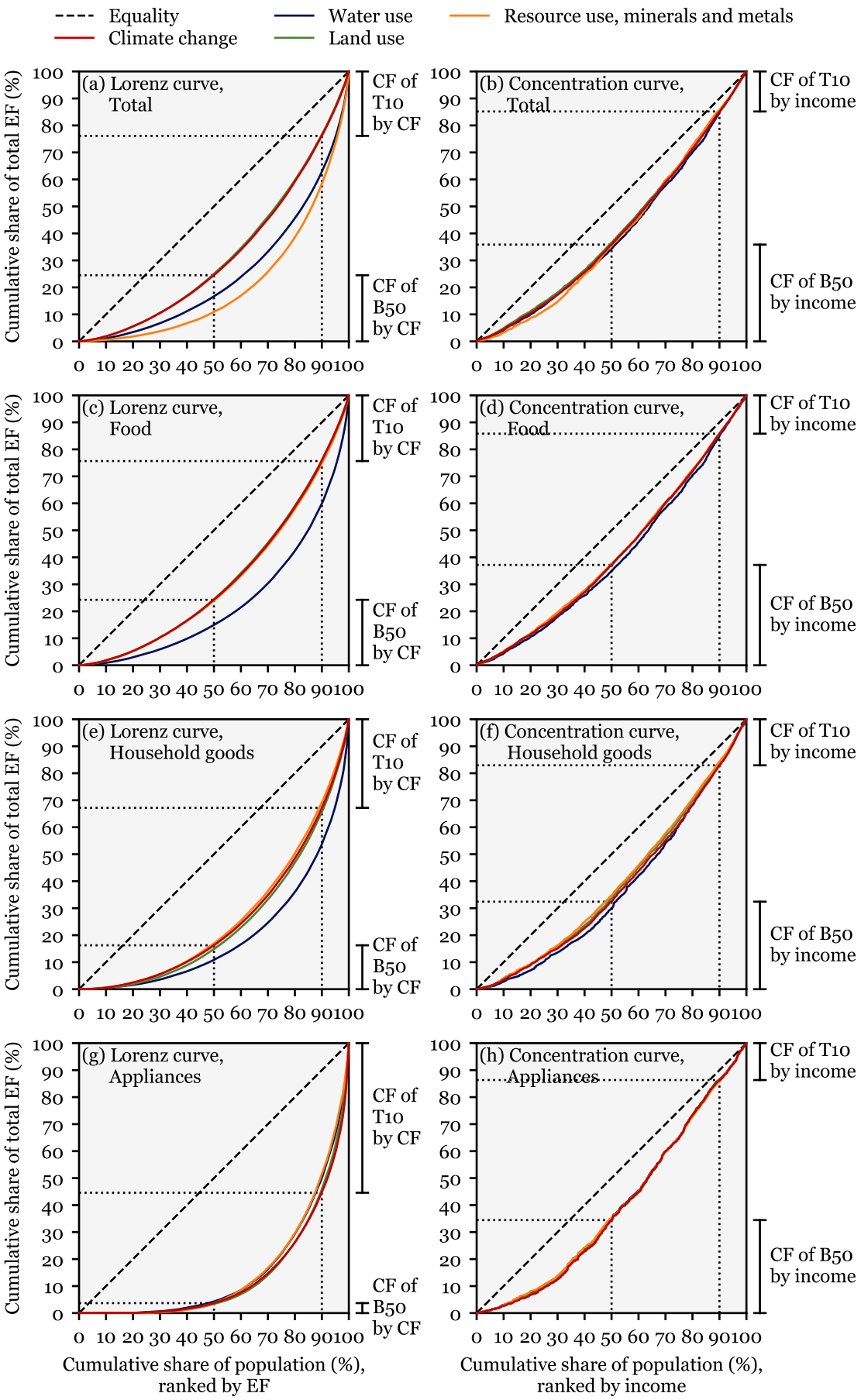

Figure 61: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Luxembourg in 2015.

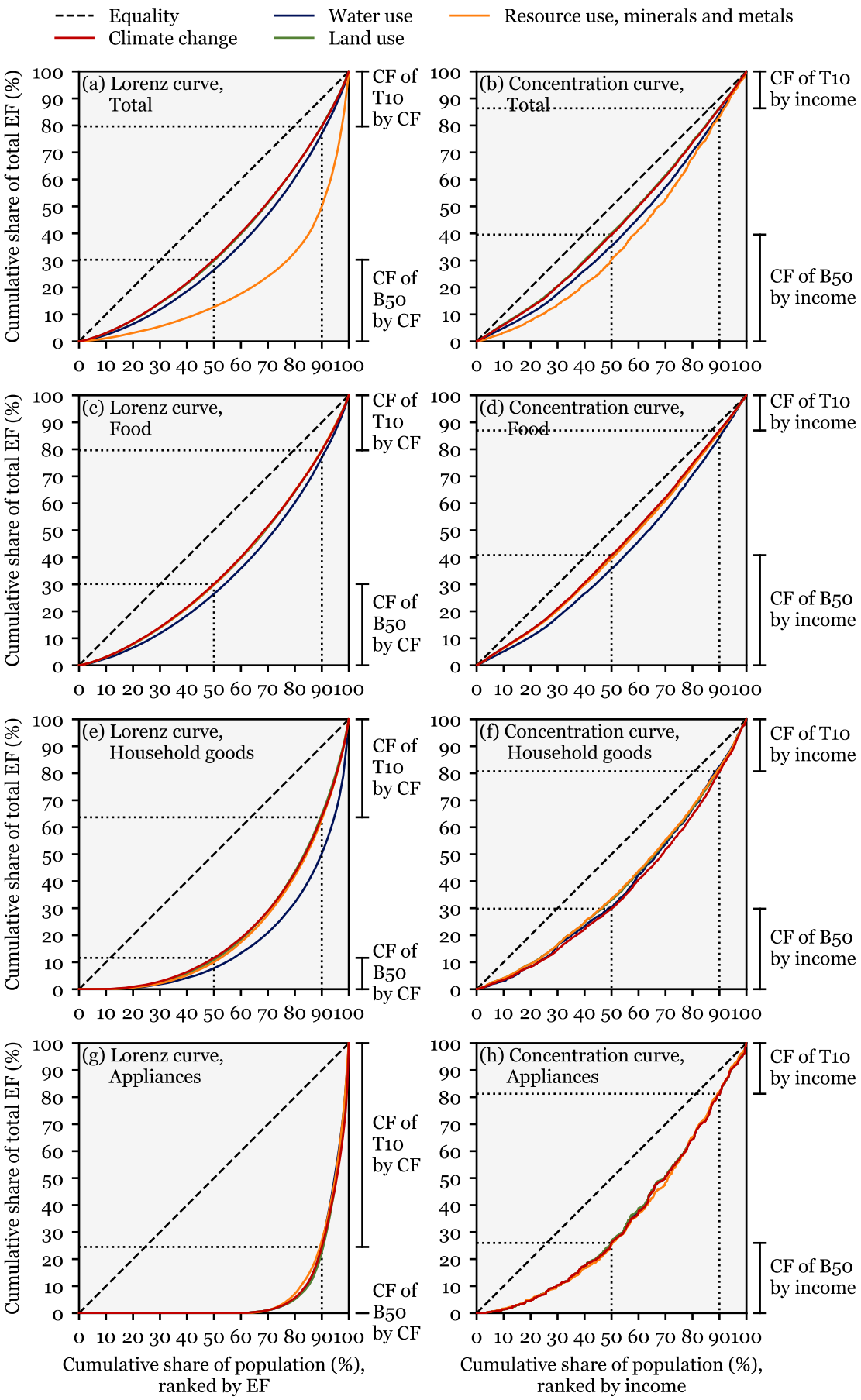

Figure 62: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Latvia in 2015.

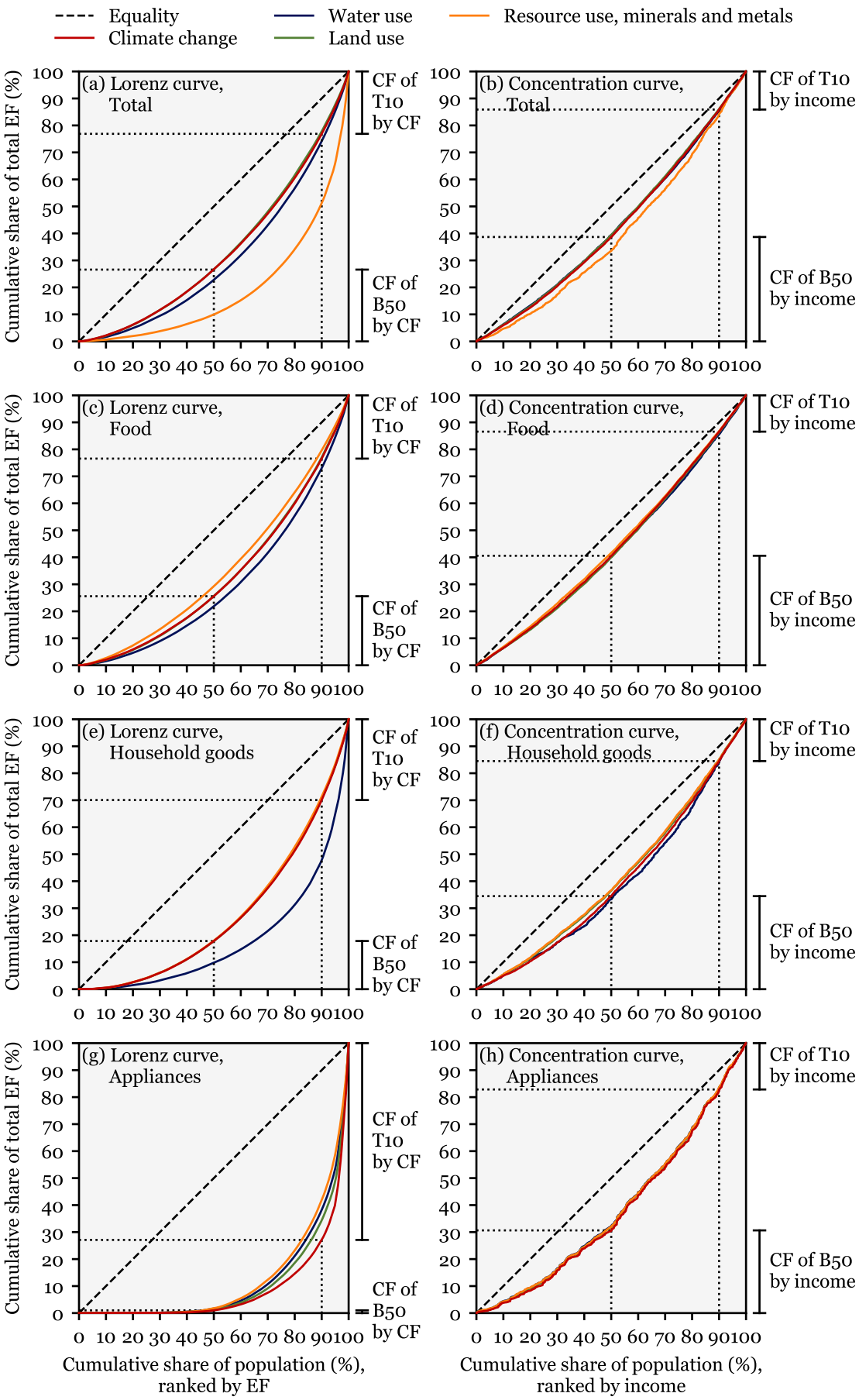

Figure 63: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Malta in 2015.

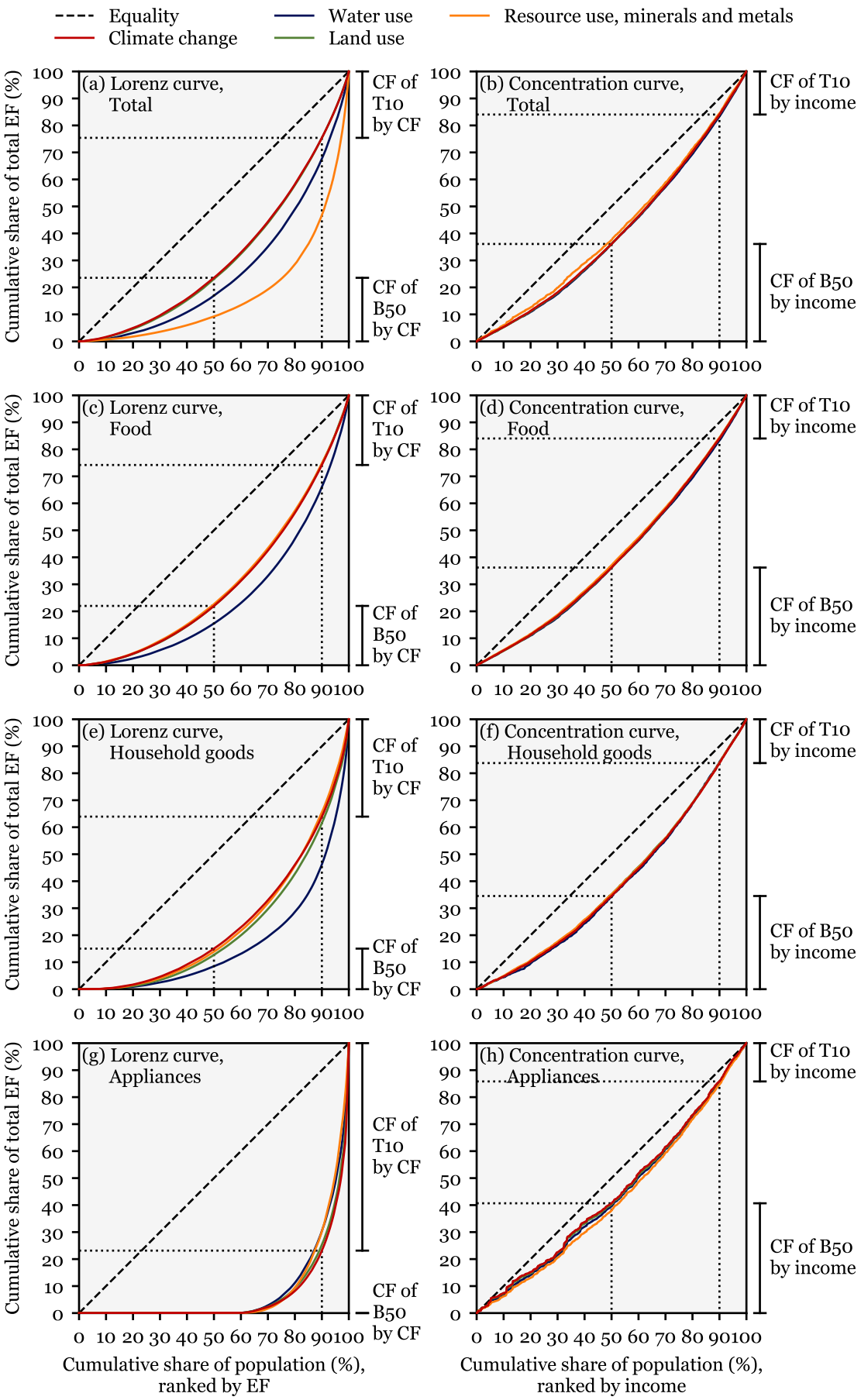

Figure 64: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in the Netherlands in 2015.

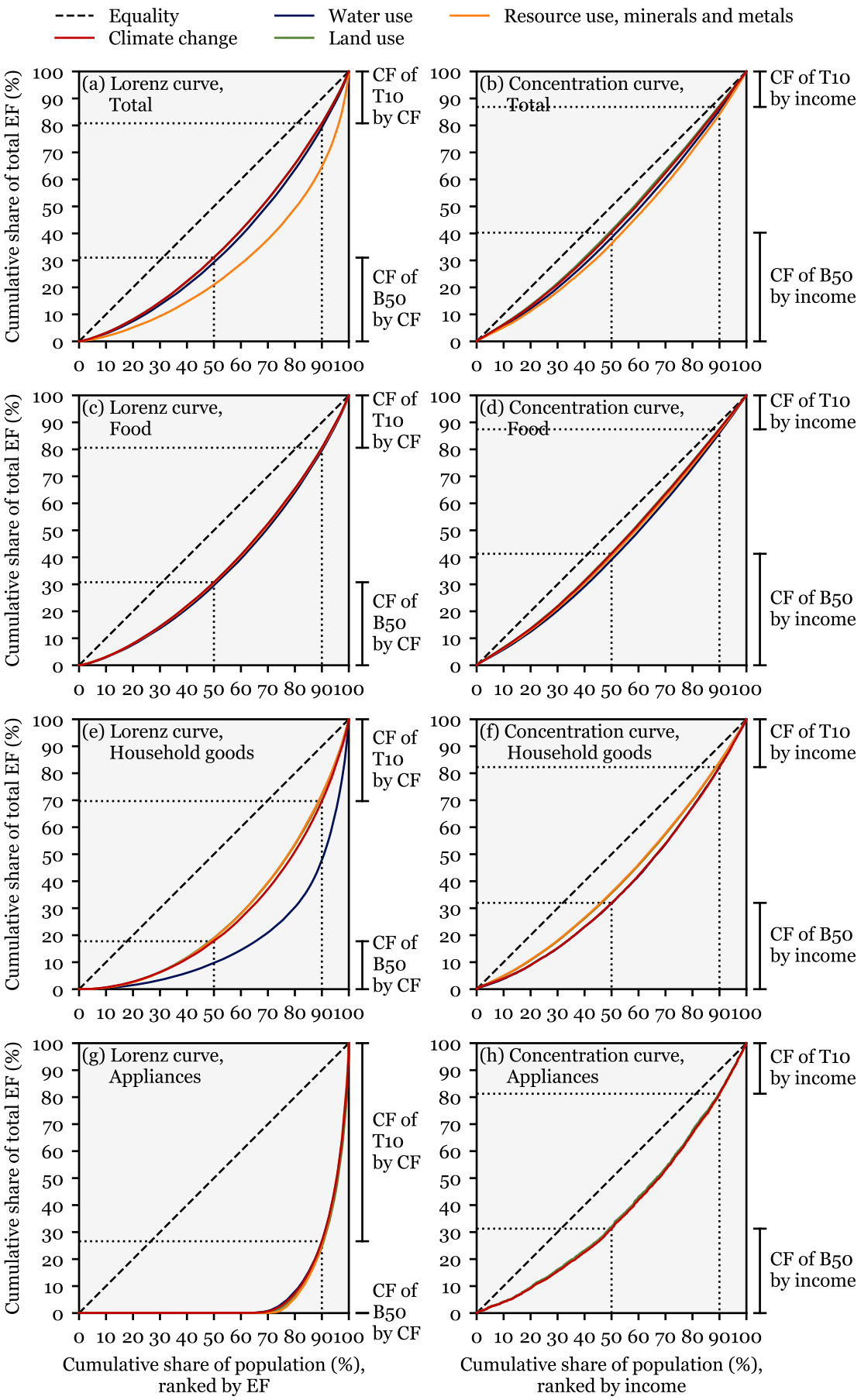

Figure 65: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Poland in 2015.

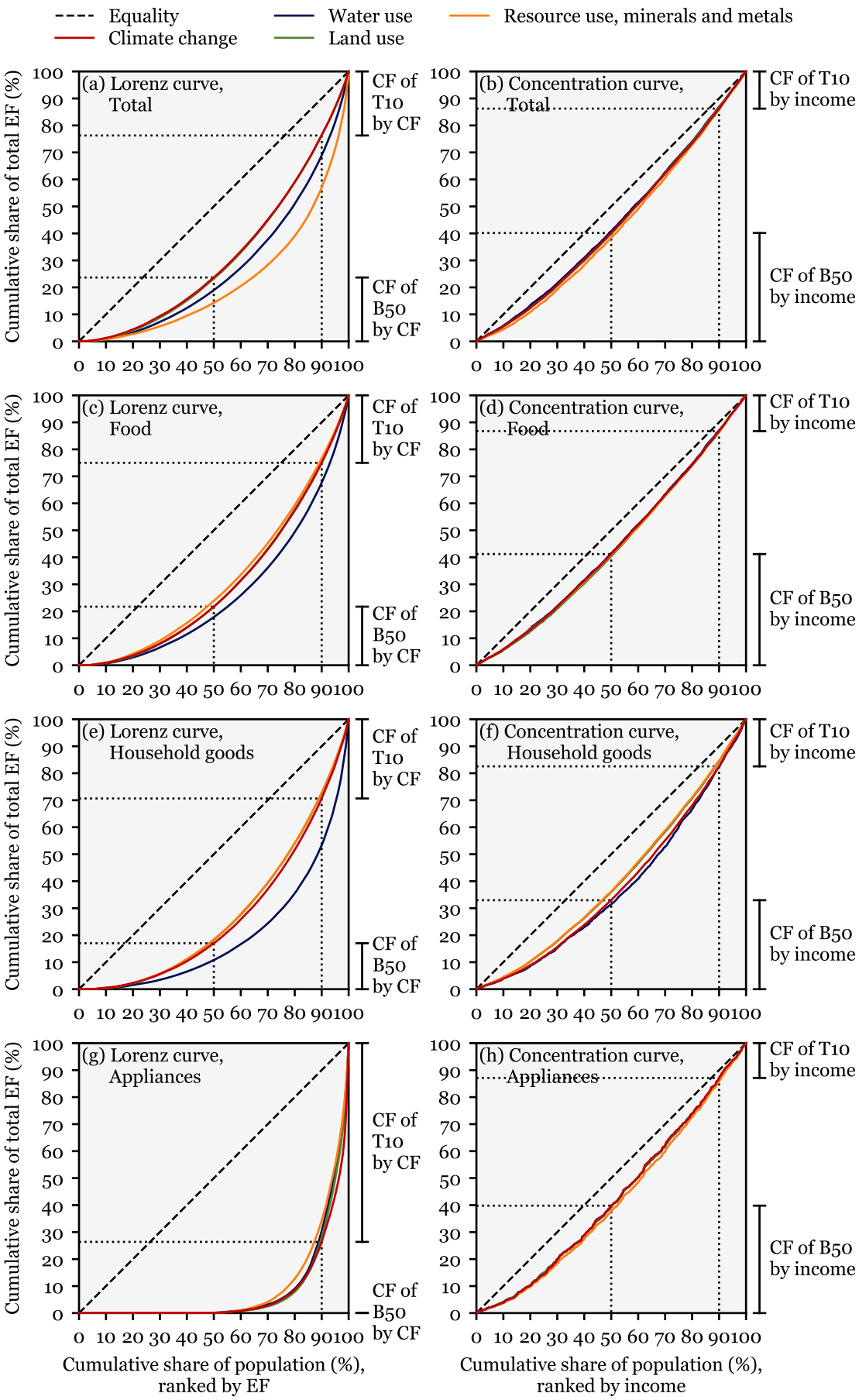

Figure 66: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Portugal in 2015.

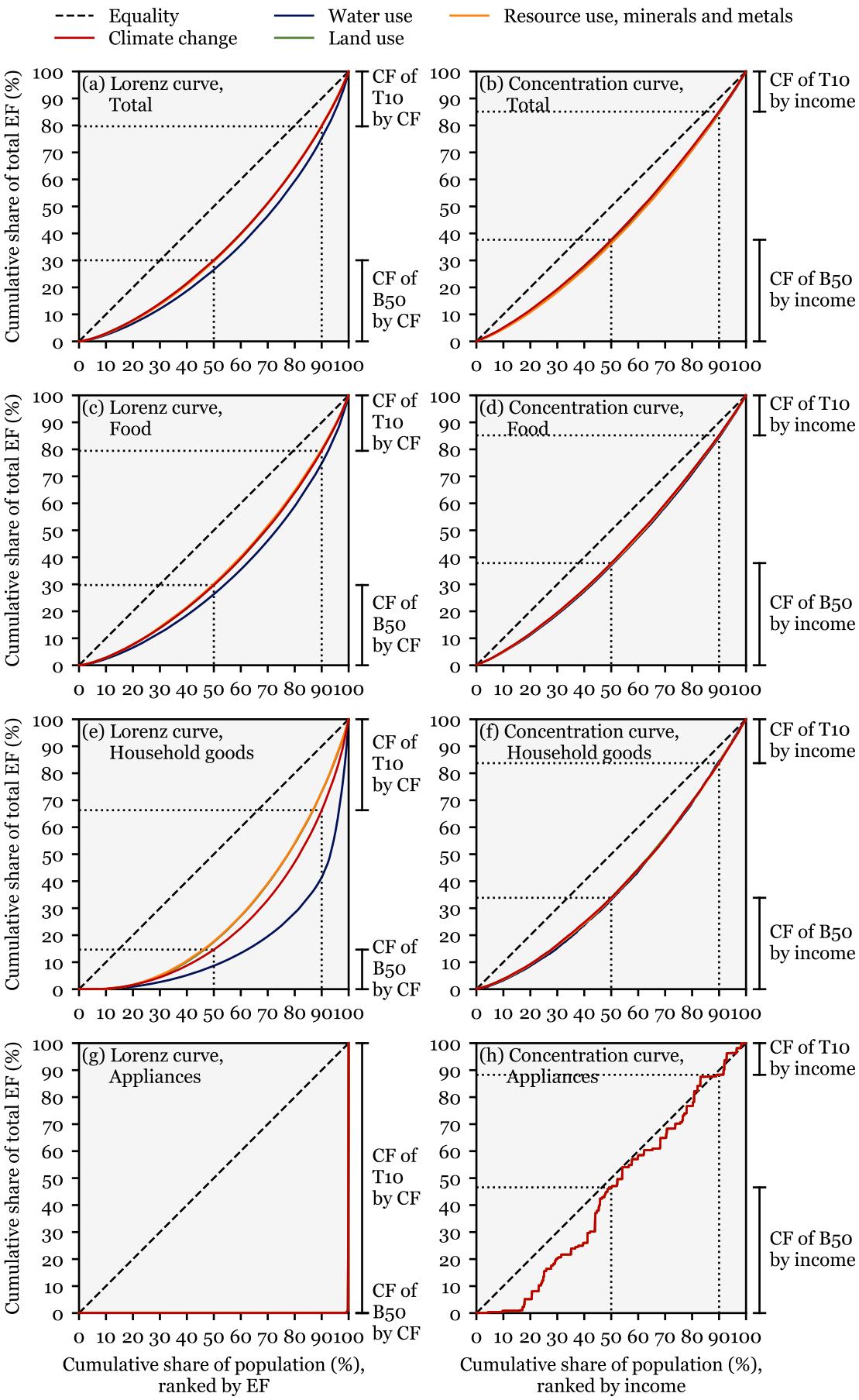

Figure 67: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Romania in 2015.

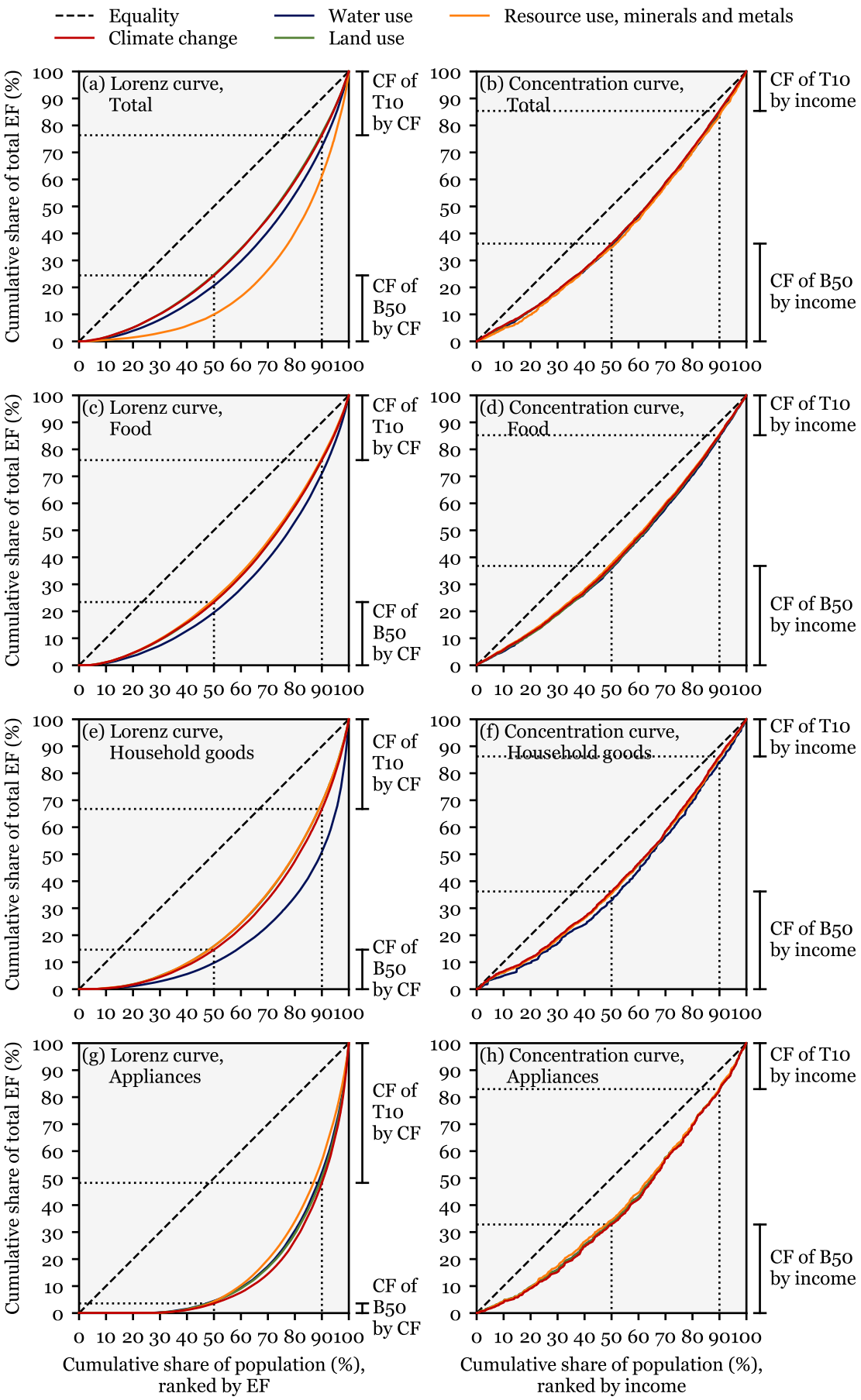

Figure 68: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Sweden in 2015.

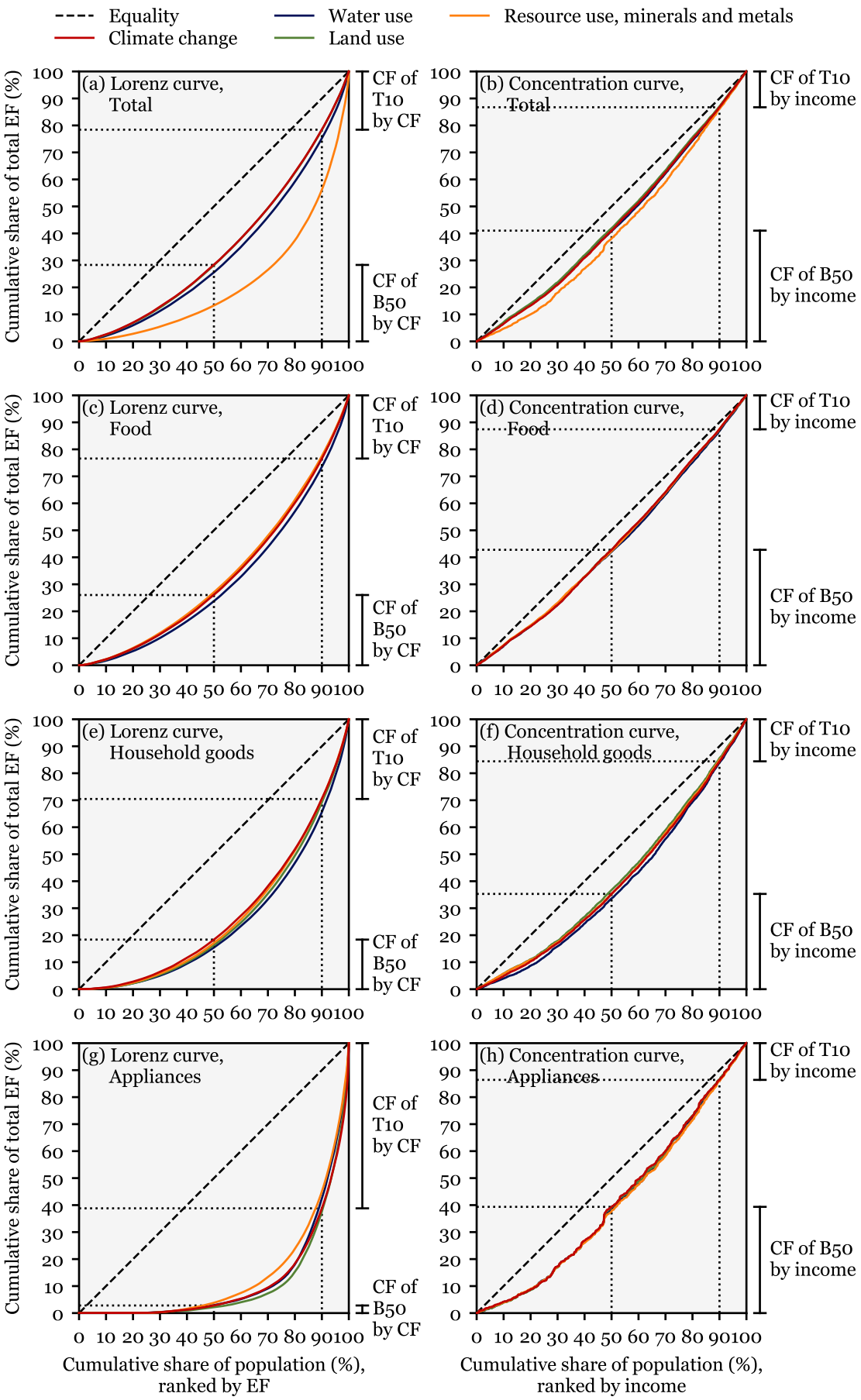

Figure 69: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Slovenia in 2015.

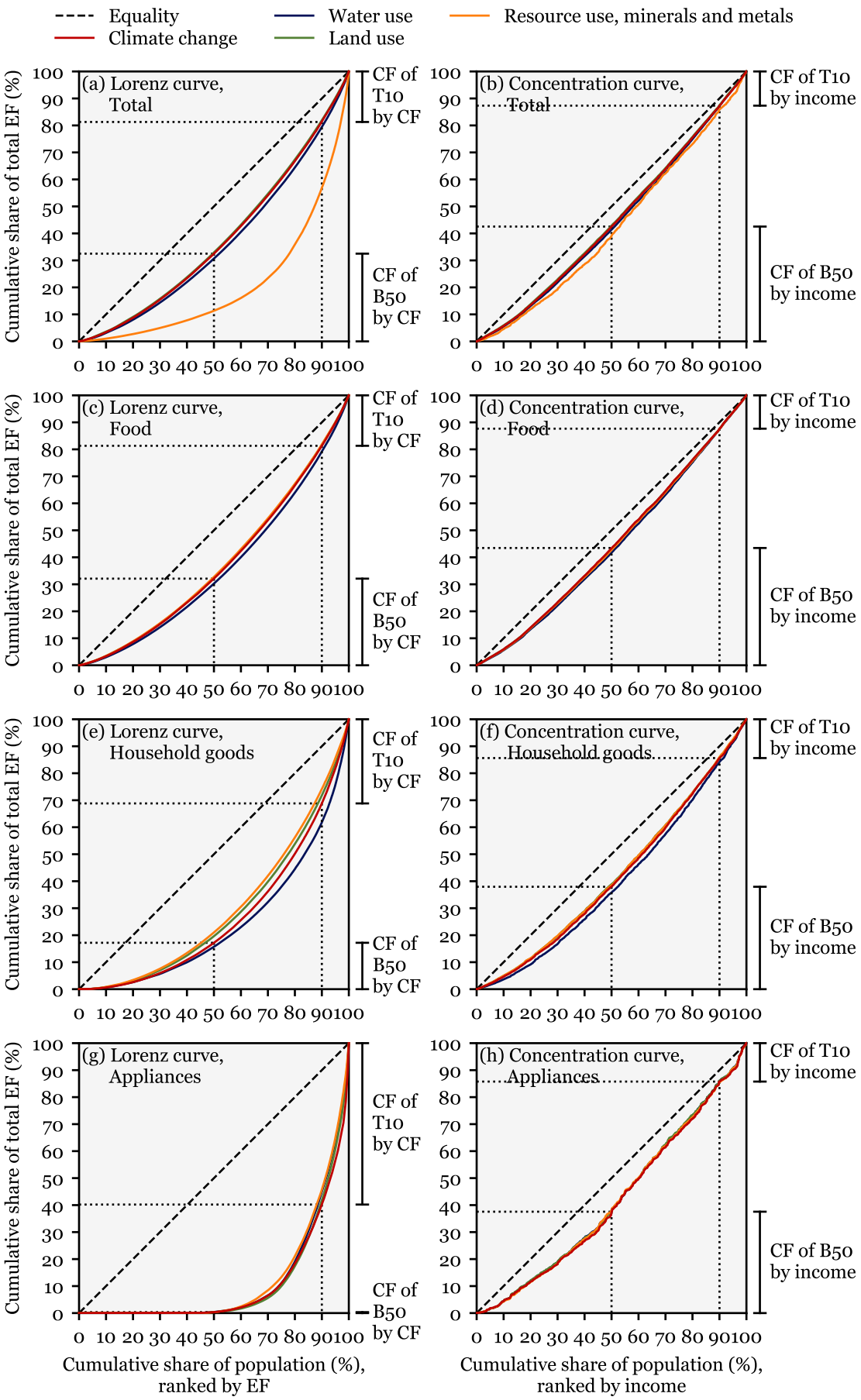

Figure 70: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in Slovakia in 2015.

Appendix 13: Lorenz and concentration curves with separated durable goods

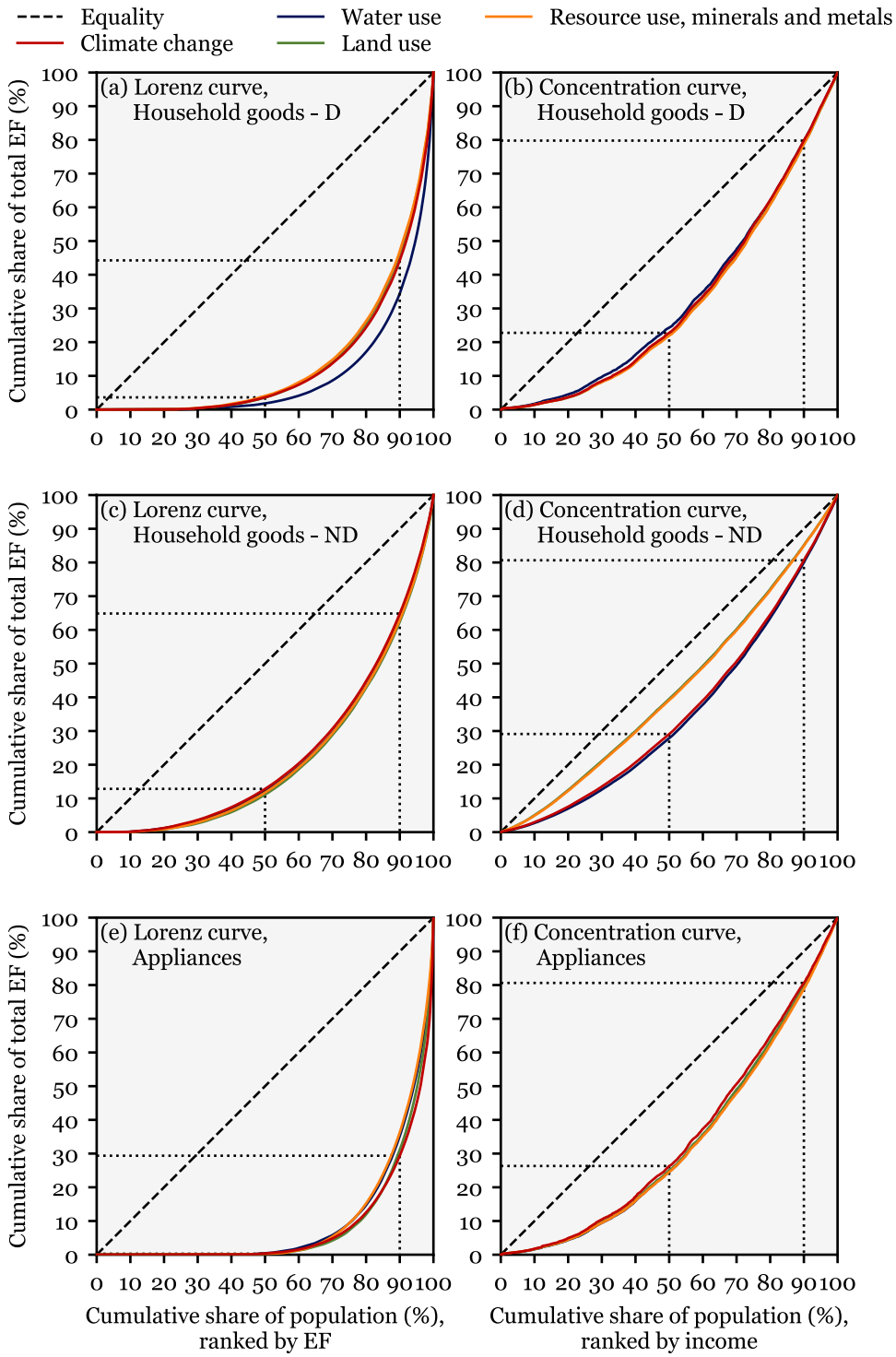

Figure 71: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the EF of durable household goods (HG-D) (plots (a) and (b)), non-durable household goods (HD-ND) (plots (c) and (d)) and appliances (plots (e) and (f)) of households in the EU (without Germany, Italy and Austria) in 2015. The annotations show examples for how to read the curves for the carbon footprint (CF). The upper guiding brackets show the share of the cumulative impact that the top 10% (T10) of the households sorted by impact (Lorenz curve) or income (Concentration curve) are responsible for. The bottom guiding brackets shows the same for the bottom 50% (B50).

Appendix 14: Lorenz and concentration curves with household income curve

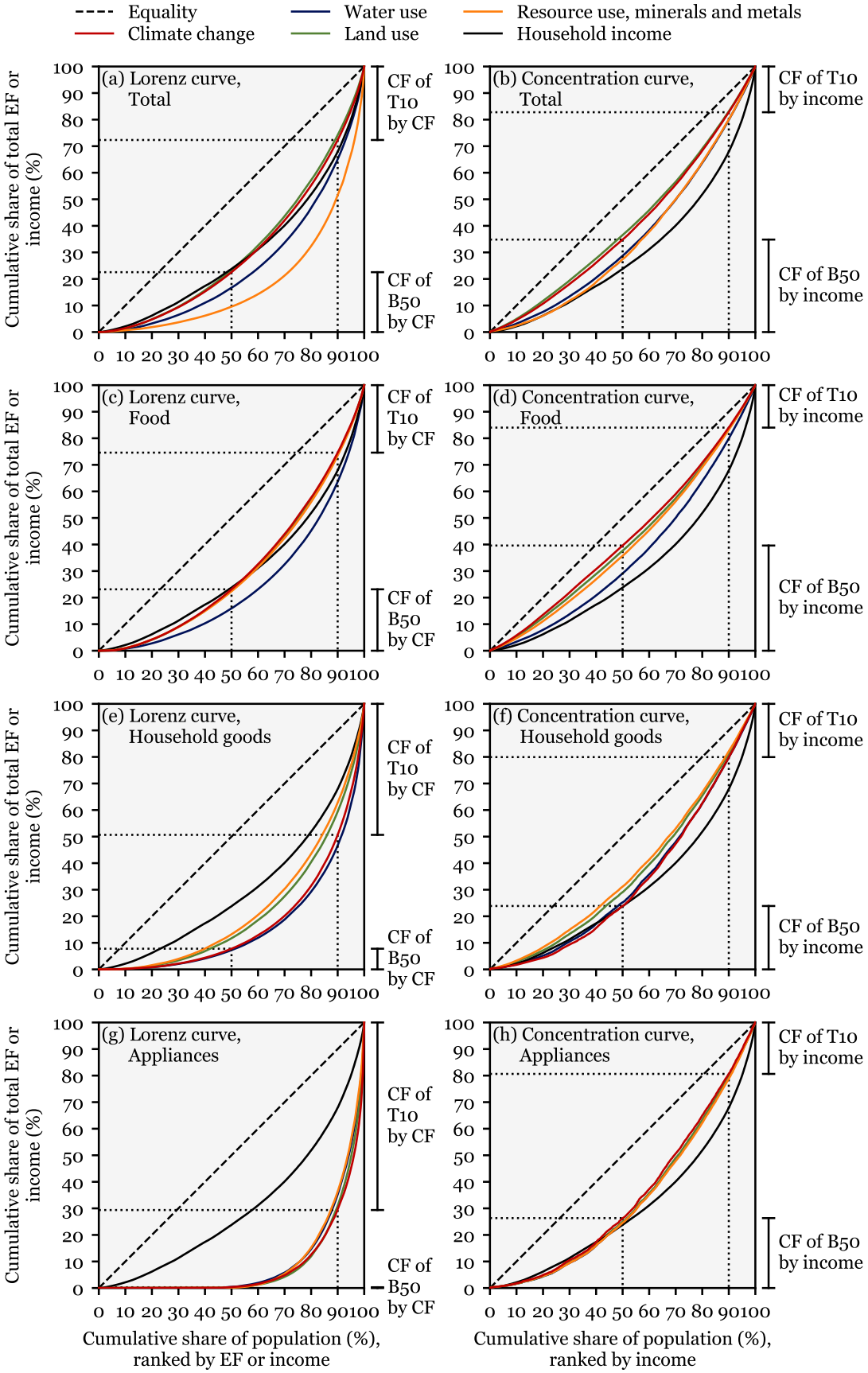

Figure 72: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in the EU (without Germany, Italy and Austria) in 2015. The household income curve shows the distribution of cumulative household income across household ranked by their income. It is the same in all plots.

Appendix 15: Range of mean footprints sorted alphabetically

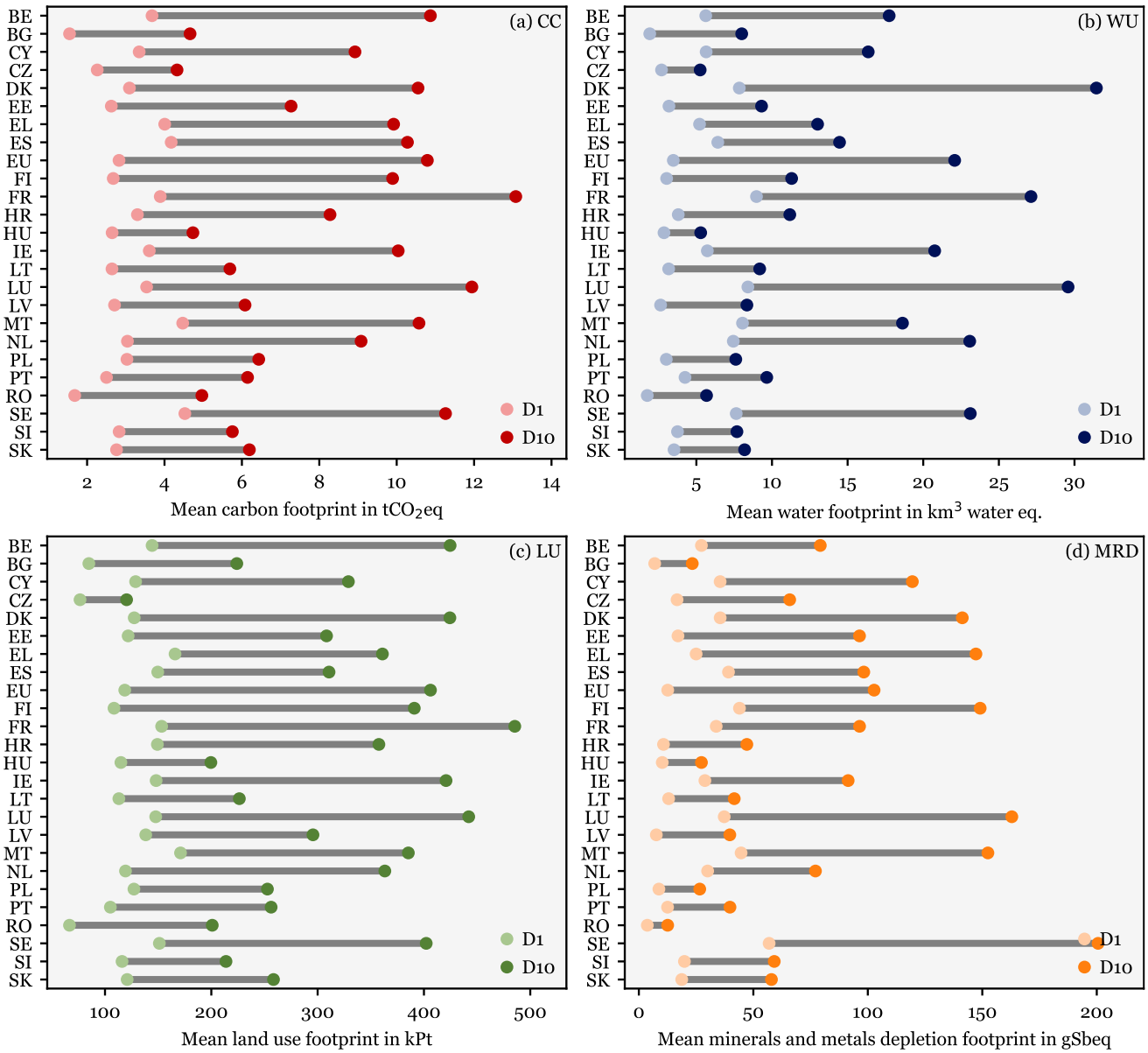

Figure 73: Range of mean footprints of the lowest and highest income decile in 2015 for each country included in this study. The countries are sorted by the D10 mean of the respective environmental footprint. EU without Austria, Italy and Germany. (a) Climate change (CC), (b) Water use (WU), (c) Land use (LU), (d) Resource use, minerals and metals (MRD). Note that the countries are sorted alphabetically from top to bottom. Also note that the differences between the countries stem only from the consumption, because EU-average impact intensities per product were used.

Appendix 16: TB50/T10 ratio for all baskets of consumption separately

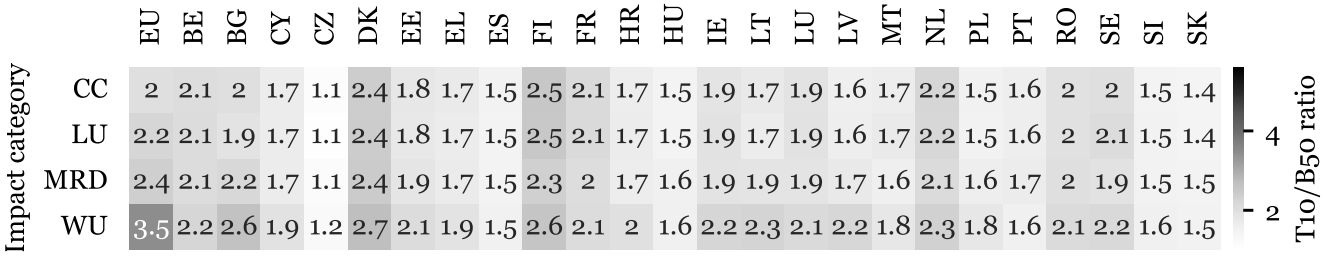

Figure 74: Ratio between mean EF from the consumption of food of the top 10% households (T10) and the bottom 50% (B50) by income for the countries included in this study. Higher ratios, meaning that the T10 has a higher EF compared to the B50, are shown in a darker shading. EU without Austria, Italy and Germany. Note that the shading is scaled to the highest ratio of all baskets (5.6) and differs from Figure 8 in the main text.

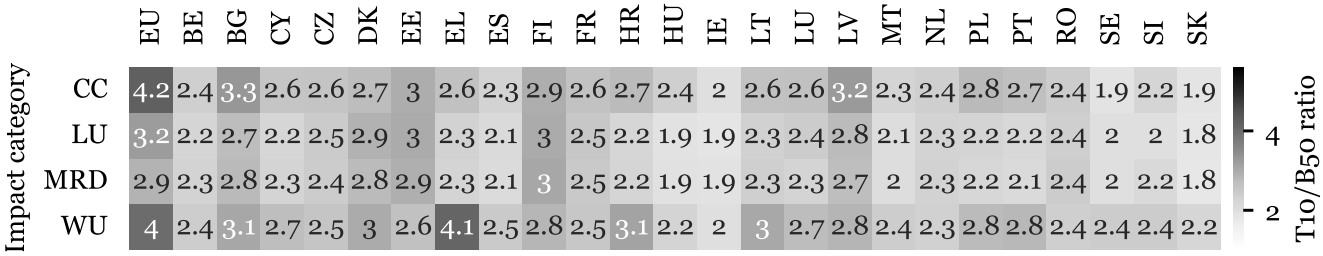

Figure 75: Ratio between mean EF from the consumption of household goods of the top 10% households (T10) and the bottom 50% (B50) by income for the countries included in this study. Higher ratios, meaning that the T10 has a higher EF compared to the B50, are shown in a darker shading. EU without Austria, Italy and Germany. Note that the shading is scaled to the highest ratio of all baskets (5.6) and differs from Figure 8 in the main text.

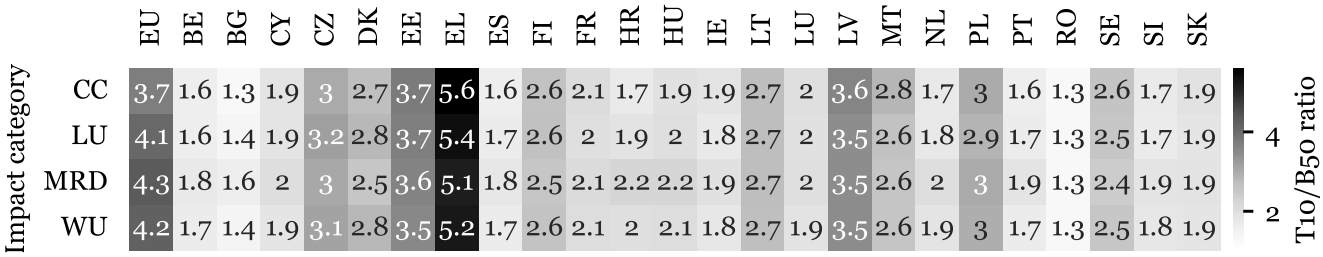

Figure 76: Ratio between mean EF from the consumption of appliances of the top 10% households (T10) and the bottom 50% (B50) by income for the countries included in this study. Higher ratios, meaning that the T10 has a higher EF compared to the B50, are shown in a darker shading. EU without Austria, Italy and Germany. Note that the shading is scaled to the highest ratio of all baskets (5.6) and differs from Figure 8 in the main text.

Appendix 17: Sensitivity analysis results

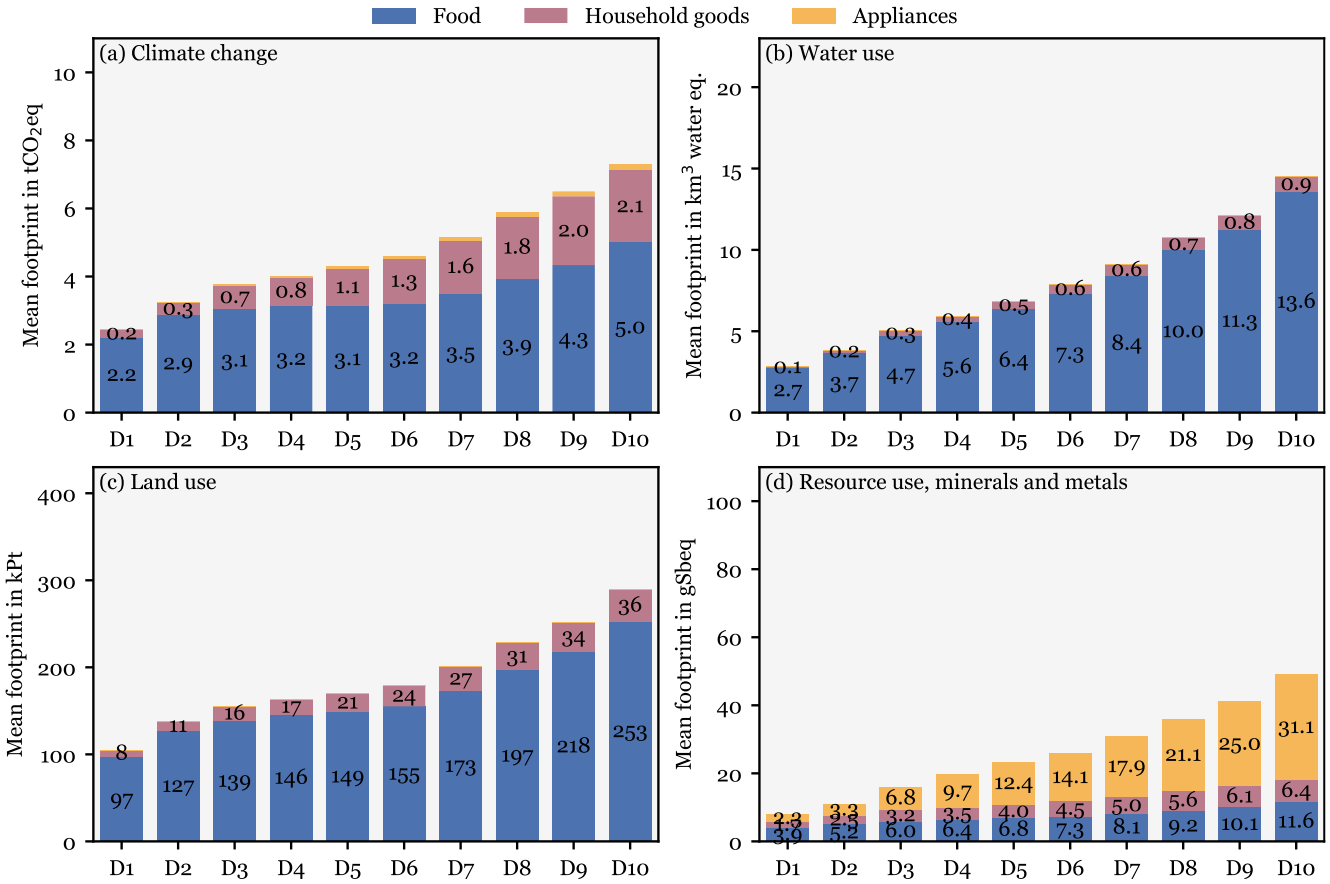

Figure 77: Mean EFs for EU household income deciles (not including Germany, Italy and Austria) for the year 2015 by basket of consumption for replacing 5% of the top expenditure and quantity values per subclass. Data labels for appliances are hidden in (a), (b) and (c). Note that the y-axis is scaled the same way as Figure 3, which showed the results for the 1% threshold.

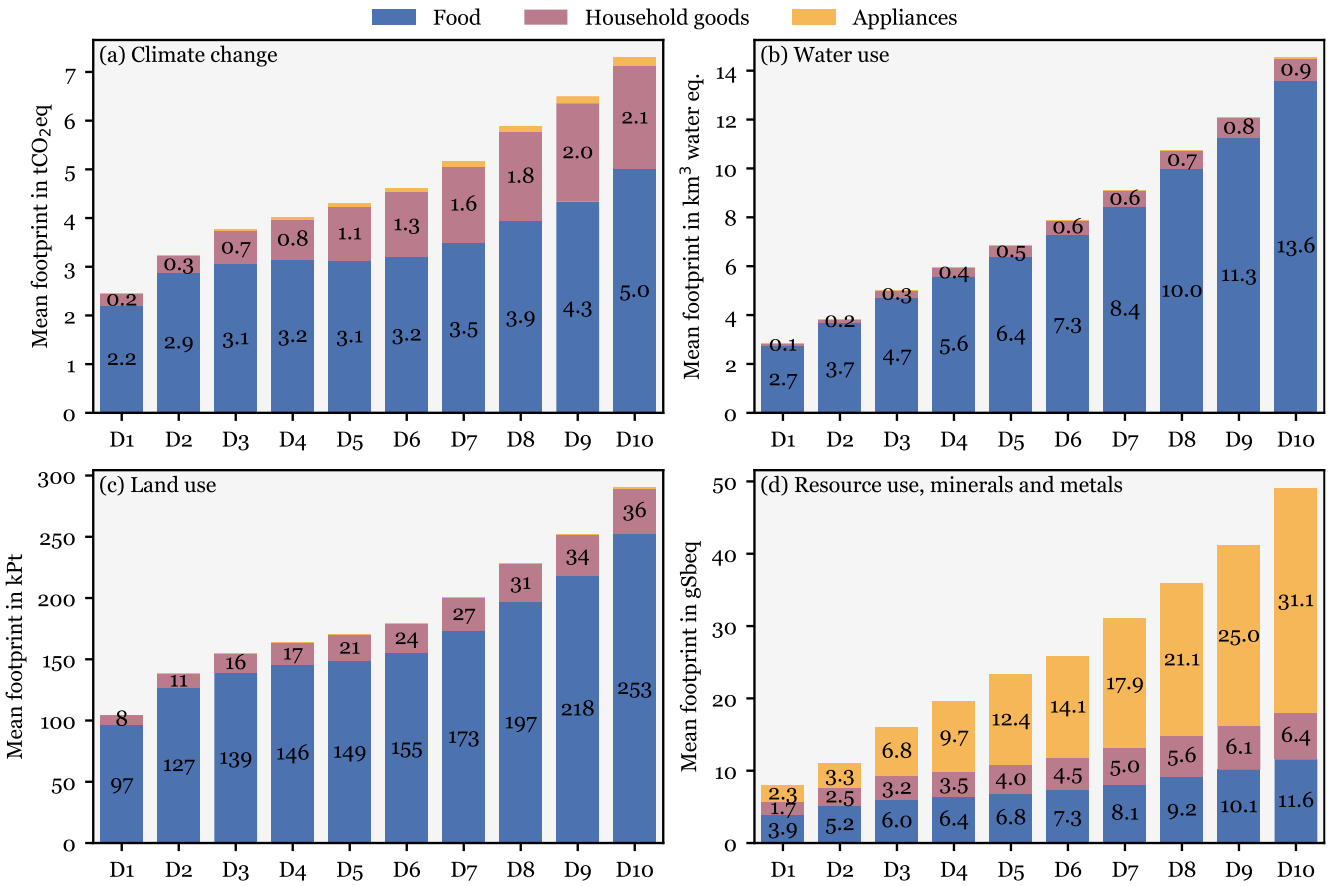

Figure 78: Mean EFs for EU household income deciles (not including Germany, Italy and Austria) for the year 2015 by basket of consumption for replacing 5% of the top expenditure and quantity values per subclass. Data labels for appliances are hidden in (a), (b) and (c). Note that the y-axis is not scaled the same way as Figure 3, which showed the results for the 1% threshold.

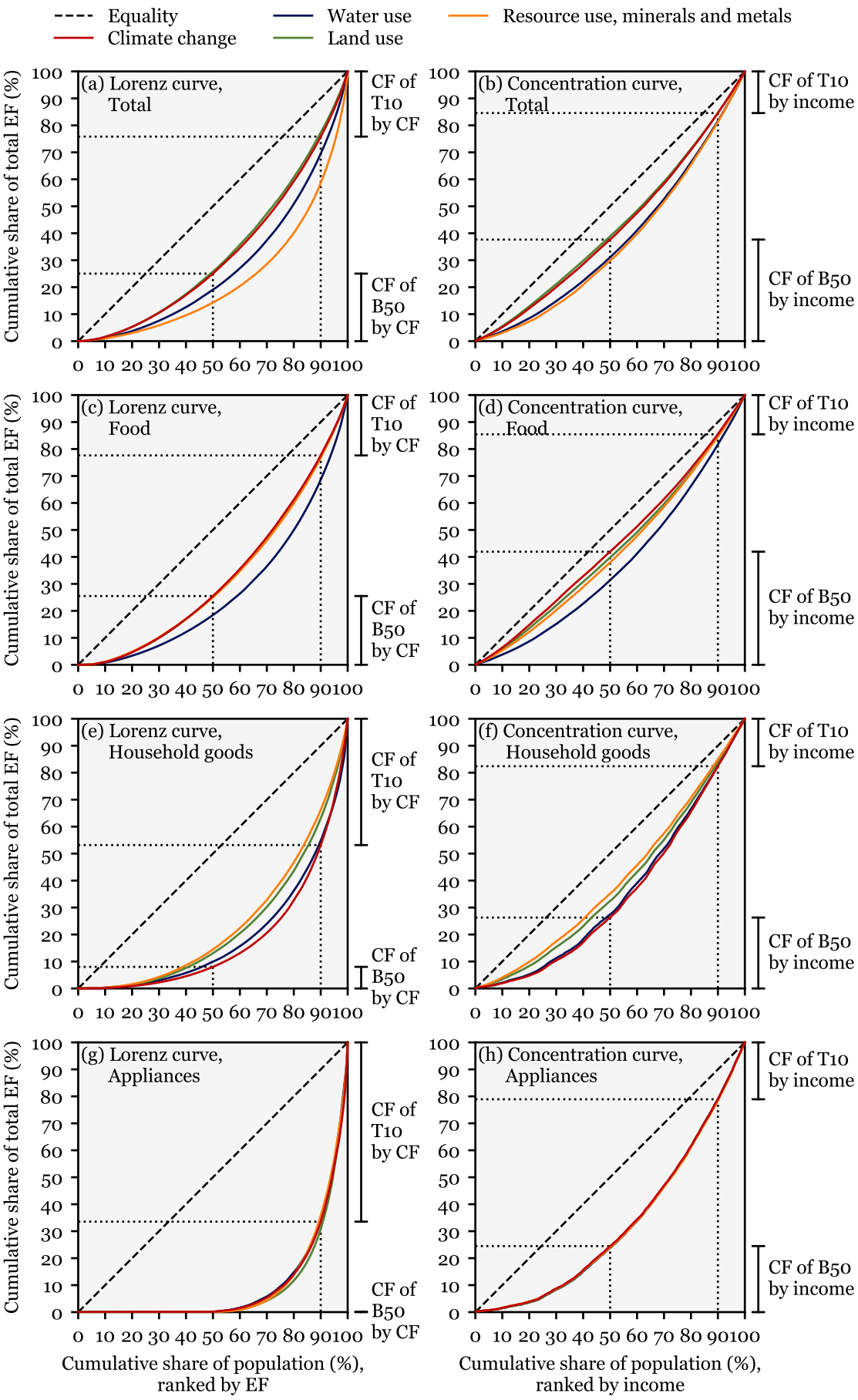

Figure 79: Lorenz (left, households ranked by EF) and Concentration curves (right, households ranked by income) for the total EF (plots (a) and (b)) as well as for the EF from each basket of consumption alone (plots (c) to (h)) of households in the EU (without Germany, Italy and Austria) in 2015 for replacing 5% of the top expenditure and quantity values per subclass.