This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036458.

Report on energy justice for vulnerable households

D6.2

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LOCALISED

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How to quote this document

Martínez Görbig, G.; Flacke, J.; Reckien, D. (2024), Report on energy justice for vulnerable households (LOCALISED Deliverable 6.2)

General information about this Document

Project acronym	LOCALISED
Project full title	Localised decarbonisation pathways for citizens, local administrations and businesses to inform for mitigation and adaptation action
Grant Agreement no	101036458
Deliverable number	D6.2
Deliverable title	Report on energy justice for vulnerable households
Deliverable nature	Report
Dissemination level	Public
Work package and Task	WP6 – Task 6.2
Contractual delivery date	March 2024
Actual delivery date	March 2024
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Reviewers	Katja Firus, T6 Ecosystems Bernd Hezel, Climate Media Factory

Revision History

Version	Date	Name
V1.0	18/03/2024	Gerard Martínez Görbig Johannes Flacke Diana Reckien
V2.0	27/03/2024	Gerard Martínez Görbig Johannes Flacke Diana Reckien
V3.0	10/03/2025	Gerard Martínez Görbig Johannes Flacke Diana Reckien

Table of Contents

List of Figures

List of Tables

List of Abbreviations

EPAH	Energy Poverty Advisory Hub
EU	European Union
CoM	Covenant of Mayors
GIS	Geographic Information Systems
NDI	Normalised Disposable Income
OECD	Organisation for Economic Co-operation and Development
FAO	Food and Agriculture Organisation
HBS	Household Budget Survey
EXP	Expenditure
NUTS	Nomenclature des Unités territoriales statistiques
LAU	Local Administration Units

Executive Summary

This report intends to identify European households and demographic groups that might suffer from energy poverty when obliged to change lifestyles or living patterns. Being energy poor is different from being at risk of energy poverty. While other studies aimed to map current levels of energy poverty, this research wants to unearth and plot the factors that might produce it, particularly those related to a low-carbon transition and the implementation of climate actions that impact citizen's lifestyles. Lifestyles are operationalised by investigating household activities in different domains, e.g. by way of expenditure patterns. In Europe, the accessibility to domains and their related emissions strongly correlates with economic aspects, hence, this report analyses socioeconomic data from Eurostat, OECD, and FAO to identify socioeconomic groups that might face the risk of energy poverty due to a low-carbon transition. The results allow the creation of a framework to inform the selection of equitable and just mitigation and adaptation measures based on households' contexts, lifestyles and demographic characteristics.

This report documents research done as part of the LOCALISED project (D6.2), i.e. research on identifying vulnerable groups at risk of energy poverty due to policy options and low-carbon lifestyles in Europe. It represents a crucial step towards understanding societal and social needs as part of a just and equitable transition, starting from the measures compiled in the "Database of current, planned and potential adaptation and mitigation measures" (LOCALISED - D4.1). The report builds on the work developed in the "Report on key approaches of low-carbon lifestyle changes" (LOCALISED - D6.1) and aims to provide a baseline to complement the "Blueprint for Citizen Engagement in Regions and Cities" (LOCALISED - D6.3).

The work uses three methodological approaches to identify vulnerable populations at risk of energy poverty. Firstly, the regional context defines a household's vulnerability, for example, when regional infrastructural characteristics produce externalities that impact household lifestyles. Secondly, household groups might be at higher risk of energy poverty due to their lifestyle. It occurs when households struggle to keep their house warm and pay energy bills due to expenditures in other lifestyle domains. Finally, some demographic groups suffer from structural injustices, such as minorities or migrants.

The results of the analysis conclude by (1) mapping the regional characteristics that might increase the risk of energy poverty, (2) identifying groups that might be at elevated risk of energy poverty due to lifestyle changes, and (3) understanding how demographic characteristics might increase risk. The final section compares the results to potential externalities of measures in different lifestyle domains and discusses potential beneficial opportunities generated by such changes. In that way, it is possible

to build the base for selecting equitable and just measures per region in the European context.

1 Introduction: Energy Poverty in Europe

The European Union defines Energy poverty as "the inability of households to access basic energy services and products". It further defines it as "a multi-dimensional phenomenon caused by a combination of low income, high energy expenses, and poor energy efficiency in buildings" (European Parliamentary Research Service, 2022). Details of definitions may vary from context to context, though, as e.g. “access" and ”energy services and products” can be measured by different indicators also depending on stakeholders' interests and perspectives (Lippert & Sareen, 2023). Therefore, another definition suggested by the European Commission and its Energy Poverty Advisory Hub is that “energy poverty reflects the lack of affordability of keeping the house warm” (Gouveia et al., 2023).

The European Commission recognises energy poverty as a critical societal problem (Gouveia et al., 2023). Energy poverty is one of the most common injustices in the energy transition and a counterpart of the energy aspect of environmental justice, known as energy justice (Hanke et al., 2023). Thus, understanding energy poverty and the factors that might generate, influence or eliminate energy poverty is crucial to understanding the potential impacts of an energy transition on justice and equity dimensions.

Supporting the importance of that argument, the Covenant of Mayors (CoM) included Energy Poverty as a pillar in developing their Sustainability and Energy Climate Action Plans (SECAPs) for 2024. Also, the EU Energy Poverty Advisory Hub (EPAH) keeps track of the issue and regularly publishes reports on Energy Poverty (Gouveia et al., 2022, 2023). They review the state of the art of energy poverty as discussed in the scientific literature, highlight relevant indicators, and analyse the current state of Energy Poverty in Europe. The recent EPAH report (Gouveia et al., 2023) focuses on identifying indicators capable of offering a consistent framework of the issue, resulting in a list of 29 indicators, classified into four primary topics: climate, facilities and housing, mobility, and socioeconomic aspects. The complete list of indicators can be found in Table 1.

Table 1: List of indicators to assess the current status of Energy Poverty. Source: Gouveia et al., 2023.

Topic	**Subtopic**	**Indicator**
Climate		Cooling degree days

		Heating degree days
Facilities / Housing	Building stock	Dwellings with energy label A
		Final consumption expenditure of households
		Population living in a dwelling with presence of leak, damp and rot
		Population living in a dwelling equipped with heating
		Population living in a dwelling equipped with air conditioning
		Population considering their dwelling as too dark
	Energy consumption and equipment	Final consumption expenditure of households
		Final energy consumption in households by energy use
		Final energy consumption in households by type of fuel
Mobility		Final consumption expenditure of households
		Population who cannot afford a regular use of public transport
Socioeconomic aspects	Socioeconomic and living conditions	Arrears on utility bills
		At risk of poverty or social exclusion
		Disposable annual household income
		Inability to keep home adequately warm

		Final consumption expenditure of households
		Housing cost overburden rate
		Population living comfortably cool during summer time
		Population living comfortable warm during winter time
	Energy expenditure and energy markets	Energy expenses by income quintile
		Energy prices
		High share of energy expenditure in income
		Low absolute energy expenditure
	Health	Causes of death
		Excess winter mortality/deaths
		Final consumption expenditure of households
		Population reporting a chronic disease

The EPAH report offers a broad diagnosis of the current state of energy poverty in Europe using European harmonised data from Eurostat. However, that diagnosis does not provide detailed insights into the systemic reasons causing energy poverty, nor does it acknowledge regional differences or a specific energy transition approach accounting for individuals' needs or behaviours towards living in a low-carbon Europe. The EPAH report highlights the importance of building connections between indicators and stages – e.g., cause and consequence of energy poverty – complementing the analysis with disaggregated data and exploring the multidimensionality of the issue (Gouveia et al., 2023).

Energy poverty may occur in several variations. Even though energy systems and the economy are core to the issue, citizens might struggle to afford minimal energy services due to intersectionality with other basic needs (Fry et al., 2023). Depending on each household's style of living, they might be differently exposed to energy poverty. Hence, a household's lifestyle plays an important role.

This report will investigate how the change(s) in citizens' lifestyles produced by low-carbon transition policies will potentially put European citizens/households at risk of being energy-poor. This LOCALISED report aims to map different vulnerable households and demographic groups that might face an increased risk of energy poverty due to mitigation strategies but also explores how those changes generate opportunities when challenges are appropriately addressed. According to the literature, different factors can impact the energy poverty level of households when transitioning to a low-carbon Europe. Firstly, depending on the region's characteristics, implementing measures and policies might produce externalities that households will feel. Second, depending on their lifestyle, some households can suffer from increased energy poverty risk differently. Finally, some demographic characteristics, like being a woman or immigrant, might worsen the risk due to structural injustices. To conduct the analysis, the report first looks at the causal relations of the EPAH-suggested indicators, i.e. identify the ones causing energy poverty rather than being a consequence (Section 3.2). It then complements these cause-effect relationships with household indicators of energy poverty (Sections 3.3 – 4) and then analyses further socioeconomic household indicators at a regional scale. Consequently, the report dwells on three questions to identify the risk of energy poverty: (1) how regional infrastructure characteristics can increase energy poverty risk for certain regions; (2) how lifestyle changes can increase energy poverty risk for certain household types; and (3) how demographic characteristics define energy poverty.

The report is structured as follows:

- Section 2 describes the methods applied to develop a mapping procedure, ranging from the construction of a conceptual framework based on a literature review to the statistical analysis and GIS mapping of groups.
- Section 3 explains the underlying concepts of (1) energy poverty, (2) lifestyles, and (3) the risk of energy poverty due to low-carbon lifestyles.
- Section 4 identifies how different vulnerable populations may be at increased risk of energy poverty due to a low-carbon transition because of regional characteristics, lifestyle characterisations and demographic characteristics.
- Section 5 discusses the results from Section 4, identifying the most vulnerable groups in Europe, considering their lifestyle and socioeconomic and demographic characteristics.
- Finally, Section 6 reflects on the results. First, it shows their applicability in policy-making by conceptualising a framework on how the previous methods can be used for assessing the most equitable and just measures. Second, it studies how switching to low-carbon lifestyles using appropriate policies and measures could bring several co-benefits to the same vulnerable groups.

2 Data and Methods

Four different methods are used to complete this report. The workflow diagram is shown in Figure 1. First, a literature review has been conducted to define the relationship between low-carbon lifestyle options and vulnerable groups at risk of increased energy poverty, identify the relevant indicators for the issue, and develop the research's conceptual framework (Section 3.3). After that, a search for available data in open-source databases was performed. The data was selected based on the literature review results and downloaded from Eurostat, the Organisation for Economic Co-operation and Development (OECD) Database, the Food and Agriculture Organisation (FAO) Database, and the World Bank Open Data. Later, the data was processed and analysed based on the conceptual framework previously developed, using statistical analysis methods – descriptive analysis, correlation analysis and regression analysis – and mapped using Geographic Information Systems (Section 4). Finally, the results have been qualitatively analysed, compared to existent literature and official reports, and interpreted to suggest a method to assess more equitable and just measures in European regions (Sections 5 – 7).

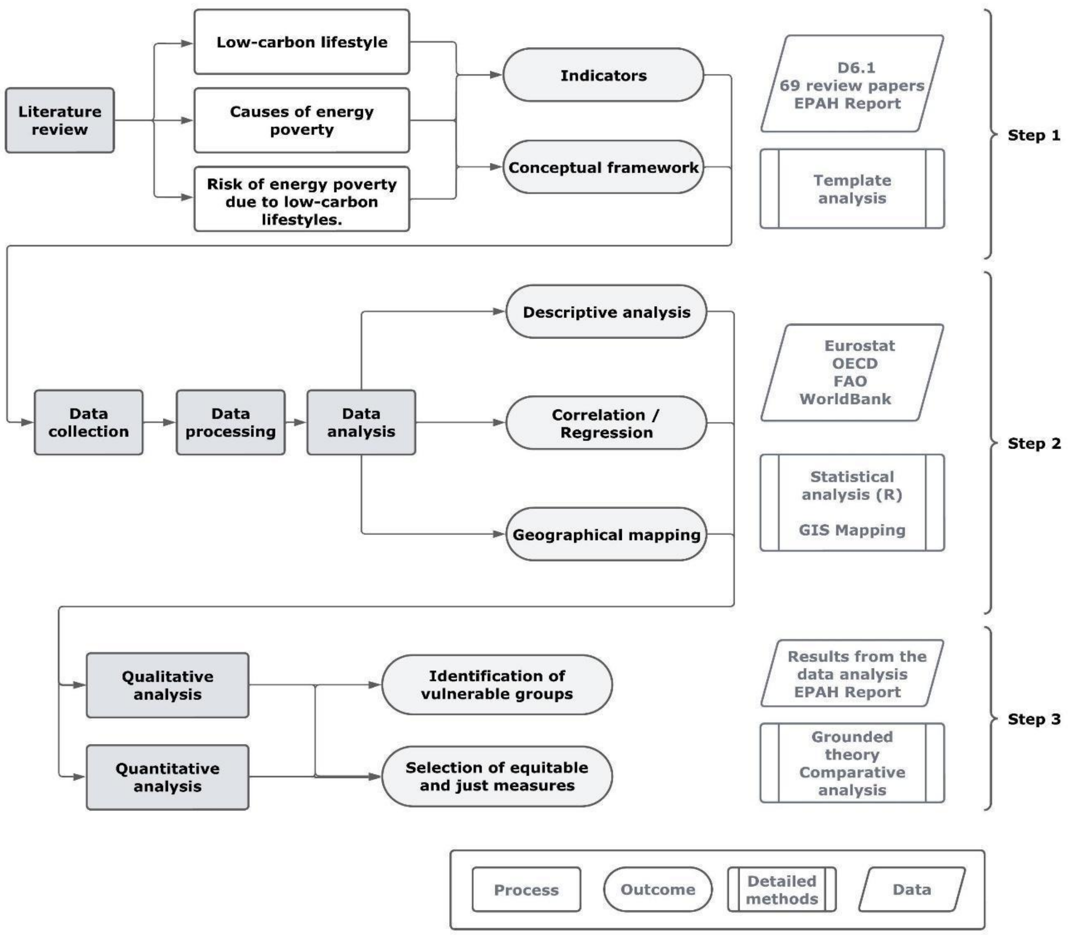


Figure 1: Workflow diagram. Source: Authors.

2.1. Literature review

The first step in the report development was conducting a systematic literature review to understand *being at risk of increased energy poverty due to identified low-carbon lifestyle options* and their relation to *energy justice*. The scholarly literature on Scopus or Web of Science showed scarce results when using the strings "low-carbon lifestyles", "energy justice", and "vulnerability to energy poverty" combined.

The following steps were conducted in Scopus, using the terms "vulnerability", "justice", "climate action", and "low-carbon", combined by pairs, groups of three or the four of them. As the number of matches was substantial, results were filtered by year (recent literature from 2020 onwards was included) and type (only review articles were included). Moreover, studies related to the biological or medical field were excluded. The search concluded with 69 peer-reviewed review papers (Table 2). Those were carefully scrutinised by full-text reading and analysis. A template analysis methodology was used to extract results and conclusions from the papers, finding concrete answers for 15 questions – see Appendix A.1. (Table 17). The results were compared with the Energy Poverty Advisory Hub Report (Gouveia et al., 2022, 2023), LOCALISED Deliverable 6.1, and its references to ensure no gaps were left in the analysis. A summary of the conclusions can be found in Appendix A.1. (Table 18).

Table 2: Exclusion table of the literature review. Source: Authors.

Literature review steps	**Details**	**Nº of hits**
Database/sources	Scopus	
Limitations and settings	The concept is multidimensional and transdisciplinary. Thus, the different strings were always combined, at least, with another one. Only review articles from 2020 to 2023 were included in the research. Fields related to biological and tech-med fields were excluded from the research.	
Number of hits	"JUSTICE" AND "CLIMATE ACTION"	28
	"JUSTICE" AND "CLIMATE ACTION" AND "VULNERABILITY"	30
	"JUSTICE" AND "LOW CARBON"	32

	"VULNERABILITY" AND "CLIMATE ACTION"	18
	"VULNERABILITY" AND "LOW CARBON"	14
Total number of hits		122
Manual filtering	Checking for duplicates Abstract reading	69
Review of EPAH Report	Relevant literature for the development of the EPAH Report and Deliverable 6.1.	6
Final number of hits		**75**

The second step of the research was to define the role of the lifestyle concept within the *risk of being energy-poor* context. This report builds on Deliverable 6.1 of the LOCALISED project, taking its suggested lifestyle definition as a starting point. The content was also extended using the Equitable 1.5-Degree Lifestyles Policy Report (Lorek et al., 2021) and its associated literature. However, more details were needed to know about how energy poverty relates to different lifestyle domains. Thus, another brief literature review was conducted in Scopus, following the strings presented in Table 3. The results of the whole literature review will be discussed in Section 3.

Table 3: Questions and strings used for lifestyles vs energy poverty literature review, and number of relevant hits. Source: Authors.

Question	String and constraints	Relevant results
How does food relate to energy poverty?	"Food" and "Energy poverty" from 2015. Only Review.	14
How does housing relate to energy poverty?	"Housing" and "Energy poverty" from 2015. Only Review.	4
How does transport relate to energy poverty?	"Transport" and "Energy poverty" from 2015. Only Review.	2
How do other lifestyle domains relate to energy poverty?	"Health" or "Clothing" or "Manufacturing" or "Education", and "Energy poverty" from 2020. Only Review.	2

2.2. Data availability

To map the risk of energy poverty throughout Europe, the data was extracted from the following Open-Source databases: Eurostat, the Organisation for Economic Co-operation and Development (OECD) Database, the Food and Agriculture Organisation (FAO) Database, and the World Bank Open Data. According to the literature review, three types of data were targeted: data regarding regional characteristics, data regarding citizens' lifestyles, and socioeconomic and demographic data of the population. Five different criteria were set in order to select appropriate data: (1) data should respond directly to any indicator found in the literature review; (2) it should be in Europe and available for most of the countries; (3) it should be the most recent possible; (4) it should be, if possible, at NUTS3 level; (5) it should be, when socioeconomic, disaggregated into different demographic groups. The list of targeted indicators, criteria, and data availability can be found in Table 4.

Table 4: Availability of data. Source: Authors

Category	**Indicator**	**Public datasets available**	**Criteria**
Infrastructure and regional characteristics	Energy access	*Not available.* *Proxy indicator: Energy affordability*	*Respond directly to indicator: -* *Europe: -* *Recent year: -* *Scale: -* *Demographic: -*
	Decentralisation and diversification of energy production	Share of the main producer – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: Country* *Demographic: No*
		Share of energy imports – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: Country* *Demographic: No*

		Share of renewable energy consumption – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: Country* *Demographic: No*
	Energy affordability	Electricity prices – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: Country* *Demographic: Yes*
		Gas prices – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: Country* *Demographic: Yes*
		Household Budget Expenditure Survey – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2020* *Scale: Country* *Demographic: Yes*
		Income of households – OECD, Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: NUTS2* *Demographic: Yes*
	Food Security [1]	Food price index variation regarding 2015 – Eurostat, FAO	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023*

			Scale: Country *Demographic: Yes*
		Population who cannot afford a healthy diet – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: Country* *Demographic: Yes*
	Housing affordability	€/sqm rent - Numbeo	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: Local Administration Units* *Demographic: Yes*
	Institutional capacity and type of government	*No data are available.*	*Respond directly to indicator: -* *Europe: -* *Recent year: -* *Scale: -* *Demographic: -*
Basic domains' relation with energy expenditure		Household Budget Survey (2020). – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2020* *Scale: Country* *Demographic: Yes*
Population characteristics	Income	Income of households – OECD, Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: NUTS2* *Demographic: Yes*

		Household Budget Survey – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2020* *Scale: Country* *Demographic: Yes*
	Gender inequity	Not available. Proxy indicator: Population by Gender – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: NUTS3* *Demographic: Yes*
	Ethnicity	Population by country origin – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: NUTS3* *Demographic: Yes*
	Housing conditions and tenure	Distribution of households – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: NUTS3* *Demographic: Yes*
	Elderly and children	Population by age and gender – Eurostat	*Respond directly to indicator: Yes* *Europe: Yes* *Recent year: 2023* *Scale: NUTS3* *Demographic: Yes*

Most data are updated annually and were updated in 2023. However, the Household Budget Expenditure (HBS) data were only available in five-year ranges, with 2020 being the last update. Hence, for all indicators data of 2020 were selected.

2.3. Data processing

The first step in the Data processing was to decide how to treat missing values. In this case, missing values were not used for the analysis and were marked as "not available". The data was collected from different countries, and in some of them, it was simply not available. Thus, missing values were irrelevant to the analysis and did not indicate relevant trends. The same reasoning was used when evaluating missing data for lifestyles, as they were also divided by countries. Regarding demographic data, no missing values were found for the year 2020.

The second step in the process was to identify and analyse outliers in the data. The report aimed to identify risk groups that can differ from others due to many factors. For example, the high variability of socioeconomic characteristics in some countries can determine outliers, which are, however, important in a cross-country analysis. Thus, outliers were kept while analysing all three indicator types.

2.3. Data analysis

The analysis of the data was conducted using three software packages. First, MS Excel was used to extract the data from the downloaded datasets and assemble them. Once the datasets were clear, they were imported to RStudio, where the data were analysed and evaluated. Three different data analyses were conducted in R: (1) descriptive analysis, (2) correlation analysis, and (4) regression analysis. AI tools such as ChatGPT and blackbox.ai were used as help assistants with code debugging and code optimisation. The results are described in Section 4 – Results, and the code is available upon request.

Finally, once the data was processed and analysed, resulting datasets were mapped using the open-source Geographic Information Systems software QGIS. All data was georeferenced using the standardised ISO-3166 codes by country and, when possible, by NUTS2 and NUTS3 levels.

The analysis was conducted under the umbrella of three different approaches: 1) identifying which regions in Europe are more at risk of energy poverty due to impacts on their systems and infrastructures; 2) identifying household structures that are more at risk of energy poverty due to changes in their lifestyle domains; and 3) disentangling how demographic characteristics can shape the obtained results under 1) and 2) and identifying those demographic groups in the European regional fabric. For each approach, specific data analysis methods were used. The processes can be found in Table 5.

Table 5: Data analysis methods. Source: Authors.

Approach	**Data analysis methods**	**Software**
1. Identifying which regions in Europe are more at risk of energy poverty due to impacts on their systems and infrastructures	Descriptive analysis. Normalisation of indicators. GIS Mapping.	MS Excel RStudio QGIS
2. Identifying household structures that are more at risk of energy poverty due to changes in their lifestyle domains	Correlation analysis. Regression analysis. Descriptive analysis.	RStudio
3. Disentangling how demographic characteristics can shape the obtained results under 1) and 2) and identifying those demographic groups in the European regional fabric	Correlation analysis. Descriptive analysis. GIS Mapping.	RStudio QGIS

2.4. Results evaluation

The results are evaluated using two types of comparative methods, depending on the analysis's outcome (Section 5.3). Firstly, for geographical outcomes, such as mapping regional characteristics and identifying countries with the largest vulnerable groups, the data are compared to the geographical outcomes from the EPAH Report (Gouveia et al., 2023). This allows us to validate the results and identify why some regions might have an increased risk of energy poverty compared to others.

Secondly, data of vulnerable groups (such as household types and demographic groups) are evaluated using a qualitative analysis matrix. The household types at risk of energy poverty identified through their lifestyle patterns are cross-checked with the vulnerable groups due to their demographic characteristics. Table 6 shows a generic example. A matrix is developed per domain (for example, Healthcare). In the matrix, the rows list the household types at risk of energy poverty due to lifestyle changes (e.g., the elderly population are more prone to suffer from energy poverty if their accessibility to healthcare decreases), and the columns show the different demographic characteristics that play a role in the risk of becoming energy-poor (e.g., gender). Then, the data from both results are cross-checked in the matrix. Once done, fuzzy logic is applied, and three risk levels of energy poverty (based on the variability of the data) are assigned: 0 – No differences; 1 – Slightly higher risk for [...]; 2 – Higher risk for [...]. The resulting matrix allows us to understand visually how demographic characteristics shape groups at risk of being energy-poor due to lifestyle changes. For example, the elderly population is always at risk of energy poverty due to changes in their healthcare accessibility (row X). As a tenant, however, the risk slightly increases further (column Tenure). However, the risk escalates significantly when being female (gender), immigrant (migration), having a low income (income), or having dependent children (families with children).

Table 6: Example of the matrix to identify vulnerable groups. Source: Author.

<table>
<tr><th>Domain</th><th>Income</th><th>Gender</th><th>Ethnicity</th><th>Tenure</th><th>Elderly</th><th>Families with children</th></tr>
<tr><td>Household structure 1</td><td rowspan="5">0 – No differences; equal risk

1 – Slightly higher risk for the poor

2 – Higher risk for poor

NA – Not applicable</td><td rowspan="5">0 – No differences; equal risk

1 – Slightly higher risk for women

2 – Higher risk for women

NA – Not applicable</td><td rowspan="5">0 – No differences; equal risk

1 – Slightly higher risk for immigrants

2 – Higher risk for immigrants

NA – Not applicable</td><td rowspan="5">0 – No differences; equal risk

1 – Slightly higher risk for those renting a property

2 – Higher risk for those renting a property

NA – Not applicable</td><td rowspan="5">0 – No differences; equal risk

1 – Slightly higher risk for older people

2 – Higher risk for older people

NA – Not applicable</td><td rowspan="5">0 – No differences; equal risk

1 – Slightly higher risk for families with children

2 – Higher risk for families with children

NA – Not applicable</td></tr>
<tr><td>Household structure 2</td></tr>
<tr><td>Household structure 3</td></tr>
<tr><td>Household structure 4</td></tr>
<tr><td>Household structure 5</td></tr>
</table>

3 Background

3.1. Definition of lifestyles

Low-carbon transition and citizen's lifestyles are closely related. Lifestyles are considered "the distinctive pattern and manner of living an individual or group use to meet their biological, economic, emotional, and social needs that typically reflect their attitudes, beliefs, and values" (Bell, 2014). Regarding the energy transition, studies have focused on defining lifestyles based on the carbon footprint (Ivanova et al., 2017; Ivanova & Wood, 2020) and identified those with the smallest tend to be the poorer. However, most European lifestyles are typically associated with a higher carbon footprint, meaning households must embrace several behavioural changes when aiming to mitigate GHG emissions.

Household lifestyles differ based on preferences and related expenditures in certain domains (Akenji et al., 2021; Ivanova et al., 2017; Ivanova & Wood, 2020), i.e. food, housing, transport, goods, leisure, and services, as the most common ones (Akenji et al., 2021). In Europe, there is a strong correlation between carbon emissions and economic aspects, making lifestyles mainly dependent on income and expenditure, plus some other factors such as urbanisation degree (Ivanova et al., 2017; Ivanova & Wood, 2020).

The household expenses are distributed across the domains, showing the households' proportional preferences and needs. Usually, that proportional distribution changes for different income groups. For example, the more income a household receives, its share of the services domain increases, while the percentage spent on food remains stable or decreases (see Figure 2). The more a domain increases its share concerning the absolute expenditure of different household groups, the more elastic it is. This phenomenon is known as elasticity.

The least elastic domains are associated with basic needs, as those are the ones households must, in all cases, spend money on to live. Contrastingly, those with higher elasticity are associated with luxuries, as households will go from being unable to afford them to including them as a part of their lifestyle. Typically, food and housing are the least elastic domains and, thus, represent basic needs (Ivanova et al., 2017; Ivanova & Wood, 2020). The poorer a household is, the higher the share of their expenditure for basic needs, i.e., their spending on goods in the basic domains. However, for specific social groups, other factors can also define basic needs, such as transport, which is important for rural households.

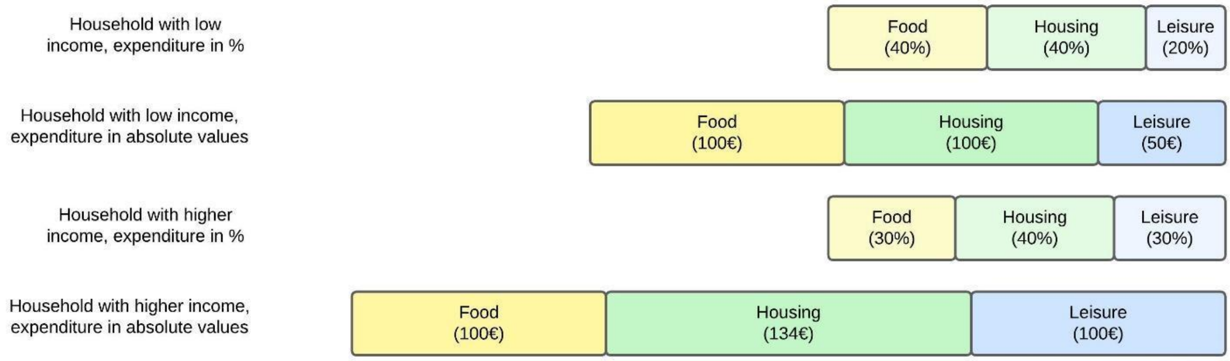


Figure 2: Example of elasticity. Even though the absolute values increased (Bars 2 and 4, full colour), the share (Bars 1 and 3, in mild colors) of Food and Housing did not increase. Meanwhile, the expenditure share ("exp" in the picture) in the Leisure domain increased significantly. Source: Authors.

Identifying basic domains is relevant to understanding how transitioning to low-carbon lifestyles might create energy poverty, as increased costs in basic domains might put the poorest households at risk of energy poverty: at-risk-of-energy-poverty households should typically choose between spending their resources on keeping their homes warm or providing themselves with other basic services (Carley et al., 2022). It poses a dilemma with relevance to the current energy poverty thresholds, as some households might prefer not to spend money on keeping their house warm in exchange for accessing other basic domains, such as food, transport, or healthcare (Carley et al., 2022; Cong et al., 2022; Diaz-Barriga & Barnhart, 2022; Drago & Gatto, 2023; Fry et al., 2023).

Eurostat's Household Budget (HBS) provides detailed data on expenditure distributions of different types of households in twelve domains and subdomains. The households are categorised in the data according to four household characteristics: per income quintiles, urbanisation degrees, age ranges, and family structures (with and without dependent children). This dataset structure allows us to identify the most basic domains for each household group. Two conclusions can be reached: (1) from the elasticity perspective, the results are consistent with the literature, showing Housing – including energy expenses – and Food as basic domains for all identified groups. (2) Contrastingly, the share distribution of different domains shows relevant changes when analysing different household types within the same categorisation – e.g., lowest income quintile vs. highest income quintile or younger than 30 vs. older than 65. In that sense, transport spending is particularly high for rural areas. Health and social services are an important domain for people older than 65, while education is taking a huge part of the share for those households with dependent children. No data is available to analyse how lifestyles differ according to gender, ethnicity or migration.

Figures 3 to 6 show the distribution of household expenses for different types of households in twelve different domains[1]:

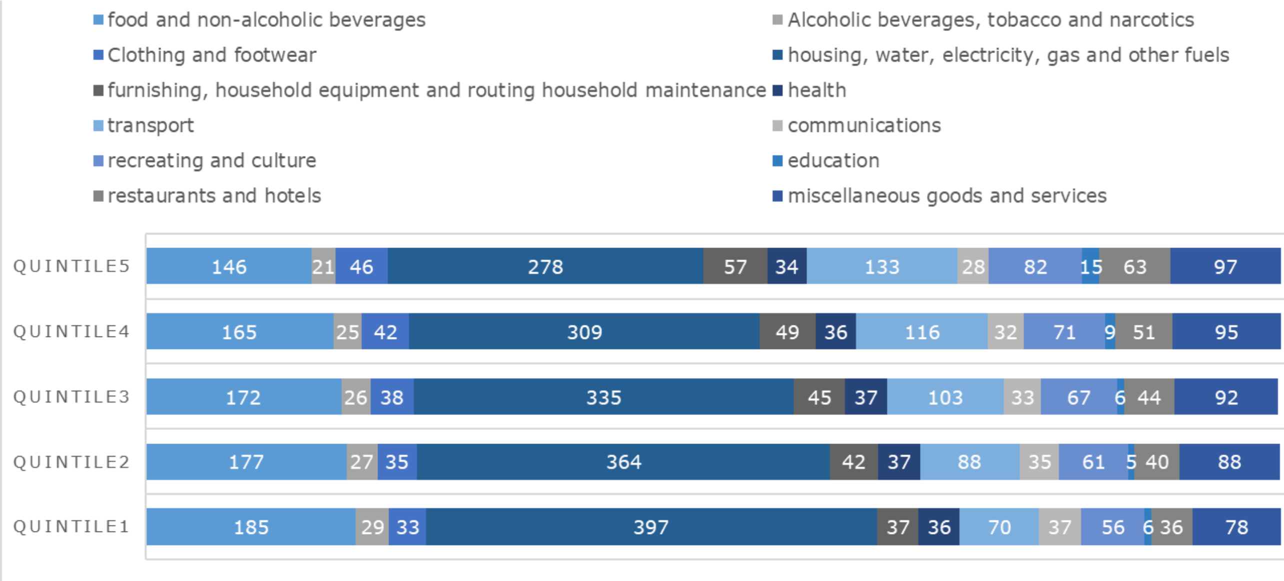


Figure 3: Average share of expenditure (parts per thousand) distribution in domains of the different income quintiles. Quintile 1 is the lowest income quintile. Source: Authors. Data: HBS for 2020 - Eurostat (2022f).

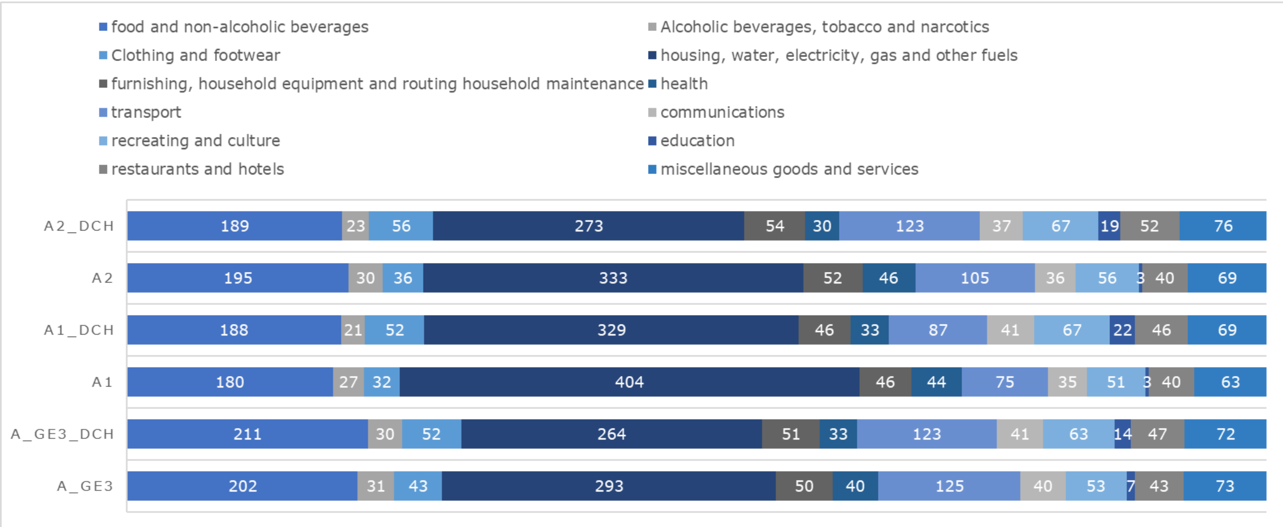


Figure 4: Average share of expenditure (parts per thousand) distribution in domains of the different family structures. A1: single adult; A2: two adults; A3: three adults; when _DCH: the structure also has dependent children. Source: Authors. Data: HBS for 2020 - Eurostat (2022g).

[1] The expenses are distributed in twelve different domains: Food and non-alcoholic beverages (CP01); Alcoholic beverages, tobacco and narcotics (CP02); Clothing and footwear (CP03); Housing, water, electricity, gas and other (CP04); Furnishing, household equipment and housing maintenance (CP05); Health (CP06); Transport (CP07); Communications (CP08); Recreating and culture (CP09); Education (CP10); Restaurants and hotels (CP11); and Miscellaneous good and services (CP12).

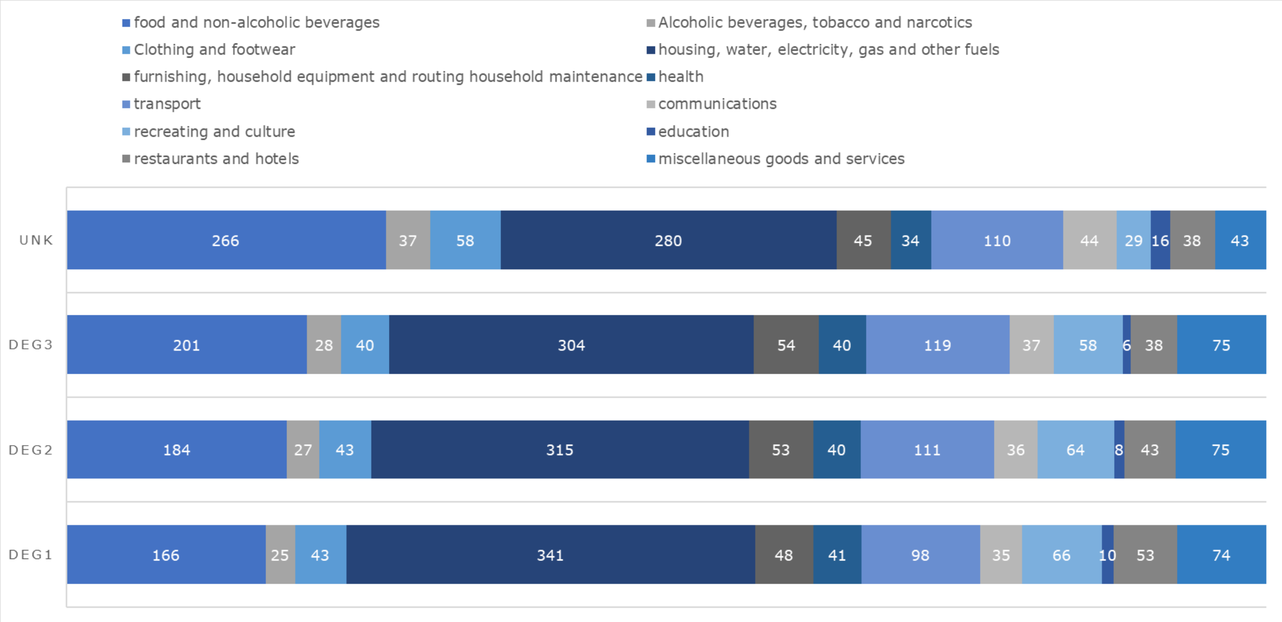


Figure 5: Average share of expenditure (parts per thousand) distribution in domains of the different urban-rural types, being DEG3 rural, DEG2 intermediate, and DEG1 urban. Source: Authors. Data: HBS for 2020 - Eurostat (2022i).

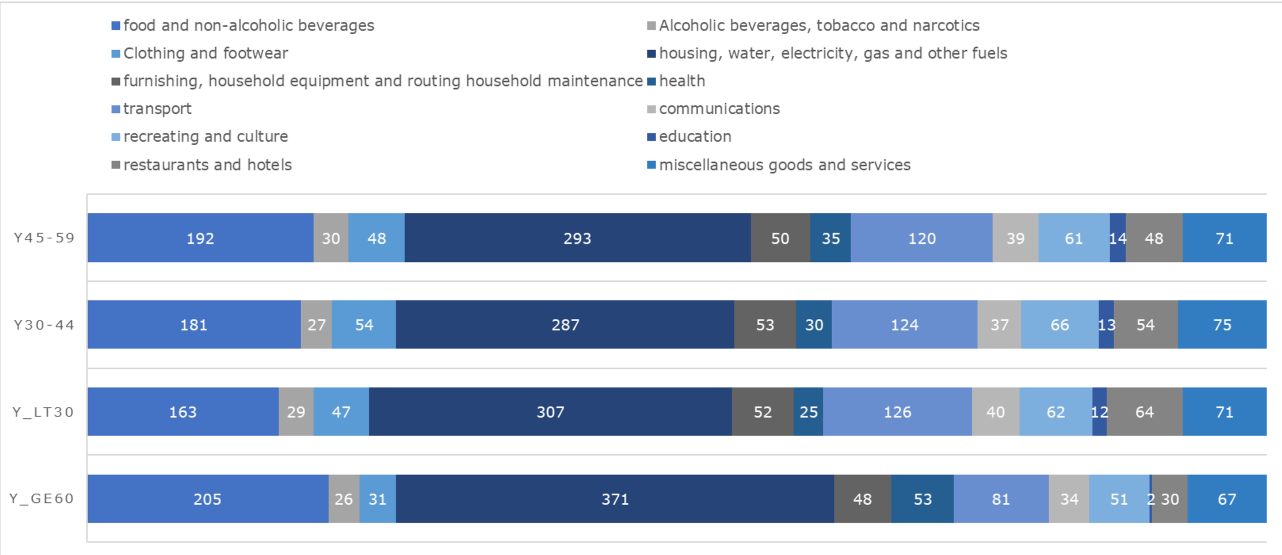


Figure 6: Average share of expenditure (parts per thousand) distribution in domains of the different age ranges. Y_LT30: less than 30; Y_GE60: older than 60; Y30-44: between 30 and 44; Y45-59: between 45 and 59. Source: Authors. Data: HBS for 2020 - Eurostat (2022h).

3.2. Causal indicators of energy poverty due to low-carbon options

Even though falling outside the category of energy-poor citizens, some groups might still be *at risk* of energy poverty. Several studies have been conducted within the European context to map the energy poverty issue. Research and reports map the current state of energy poverty throughout the continent. However, fewer outcomes focus on mapping the underlying reasons behind that societal problem. As explained, this report aims to disentangle how low-carbon transition and implementing climate actions might produce energy poverty by impacting citizens' lifestyles.

More insights are needed to relate energy poverty indicators in the proper cause-effect relationship (Gouveia et al., 2023) – e.g., which indicators can measure the current level of energy poverty, and which ones can measure the needed conditions for energy poverty to appear. The study starts by qualitatively analysing the shortlist of indicators provided by the EPAH report (Gouveia et al., 2023), splitting those that act as causes from those that are a consequence. Some examples can be found in Table 7.

Table 7: Examples of how indicators can be a cause or a consequence of energy poverty. Source: Authors, interpretation of the list of Gouveia et al., 2023

Topic	Subtopic	Indicator	Cause	Consequence
Climate		Cooling degree days	Cooling or heating degree days are causal factors of energy poverty, influencing energy consumption.	-
		Heating degree days		
Facilities / Housing	Building stock	Dwellings with energy label A	Causal factor of energy poverty, as they influence the consumption of energy.	-
		Final consumption expenditure of households	-	It will vary depending on other indicators, such as heating or cooling degree days or the efficiency of the dwelling.
Socioeconomic aspects	Socioeconomic and living conditions	Arrears on utility bills	-	Prices, income, needs of the household, etc, condition it.
		At risk of poverty or	-	A consequence of many other factors.

		social exclusion		
	Energy expenditure and energy markets	Energy expenses by income quintile	-	Prices, income, needs of the household, etc, condition it.
		Energy prices	It is a cause. The higher the price, the more expenditure and the more difficulty paying.	-

Once brought into a correct cause-effect relation, those indicators influenced by the energy transition and/or the implementation of climate actions need to be identified. Since little information is given to explain how those might be the underlying reasons behind the energy poverty phenomenon, a systematic literature review has been conducted - details can be found in Appendix A.1. (Table 19).

Two types of indicators are detected based on their target: (a) those that describe populations and their characteristics and (b) those that map regional characteristics and infrastructure conditions – Table 8. All citizens will be exposed to potential lifestyle changes due to the low-carbon transition. Infrastructure and systemic changes can impact everyone in any lifestyle domain. However, not all citizens are equally exposed to those changes and have the same capacity to adapt (Amorim-Maia et al., 2022; Hanke et al., 2023; Swanson, 2021), such as women, marginalised communities, elderly, children, disabled, or people with low incomes. Table 9 summarises the groups more likely to suffer the side effects of societal changes, especially those related to energy transition and mitigation. Details on the literature can be found in Appendix A.1. (Table 19).

Table 8: Types of indicators found in the literature review, followed by definitions and examples. Source: Authors.

Type	**Definition**	**Example**
Population characteristics	Define the characteristics of population or region groups	Disabilities (Kato-Huerta et al., 2023), immigrants (Cunha & Silva, 2023), uneducated (Tschakert et al., 2023)
Systems and infrastructure	Define the characteristics of infrastructure or the region	The type of region (Lacey-Barnacle et al., 2020), the exposure to hazards (Tamasiga et al., 2023), the dependency on industries (Garvey et al., 2022), institutional support (Amorim-Maia et al., 2022)

The most common regional systems and infrastructure indicators related to energy poverty due to the transition to a low-carbon Europe as: energy accessibility (Hughes & Hoffmann, 2020; Kalt & Tunn, 2022; Lacey-Barnacle et al., 2020; Lippert & Sareen, 2023; Upham et al., 2022), decentralisation and diversification of energy production (Garvey et al., 2022; Lacey-Barnacle et al., 2020; Wang & Lo, 2021), energy affordability (Hanke et al., 2023; Upham et al., 2022; Wang & Lo, 2021), and energy costs (Dwarkasing, 2023; Hanke et al., 2023). Besides those, several other different drivers are related to institutional capacity and governance, such as the dedication of funding and the type of government (Wang & Lo, 2021) or corruption (Lacey-Barnacle et al., 2020). Scholarly literature acknowledges the importance of distributive, procedural, and recognitional aspects, bringing into the discussion impacts on health and safety (Shelton & Eakin, 2022) and gender inequity and marginalised communities (Lacey-Barnacle et al., 2020).

When integrating the lifestyle domain perspective, searching for relevant indicators that might cause a forced decrease in food, housing, transport, health, and education accessibility, literature shows strong evidence of the multidimensionality of energy poverty (Cong et al., 2022; Diaz-Barriga & Barnhart, 2022; Drago & Gatto, 2023). There are empirical analyses of the relationship between poverty and expenditure in the food, housing, and transport domains (Alonso-Epelde et al., 2023; Diaz-Barriga & Barnhart, 2022; Fry et al., 2023). However, even though health issues might be a consequence of energy poverty (Gouveia et al., 2023), there is a lack of data on studying how pressure in healthcare systems and education is specifically related to energy poverty. The final shortlist of indicators defining the risk of energy poverty due to low-carbon lifestyles, their definition, references, and data availability can be found in Table 9.

Table 9: Final shortlist of indicators identified that might increase the risk of energy poverty due to changes in household lifestyles due to low-carbon transition. Source: Authors.

Category	Indicator	Definition	Unit	Reference
Infrastructure and regional characteristics	Energy accessibility	Refers to the availability of energy infrastructure. *In Europe, it is mainly related to households' economic capacity.* *It can be conceptually divided into the following two indicators.*	Proxy indicator: Energy affordability	(Hughes & Hoffmann, 2020; Kalt & Tunn, 2022; Lacey-Barnacle et al., 2020; Lippert & Sareen, 2023; Upham et al., 2022)
	Decentralisation and diversification of energy production	Linked to resilience potential. Local and diversified energy production ensures system resilience.	Share of the main producer – Eurostat +	(Garvey et al., 2022; Lacey-Barnacle et al., 2020; Wang & Lo, 2021)

		It depends on several factors. It can be measured by analysing the share of producers, dependency on fossil fuels, and energy imports.	Share of energy imports – Eurostat + Share of renewable energy consumption – Eurostat	
	Energy affordability	Refers to the amount of energy households can afford with their current capacity. *It can be measured by comparing energy prices to the income that households are spending on energy. It is important to compare with other building and climate indicators, such as the number of buildings with A-labels or cooling and heating degree days.*	Electricity prices – Eurostat + Gas prices – Eurostat + Household Budget Expenditure Survey – Eurostat + Income of households – OECD, Eurostat	(Hanke et al., 2023; Upham et al., 2022; Wang & Lo, 2021)
	Food Security 1	Having access to a minimum amount of food covering basic nutrition needs. *Several units can be useful to measure it. The population who cannot afford a healthy diet could be one, and a normalised food price index takes expenses in food into account, too.*	Food price index variation regarding 2015 – Eurostat, FAO + Population who cannot afford a healthy diet – Eurostat	(Cong et al., 2022; Diaz-Barriga & Barnhart, 2022; Drago & Gatto, 2023; Fry et al., 2023)
	Housing affordability 1	It relates the price of sqm to the income of the population. *Measure the €/sqm per region and compare it to the household expenditure and income.*	€/sqm rent - Numbeo	(Diaz-Barriga & Barnhart, 2022)
	Institutional capacity and type of government	Refers to the ability of the administration to cope with the issues related to energy poverty.	No data are available.	(Lacey-Barnacle et al., 2020; Wang & Lo, 2021)

Basic domains' relation with energy expenditure		The relation between basic domains and energy expenditures becomes central when analysing the thresholds of energy poverty. *It can be measured by looking at the correlation between expenses in basic domains and energy. Then, we will analyse those close to the energy poverty threshold.*	Household Budget Expenditure Survey – Eurostat	(Cong et al., 2022; Diaz-Barriga & Barnhart, 2022; Drago & Gatto, 2023; Fry et al., 2023)
Population characteristics	Income	Disposable income (e.g., income after taxes) would be useful to define access capacity to services for different household groups. Also, it is closely related to energy poverty. *Median income for different household and demographic groups gives hints about the conditions of each group. Median income is also used to define poverty thresholds in Europe.*	Household Budget Expenditure Survey – Eurostat + Income of households – OECD, Eurostat	(Amorim-Maia et al., 2022; Cunha & Silva, 2023; Kashwan, 2021; Lawrance et al., 2022; Mintz-Woo, 2023; Swanson, 2023; Tschakert et al., 2023)
	Gender inequity	Gender inequity causes increased vulnerability for certain population groups, e.g., women. *Looking at differences in income groups per gender and mapping the population representation would be useful to assess it.*	Not available. Proxy indicator: Population by Gender – Eurostat	(Amorim-Maia et al., 2022; Lacey-Barnacle et al., 2020; Lawrance et al., 2022; A. Srivastava et al., 2021)
	Ethnicity	Ethnicity determines vulnerability, as minority groups or immigrants tend to face more issues in economic and accessibility terms. *Looking at differences in income groups per country of origin and mapping the population representation would be useful to assess it.*	Population by country origin – Eurostat	(Amorim-Maia et al., 2022; Cunha & Silva, 2023; Kashwan, 2021; Lawrance et al., 2022; Mintz-Woo, 2023; Swanson, 2023; Tschakert et al., 2023)
	Housing conditions and tenure	Housing conditions refer to the ownership of the property. When speaking about implementing climate action, it impacts the	Distribution of households – Eurostat	(Amorim-Maia et al., 2022; Kato-Huerta & Geneletti,

		capacity of making changes to a dwelling. *Looking at how incomes differ between owners and renters could help disentangle the issue, also disaggregating by gender and age.*		2023; Rao et al., 2023)
	Elderly and children	Elderly and children are facing increased energy poverty risk and impacts due to their extra needs for health, services, and education, among other reasons. *Understanding their economic capacity, but also the capacity of families with elderly and children, would help map them and understand their role.*	Population by age and gender – Eurostat	(Al-Jawaldeh et al., 2022; Amorim-Maia et al., 2022; Cunha & Silva, 2023; Lawrance et al., 2022; Swanson, 2021; Tschakert et al., 2023)

3.3. Benefits of properly implemented mitigation

The decarbonization also provides opportunities. For example, being forced to share a car might be seen as a loss of independence for some households, but it might provide several economic benefits, particularly for those living in rural areas (Narayanan & Antoniou, 2022). Similarly, properly implemented mitigation measures can also positively impact certain vulnerable households' lifestyles through improving environmental and energy conditions (Santamouris & Kolokotsa, 2015). Enhancing energy quality might even produce more benefits to low-income population than a potential increase in energy costs (Santamouris, 2016).

Some vulnerable groups might particularly benefit from specific changes in a domains' infrastructural systems. For instance, regarding the transport sector, increasing and improving public transport infrastructure can benefit gender minorities, as they are less likely to own private vehicles (Torné & Trutnevyte, 2024). Adopting remote-working strategies, even though it might translate into an increase in the housing energy bill, can provide several benefits for women and people with care responsibilities, as it offers them higher flexibility to deal with family responsibilities (Giovanis, 2018). Therefore, following the same logic, even though climate action might cause energy-poverty through citizens' lifestyles, it can improve other aspects related to living circumstances and livelihoods when properly implemented.

3.4. Defining risk of energy poverty due to low-carbon lifestyles: Conceptual framework

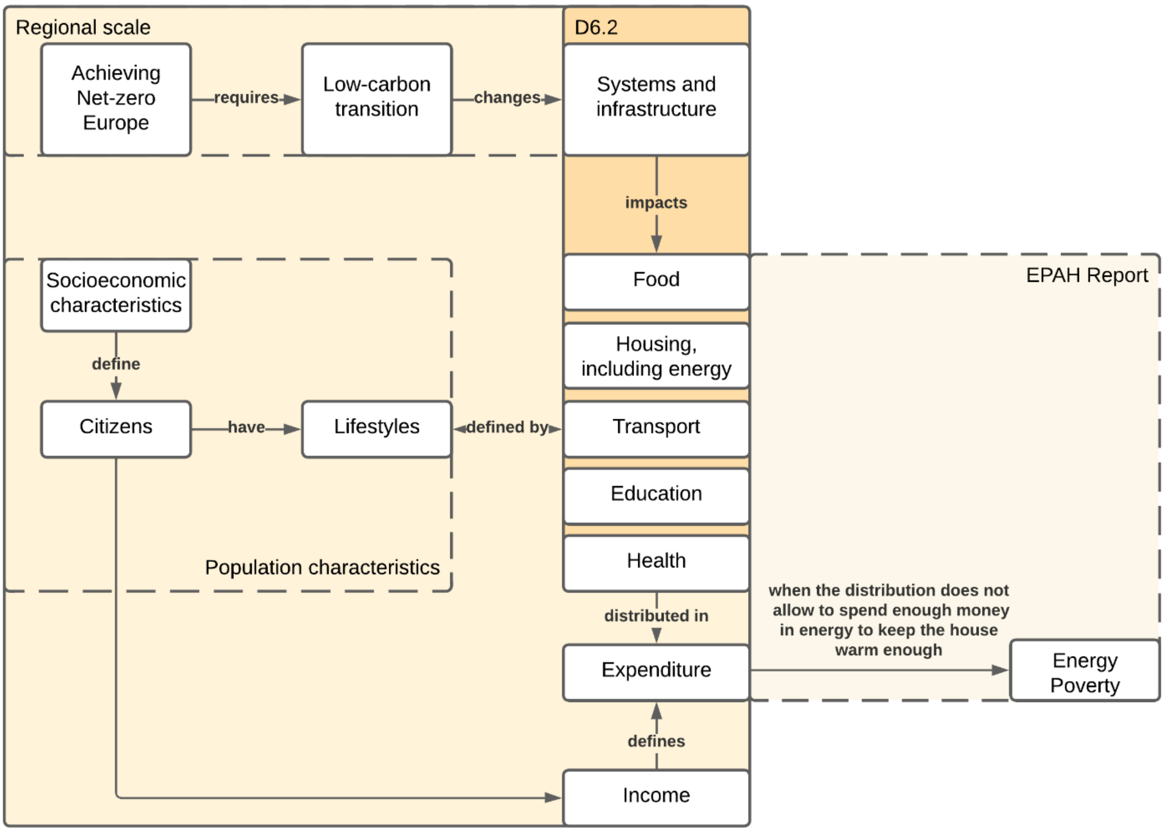


Figure 7: Conceptual framework of how the risk of energy poverty might increase due to changes in lifestyles brought about by the low-carbon transition. Source: Authors.

The findings of the previous paragraphs can be summarised in Figure 7. On the one hand, European citizens' lifestyles can be defined based on expenditure in different domains (Akenji et al., 2021; Ivanova et al., 2017). Five of them are considered basic domains for different household types and population groups (as seen above): food, housing, and transport essential for all populations, education for those with dependent children, and health and social services for elderly people. When households spend all their money on basic domains, they will likely lose flexibility in coping with the changes due to the low-carbon transition (Ivanova & Wood, 2020). Moreover, some socioeconomic characteristics entail a higher risk of becoming energy-poor due to structural injustices.

On the other hand, any of these domains might suffer changes due to the transition to a low-carbon Europe, resulting in unexpected externalities that might impact households' accessibility to them. Ultimately, these changes can also produce changes in citizens' lifestyles.

4 Results: Identifying vulnerable groups with an increased risk of energy poverty due to low-carbon lifestyle options

This section first presents how systemic and infrastructural changes introduced in regions and countries – e.g., climate mitigation measures and instruments – might stress basic domain accessibility. Later, it presents how expenditures of different household types and their lifestyle changes relate to energy poverty. Finally, it zooms into the identified vulnerable household types to understand how they are demographically characterised and distributed.

4.1. The regional approach: Infrastructure characteristics

Transitioning to a low-carbon Europe implies societal and infrastructural changes (Newell et al., 2022). Adaptation and mitigation measures or instruments might have an impact on regional characteristics. Those impacts can also be side-effects, producing externalities on regional infrastructure and systems that might ultimately impact citizens. Potential externalities can produce changes in the accessibility of domains, meaning citizens must adapt their lifestyles and, therefore, be at a certain risk of becoming energy poor. This section analyses the risk of becoming energy-poor from an infrastructural and regional perspective. The analysis is conducted for basic domains, assuming that, in Europe, accessibility is closely related to affordability.

4.1.1. Energy accessibility

The resilience of the energy systems might help avoid externalities. In Europe, accessibility to energy infrastructure is mainly conditioned by income. However, improving or worsening energy accessibility is conditioned by the stability of the energy market. An unstable market might result in an undesired externality, like increased household energy prices. Even though resilience relies on several factors, decentralisation and energy diversification are the most widely acknowledged (Garvey et al., 2022; Lacey-Barnacle et al., 2020; Wang & Lo, 2021).

From the infrastructure perspective, decentralisation and energy diversification have become highly relevant. However, picturing the state of it is not straightforward. Eurostat offers several energy infrastructure indicators, such as the Share of the Main Producer of Energy (Figure 8), the Share of Renewable Energy in final consumption (Figure 9), and the Share of Imports in Energy (Figure 10). The first shows the share of energy production that depends on the main producer. The higher the share of the main producer, the more dependent the system is on a single energy producer. When discussing resilience, more dependence on one producer indicates that any impact it suffers might have a wide impact. The share of Renewable Energy in final consumption is useful to indicate how much final users rely on which type of fuel. The more the final users rely on fossil fuels, the more changes the system needs to suffer; hence, there are more chances to impact accessibility when phasing them out potentially. Finally, European countries depend on imported energy from third-party countries. Localising energy production is essential to ensure a resilient energy system. The more a country reduces its dependence on external factors, the more resilient it is.

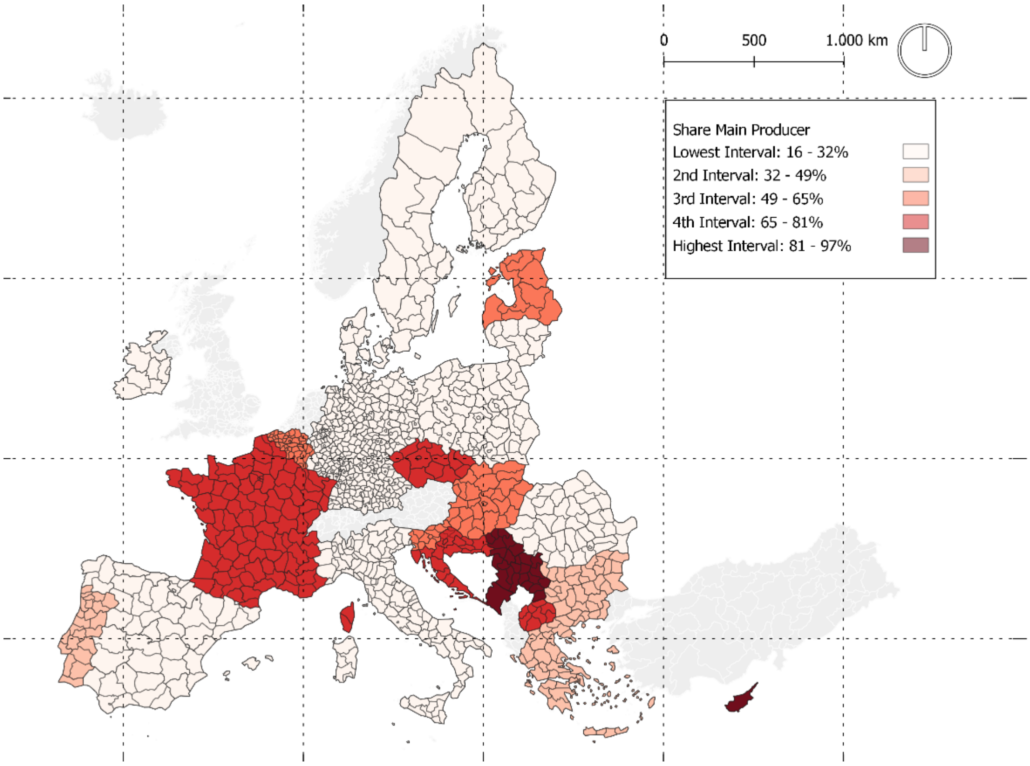


Figure 8: Share of the Main Producer in 2020. The higher the share of one producer, the higher the likelihood that potential negative consequences will have a wide impact. Source: Authors. Data: Eurostat (2022a).

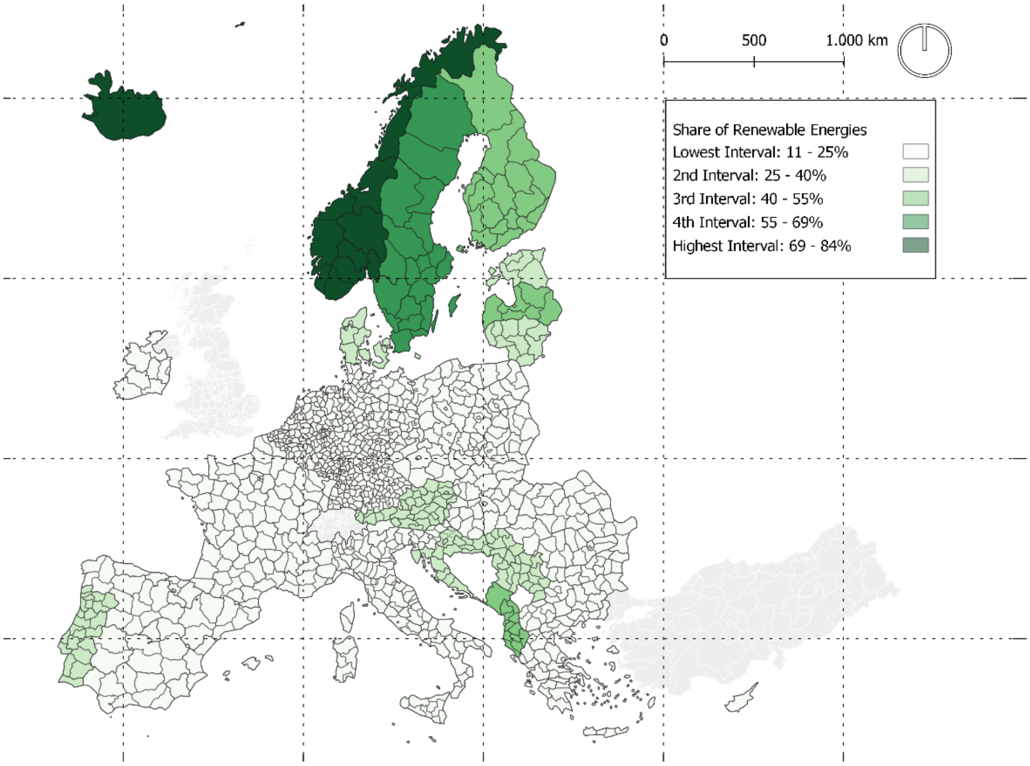


Figure 9: Share of Renewable Energies in energy consumption in 2020. The more a country depends on Renewable energies, the fewer changes they will need to deal with. Source: Authors. Data: Eurostat (2022b).

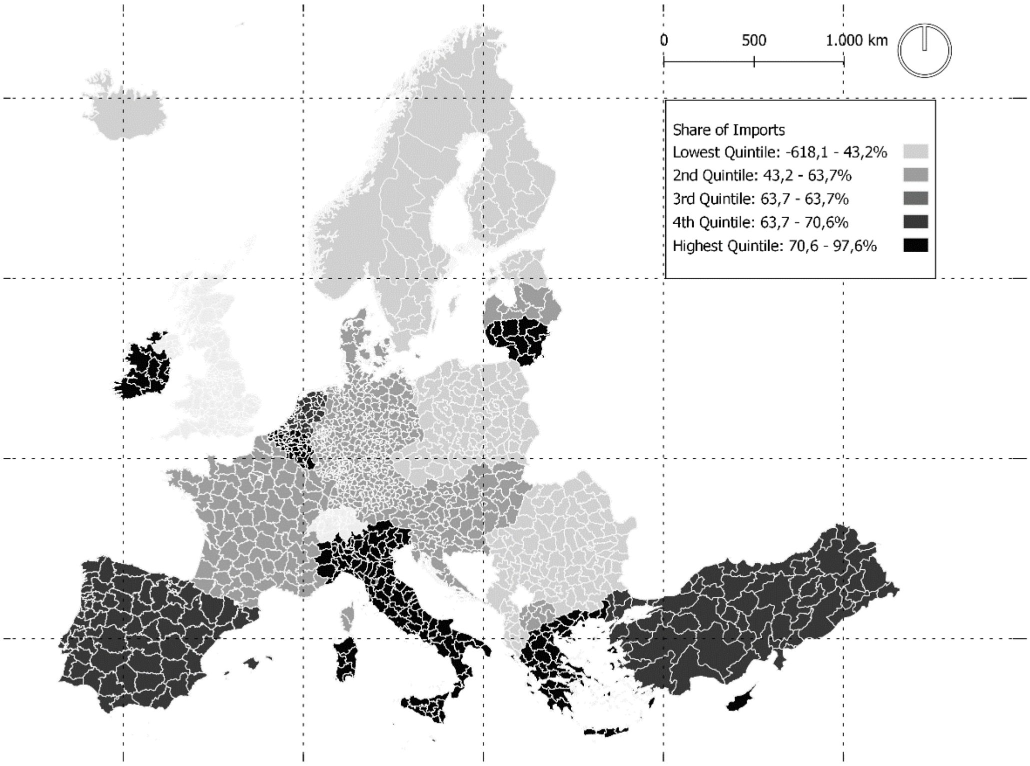


Figure 10: Share of Imports in 2020. The more a country depends on external sources, the higher the risk of unexpected changes or events. Source: Authors. Data: Eurostat (2022c).

Combining the three indicators offers a clear picture of the energy system's resilience. It can be conceptualised in the diagram in Figure 11, where each triangle vertex represents the maximum share (100) in the three indicators: Share of Main Producer, Share of Non-RE in final consumption (e.g., 100 - Share of Renewable Energies), and Share of Imports. When using it as a geometrical space, the value of each indicator can be placed in the imaginary line going from the centre of the triangle to the vertex, transforming it into an informative spider chart. There, the area of the smaller triangle can also be used as a composite index. Thus, the smaller the area, the more resilient the energy system will be to changes and the lower the risk of energy poverty for vulnerable households. Figure 12 shows how Balkan countries and France have a less resilient energy system. When looking into the details, the main issue in France is an extremely high share of the main producers, while Balkan countries are highly dependent on third-party imports.

$$
\begin{aligned}
Area = ABS|cos30 * Share\_of\_Main\_Producer * ((-Share\_of\_non\_Renewable\_Energies \\
* sin30) - (100 - Share\_of\_Imports))) + (-cos30 \\
* Share\_of\_non\_Renewable\_Energies * ((100 - Share\_of\_Imports) \\
- (-Share\_of\_Main\_Producer * sin30))))/2|
\end{aligned}
$$

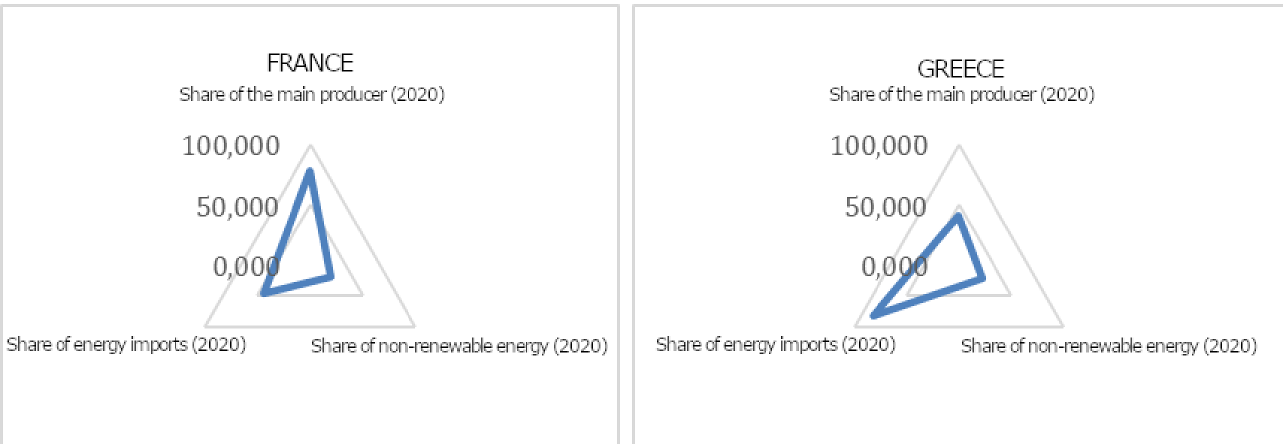


Figure 11: Equation and graphical representation of the risk of negative impacts on the energy systems. France and Greece are both at risk due to different characteristics. Source: Authors.

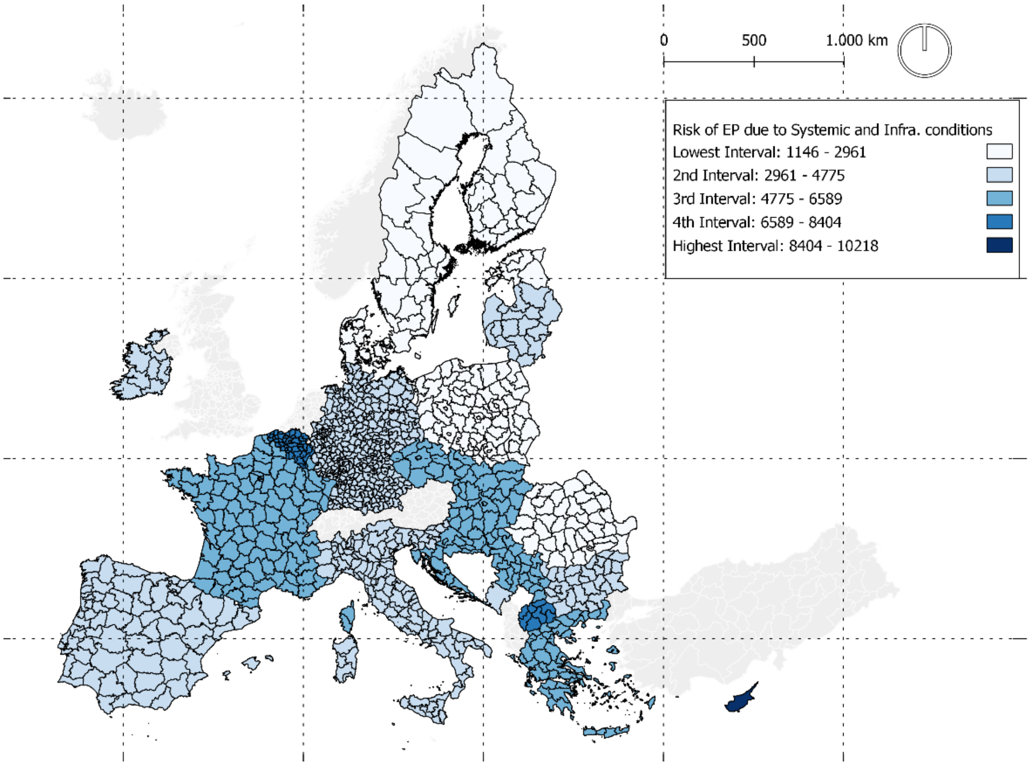


Figure 12: Total risk of energy poverty due to systemic and infrastructural conditions in 2020. Source: Authors.

4.1.2. Affordability of domains

The EPAH Report (Gouveia et al., 2023) suggests several affordability-related indicators, such as energy prices or final energy expenditure. However, their interpretation is attached to contextual factors. Thus, some must be normalised to make them comparable.

Households' purchasing power varies according to countries and regions. The combination of energy prices, % of expenditure on energy, and disposable income in a single index shows the amount of energy units (kWh) a household can afford. It might be used as a proxy indicator of energy affordability.

Energy Purchases Index (EPI) = 1/(Energy price, in €/kWh) * (disposable Income * % of expenditure in Energy)

Figure 13 sets an example of the calculation, using the average relative expenditure in energy, the average income, and the average energy prices for the DD band[2] (5000-14999kWh) for different European regions. The map shows the theoretical amount of energy units households are purchasing, on average, in the different regions. However, the map hides certain uncertainties, as some institutional and contextual factors might

[2] Household energy price data is divided into five bands according to their kWh consumption. For DD Band, customers consume 5000kWh or more but less than 15000kWh. It is the band where European households typically fall in.

not be considered. Thus, Section 5.1 will compare the maps obtained with other energy poverty indicators by EPAH.

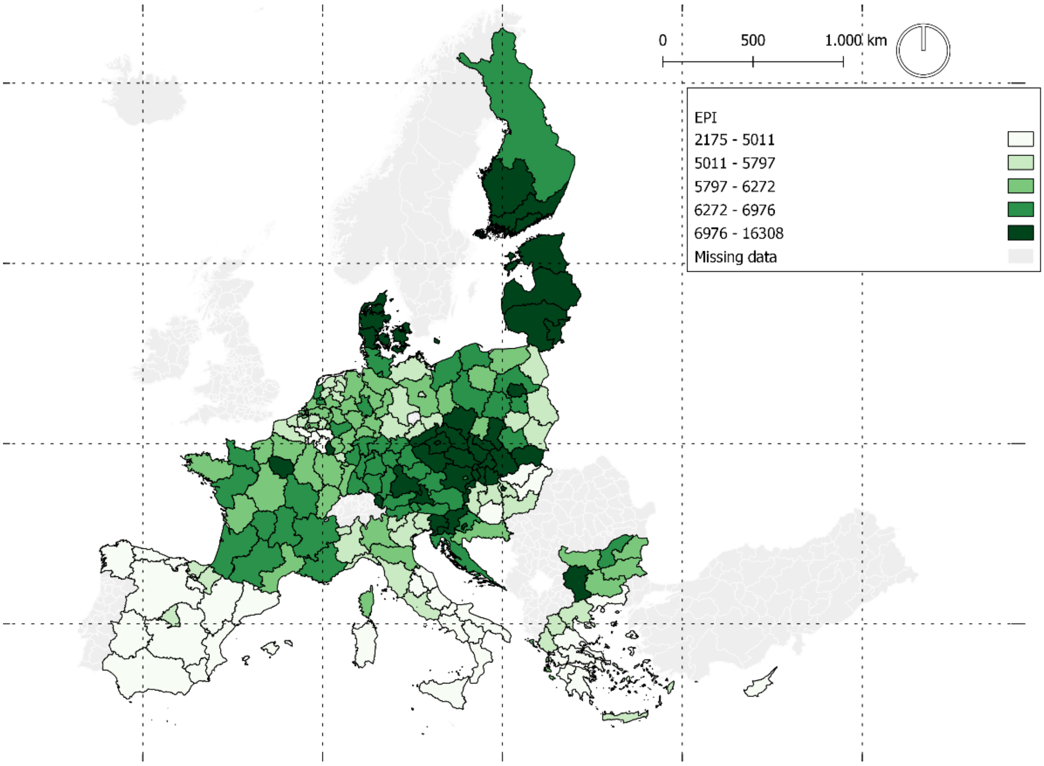


Figure 13: Energy Purchase Index map in 2020, showing the amount of energy a household typically purchases per month using average income data. Source: Authors Data: Eurostat (2022f; 2022d; 2022t).

As explained, energy poverty is a multidimensional issue. Thus, analysing the affordability of other basic lifestyle domains is also essential. Households suffering more pressure to access basic services might be more vulnerable to energy poverty due to their need to choose which domain deserves more effort. Housing and food are shown to be basic domains for all households (Ivanova et al., 2017; Ivanova & Wood, 2020). Thus, normalising the affordability of those domains within countries and comparing them to energy affordability can help disentangle which households will be at a higher risk of the eat-or-heat dilemma. Table 10 shows how food or housing systems might be impacted by low-carbon transitions and decrease households' accessibility to them.

Table 10: Potential regional impacts that might worsen basic domain accessibility. Source: Authors.

Domain	Description	Potential impacts
Energy	Switching to renewable energy production might create injustice by switching consolidated energy and economic systems to new systems with potentially less capability to manage externalities (N. Srivastava & Kumar, 2022). Besides, decentralised energy systems help ensure equal distribution and energy justice in energy transition (Lacey-Barnacle et al., 2020). Finally, local energy production brings aspects of accessibility and environmental, procedural, and recognitional justice into the transition.	Higher costs due to changes in energy production (Hanke et al., 2023; Shelton & Eakin, 2022).
Food	Energy needs influence food accessibility, as some households need to cover both basic needs with a low income (Carley et al., 2022; Cong et al., 2022). Moreover, affordability and availability of water and energy greatly impact food production (Bamisile et al., 2023).	Higher food production costs. Food restrictions.
Housing	Housing infrastructure and building stock are important dimensions of the energy poverty issue (Amorim-Maia et al., 2023). Moreover, housing is a basic need, so households must deal with it.	Higher housing prices.

Any change in the food supply chain might impact food prices and put more pressure on households through the food domain. When normalised, the Food Price Index can also be useful to visualise how much stress households suffer in the food domain. Food price indexes (FPI) can be normalised using the expenditure in the food domain. When multiplying the FPI by the relative expenditure in the food domain, the resulting number will indicate how stressed households are due to inflation by indicating the real % of household expenditure they would need to spend to afford the same amount of food they could obtain in 2015 while spending the same %, as shown in Table 11.

Table 11: Example of a normalised index for the Food Domain. Source: Authors. Data from FAO, from 2020.

	Country A	Country B
Expenses in the Food Domain (2020)	25%	25%

FPI (base year 2015)	1.15	1.30
Real affordability	1.15 * 0.25 = 28.75%	1.30 * 0.25 = 32.50%
Interpretation	To purchase the same amount of food as in 2015, households must spend 28.75%.	To purchase the same amount of food as in 2015, households must spend 32.50%.
Conclusion	This means that households in country B are now under higher pressure regarding food acquisition than in country A, even though they both spend 25% of their expenses.	

Figure 14 shows the geographical distribution of such an index. due to the availability of the data, no differences between regions within the same countries can be observed.

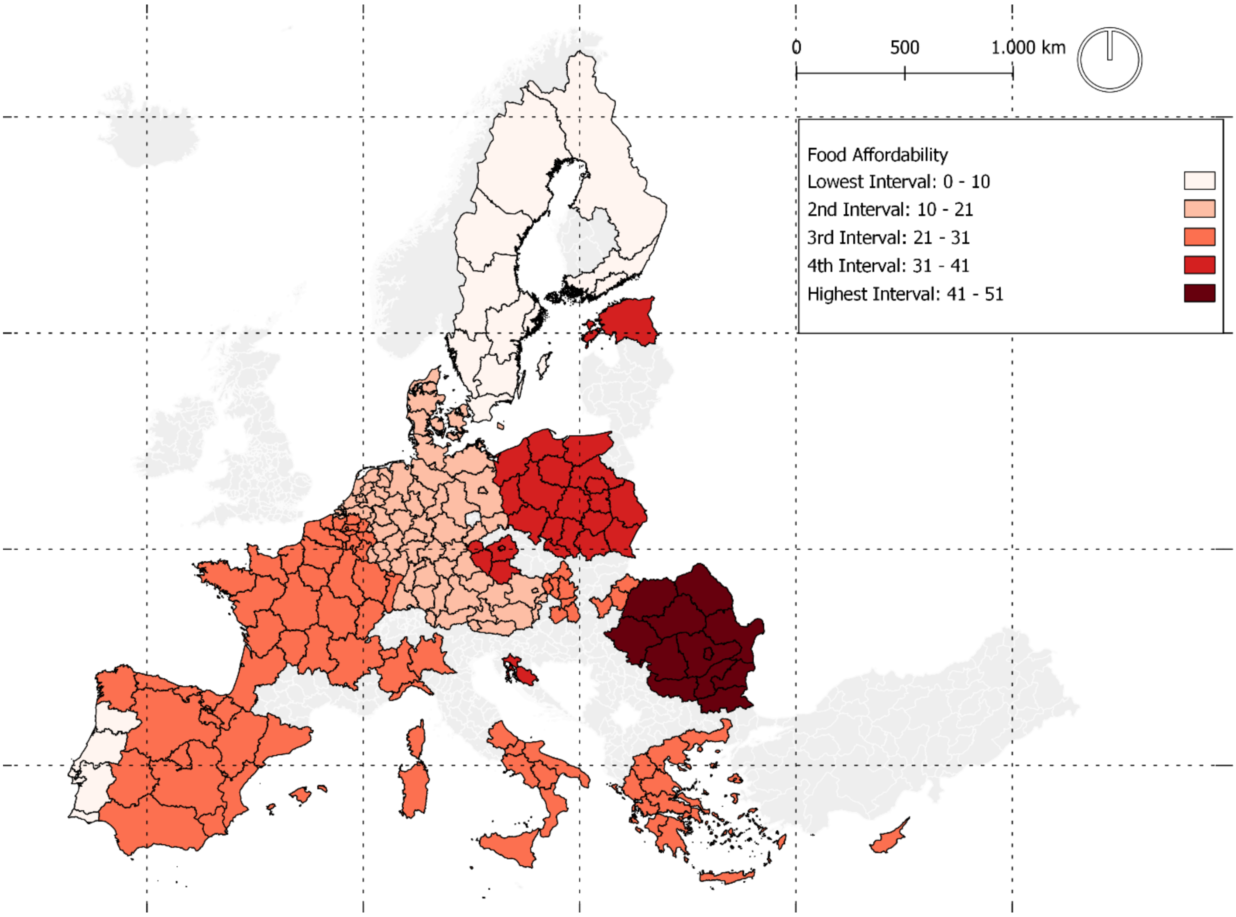


Figure 14: Normalised Food Price Index in 2020, using average expenditure in the food domain, average income per region, and national FPI. Source: Author. Data: Eurostat (2022i; 2022p).

Similar to the previous analysis, conducting the same procedure with the housing domain is possible. When taking the price per sqm (rent), expenditure in housing, and average income per region, an index of housing affordability shows how much space households can afford per month (Figure 15). A tentative overview is provided in Figure 15, using housing data from a third-party source in 2023 for renting a 3-room apartment close to the city centre. Even though that last one is not immediately comparable to previous maps due to date mismatching, results for the whole subsection will be in Section 8.

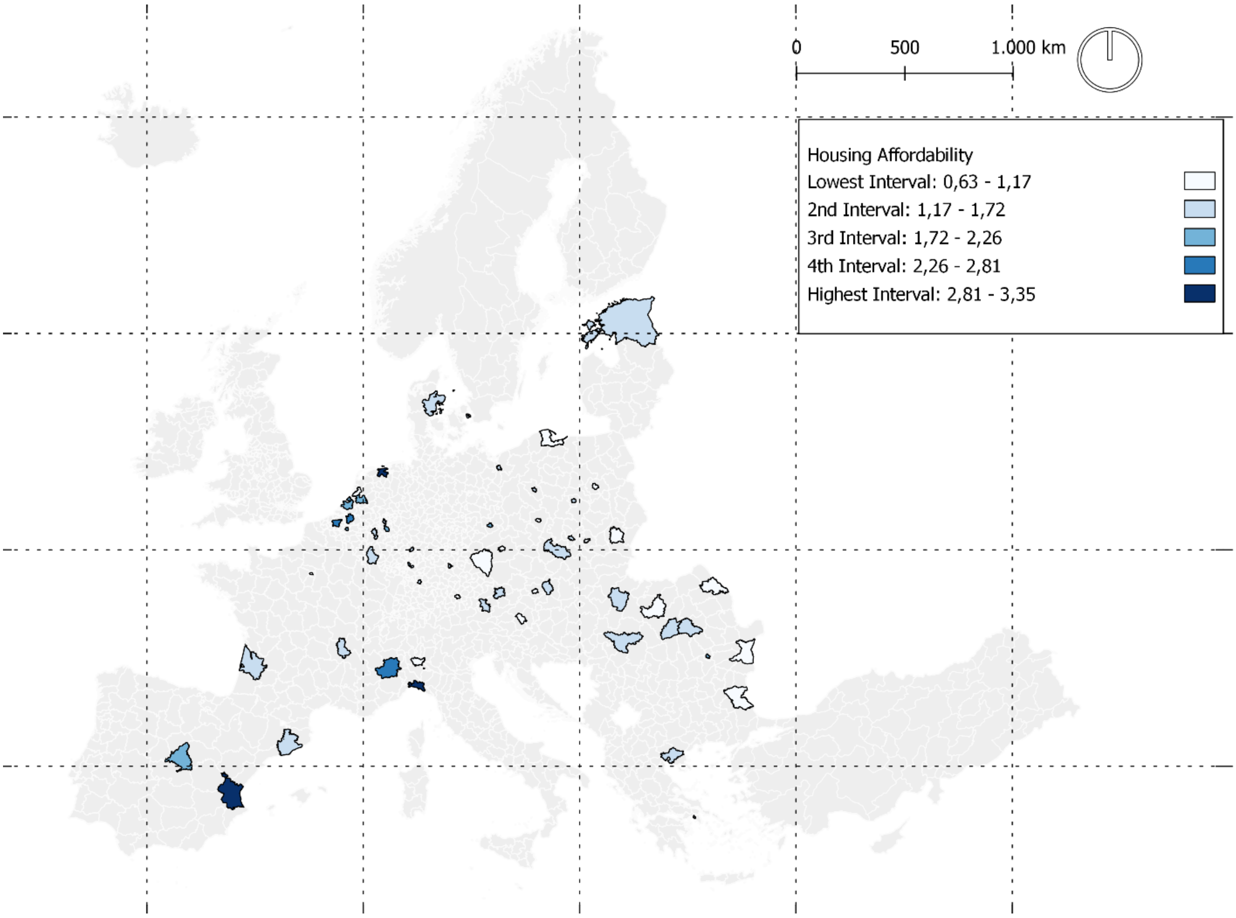


Figure 15: Housing Affordability. Data: Price values extracted from numbeo.com, for the year 2023. Other values were available from EUROSTAT for 2020. Source: Authors. Source: Authors. Data: Numbeo (2024); Eurostat (2022i; 2022t).

4.2. The Lifestyle approach: Pressure on Lifestyle Domains

The last section explained the importance of the multidimensionality of energy poverty, particularly how the collisions of accessibility and affordability of energy and other basic domains might produce energy poverty at the regional scale. However, not everyone is equally at risk (Hughes & Hoffmann, 2020; Shelton & Eakin, 2022). Identifying energy poverty thresholds from the lifestyle perspective is yet to be explored. Specifically in the field of policy-making, energy poverty definitions typically overlook domain interactions (Cong et al., 2022; Drago & Gatto, 2023; Fry et al., 2023). On the one hand, from the point of view of expenditure, spending more than 10% of the disposable income to afford energy expenses has been accepted as a common threshold to identify the energy poor (Legendre & Ricci, 2014; Robinson et al., 2018; Thomson et al., 2017). On the other hand, energy poverty definitions are switching to a more citizen-centred approach, embracing the multidimensionality of the issue.

The upcoming section reflects on the role of citizens' lifestyles when identifying the risks of an energy transition. First, the relations between energy and basic household expenditures are analysed for different household types. Later, the relation between both limits is assessed to identify the groups most at risk of energy poverty due to lifestyle changes.

4.2.1. Expenditure and energy

Table 12: Energy expenditure data by household types and geographical units are available to conduct the analysis. Source: Authors, summary of Eurostat.

Household types		**Geographic entities**
By age range	Older than 60 – Y_GE60 Younger than 30 – Y_LT30 Population between 30-44 – Y_30-44 Population between 45-59 – Y_45-59	Austria – AT; Luxembourg – LU ; Belgium – BE; Bulgaria – BG ; Czech Republic – CZ; Cyprus – CY; Germany – DE; Denmark – DK; European Area (12,13,17,18) – EA; Estonia – EE; European Economic Area (28, 30) – EEA; European Free Trade Association – EFTA; Greece – EL; Spain – ES; European Union (15, 25, 27) – EU; Finland – FI; France – FR; Croatia – HR; Hungary – HU; Ireland – IE; Italy – IT; Lituania – LT; Latvia – LV; Montenegro – ME; North Macedonia – MK; Malta – MT; Netherlands – NL; Norway – NO; Poland – PO; Portugal – PT; Romania – RO; Serbia – RS; Sweden – SE; Slovenia – SI; Slovakia – SK; Turkyie – TR; United Kingdom – UK; Kosovo – XK
By income quintile	First-lowest income quintile – QUINTILE1 Second quintile – QUINTILE2 Third quintile – QUINTILE3 Fourth quintile – QUINTILE4 Fifth quintile – QUINTILE5	
By family structure	Three adults – A_GE3 Three adults with dependent children – A_GE3_DCH Single adult – A1 Single adult with dependent children – A1_DCH Two adults – A2 Two adults with dependent children – A2_DCH	

By degree of urbanisation	Population in urban areas – DEG3 Population in rural areas – DEG1 Population in urban-rural areas – DEG2	
Total data point entries for 2020		**431**

The Household Budget Survey reports, until 2020 and every five years, detailed energy expenditure data for different types of households, categorised by income groups, age ranges, family status, and degree of urbanisation. Even though the datasets provide data on relative expenditure, there is strong evidence that it highly correlates with the proportion of disposable income of households (Hindls et al., 2022). There are 21 household types listed for 46 geographical units, resulting in 431 data points (see Table 12). The report focuses only on data for the last reporting period, 2020. Even though some countries do not have their data available for certain household groups, there is enough variability (21 groups for 25 different countries) and several inputs (431) to consider the 2020 data a relevant sample to conduct the analyses. Figure 16 shows the generic distribution of those inputs per energy expenditure value. Each cell represents one household group in a specific country, and each household type categorisation is coloured using a specific colour scale. For example, light green represents younger groups in each country, while dark green represents the population older than 60. From the total values, only 8.58% surpass the 10% of expenditure on energy. However, it can also be seen that the distribution of values increases significantly right below the 10% threshold. The most typical groups above 10% are listed in Figure 19.

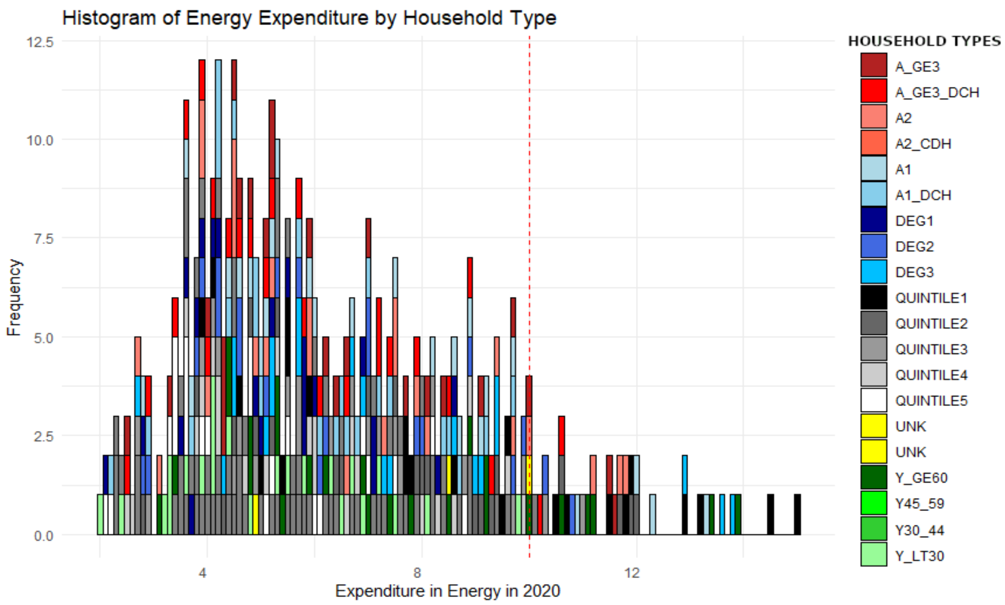


Figure 16: Histogram of the distribution of relative energy expenditure values for 2020. The red line traces the theoretical 10% threshold. Bars show the number of values that exist per expenditure value. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

The distribution of energy expenditure values varies according to the household type and country. Figure 17 shows that some groups, such as single adults, the lowest income quintile, or the elderly, tend to have more values distributed closer and over the 10% threshold. Contrastingly, Figure 18 shows that, geographically, at least 10 countries out of the 25 have values surpassing the 10% threshold, and three more countries are less than 1% closer to that threshold. This observation highlights that energy poverty is an extended issue throughout Europe.

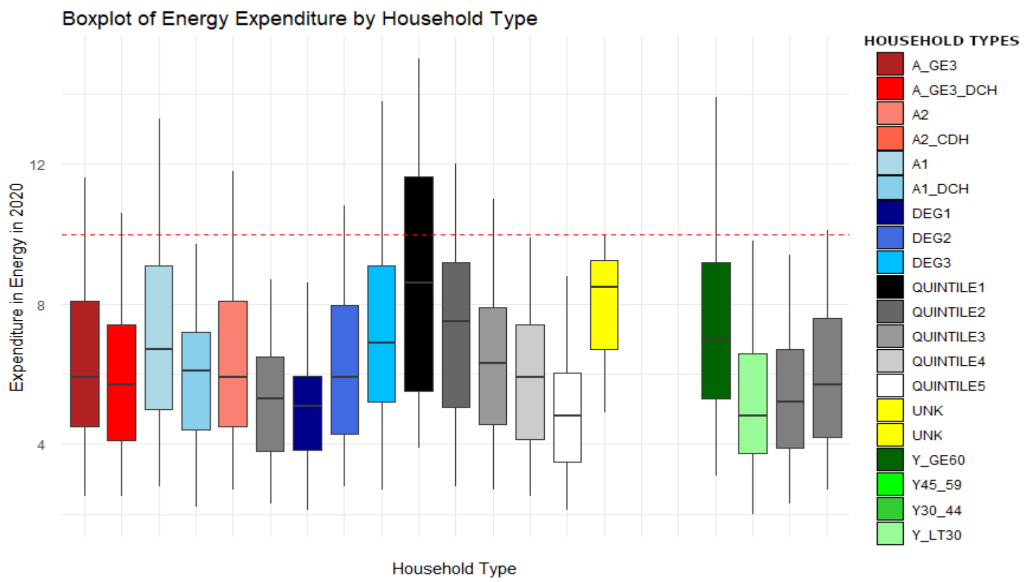


Figure 17: Boxplot diagram, by household type. It shows the distribution of values in energy expenditure in 2020. Red line draws the 10% energy poverty threshold. Each box represents one household type. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

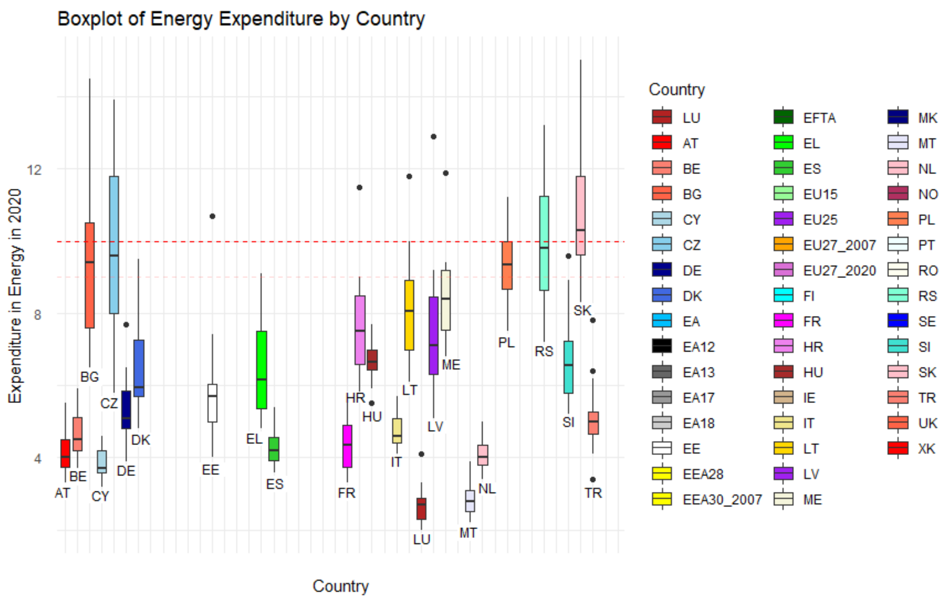


Figure 18: Boxplot diagram, by countries in 2020. It shows the distribution of values in energy expenditure. The dark red line draws the 10% energy poverty threshold. The light red line shows 9% of expenses in energy poverty. Each box represents one household type. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

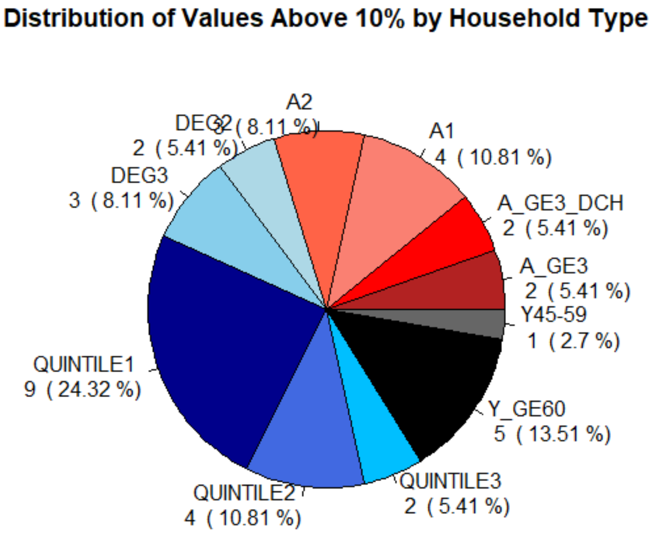


Figure 19: Most common household types that are over the 10% threshold, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

However, not spending more than 10% of the household expenses on energy does not mean households are not energy-poor, especially considering the potential basic domain conflicts mentioned above (Cong et al., 2022; Drago & Gatto, 2023; Fry et al., 2023; Ivanova & Wood, 2020). A simple correlation between the expenditure of the most basic domains – Food and Housing – and energy shows a significant positive correlation between them (P-value < 2.2e-16) (Figure 20). The more budget a household spends on energy, the more it also spends on other basic domains.

The relation between expenditure in basic domains might help identify household types at risk of energy poverty who are not reported because they prioritise other basic needs, such as food, housing, or even transport or education for others. Data shows that households placed above the 10% threshold are likely to spend, with high confidence, 40% to 60% of their budget on other basic domains, which is considerably high (Figure 20 and 21). Inversely, when examining values falling above the 40% to 60% expenditure interval in basic domains, it can be seen that (1) the countries where they belong coincide with those exhibiting poorer accessibility and energy poverty conditions, according to the previous section and the EPAH report (Figure 21), and (2) the household types are the same that can be found above the 10% threshold in energy expenditure. The following subsections analyse, one by one, the relationship between each basic domain and energy expenditure.

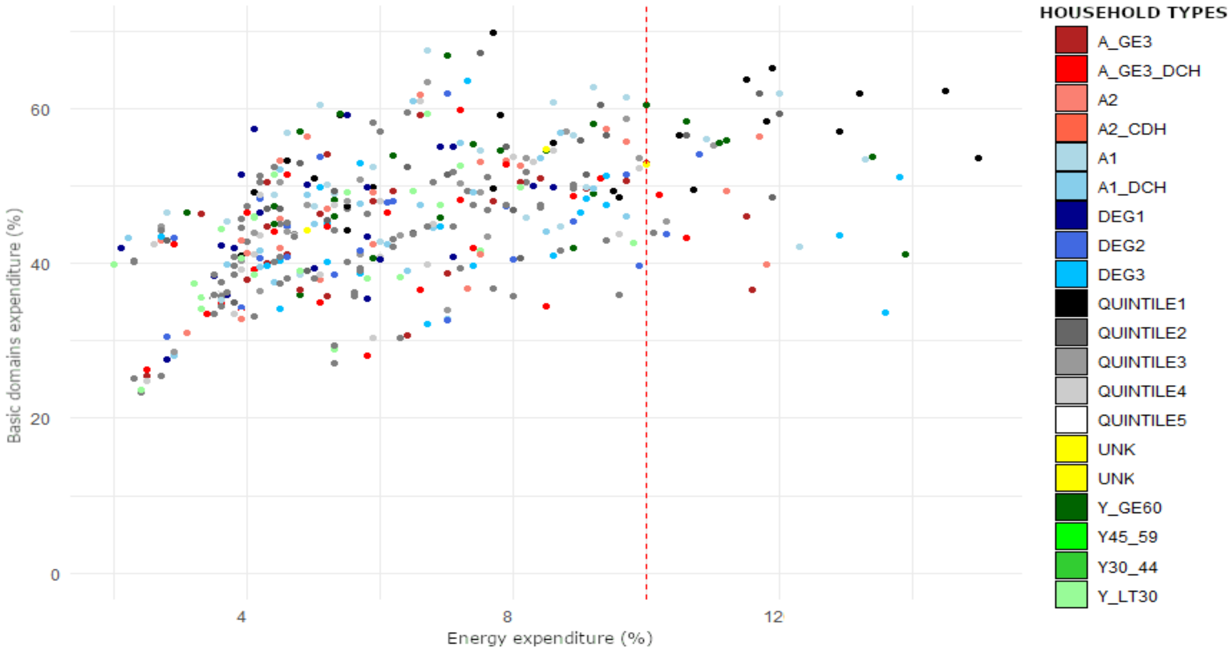


Figure 20: Scatter plot relating energy expenditure (X axis), and expenditure in basic domains (Y axis) Values are categorised by colors according to household types. Red vertical line shows the energy poverty threshold (10%), for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

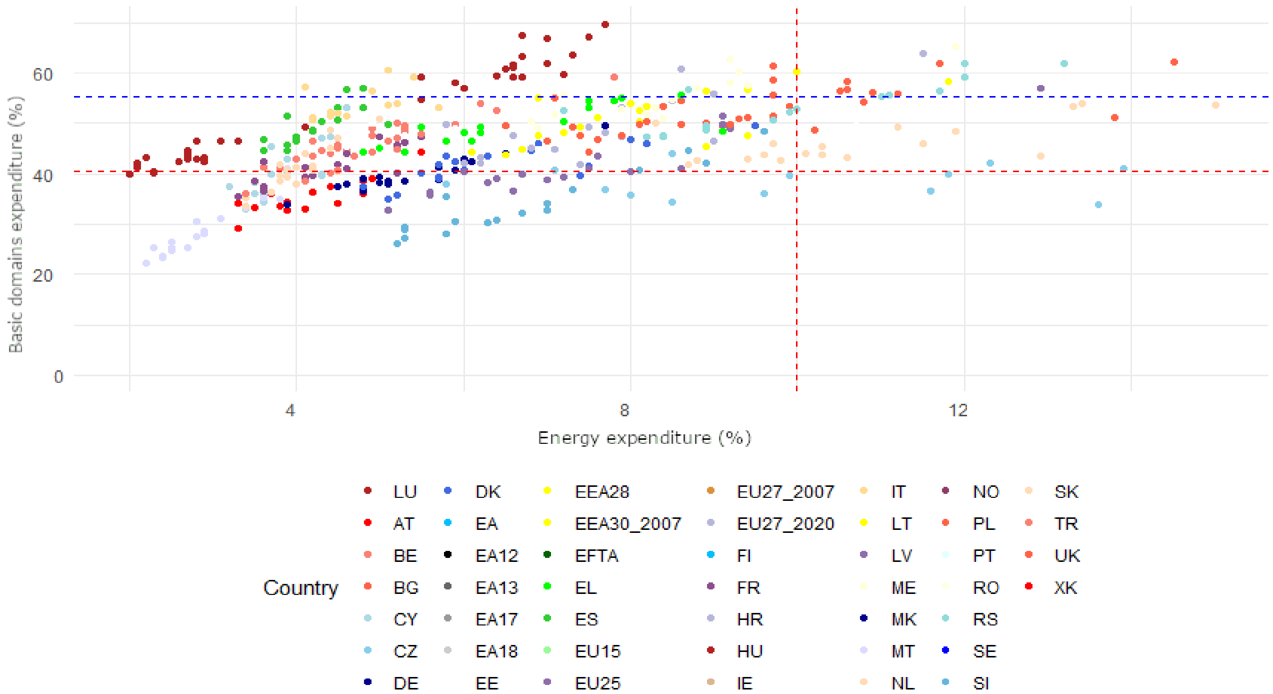


Figure 21: Scatter plot relating energy expenditure (X axis), and expenditure in basic domains (Y axis) Values are categorised by colors according to countries. Red vertical line shows the energy poverty threshold (10%), for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

4.2.2. Food

Recent literature has proven a relationship between energy and food sectors (Cong et al., 2022; Diaz-Barriga & Barnhart, 2022; Drago & Gatto, 2023). When they cannot afford basic needs, households in the lower income quintiles might find in the food domain enough flexibility to cut their budgets to afford other needs (Guzmán-Rosas, 2022), reducing the amount of food they consume or prioritising money over nutritional values. As proved, high expenditure on energy combined with high expenditure on any basic domain might also put households at risk of energy poverty.

When looking into the expenditure data, food domain expenditure increases linearly with energy expenditure (cor=0.6820224; P-value < 2.2e-16) (Figure 22 and 23), meaning that high expenditure percentages in food are confidently related to high expenditure in energy, increasing 1.6377 food units per each energy unit spent (conf. 95%; P-value<2e-16). Households spending more than 18.11 to 36.16% (conf. 95%) on food will likely exceed the 10% threshold in energy expenditure. Thus, it might be hypothesised that households spending within or above that interval are also likely to be energy-poor. Although a further definition of thresholds might need more detailed data and proper model development – which is outside the scope of this deliverable – the correlation establishes a broad threshold with which some specific households might face increased energy poverty risk if any change occurs in their food habits.

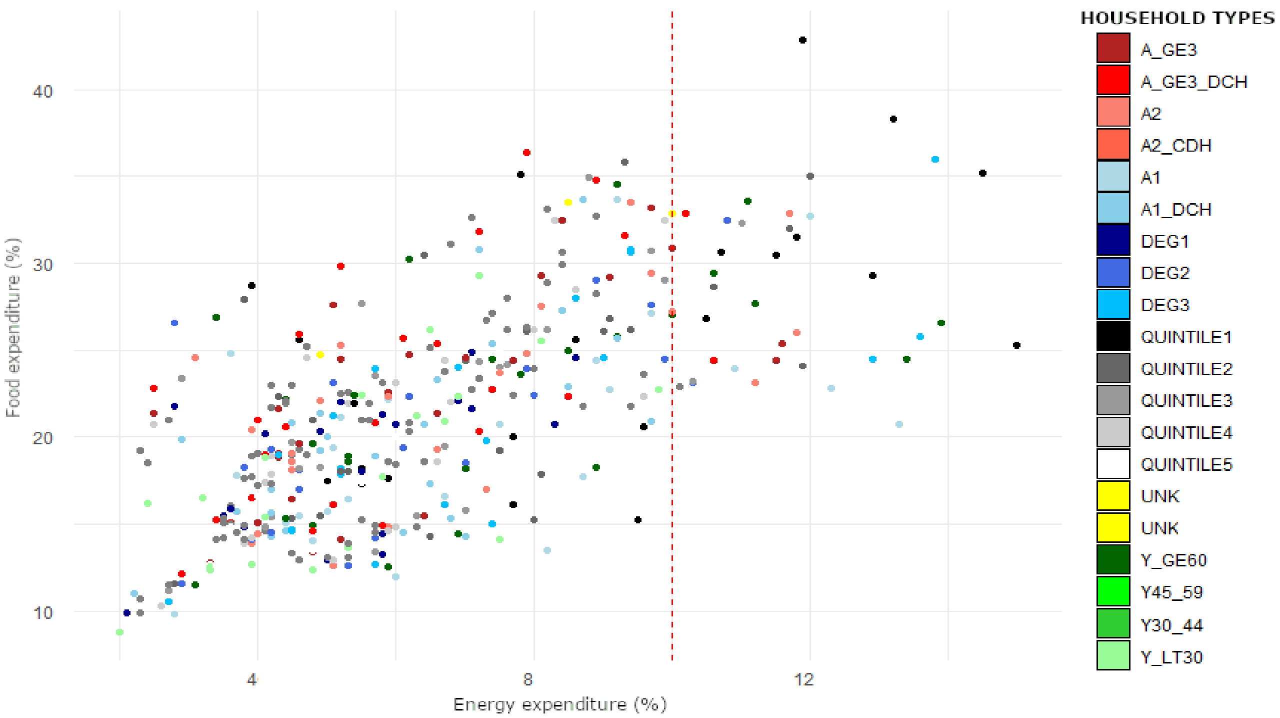


Figure 22: Correlation between energy expenditure (X-axis) and food expenditure (Y-axis). Categorised by household type, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

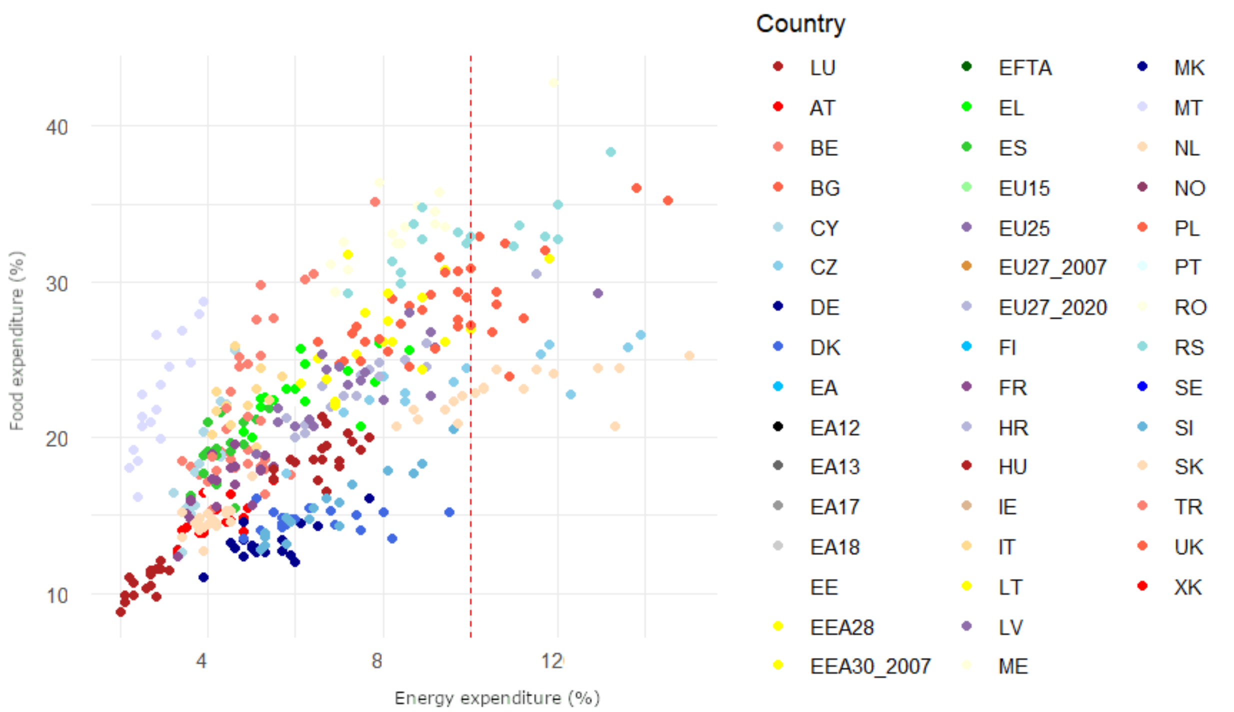


Figure 23: Correlation between energy (X-axis) and food expenditure (Y-axis). Categorised by country, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

The households that might suffer more due to changes in their food domain can be identified by looking at the values that are above the food threshold, categorising them by household types and countries. By looking at the household types, it can be seen that those who are more likely to face conflicts when choosing between the food and the energy domain are the population who are older than 60 years old (22 times), three adults sharing a house (21 times), three adults sharing a house with children (20 times), two adults sharing a house (20 times), and those who are in the lowest income quintile (19 times). Nevertheless, more groups share the number of times with this last one, such as people between 45-59 years old or people in the third lowest quintile, and the differences within the groups are marginal (Figure 24). In terms of countries, Balkan and Baltic countries are among the ones that embrace the largest number of household groups (Figure 25).

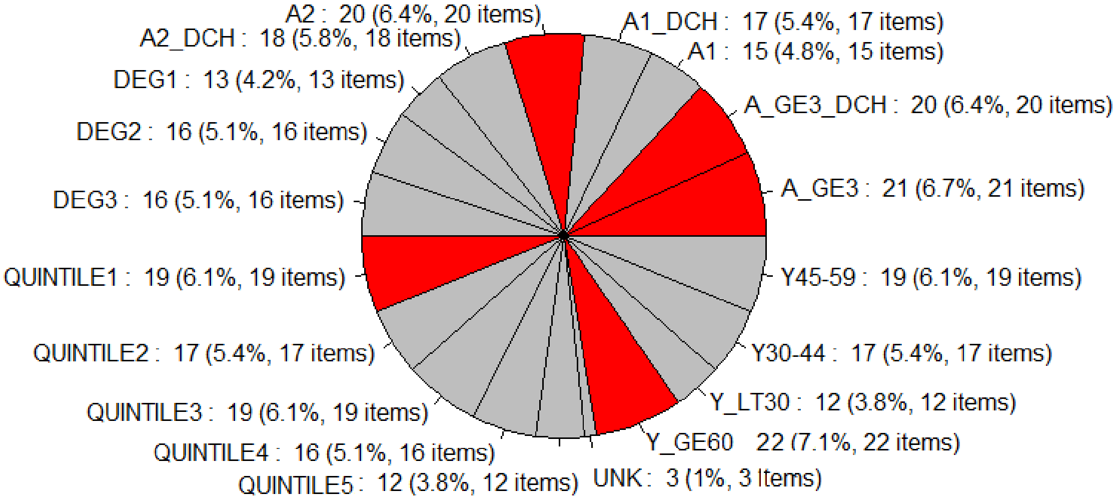


Figure 24: Distribution of groups in or above the defined interval of food expenditure. The top 5 household types are in red, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

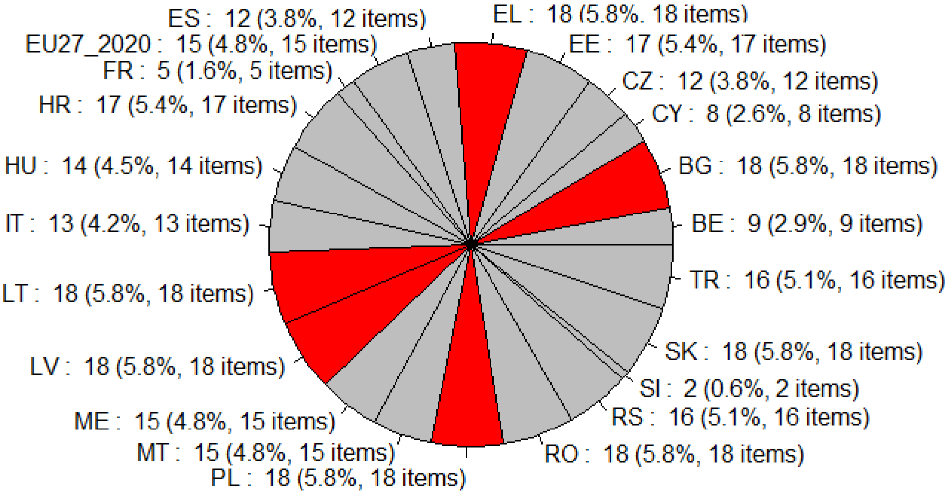


Figure 25: Distribution of countries with more values in or above the defined interval of food expenditure. In red, the top 5 countries, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

4.2.3. Housing

Housing is the other basic domain for all households. Being able to afford proper housing is essential to ensure a just and equitable energy transition. Housing conditions are critical to energy poverty, as inadequate and substandard housing conditions are often associated with higher energy poverty rates (Alba-Rodríguez et al., 2022; Amorim-Maia et al., 2023). Thus, understanding how household expenditure in housing relates to energy expenditure will help better identify energy-poor households.

Housing expenditure data also shows a significant positive correlation compared to the energy domain (cor=0.3344894; P-value = 1.001e-12) (Figure 26). Following food and generic basic trends, households tend to increase their energy expenditure simultaneously with housing. Statistically, households who spend 10% or more of their budget on energy are likely to spend 34.53% of their expenses on housing, with a confidence interval of 19.64% to 49.43% (95% conf.). Moreover, geographically speaking, it can be observed that some countries follow a much more increased linear correlation than others, with their households spending at least 30% of their expenditure on housing.

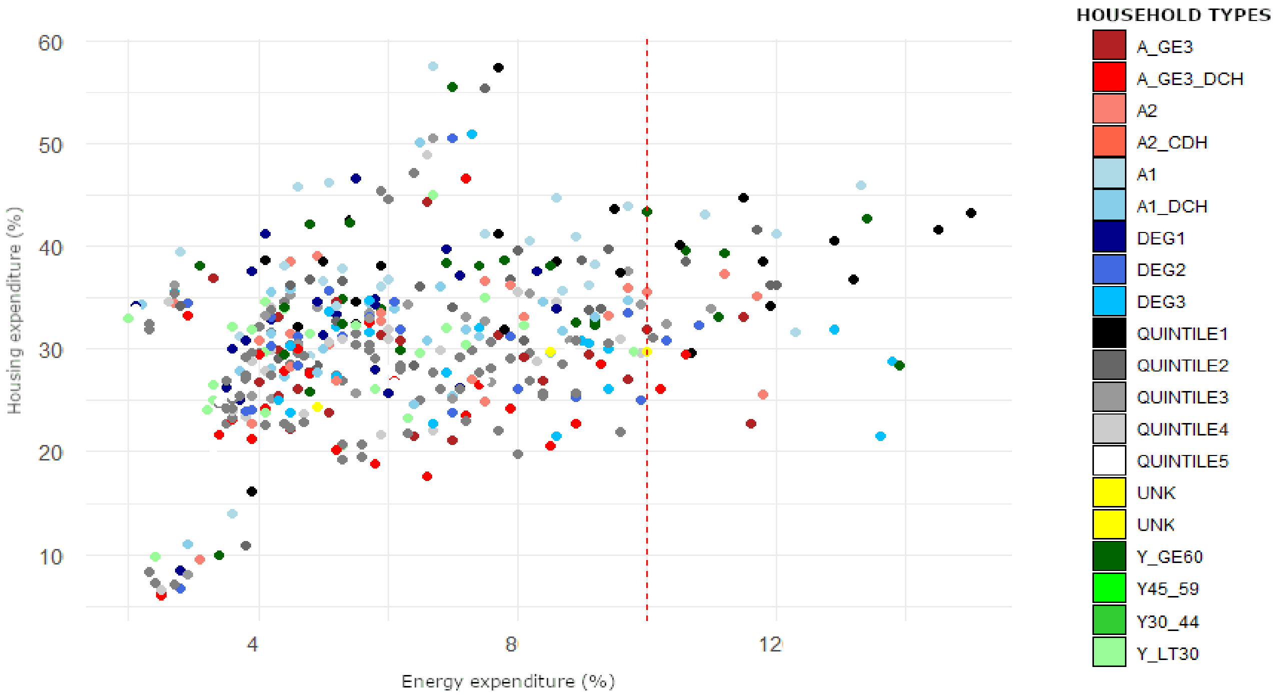


Figure 26: Correlation between energy expenditure (X-axis) and Housing expenditure (Y-axis). Categorised by household type, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

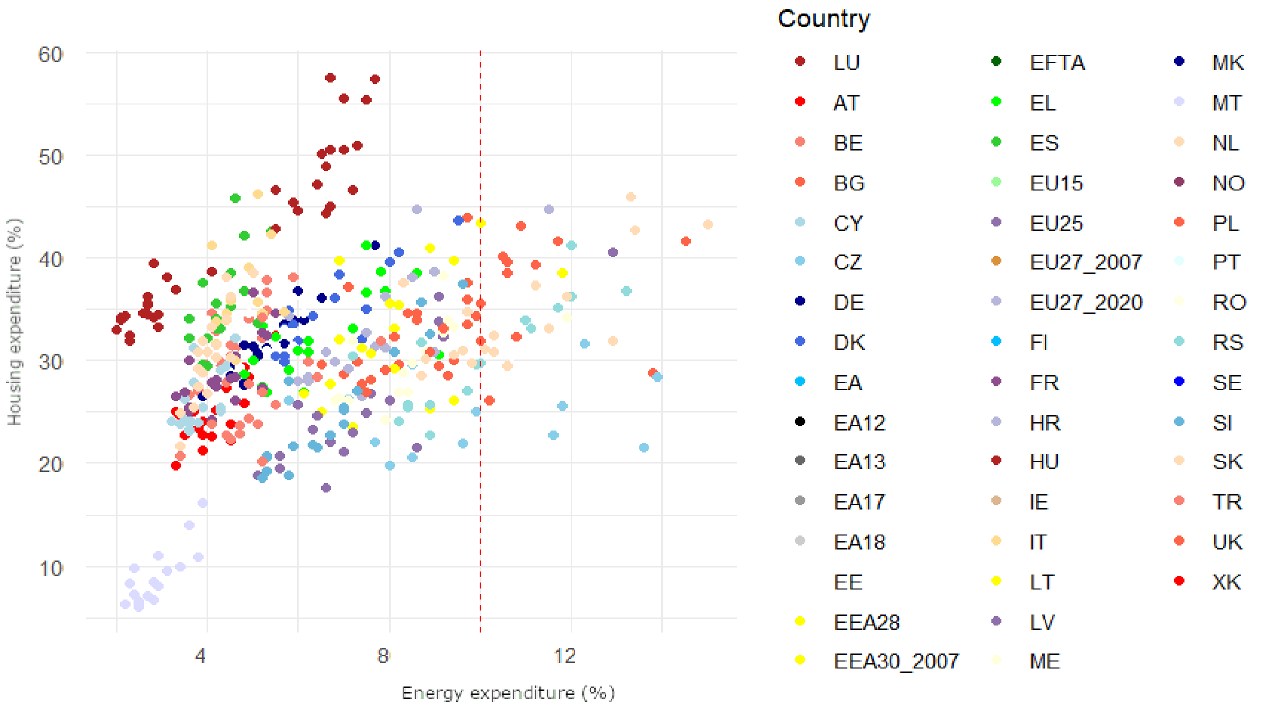


Figure 27: Correlation between energy expenditure (X-axis) and housing expenditure (Y-axis). Categorised by country, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

There are fewer countries (21) where the values for food expenditure surpass the calculated threshold of 18.11 to 36.16% than countries (all countries) where the housing expenditure is above the calculated threshold of 19.64% to 49.43% (Figure 28). Data show that households might suffer more pressure from the housing domain than the food domain. When looking at the household types placed within or above the interval, even though the distribution seems much equally distributed, three or more adults in the same house (26 times), single adults (26 times), single adults with children (26 times), two adults (26 times), and any age group above 30 (26 times) seem to have higher housing and energy expenditures together (Figure 28). There is no clear differentiation between countries (Figure 29).

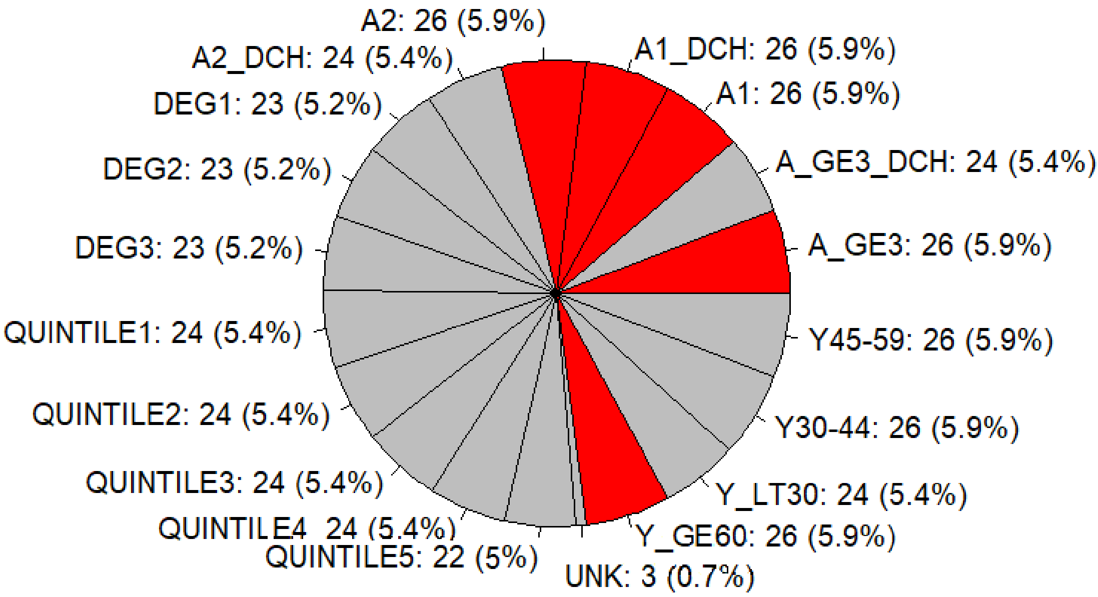


Figure 28: Distribution of household types with more values in or above the defined interval of housing expenditure. In red, the top 5 household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

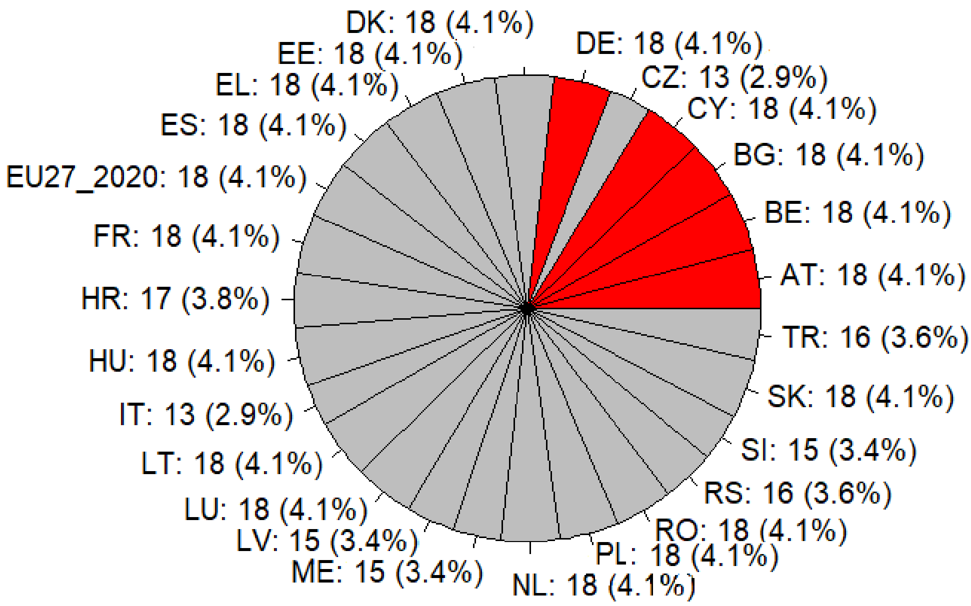


Figure 29: Distribution of countries with more values in or above the defined interval of housing expenditure. In red, the top 5 countries, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

4.2.4. Healthcare

The healthcare domain is also important for European households. As shown in Figure 30, the healthcare domain and energy expenditure also share a significant positive correlation (cor=0.2239646; P-value = 2.654e-06). However, unlike in previous domains, the geographical distribution of values tends to be more individualised regarding countries, as a visual check of Figure 31 can confirm. The institutionalisation of the healthcare systems at a national level and the differences in their functionality might explain that. In fact, even though the correlation is significant, that difference within countries also makes the calculation of an interval unclear, giving a broad range of 11.29-76.16% (95% conf.).

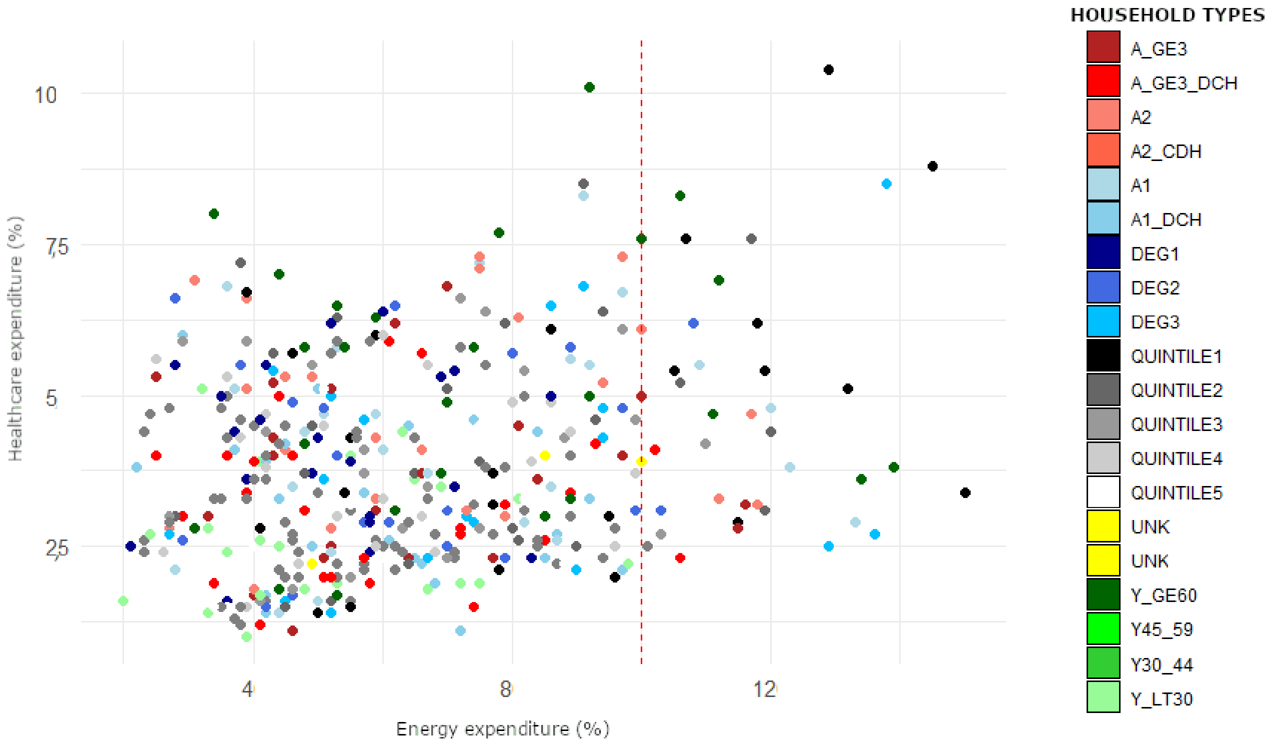


Figure 30: Correlation between energy expenditure (X-axis) and healthcare expenditure (Y-axis). Categorised by household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

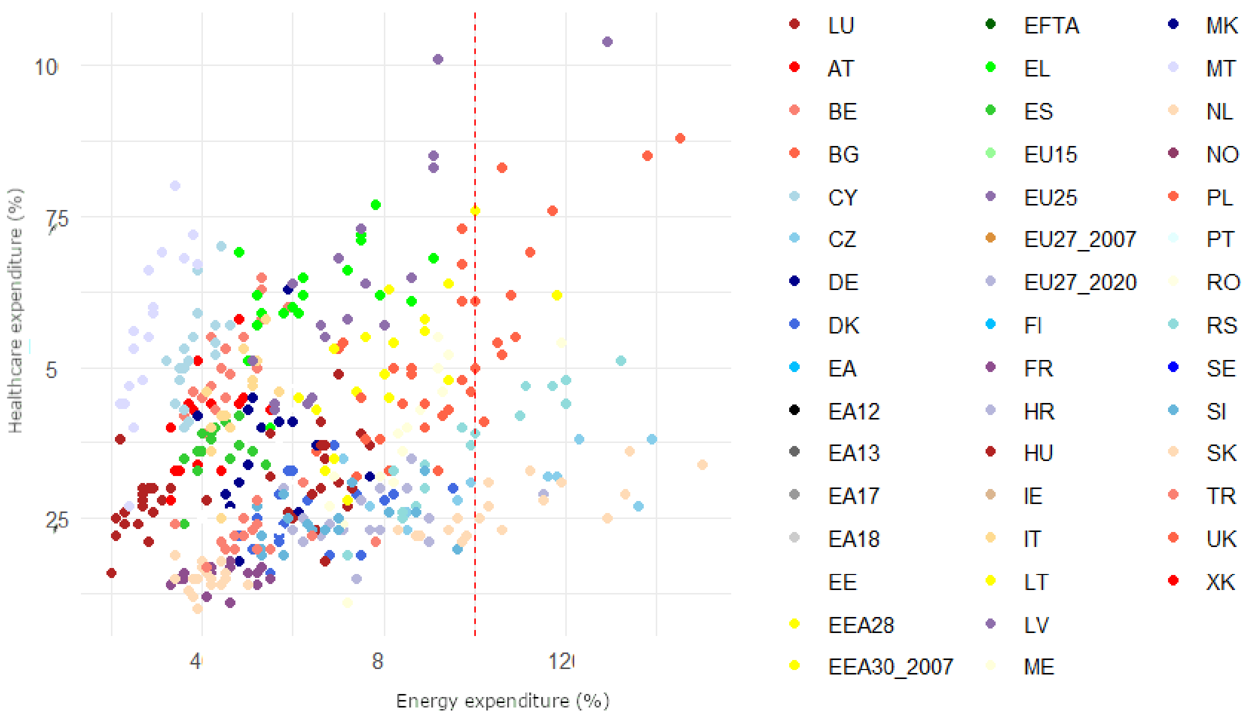


Figure 31: Correlation between energy expenditure (X-axis) and healthcare expenditure (Y-axis). Categorised by country, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

Due to the high uncertainty when conducting the interval analysis, only the top 50% of the interval was considered. Even though some values might be skipped, analysing the top 50% of the interval might establish a base for further studies. Thus, only values ranging from 43.72% to 76.16% in healthcare expenditure are used for household identification analysis. As could have been expected after the initial analysis on domain elasticity in the introduction, older people are most at risk of energy poverty due to their healthcare needs (17 times), followed by two adults living together (15 times), single adults (14 times), and people from the two lowest income quintiles of their respective countries (12 and 13 times) (Figure 32). When looking at the geographical distribution, a few countries show values above the interval, such as Greece, Cyprus, Latvia, Malta, and Belgium, with quite high percentages compared to the others (Figure 33).

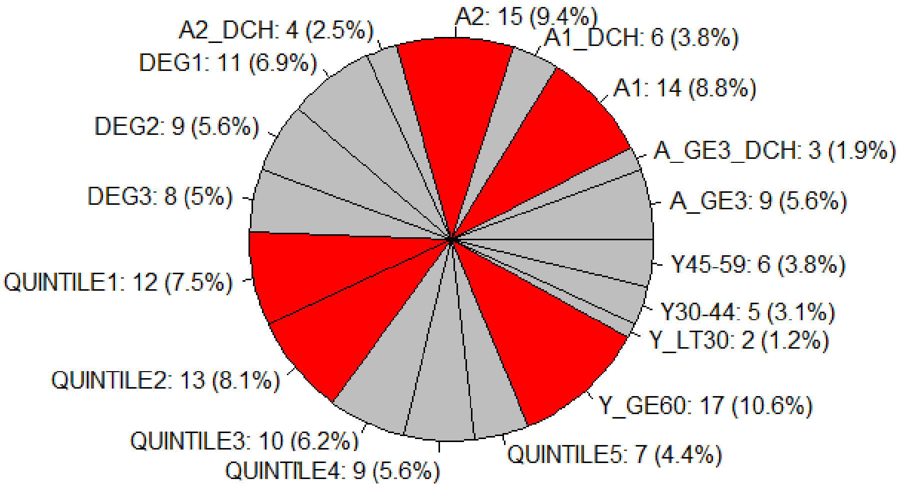


Figure 32: Distribution of countries with more values in or above the defined interval of healthcare expenditure. In red, the top 5 household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

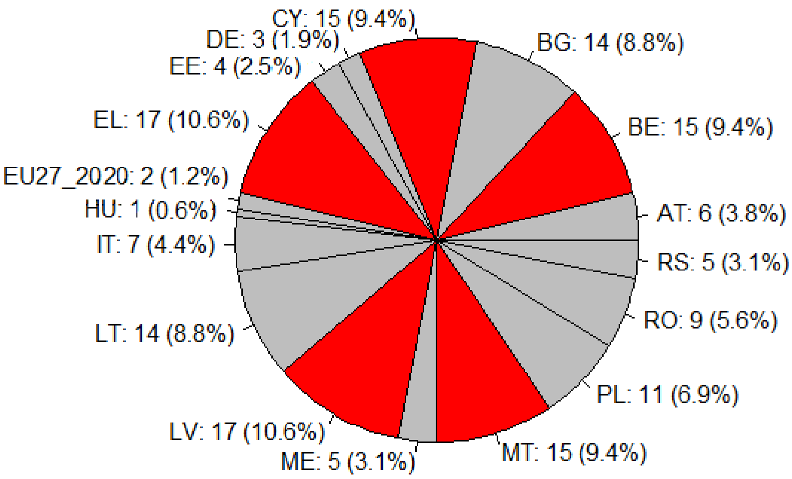


Figure 33: Distribution of countries with more values in or above the defined interval of healthcare expenditure. In red, the top 5 countries, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

4.2.5. Education

The elasticity analysis shows that, in general terms, the education domain does not behave as a basic domain but as a luxury one. However, when analysing the different household groups separately, structures with children show significantly greater expenditure on education than other household groups, highlighting the sector as essential for them (Section 3.1). However, in contrast to other basic domains, education negatively correlates with energy expenditure (rho=-0.41666; P-value < 2.2e-16), meaning that European households reduce their expenditure on education over the capacity to afford energy (Figures 34 and 35).

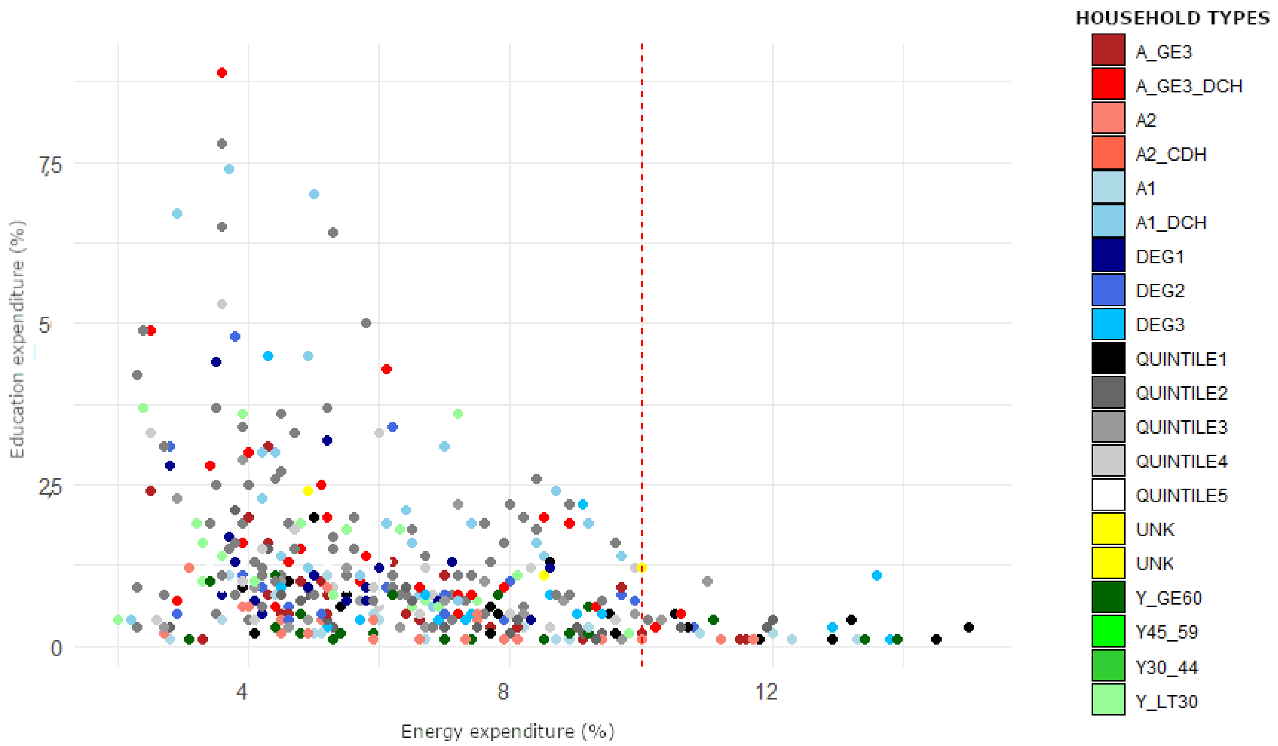


Figure 34: Correlation between energy expenditure (X-axis) and education expenditure (Y-axis). Categorised by household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

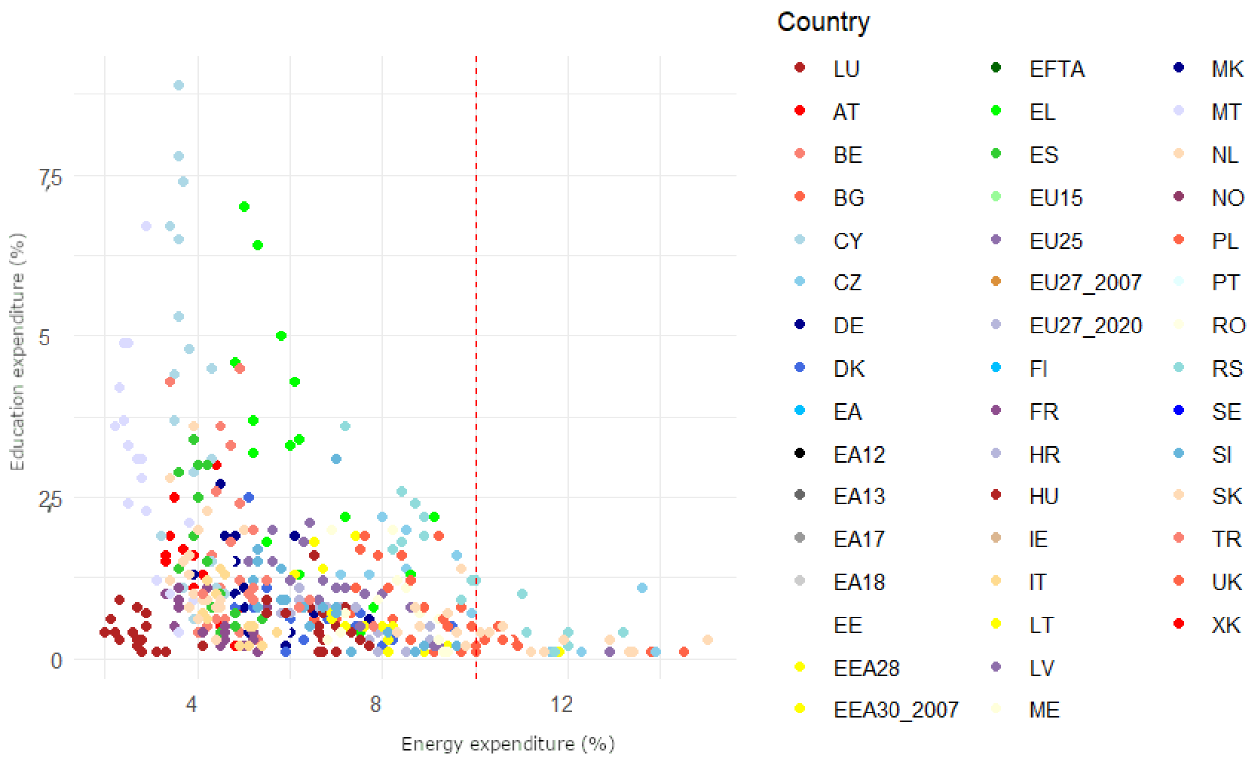


Figure 35: Correlation between energy expenditure (X-axis) and education expenditure (Y-axis). Categorised by countries, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

As different levels of education have different costs, more disaggregated data might be needed to understand the issue. HBS provides separate data for pre-primary, primary, secondary, and other education types, which allows an analysis of the different education types. When doing so, it can be observed that the negative coefficient decreases (cor=0.-0.2617001; P-value=7.033e-06) when only primary and secondary data are considered (Figure 36), aligning it more with the other basic domains.

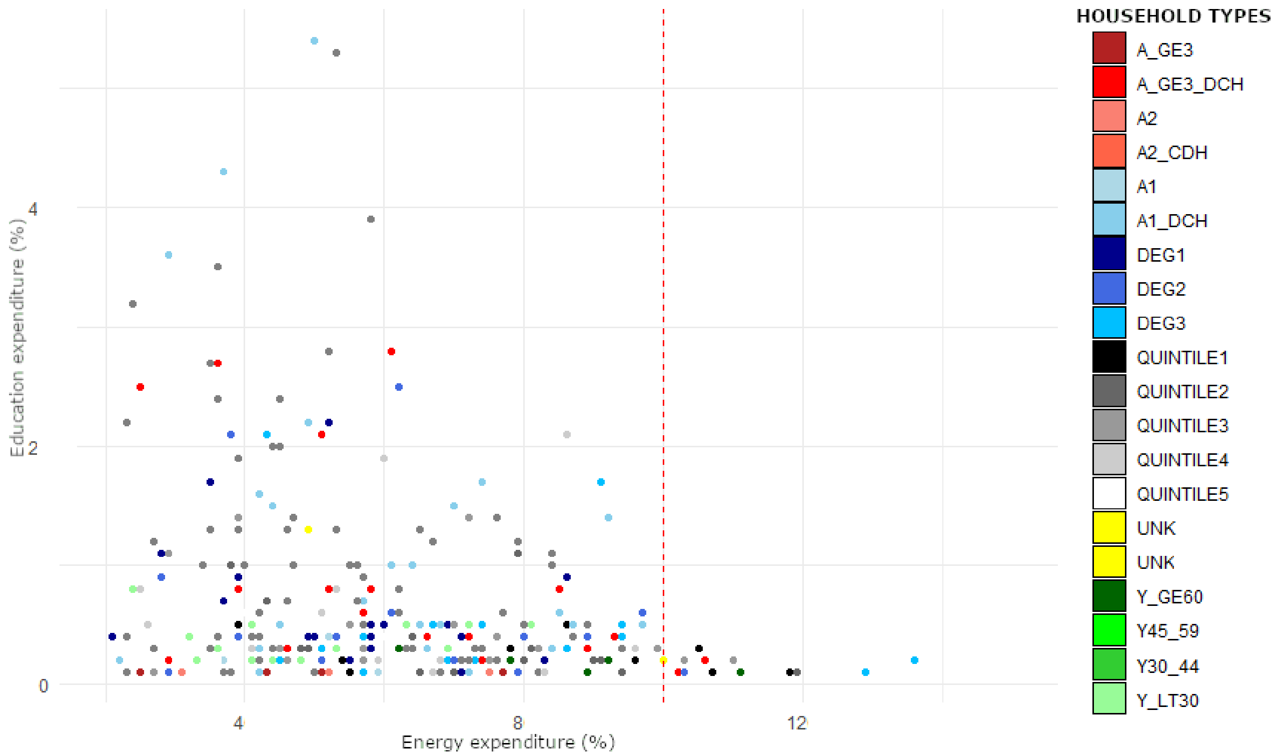


Figure 36: Correlation between energy expenditure (X-axis) and only primary and secondary education expenditure (Y-axis). Categorised by household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

However, the correlation is still negative. Primary and secondary education is mandatory in Europe (Compulsory Education in Europe 2022/2023, European Commission), which means those expenses can be considered, by law, basic domains for those with children. Thus, it can be hypothesised that those who suffer more in affording other basic domains are the ones who spend less in the education domain. The data analysis shows that households with an education expense lower than 3.128399 ([-13.15 – 19.41, 95% conf.) are likely to spend more than 10% of their expenses on energy. Similarly, as done with the healthcare domain, and due to the high variability in education access in different European countries, only 50% of the interval is taken. In this case, the lowest (below 3.128399%).

Figure 37 shows that those within the second and third income quintiles, rural households, adults between 45 and 59 years old, and those sharing a house with dependent children have less education expenditure than energy expenditure, followed by single households with dependent children. It should be considered that people between 45 and 59 years old, with a bit higher income than the lowest, are typically the ones with children in charge.

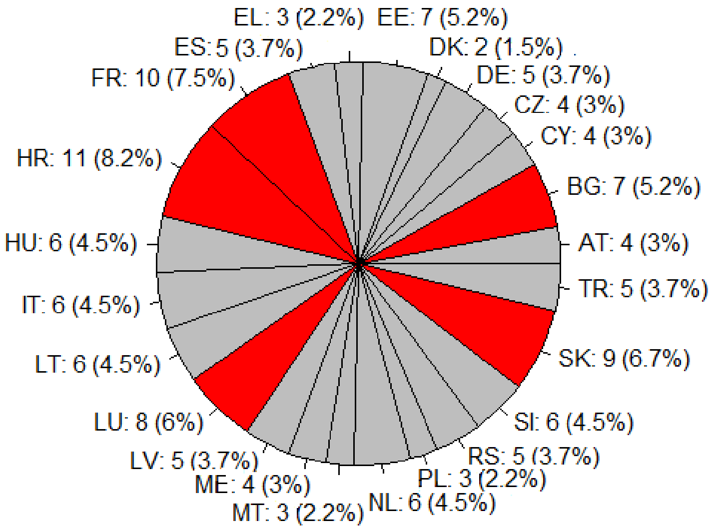


Figure 37: Distribution of countries with more values in or above the defined interval of education expenditure. In red, the top 5 countries, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

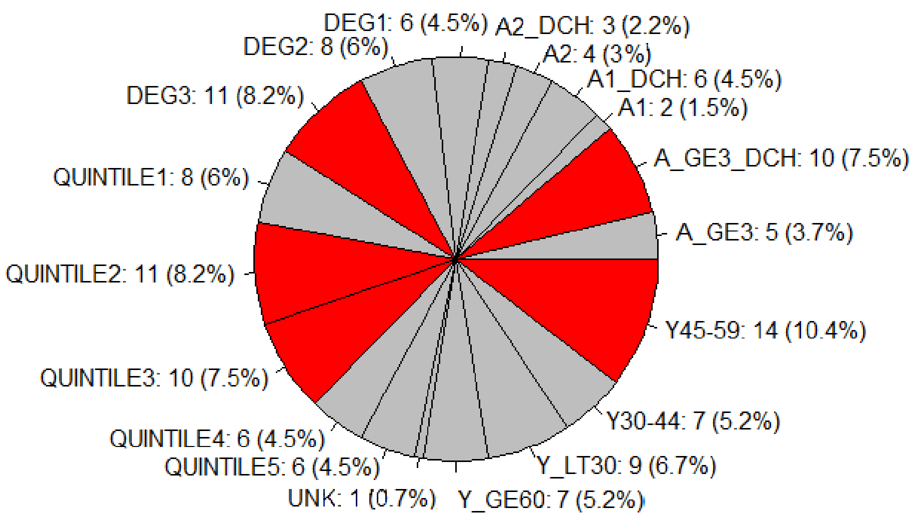


Figure 38: Distribution of countries with more values in or above the defined interval of education expenditure. In red, the top 5 household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

4.2.6. Transport

Ivanova and Wood (2020) determined that the land transport sector can be considered a basic domain for those living in rural areas. However, an initial analysis of all the sectors shows a significant negative correlation (cor=-0.5912039; P-value<2.2e-16) (Figure 39), positioning the transport domain as non-basic. HBS Transport data includes, in its initial values, personal vehicle purchases and air transport expenditures, considered luxury domains (Ivanova et al., 2017; Ivanova & Wood, 2020). Even though data about personal vehicle purchases can be separated, air transport cannot be extracted from the initial values.

When separating only the values by the degree of urbanisation (Figure 40), it can be seen that households in the intermediate and rural areas show a more neutral correlation between their expenditures in energy and transport, highlighting the potential alignment with the results of Ivanova and Wood, 2020. However, further research with more detailed data would be needed to obtain confident results, especially when air transport is highly relevant to household carbon emissions.

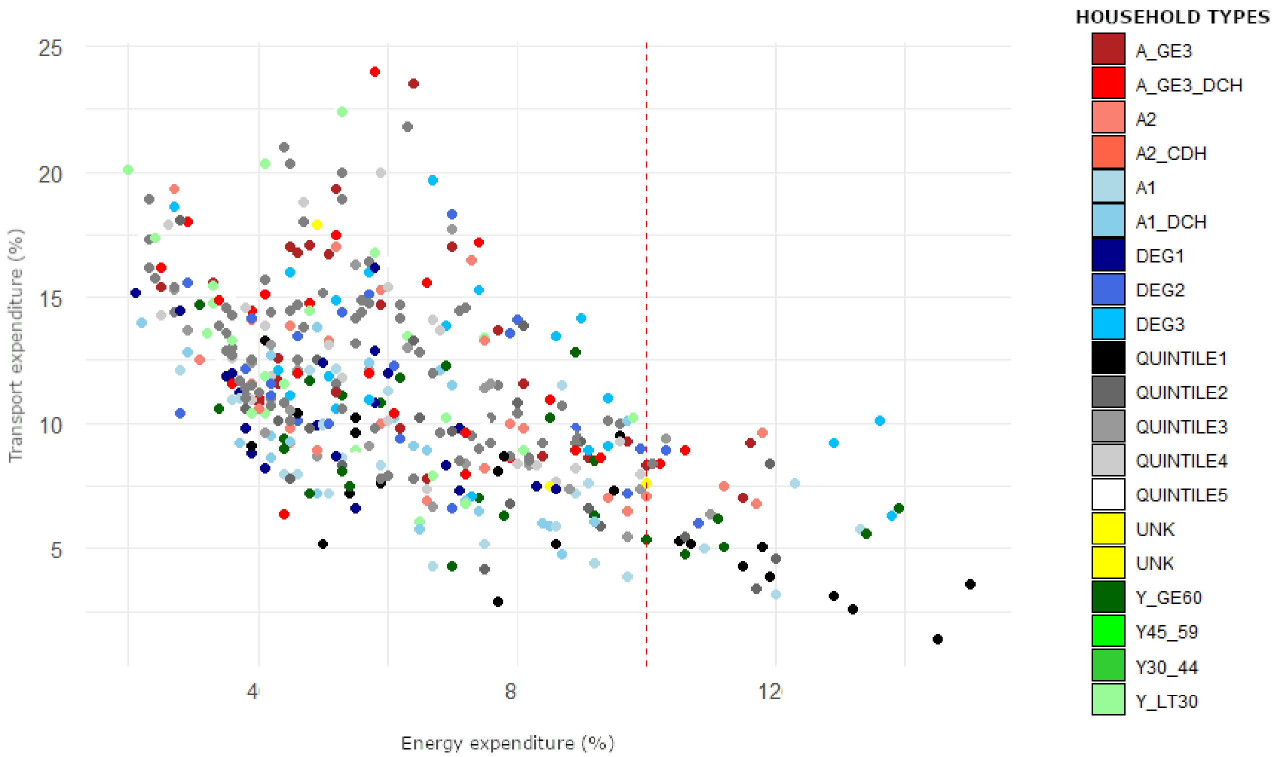


Figure 39: Correlation between energy expenditure (X-axis) and transport expenditure (Y-axis). Categorised by household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

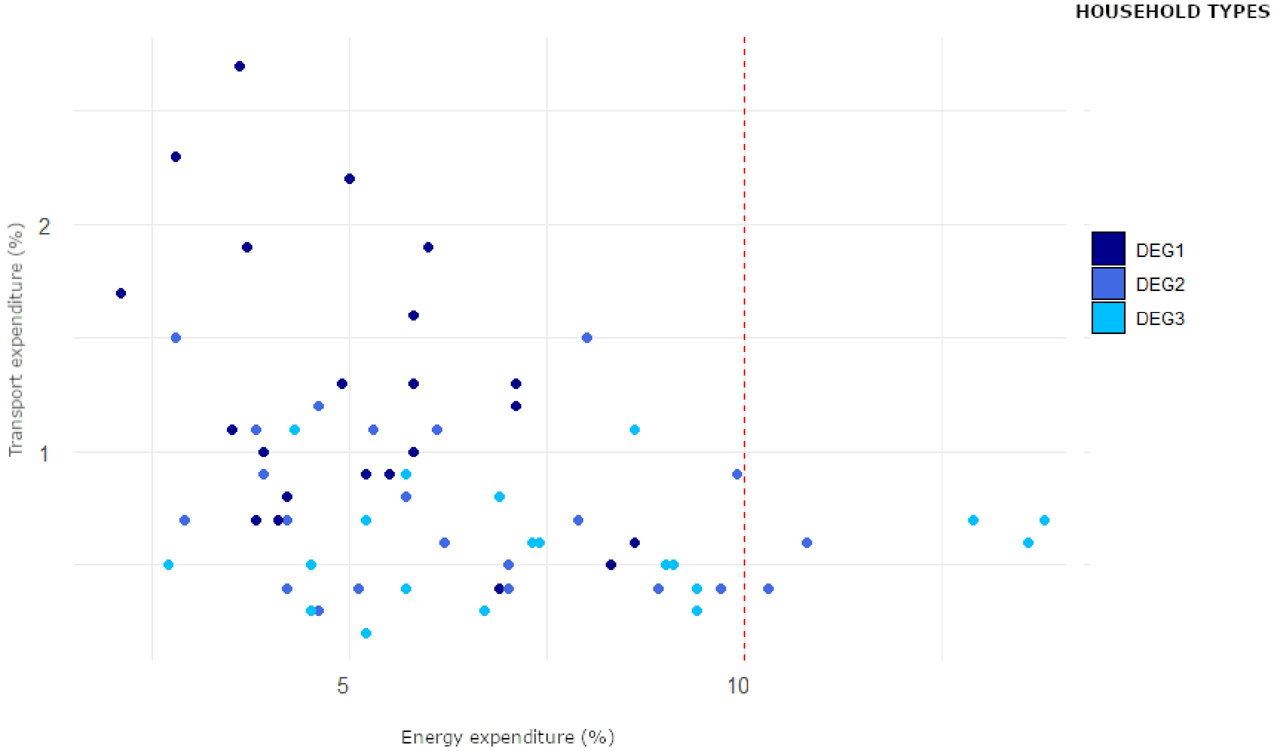


Figure 40: Correlation between energy expenditure (X-axis) and transport expenditure (Y-axis). Only households by degree of urbanisation, for the year 2020. Categorised by household types. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i).

4.3. The Socioeconomic and demographic approach: Population characteristics

Analysis of lifestyles through expenditure can explain how different types of households are exposed to energy poverty not only from the energy dimension but also from other domains. However, certain socioeconomic and demographic characteristics, such as gender, age, ethnicity, and at-poverty-risk, which were not fully accounted for or included in the previous section, can help sharpen the identification of vulnerable groups (Roy et al., 2021).

Eurostat offers other indicators that are decomposed to such detail. Besides expenditure, disposable income is the other closely related factor determining European energy accessibility and affordability. Particularly, those who with lower incomes are also likely to face energy poverty (Amorim-Maia et al., 2022; Cunha & Silva, 2023; Kashwan, 2021; Lawrance et al., 2022; Mintz-Woo, 2023; Swanson, 2023; Tschakert et al., 2023). Moreover, considering its detailed availability, income datasets pose a good chance for accurately identifying groups at risk of becoming energy-poor.

Several available datasets measure income, ranging from regional averages to specific decile divisions per demographic group. Indicators such as Purchasing Power Parity (PPP) save these differences and offer an equalised indicator by eliminating differences in price levels per country and other variables. However, even though PPP can be useful for measuring the affordabilities of domains, disposable income data offers better-detailed data about demographic groups. Of course, disposable income also needs to be normalised.

On the one hand, the threshold for being at risk of poverty or social exclusion in Europe is 60% of the national median disposable income (European Commission, Statistics explained). On the other hand, the disposable income data only considers available income after paying national taxes. Thus, the difference between both might help better understand which demographic characteristics are key to identifying groups at risk of being energy-poor – from here onwards, Normalised Disposable Income – NDI.

$$Normalised\ disp.income\ (NDI) = \\ 60\%\ of\ the\ median\ disp.income - median\ disp.income\ of\ each\ demographic\ group$$

When comparing the difference of the NDI of the same household types to their energy expenditure, there is a significant negative correlation (cor = -0.49; P-value = 2.2e-16), meaning that the closer the NDI to the poverty threshold, the more the households are spending on energy services. This significant correlation confirms the importance of disposable income in identifying groups at risk of energy poverty groups.

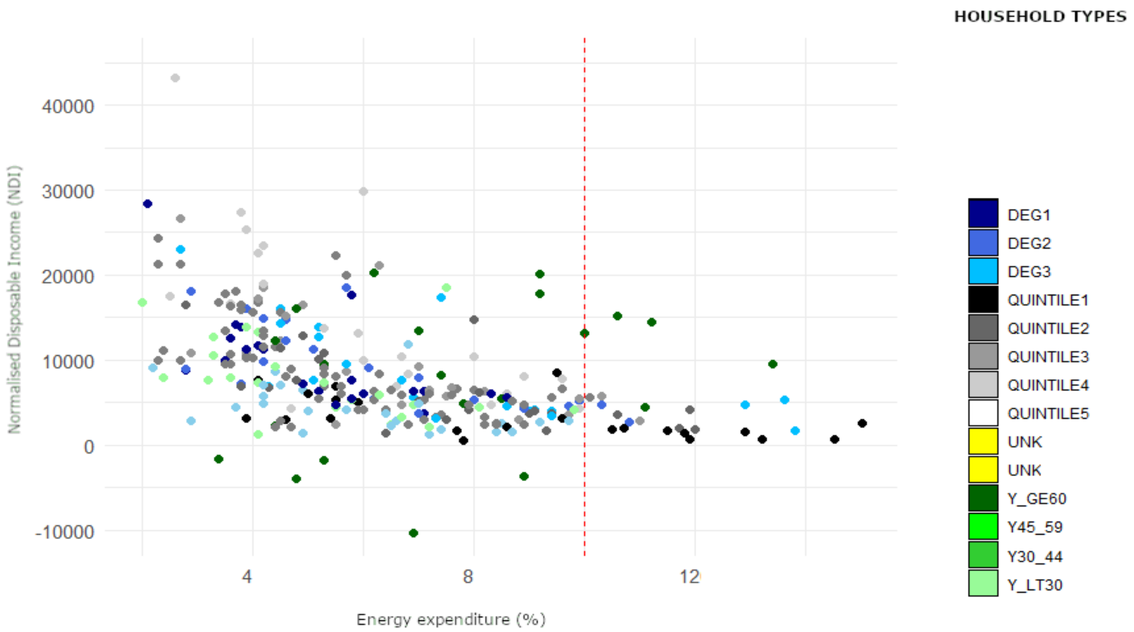


Figure 41: Correlation between energy expenditure (X-axis) and NDI (Y-axis). Categorised by household types, for the year 2020. Source: Authors. Data: Eurostat (2022f; 2022g; 2022h; 2022i); Eurostat (2022j; 2022k; 2022l; 2022m; 2022o; 2022q).

4.3.1. Income regional distribution

As the previous section shows, households from the first or second lowest income quintile are typically identified as groups that might suffer more from lifestyle changes. However, when analyzing the NDI for each household income quintile, it can be seen that values of the lowest income quintiles have higher variance than those in the highest income quintiles (Figure 42). Geographically speaking, it means that, independently of the country, the population on the lowest income quintile will likely be at risk of energy poverty, while the population belonging to the second lowest quintile might be much safer depending on the country. Figure 43 shows, by country, the NDI of the lowest income quintile.

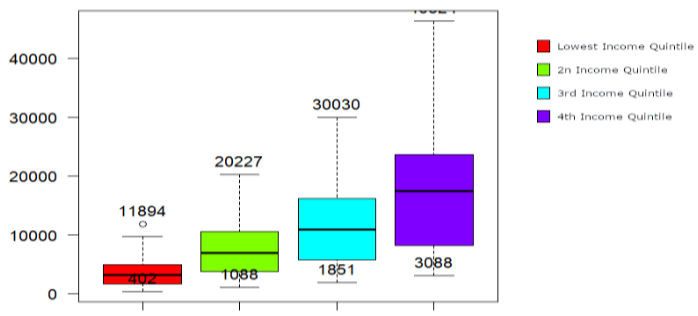


Figure 42: Boxplot diagram of the NDI (Y axis) for the four lowest income quintiles for the year 2020. Source: Authors. Data: Eurostat (2022u).

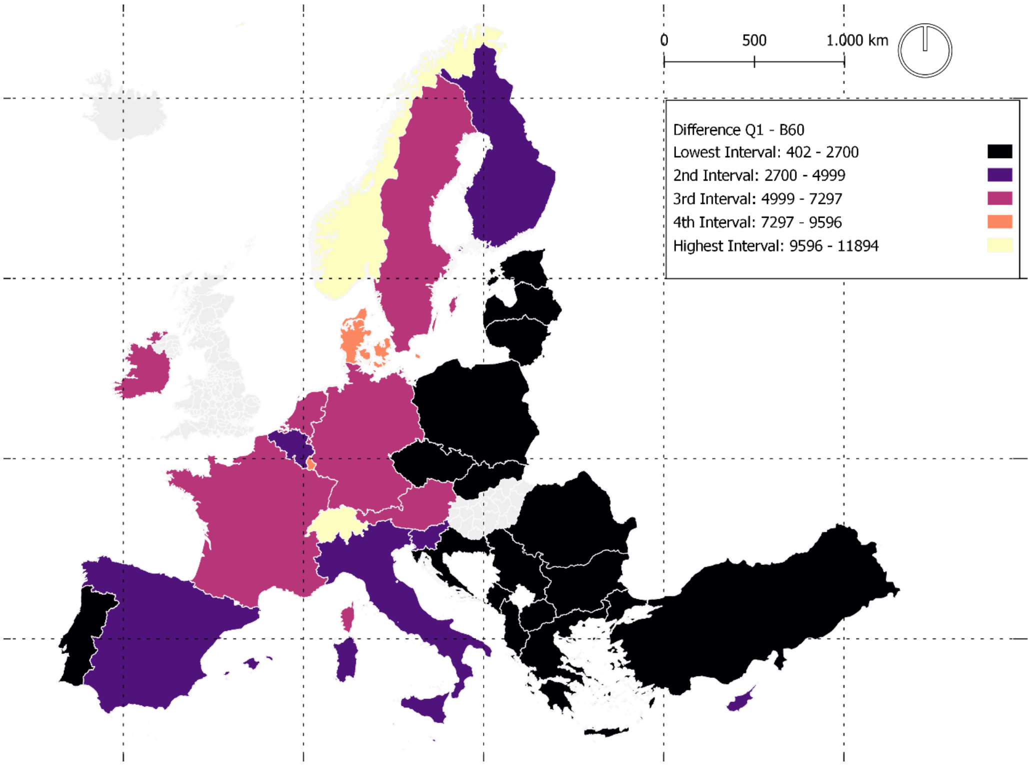


Figure 43: Map of the differences between the poverty threshold and each country''s median income lowest quintiles (NDI) for the year 2020. Source: Authors. Data: Eurostat (2022u; 2022q).

4.3.2. Gender

Gender is a relevant factor to consider in energy poverty, as women are typically more at risk of being energy poor (Al-Jawaldeh et al., 2022; Amorim-Maia et al., 2022; Lacey-Barnacle et al., 2020; Lawrance et al., 2022; N. Srivastava & Kumar, 2022). Using income data and NDI allows us to understand how the vulnerability of households varies according to gender inequality. When analysing the NDI data for different household types, divided by gender, it can be seen that the NDI for women tends to be lower than men's (Figure 44). Therefore, women tend to be closer to the poverty and social exclusion threshold, indicating that they experience an increased risk of becoming energy-poor.

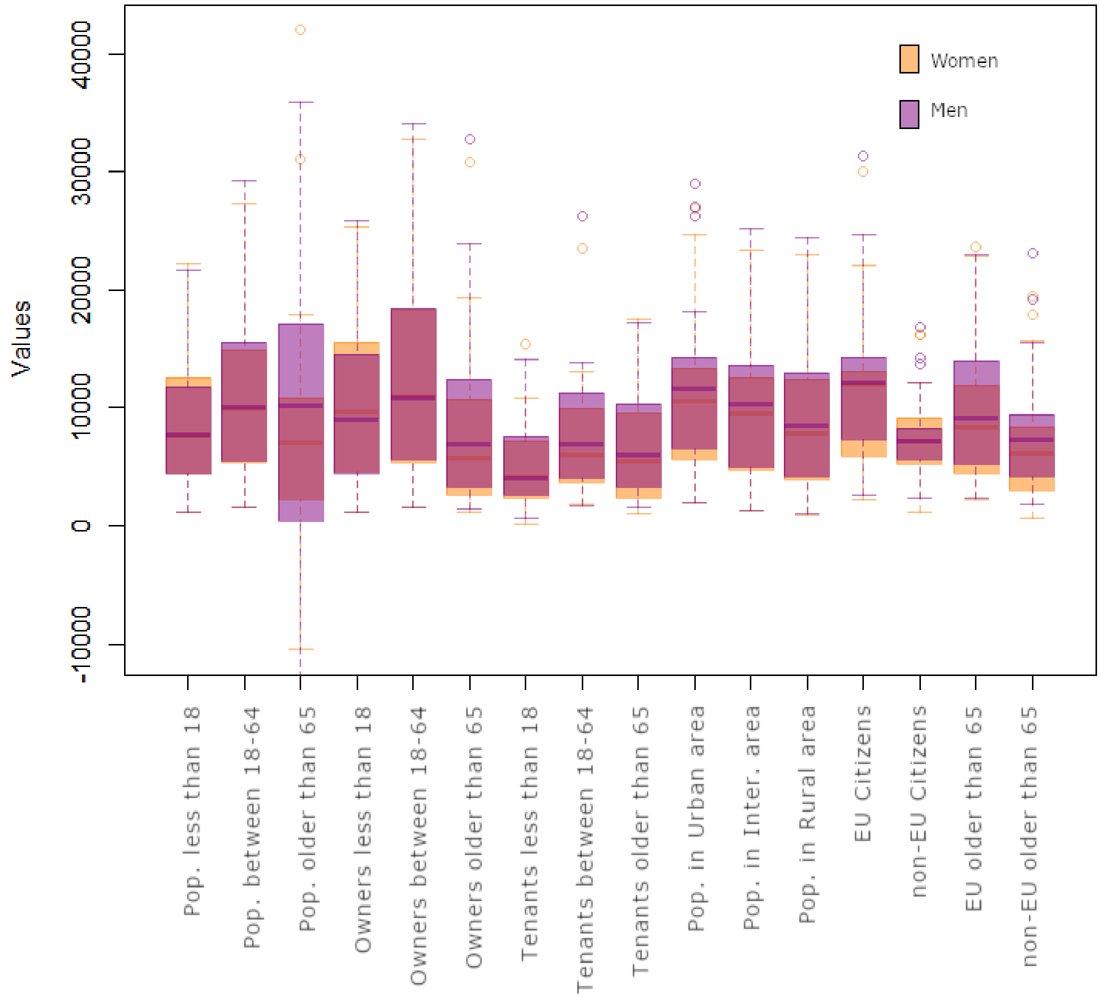


Figure 44: Comparative boxplot between the differences between the median income of each household type and the national poverty threshold. The closer or lower than 0, the more risk they suffer. As seen, women (orange) are always closer to the threshold. Source: Authors. Data: Eurostat (2022j; 2022k; 2022l).

When looking at specific categorisations that are relevant for lifestyles, such as age, women tend to have slightly lower NDIs. However, the difference becomes noticeable in population older than 65 (Figure 45). Compared to other age groups, the NDI variance for women older than 65 is much lower than the one for men and closer to the poverty threshold line, indicating that women older than 65 will likely be at increased risk of being energy-poor compared to men and that gender becomes extremely relevant after the age of 65.

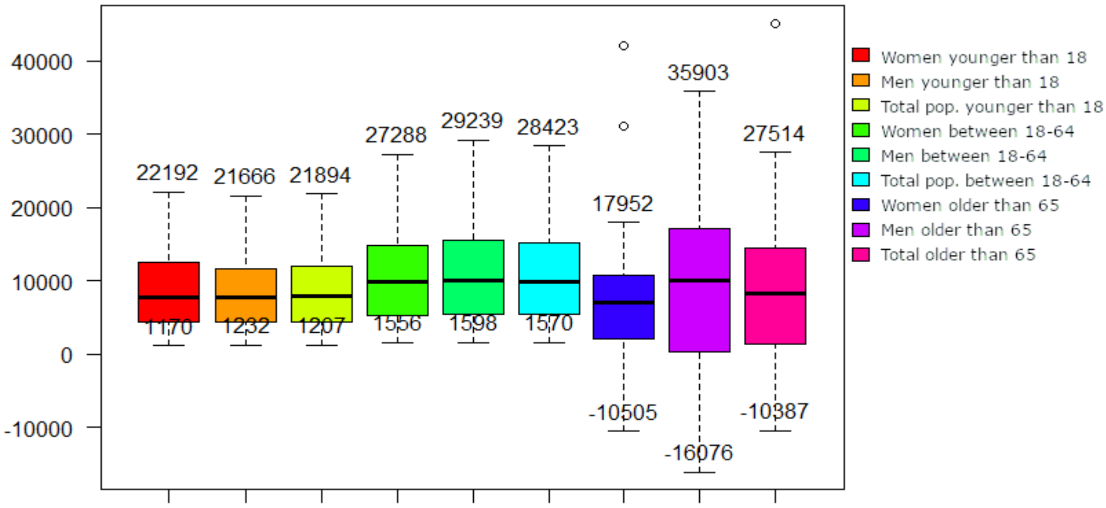


Figure 45: Boxplot diagram. Distribution of values of different age ranges households, by gender for the year 2020. Source: Authors. Data: Eurostat (2022j).

Differences across urbanisation degrees are also noticeable, with rural households closer to the threshold than urban households. Even though the differences between genders are minimal, male households are less vulnerable than women, and this difference is exacerbated in urban environments (Figure 46).

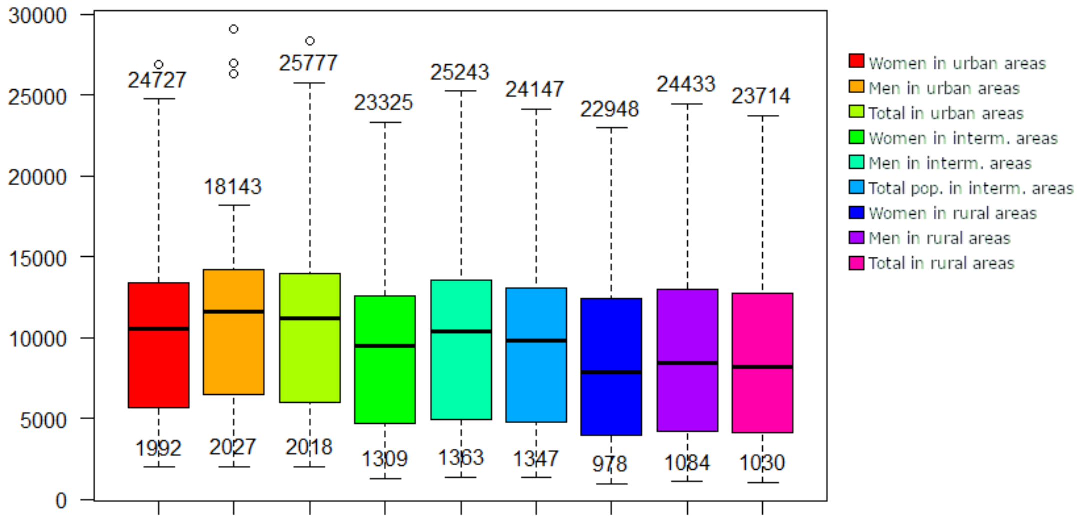


Figure 46: Difference between income and poverty threshold in urban-rural households, by gender for the year 2020. Source: Authors. Data: Eurostat (2022o).

When mapping the NDI for elderly females (Figure 53), it can be seen that they might face an increased risk of energy poverty in Irish, Balkan and Scandinavian regions, (Figure 47). Even though the percentage of women older than 65 seems balanced throughout Europe, some Balkan regions show a higher share of the population belonging to that group (Figure 48).

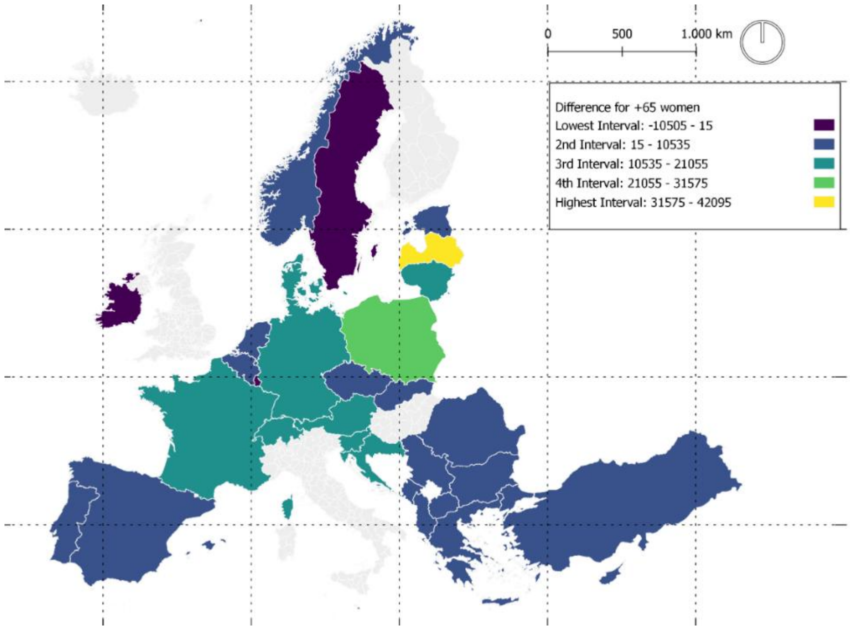


Figure 47: Differences between median income for elderly women and poverty threshold for the year 2020. Source: Authors. Data: Eurostat (2022o; 2022q).

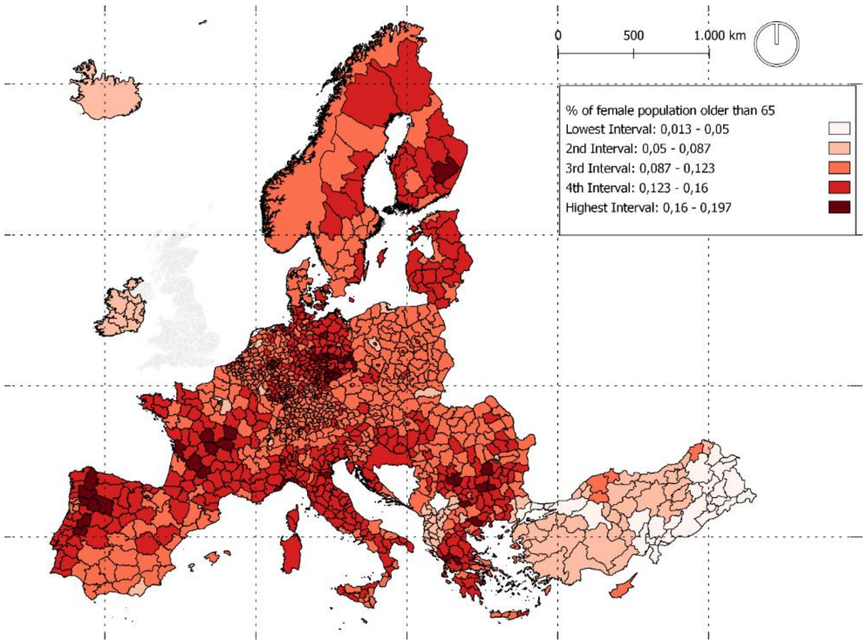


Figure 48: Percentage of population who are women, and older than 65. Source: Authors. Data: Eurostat (2022r).

4.3.3. Ethnicity

Minority ethnic and racial groups are typically more vulnerable to suffering negative effects from societal changes (Al-Jawaldeh et al., 2022; Amorim-Maia et al., 2022; Lacey-Barnacle et al., 2020; Lawrance et al., 2022; N. Srivastava & Kumar, 2022). Structural racism and colonialism might explain this phenomenon (Kinol et al., 2023; Mattar et al., 2021). Ultimately, these non-integrative behaviours result in discrimination and lower economic capacity and opportunities. Few economic datasets are available at a disaggregated regional level or by specific ethnic and racial groups. Eurostat offers the possibility of analysing the disposable income by country of birth, age group, and gender.

The population born outside the EU is much closer to the risk of poverty threshold than the EU population (Figure 49). Following the same trend as the generic analysis in the gender section, (1) women born outside the EU tend to perceive less income than men and (2) the elderly[3] less than younger age groups. However, the variance of values in non-EU groups remains lower and closer to the poverty threshold than groups born in the EU, indicating a higher vulnerability to energy poverty risk.

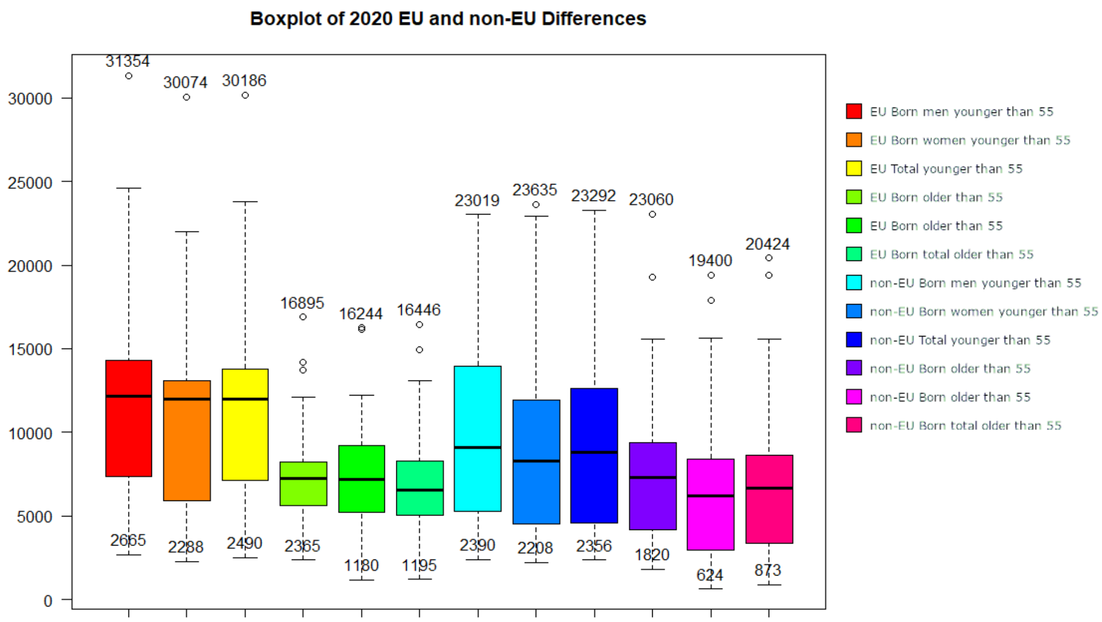


Figure 49: Differences between disposable income and threshold, by origin of country. Source: Authors. Data: Eurostat, (2022m).

Balkan, Baltic and Southern European countries show a smaller difference between the NDI of elderly women born outside the EU (Figure 50). Contrastingly, Balkan countries have a lower share of immigrants coming from outside the EU, while Southwest and Baltic countries have a higher percentage of immigrants coming from outside the EU within their population compared to other countries.

[3] In this case, older tan 55 years old due to data availability.

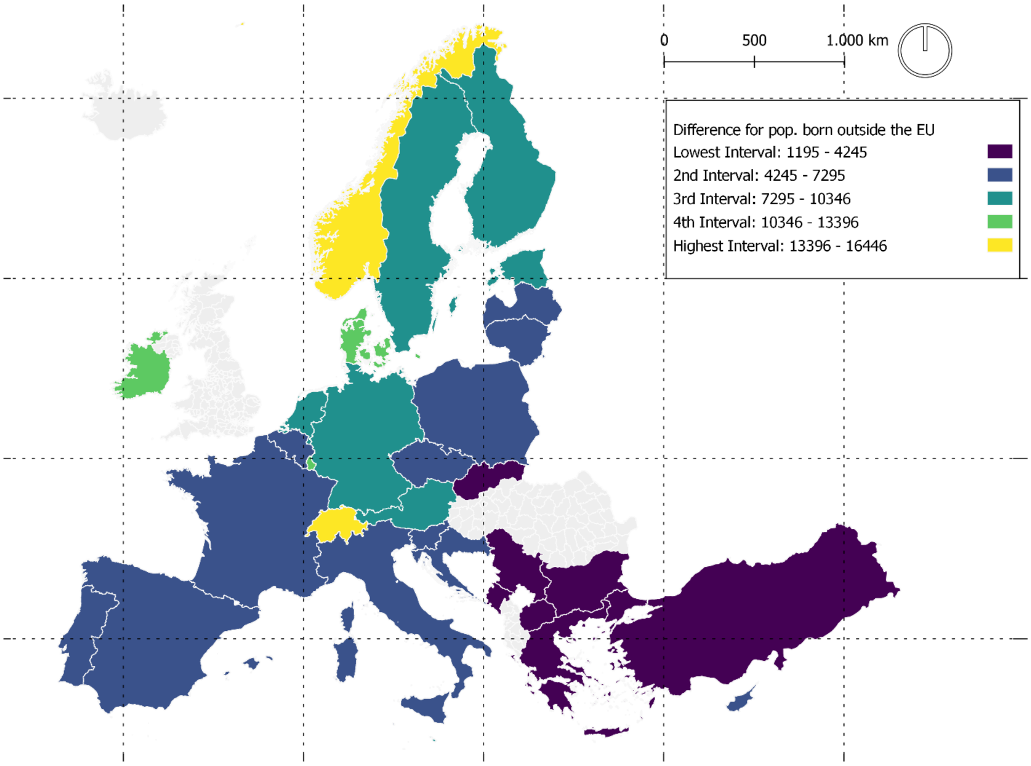


Figure 50: Income difference with threshold, average of medians of all groups, for non-EU groups for the year 2020. Source: Authors. Data: Eurostat (2022m; 2022q).

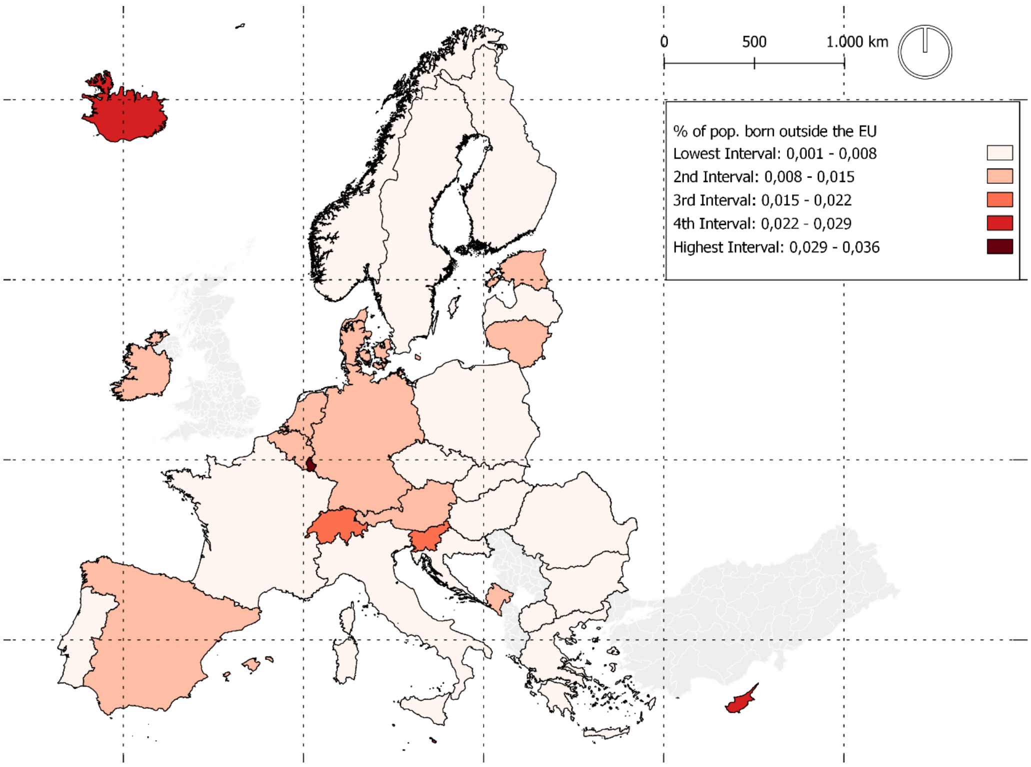


Figure 51: Percentage of non-EU population in each country for the year 2020. Source: Authors. Data: Eurostat (2022s).

4.3.4. Housing conditions and tenure

Energy poverty depends on housing and building conditions (Alba-Rodríguez et al., 2022; Amorim-Maia et al., 2023). Tenure of housing might be a determinant when applying climate actions at the household level, especially when applying to the building and infrastructure sectors. Not owning a property increases the risk of becoming energy-poor because the household is not free to decide on the uptake of climate action. Thus, looking more closely into tenure conditions might also help identify vulnerable groups.

When analysing the NDI, households renting a property tend to be closer to it, with a lower variance. The population younger than 18 years old are especially close to that threshold compared to others, with women showing a slightly worse condition than men. Regarding the groups owning a property, women older than 65 have lower NDI values with a lower variance, following the findings from previous sections (Figure 52).

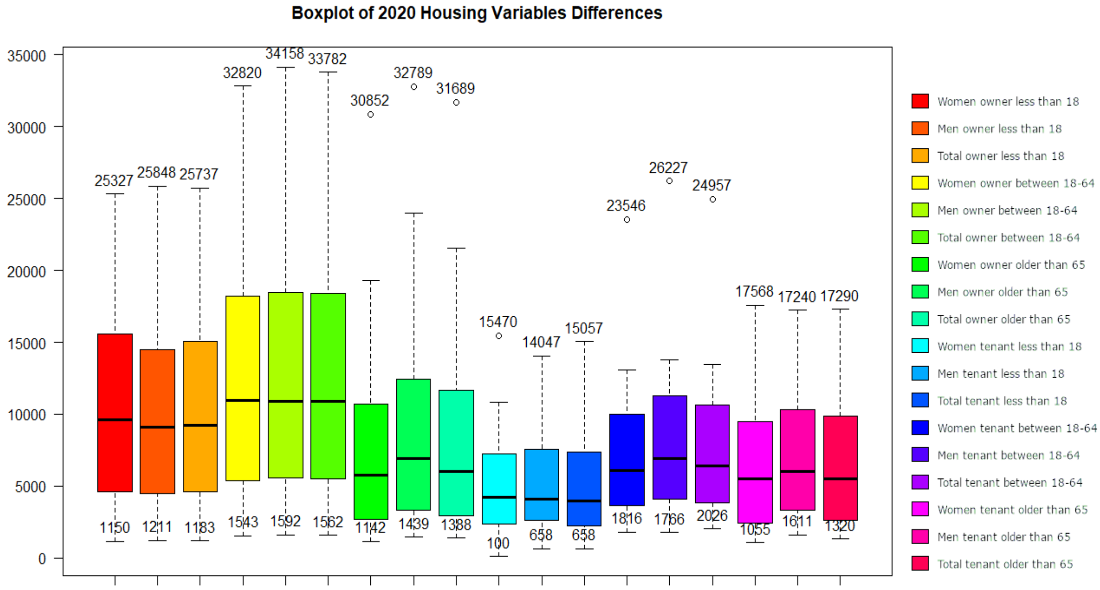


Figure 52: Differences between disposable income and poverty threshold by tenure, gender, and age for the year 2020. Source: Authors. Data: Eurostat (2022l).

When mapping the values for younger women renting a property, Balkan and Baltic countries seem to have the worst conditions. Unfortunately, no data is available to map the % of the population according to their tenure status.

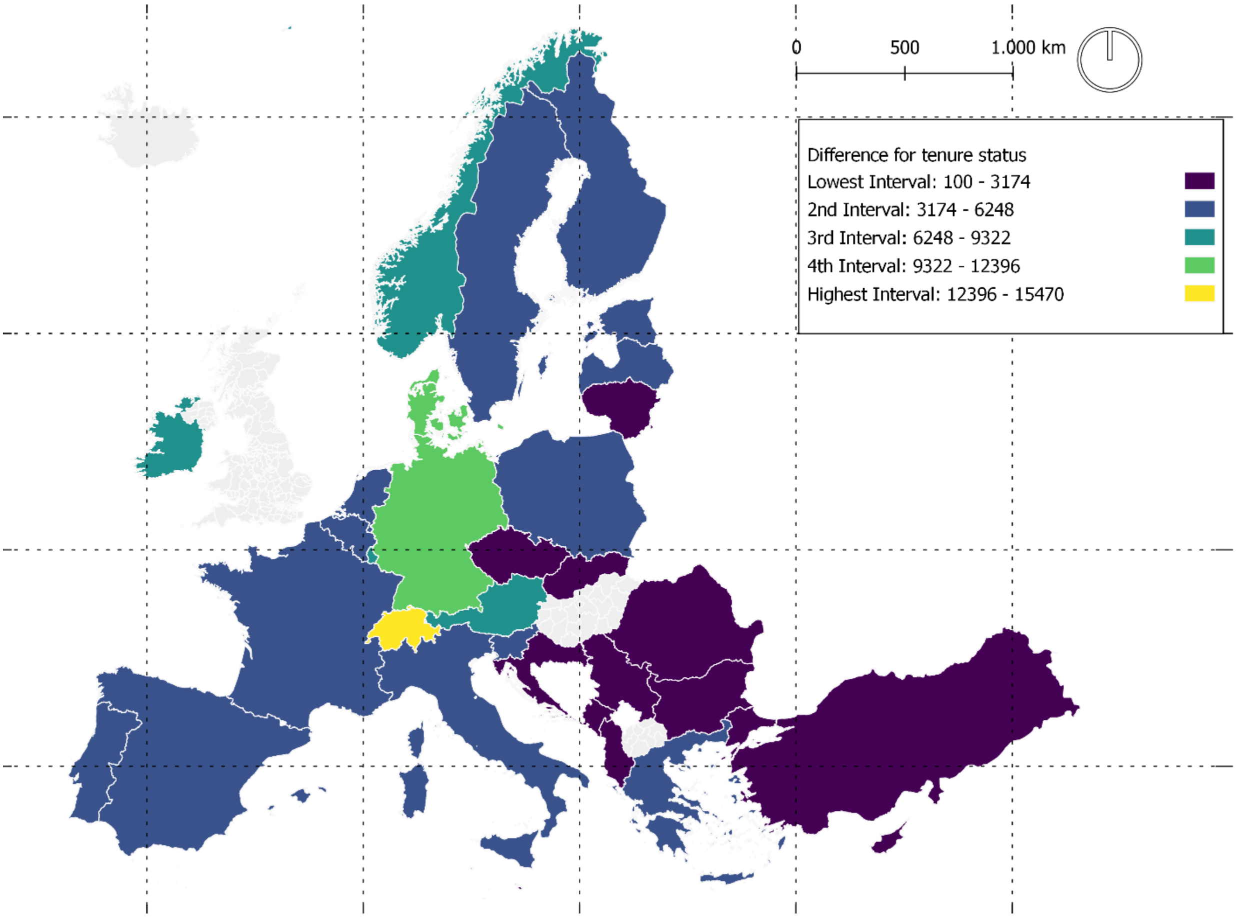


Figure 53: Difference between income for female renting young for the year 2020. Source: Authors. Data: Eurostat (2022l; 2022q).

4.3.5. Elderly and children in household structures

As detected in previous demographic analysis, the older population's NDI is typically lower. However, people older than 65 might depend on other household types, impacting their capacity to adapt to changes. Retired people typically have more healthcare and service needs and have lower incomes. Socioeconomic data shows (Figure 54) that the NDI drops drastically in household structures where one member is older than 65.

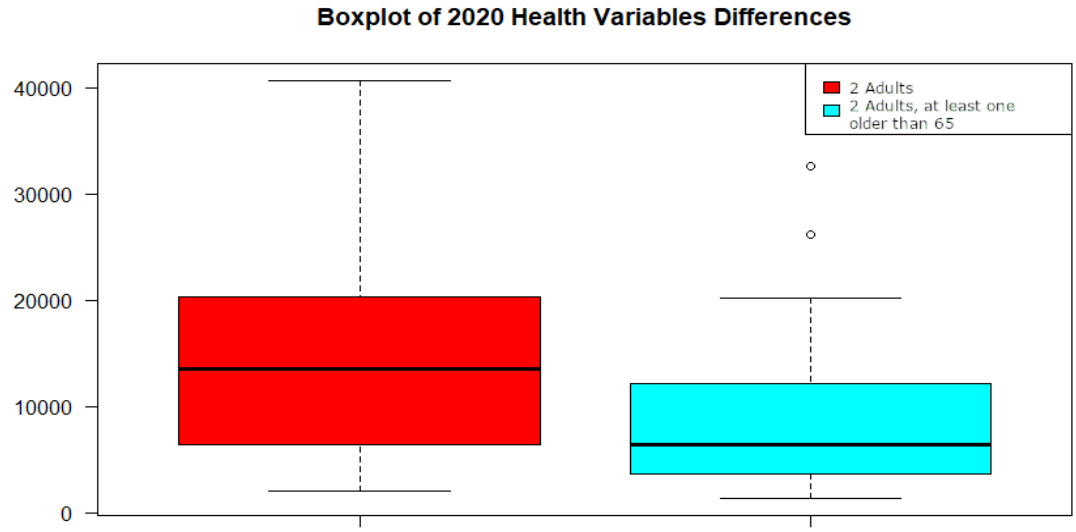


Figure 54: Difference between disposable income and poverty threshold for the year 2020. Source: Authors. Data: Eurostat (2022k).

Geographically speaking, NDI is noticeably low in the Balkan regions, followed by Baltic countries (Figure 55). Regarding population distribution, Balkan regions also have a huge share of the population older than 65 (Figure 56). Other regions, such as Southern-Western European regions or Central-North, also have a high % of the population older than 65.

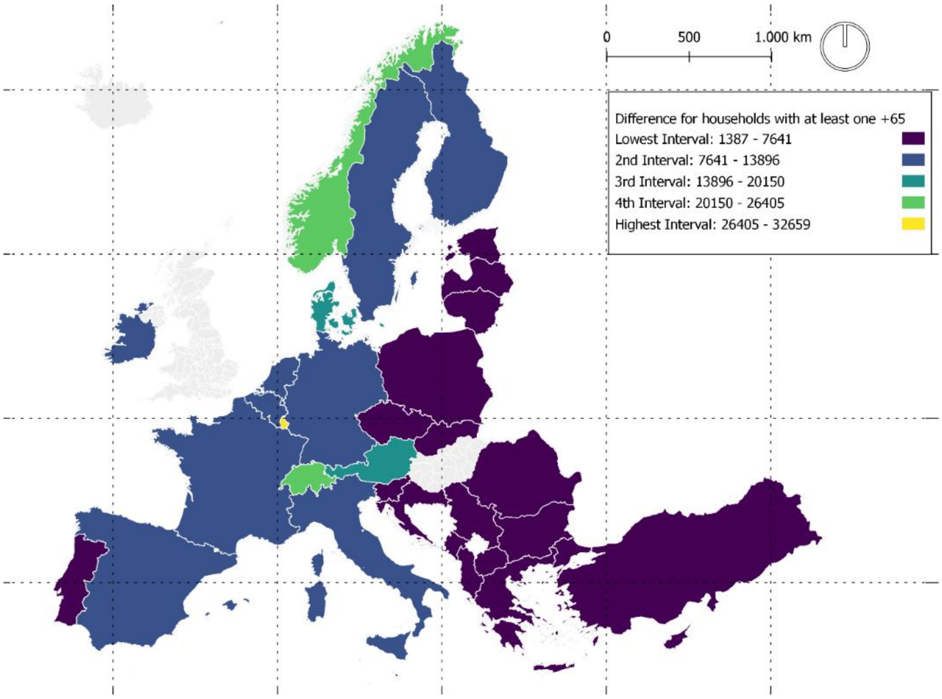


Figure 55: Differences between income and poverty threshold for households with population older than 65 years for the year 2020. Source: Authors. Data: Eurostat (2022k; 2022q).

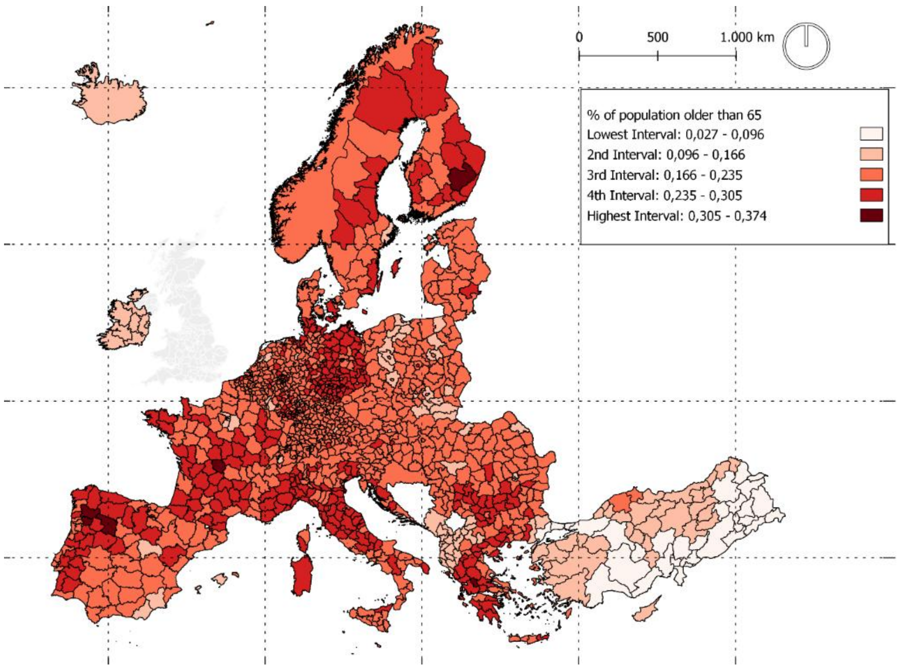


Figure 56: Percentage of population older than 65 year for the year 2020. Source: Authors. Data: Eurostat (2022r).

In the same way, those who have children are likely to have additional educational expenditures and suffer from increased pressure to keep them safe. Children are particularly vulnerable to changes, as their capacity to adapt depends on others. Moreover, Eurostat data shows that households with dependent children also tend to have lower NDI with lower variance (Figure 57). However, single parents have an increased risk of suffering energy poverty when comparing all household structures with children.

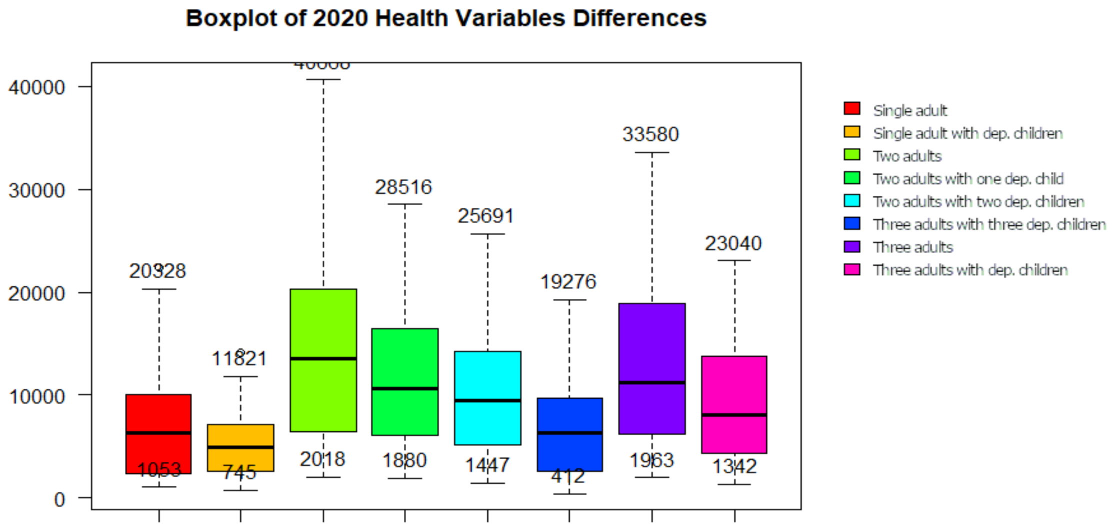


Figure 57: Disposable income vs poverty threshold, household structures with children for the year 2020. Source: Authors. Data: Eurostat (2022k).

When translating the detected groups from a geographical point of view, it can be seen that the NDI is lower in Balkan countries, followed by Northern-Eastern European countries (Figure 58). Unfortunately, there is no data to map the % of households that are single parents with dependent children. However, some regions in the Balkans and Southern Europe have a high % of kids in their population (Figure 59). Further analysis would be needed for a more accurate mapping.

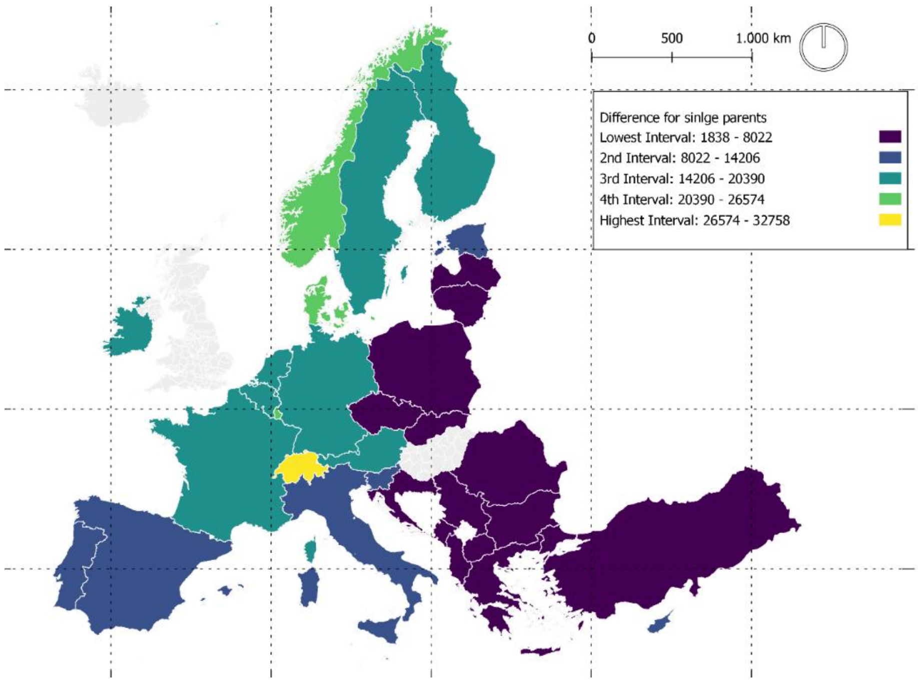


Figure 58: Geographical distribution differences between income and threshold to poverty for single parents with one kid for the year 2020. Source: Authors. Data: Eurostat (2022k; 2022q).

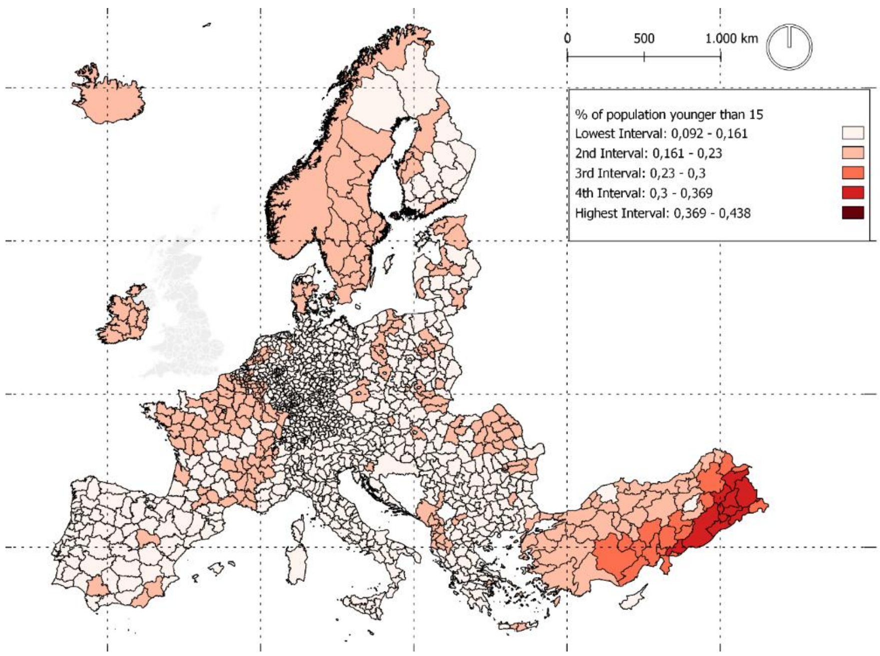


Figure 59: Percentage of children in the population. Source: Authors. Data: Eurostat, (2022r).

5 Discussion

The previous analysis disentangled (1) how regional conditions might impact household lifestyles and how certain infrastructure characteristics might increase the vulnerability of a whole region; (2) how types of households in Europe might be put at increased risk of energy poverty due to changes they might suffer in their lifestyles; and (3), how certain types of households might suffer of increased vulnerability to energy poverty due to their demographic and socioeconomic characteristics. The following section reflects on the results and contextualises some of them.

5.1. From energy poverty to regional affordability of basic domains

5.1.1. Energy

Affordability calculations developed in Section 4.1 show how regional infrastructure characteristics play a role in the risk of energy poverty. The population at risk of becoming energy-poor might suffer from increased risk in regions with low affordability of basic domains. Nevertheless, income, energy prices, and expenditure calculations might overlook potential subsidies, social policies, housing stock, or climatic factors. Comparing affordability with accepted energy poverty indicators from the EPAH can clarify the issue.

Heating degree days (Figure 60) and the inability to keep the house warm (Figure 61) are two important indicators to measure energy poverty in the European context (Gouveia et al., 2023). When comparing it to the first one, regions with higher energy affordability coincide with those with higher heating degree days, which can be interpreted as an alignment of countries to basic needs. However, regional differences within the countries might lower energy poverty issues in certain regions.

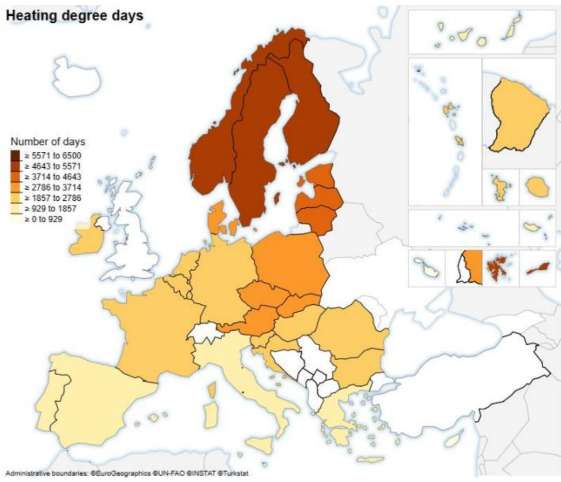


Figure 60: Heating degree days. Source: Gouveia et al., 2023.

Contrastingly, the inability to keep the house warm opposes the energy affordability map. In this case, regions with lower energy affordability belong to countries with higher Inability to keep the house warm (Figure 61). The comparisons expose an interesting contrast where the population in countries with lower heating requirements potentially suffers from increased energy poverty. Therefore, energy affordability might be a useful indicator to measure underlying reasons for the risk of becoming energy-poor. However, more insights into other institutional factors are needed.

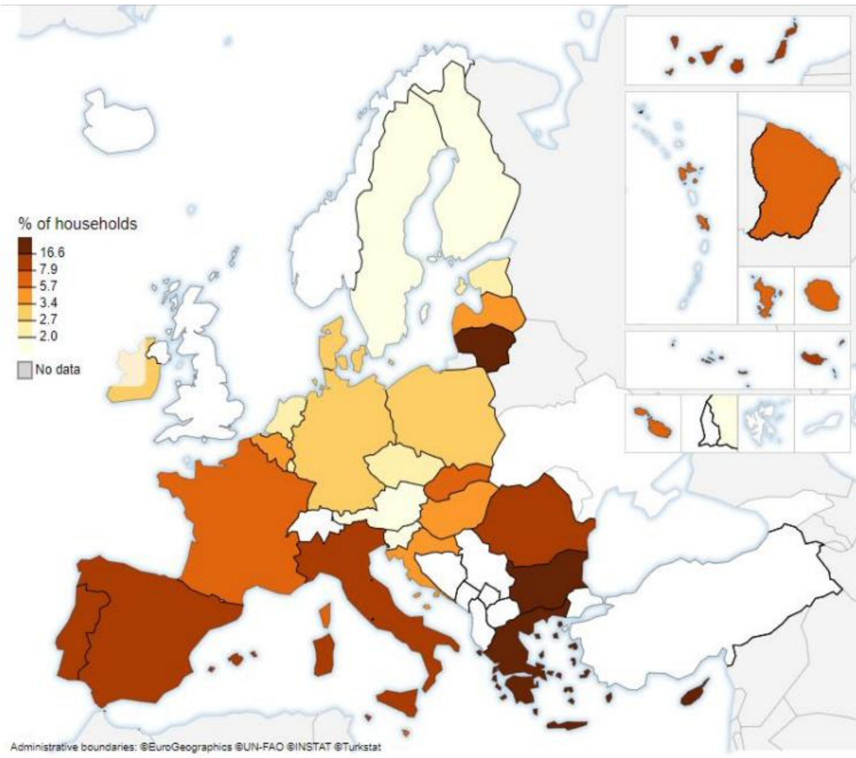


Figure 61: Inability to keep home adequately warm. Source: Gouveia et al., 2023.

Institutional factors and social care services also play a role in energy poverty (Lacey-Barnacle et al., 2020; Wang & Lo, 2021). Even though the prices depend on the market, the household's capacity to purchase energy might vary according to potential subsidies or social benefits. When subsidies apply, expenditure might be reduced, distorting calculated energy affordability. Figure 62 shows the net social protection benefits per country. It can be seen that the social benefits are low in some countries where households can afford fewer energy units. Especially in South-West Europe, even though social benefits are high, households can still not purchase energy nor keep their house warm.

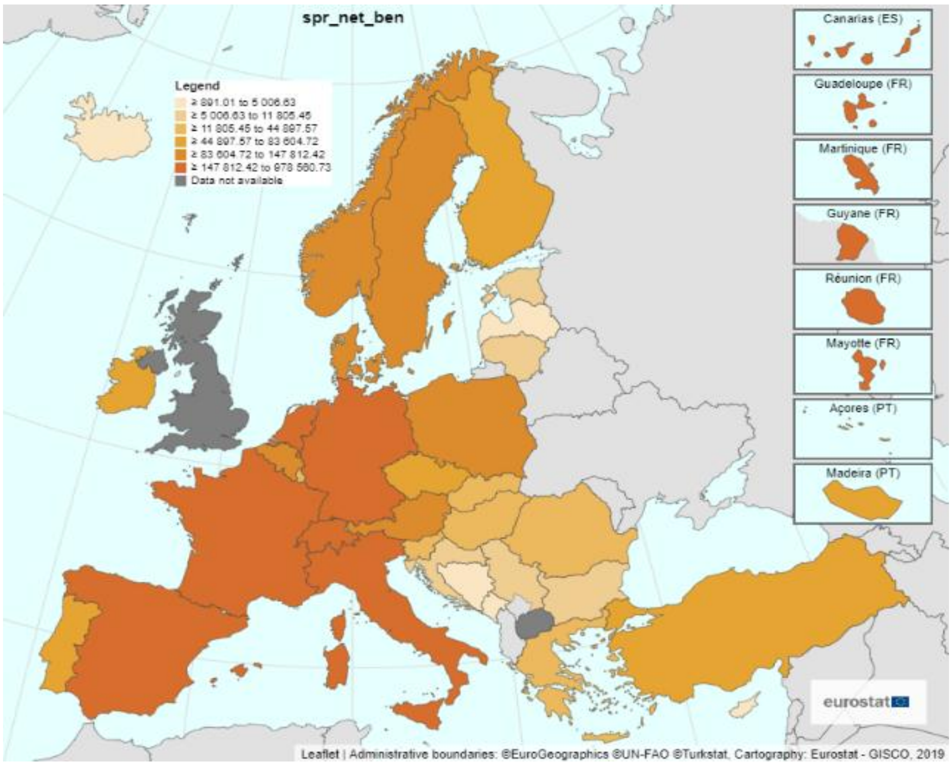


Figure 62: Net social protection benefits. Source: Eurostat (2022v).

Finally, it is important to highlight that energy affordability has been calculated using average income per region, combined with the country's energy price and national average expenditure in energy. Even though the map already offers some useful insights, developing an energy affordability indicator using regional and income data from specific households will offer better results when developing specific energy poverty analyses in specific regions.

5.1.2. Food

As explained in the lifestyle approach, adding pressure on more than one basic domain might be critical for being at risk of energy poverty. Particularly in the food domain, a comparison of the normalised food price index and energy affordability (Energy Purchasing Index) shows that the population in some regions might suffer an increased risk of energy poverty. Interestingly, regions that can afford less energy are placed in countries with more pressure in the food domain, as seen in Southern Europe. Contrastingly, Baltic countries show more stress in the food domain but less in the energy domain, meaning households might have more flexibility to allocate resources in those regions.

5.1.3. Housing

Little data was available to conduct an accurate affordability analysis. HBS offered data for 2020, while housing data was available for 2023. Therefore, results cannot be compared. Due to the complexity of compiling housing price data suitable for the study, further research is recommended. The development of the indicator in a similar way to energy or food will provide useful data to understand how housing affordability interacts with energy affordability and food affordability in different regions.

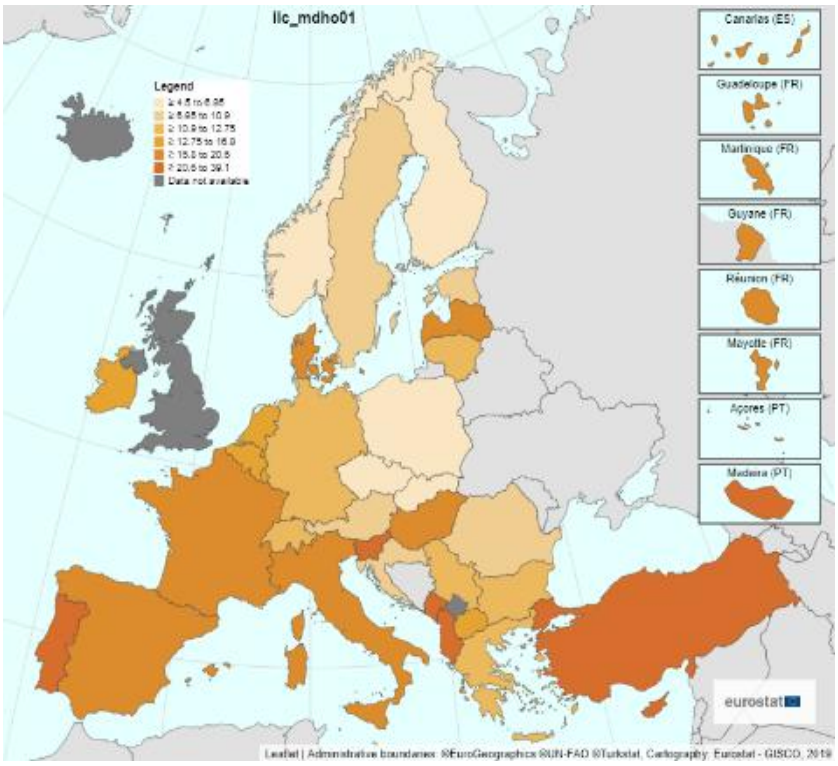
5.2. Regional context of lifestyles

Eurostat HBS offers data every five years until 2020. Data availability was reduced by 20% compared to 2015 for that year, and energy values above the 10% threshold went from 18.39% to 8.58%. However, 9.42% of the missing values for 2020 that were available for 2015 belong to the Czech Republic, North Macedonia, and Romania. When looking at those countries in the previous reports, their values always exceeded the 10% threshold. Thus, it should be considered that the energy poverty status in Europe might be worse than shown in the lifestyle analysis for 2020. When looking at the EPAH report indicators, those countries are precisely still placed among the ones with higher energy poverty.

Geographical distribution is worth analysing as well. In all domains, identified values above the respective expenditures thresholds – for food, housing, healthcare, and education – were mostly located in countries highlighted by the EPAH Report as potentially having energy poverty issues or by the conducted affordability analysis.

Regarding food, Balkan and Baltic countries showed higher values above the food expenditure threshold and higher Inability to keep the house warm. Groups from 21 countries were identified above the food threshold, with similar counts, highlighting that the eat-or-heat dilemma is extended throughout Europe for certain household groups.

Regarding housing, the patterns are similar to those of food. However, countries like Austria, Belgium, and Germany also have values above the housing expenditure threshold. The EPAH Report (Gouveia et al., 2023) claimed the importance of analysing multidimensional issues related to housing status. Thus, the data has also been compared to the Eurostat dataset: "Total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor" (Figure 63). When comparing data geographically, Austria, Germany, and Belgium also show the lowest rates of population living in substandard conditions. Typically, housing quality positively relates to housing price. Thus, it can also be stated that a higher investment in housing conditions in certain regions translates into fewer energy poverty issues. In contrast, some Balkan and Baltic countries have worse housing conditions and are most vulnerable to energy poverty simultaneously, according to their socioeconomic characteristics. However, more detailed data would be needed to reach further conclusions.



Leaflet | Administrative boundaries: ©EuroGeographics ©UN-FAO ©Turkstat, Cartography: Eurostat - GISCO, 2019

Figure 63: Total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor. Source: Eurostat (2022w).

Contextual factors potentially conditioned health distribution of values. Nevertheless, households above the calculated interval are typically located in countries with higher energy poverty rates. All values belong to countries with high rates of energy poverty, as compared with the indicator "Inability to Keep House Warm", except, interestingly, for Belgium. More research is needed to identify the dynamics behind this finding.

5.3. Groups at risk of energy poverty in Europe due to low-carbon lifestyle options

To identify and summarise the findings from identifying groups at risk of energy poverty, the following matrices (Tables 13-16) have been created to compile Europe's groups at the highest energy poverty risk.

Each table corresponds to one domain. When identifying the risk of energy poverty due to low-carbon options, knowing how the option impacts the lifestyle is crucial. Low-carbon lifestyle options might be personal or coming from broader changes. Independently of the cause, whether it is a personal decision or coming from a policy, a lifestyle change might result in energy poverty. Thus, there is one table per domain. The rows on the table compile the household types more at risk of being energy-poor per domain. As demographic characteristics were not considered in lifestyle analysis, the columns on the table provide insights about how demographic characteristics might increase the risk of becoming energy-poor. The table should not be read by cells individually but by rows. Socioeconomic and demographic characteristics are not exclusive but add to each other. For example, identifying groups at increased risk of energy poverty due to low-carbon options in the food domain should be read as: "Older than 60 years old are at risk of suffering from energy poverty due to induced changes into the food domain. When people older than 60 are in the lowest income bracket, they have more risk. If women, the risk increases again; if immigrant, again; if renting a property, a bit more".

Table 13: Compilation of results. Identification of groups at risk of energy poverty due to changes in changes in their food patterns. *NA – Not applicable: the socioeconomic-demographic (SD) characteristic does not apply to the group; No data: there is no data to determine how SD modifies EP risk; 0 – No differences; equal risk; 1 – Slightly higher risk for [...]; 2 – Higher risk for [...]. Source: Authors.*

FOOD DOMAIN						
Groups at increased risk of energy poverty	**Income**	**Gender**	**Ethnicity**	**Tenure**	**Elderly**	**Families with children**
Lowest income quintile	NA – Not applicable	1 – Slightly higher risk for women	No data	No data	2 – Higher risk for older than 65	2 – Higher risk for those with dependent children
Older than 60	2 – Higher risk for those on the lowest quintiles	2 – Higher risk for women	2 – Higher risk for those outside the EU	1 – Slightly higher risk for tenants	NA – Not applicable	NA – Not applicable
Two adults sharing	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable
Three adults sharing	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable
Three adults sharing with children	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable

Table 14: Compilation of results. Identification of groups at risk of energy poverty due to changes in changes in their housing patterns. *NA – Not applicable: the socioeconomic-demographic (SD) characteristic does not apply to the group; No data: there is no data to determine how SD modifies EP risk; 0 – No differences; equal risk; 1 – Slightly higher risk for [...]; 2 – Higher risk for [...]. Source: Authors.*

HOUSING DOMAIN						
Groups at increased risk of energy poverty	**Income**	**Gender**	**Ethnicity**	**Tenure**	**Elderly**	**Families with children**
Two adults sharing	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable
Three adults sharing	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable
Single adult	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly worse for tenants	2 – Higher risk for older than 65	NA – Not applicable
Single adult with dependent children	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable
Older than 60	2 – Higher risk for those on the lowest quintiles	2 – Higher risk for women	2 – Higher risk for those outside the EU	1 – Slightly higher risk for tenants	NA – Not applicable	2 – Higher risk for those with dependent children

Table 15: Compilation of results. Identification of groups at risk of energy poverty due to changes in changes in their healthcare patterns. *NA – Not applicable: the socioeconomic-demographic (SD) characteristic does not apply to the group; No data: there is no data to determine how SD modifies EP risk; 0 – No differences; equal risk; 1 – Slightly higher risk for [...]; 2 – Higher risk for [...]. Source: Authors.*

HEALTHCARE DOMAIN						
Groups at increased risk of energy poverty	**Income**	**Gender**	**Ethnicity**	**Tenure**	**Elderly**	**Families with children**
Two adults sharing	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable
Single adult	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	1 – Slightly higher risk for tenants	2 – Higher risk for older than 65	NA – Not applicable

Older than 60	2 – Higher risk for those on the lowest quintiles	2 – Higher risk for women	2 – Higher risk for those outside the EU	1 – Slightly higher risk for tenants	NA – Not applicable	2 – Higher risk for those with dependent children
Lowest income quintile	NA – Not applicable	1 – Slightly higher risk for women	No data	No data	2 – Higher risk for older than 65	2 – Higher risk for those with dependent children
Second lowest income quintile	NA – Not applicable	1 – Slightly higher risk for women	No data	No data	2 – Higher risk for older than 65	2 – Higher risk for those with dependent children

Table 16: Compilation of results. Identification of groups at risk of energy poverty due to changes in changes in their education patterns. *NA – Not applicable: the socioeconomic-demographic (SD) characteristic does not apply to the group; No data: there is no data to determine how SD modifies EP risk; 0 – No differences; equal risk; 1 – Slightly higher risk for [...]; 2 – Higher risk for [...]. Source: Authors.*

EDUCATION DOMAIN						
Groups at increased risk of energy poverty	**Income**	**Gender**	**Ethnicity**	**Tenure**	**Elderly**	**Families with children**
Three adults sharing with children	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	No data	2 – Higher risk for older than 65	NA – Not applicable
Adults between 45-59	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	1 – Slightly higher risk for those outside the EU	1 – Slightly higher risk for tenants	NA – Not applicable	2 – Higher risk for those with dependent children
Rural households	2 – Higher risk for those on the lowest quintiles	1 – Slightly higher risk for women	No data	No data	No data	2 – Higher risk for those with dependent children
Second lowest income quintile	NA – Not applicable	1 – Slightly higher risk for women	No data	No data	2 – Higher risk for older than 65	2 – Higher risk for those with dependent children
Third income quintile	NA – Not applicable	1 – Slightly higher risk for women	No data	No data	2 – Higher risk for older than 65	2 – Higher risk for those with dependent children

The tables compile only the five households typically at most risk of energy poverty in the European context per each domain. The following key points can be extracted from the table:

1. Age and income are critical when identifying groups at risk of being energy-poor due to lifestyle changes. Firstly, the lowest income groups and older than 60-year-old people are commonly identified as a household type in several domains, both present in three out of the four. Moreover, when analysing the socioeconomic characteristics, people with the lowest income and advanced age tend to have lower NDI and variance in all demographic characterisations.
2. Due to their variance and low NDI differences with other groups within the same category (older than 65 vs. 45-59, or single vs. single parent), age, dependent children, and income are the socioeconomic characteristics that might increase the risk of becoming energy poor.
3. From the socioeconomic and demographic characteristics, women always have, at least, a slightly higher risk than men of becoming energy-poor, independently of their household type. However, when older than 65, their risk of being energy-poor increases substantially. This group is particularly relevant in the food, housing and healthcare domains.
4. Ethnicity and tenure can only be cross-checked with household categorisation by age. In that case, the older population from outside the EU faces a higher risk of energy poverty in the healthcare and housing domain.

6 Equitable and just climate responses

6.1. How to choose equitable and just climate responses to avoid increasing levels of energy poverty

As explained, the risk of suffering energy poverty is closely related to justice and equity (Hanke et al., 2023; Kashwan, 2021; Lippert & Sareen, 2023; Newell et al., 2022; Shelton & Eakin, 2022). More just and equitable mitigation, and even adaptation, responses would reduce citizens' risk of suffering externalities compared to a non-just transition to low-carbon lifestyles (DeVar, 2021; Dwarkasing, 2023; Garvey et al., 2022). Recognising groups at risk of energy poverty and how climate and/or low-carbon transitions can impact them is crucial for just and equitable policy-making. Recent studies started highlighting the potential negative impacts of mitigation (Sovacool, 2021) and adaptation (Reckien et al., 2023) options when badly implemented and determining which vulnerable groups could be more prone to suffer those impacts. Thus, understanding how each group is affected by its lifestyle, the regional context where it belongs, and its demographic distribution offers the opportunity to choose more just and equitable measures.

Following that research string, the results obtained in the previous section allow for broadly identifying measures and instruments suitable for specific regions according to their regional characteristics and the presence of groups at risk of energy poverty. Identification of just and equitable measures is based on three different premises:

1. Measures might produce externalities that impact regional infrastructure characteristics, such as domain affordability, when not properly implemented and not attuned to regional conditions. Implementing measures to phase out fossil fuels in a region highly dependent on them will be more risky than implementing the same measures in a region where the energy system already switched to Renewable energy production.
2. Measures impact specific lifestyle domains. "Database of current, planned and potential adaptation and mitigation measures" (LOCALISED - Deliverable 4.1) in LOCALISED identified several measures implemented throughout Europe. Measures might have an inherent risk of impacting some domains' affordability. Thus, potential changes produced by a measure targeting food production will more likely be felt in the food domain for households, putting some specific groups at a greater risk of becoming energy-poor.
3. Some vulnerable groups might be more impacted than others by specific domains. Knowing which households are more pressured by which domains might help assess less risky, just and equitable measures and instruments.

The report considered the groups at risk of energy poverty as potential victims of a badly implemented low-carbon transition. However, the insights provided by regional characteristics, lifestyles, and demographic and socioeconomic characteristics support the creation of a framework to select just and equitable measures according to it. Hence, measures with a potential impact on food infrastructure would not be suitable in regions with low energy and food affordability and with a high share of the population falling into a household category vulnerable to changes in the food domain.

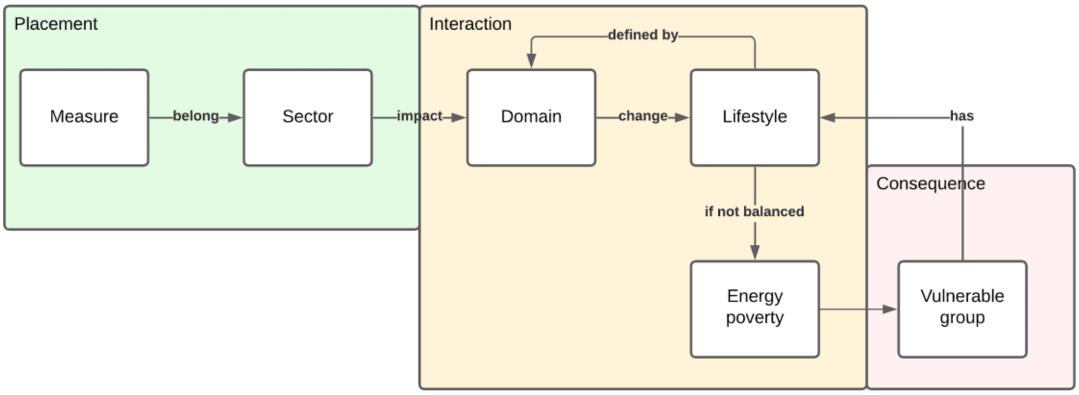


Figure 64: Relation between measure implementation and how it impacts households. Understanding which households are more vulnerable to certain domains can help assess more just and equitable measures when compared to regional considerations. Source: Authors.

6.2. Improving vulnerable groups' lifestyles through the energy transition

As seen in section 6.2, the selection of climate action can influence lifestyle domains. Being aware of the impacts climate actions might have in specific sectors and how these are shaped by implementation can be used in favour of certain population groups. Proper implementation of climate actions can be used to avoid higher energy poverty risk and potentially reduce it, particularly when measures have strong social impacts in a specific sector and for a specific group. For instance, new low-cost mitigation strategies in housing retrofitting can substantially improve the low-income population's quality of life and health (Torné & Trutnevyte, 2024).

However, most climate action could have a bi-directional impact. Particularly, actions related to renovations can have several positive effects, such as reducing energy demand or improving health conditions for seniors (Marvuglia et al., 2020), decreasing their exacerbated demand for health services – Section 4.2.4. However, their costs might increase the tenants' financial risk (Grossmann, 2019). If climate action is guided by equitable and just policy-making, it can reduce energy poverty risk and offer co-benefits for specific vulnerable groups.

7 Limitations of the research

Even though the research complied with its goal, it faces various limitations stemming from data constraints. Firstly, data availability was restricted to 2020, as it was the most recent year with expenditure data available. Moreover, no public data with high quality could be found for the housing, health, and education domains.

Particularly, the absence of disaggregated data at a regional scale makes the detailed contextualisation at regional and local scales difficult. National data can overlook context characteristics crucial for understanding localised dynamics. Also, some lack of household structure and domain expenditure data availability limits the ability to detect more detailed patterns. It has been observed that correlations between domains and household characteristics vary across European regions.

The authors want to remark on the need for a cautious interpretation of the findings and suggest replicating the methods at local and regional scales to address potential dismisses and close some suggested research gaps. Accessing more detailed data and incorporating regional contextualization might lead to more robust conclusions and informed decision-making in relevant domains.

8 Conclusions

Current studies describe energy poverty as a multidimensional issue (Lippert & Sareen, 2023), which can be defined in several ways. The most recent definitions accepted by the European Commission acknowledge a household-centred approach considering energy-poor households that are unable to keep their house warm. However, the recent reports from the Energy Poverty Advisory Hub raised the need to search for new cross-sectoral indicators that could look for the underlying reasons behind being exposed to the risk of energy poverty.

In this report, we focused our efforts on detecting potential causes of energy poverty rather than energy poverty itself. The approach followed the reasoning of the European Commission and took a multidimensional household-centred perspective by analysing the household lifestyles and expenditure patterns in different domains. Considering the current climate crisis, the study covered potential reasons coming from climate actions towards the transition to low-carbon lifestyles. The report (1) analysed the role of regional and infrastructure characteristics in the implementation of measures, (2) identified household types vulnerable to energy poverty, (3) mapped those households using demographic and socioeconomic characteristics, and (4) exemplified how identification of households through their lifestyles can provide a better assessment of just and equitable measures. The following conclusions can be extracted from the report:

1. The report identified types of households at risk of energy poverty. The applied methodology allowed for identifying in greater detail which lifestyle changes might impact the different household types groups more. Understanding how households are at risk of energy poverty allows for more accurate identification of groups, considering regional context (through regional characteristics), multidimensionality (through the integration of lifestyles), and socioeconomic patterns (through socioeconomic and demographic analysis). In the end, identifying underlying reasons is the factor that allows the suggestion of the framework to select more just and equitable mitigation.
2. Causes for energy poverty occur on multiple scales. A non-resilient energy system might lead to a higher risk for households to feel externalities when applying mitigation or adaptation measures that might imply changes in energy production. Local policies are relevant. However, changes in national and regional infrastructure might also increase energy poverty risk for the population in a region. The report exemplified how those factors can be calculated in a particular case for energy production. However, the same process should be conducted for other basic domains, such as food and housing, as measures can also impact them.
3. Analysing expenditure patterns in the basic domains (food, housing, energy) at a regional scale helps to monitor risks of energy poverty. However, it should always be contextualised using energy poverty indicators. EPAH indicators such as the inability to keep the house warm or the number of Heating Degree Days

hint at the potential risk for households to be energy-poor in a region. Analysis of accessibility and affordability of basic domains might help disentangle, at the regional scale, the reasons behind energy poverty measurements. As an example, two regions might have similar access to energy. However, if one of them has less food affordability, the problem of energy poverty might come from that other domain.

4. Analysing lifestyles using domain expenditure patterns helps to identify potential energy poverty issues. The energy poverty threshold might be set at a certain %, but the expenditure in other basic domains might condition the final expenditure of households. When running simple correlations, it is clear that a correlation between certain domains and energy domains exists. Thus, the analysis conducted in the report provides interval thresholds that might be used to identify potential at-risk-of-energy-poverty households through their expenditure on Food, Housing, and Healthcare.
5. There is a close relation between household expenditures for energy and the threshold of being at risk of poverty (60% of the median). Thus, calculating the difference between the median disposable income of a certain group and comparing it to the 60% of the national median also helps identify energy-poor households, being the ones closer to the median the ones at more risk of energy poverty.
6. Using the abovementioned difference, NDI, it is possible to understand what demographic characteristics influence the risk of being energy-poor. Thus, it was found that for certain household types, certain demographic characteristics have a greater impact. Even though gender is shown to worsen all household types, when the population is over 60 years old, it becomes even more determinant. Being an immigrant worsens the conditions independently of the household type.
7. Certain household types in certain countries are more vulnerable to becoming energy-poor due to lifestyle changes. Even though some groups are more prone to suffer from energy poverty, some specific groups might suffer energy poverty issues due to the pressure they feel in other domains. For example, the population in the first and second quintiles are more likely to suffer from energy poverty due to pressure in the food domain. However, single adults are more likely to suffer due to pressure in the housing domain.
8. Measures typically have an impact on a domain besides their sector. Comprehensive identification of households present in each region, regional conditions, and which domains have more pressure on those households will help identify suitable measures and instruments for that region. If needed, in further work, identifying which domains the measures compiled in the "Database of current, planned and potential adaptation and mitigation measures" (LOCALISED - D4.1) are impacting might facilitate the suggestion of more just mitigation and adaptation measures through LOCALISED outputs.
9. In March 2024, the European Environment Agency released its first European Climate Risk Assessment (EUCRA)(European Environment Agency, 2024). It is stated that climate impacts might worsen energy, food, housing, and other basic domains' security and accessibility. Although the report focuses on energy

transition, structural findings and methods to identify groups being at risk of energy poverty can also be transferred to the potential changes induced by climate impacts on the different domains and be used to identify those who might be put at an increased risk of suffering energy poverty or any other desired indicator.

From the authors' perspective, the report successfully *mapped out vulnerable populations across Europe that may be at risk of (increased) energy poverty due to identified low-carbon lifestyle options* by identifying which domains are more pressing for different households, indicating how some specific measures, even though when not directly impacting energy, might increase their energy poverty level while changing aspects on their lifestyles. Moreover, it introduced a framework to identify how different measures and instrument types can help achieve a more just and equitable transition to low-carbon lifestyles.

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Eurostat. (2022v). Net social protection benefits [dataset]. Eurostat. https://doi.org/10.2908/SPR_NET_BEN

Eurostat. (2022w). Total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor - EU-SILC survey [dataset]. Eurostat. https://doi.org/10.2908/ILC_MDHO01

Appendix

A.1. Results from literature review

Table 17: Template questions for the systematic literature review. Source: Author.

Question	**Nº of publications with answers**
Is the study focusing on mitigation or adaptation?	17 for adaptation; 27 for mitigation; 19 for both; 6 others.
Which sector is mainly addressed?	Variate answers.
Which are the vulnerable groups detected?	36
What is the connection between vulnerability, justice, and climate change?	27
What is the definition of vulnerability?	17
What are the main drivers of vulnerability?	36
What is the definition of justice and/or equity?	31
What are the indicators to assess justice and/or equity?	28
Which are the indicators to assess energy justice?	5
How do climate actions affect vulnerability and/or justice?	40
What is the definition of energy poverty?	2
What is the definition of energy justice?	13
What are the main indicators to assess energy poverty?	7
How does climate action affect energy poverty?	19
How does energy poverty relate to vulnerability, justice and/or equity?	10

Table 18: Results of the literature review. Source: Author.

Generic background	
Definition of vulnerability	Lit. Review
The concept of vulnerability is inherently associated with climate change. Being vulnerable means being prone to suffer any adverse impact of climate change. Vulnerability is typically defined as a function of exposure, sensitivity to risk, and adaptive capacity (Kelly & Adger, 2000; Paavola & Adger, 2006; Swanson, 2021), and it can be branched into two dimensions: social and physical vulnerability. While social vulnerability relates to socioeconomic, demographic or institutional factors, the physical dimension relates to the geographical, physical, and environmental components of it (Swanson, 2021). Several drivers can worsen vulnerability through any of both dimensions, such as gender inequality (Some et al., 2022), inadequate medical care or less social support (Lawrence et al., 2022), household-level hierarchies (Tschakert et al., 2023), or accessibility to basic infrastructure. Furthermore, recent literature claims that even climate actions to fight climate change might perpetuate or exacerbate current vulnerability levels due to overlooking inequitable patterns in development and lack of participation of recognised vulnerable communities (Hughes & Hoffmann, 2020; Amorim-Maia et al., 2022).	
What can define as vulnerability?	Lit. Review; Interpretation
Vulnerability to climate change is not equally distributed (Amorim-Maia et al., 2022; Hughes & Hoffmann, 2020; Kashwan, 2021; Lawrance et al., 2022). Regarding responsibility, those who emit less are typically the most affected by climate impacts. Besides, those most impacted are those with less adaptive capacity to prevent or react to impacts (Lawrance et al., 2022). There are several vulnerable groups identified in the literature, such as women, the elderly, the disabled, LGBTQ+ collective, the poor, ethnic minorities, and domestic producers (Amorim-Maia et al., 2022; Bowman et al., 2021; Hughes & Hoffmann, 2020; Jakob, 2021; Kashwan, 2021; Kinol et al., 2023; Lawrance et al., 2022). Those groups are defined by economic, social, demographic, and geophysical characteristics and their capability, responsibility, or acceptability for climate action (Garvey et al., 2022). However, the range of drivers that might make certain populations vulnerable is wide and diverse. ADD A TABLE WITH DRIVERS/GROUPS/TYPE OF RESPONSE In the reviewed literature, 29 vulnerable groups have been identified, with 80 drivers that can lead people to become vulnerable. Apart from the characterisation based on the geophysical, economic, social, environmental, institutional or technical dimensions, findings in the literature show two more appropriate ways to classify the drivers of vulnerability. Scale and spatial dimensions are important when assessing vulnerability (Garvey et al., 2022). Vulnerability can be assessed at different scales. 1. At the smallest scale, vulnerability can be attached to individuals as people can be vulnerable due to their conditions, independent of their location. Examples can be found in the disabled (Kato-Huerta et al., 2023), immigrants (Cunha & Silva, 2023), or uneducated (Tschakert et al., 2023), among others.	

<table>
<tr><td colspan="2">

2. Some characteristics attached to the context also increase or decrease vulnerability. The type of region (Lacey-Barnacle et al., 2020) or exposure to hazards (Tamasiga et al., 2023), like the dependency on industries (Garvey et al., 2022), institutional support (Amorim-Maia et al., 2022), are drivers that impact the whole region, independent of the characteristics of the people.
3. Finally, some traits come from the community perspective, which highly depends on the actors' role in the issue and can change according to their perspective, such as media coverage (Shea et al., 2020), or ideologies (Mullen & Widener, 2022).

Besides, independent of the scale, when cross-checking the vulnerable groups with drivers, there are three different ways in which drivers can make people vulnerable:

1. Inherent characteristics. Some drivers are inherent to the population, cause vulnerability and can't be changed. E.g., their mere presence makes a group of people vulnerable in our current society. Socio-demographic characteristics and their combination, such as gender (women), age (elderly or children), race or ethnicity (people of colour), or identity and sexual orientation (LGTBIQ+ collective), are the clearest examples for people. However, geophysical characteristics such as hazard exposure are also inherent to the regions. These characteristics can't be addressed with incremental changes but need transformational action.
2. Relative characteristics. Similar to inherent characteristics, relative characteristics are attached to the population and cause vulnerability. However, these can be overcome. Regarding people, those are mainly related to technical capabilities or economic characteristics. Drivers such as low income, unemployment, land tenure, or dependence on local production can be momentarily addressed via incremental changes. However, without transformational changes, they might arise again.
3. External characteristics. External characteristics constantly interact with both of the two previous types. Drivers such as climate isolationism, passiveness to injustice, or social norms create and exacerbate the vulnerability caused by inherent characteristics or relative characteristics.

</td></tr>
<tr><td>Which are the most common vulnerable groups</td><td>Lit. Review</td></tr>
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According to the research conducted, out of the 29 vulnerable groups detected, the most commonly detected vulnerable groups are the poor (14 papers), children (10), indigenous people (7), women (7), and the disabled, the elderly, and marginalised communities (6). From the 80 drivers detected, the most prominent ones are gender (13), race and ethnicity (12), income level (10), age (8), class (7), sexual orientation (6), and issues related to health (13). As can be seen, groups and drivers are coincident.

However, taking a closer look at the vulnerable groups, the literature also mentions several specific groups that can be grouped under the umbrella of the most prominent ones but mixed with some other drivers. This typically happens when inherent characteristics are mixed with other characteristics. Thus, even if a group like "women" (gender) is mentioned only seven times, single moms (gender + threat to loved ones) or widows (gender + marital status) are also mentioned apart. The same phenomenon happens with other groups whose vulnerability is driven by race/ethnicity, such as blacks, other people of color, ethnic and racial minorities or Asians.

</td></tr>
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<table>
<tr><td colspan="2">Moreover, vulnerable groups are also related to them. Some not-that-vulnerable groups are also at risk of falling into the most vulnerable categories. This happens when the groups are depending on relative characteristics. In this case, unemployed, small rural landholders or agricultural workers might fall into the poor group.</td></tr>
<tr><td>What indicators are relevant to assess vulnerability?</td><td>Lit. Review</td></tr>
<tr><td colspan="2">Indicators to assess vulnerability can be better structured when classifying them by scales, as they need to be measured appropriately. Moreover, both vulnerable groups and drivers need to be measured. The availability of indicators useful to measure each one of the groups and drivers still needs to be checked.</td></tr>
<tr><td>Definition of justice</td><td>Lit. Review</td></tr>
<tr><td colspan="2">Justice is typically conceived as a three-dimensional issue, combining distributional, procedural, and recognitional justice (Godinho, 2022; Hughes & Hoffmann, 2020; Kinol et al., 2023; Swanson, 2021; Hanke et al., 2023). While the first addresses the equal distribution of burdens and benefits, the second makes sure to include all affected counterparts in the process, and the third ensures not to leave anyone behind, recognising all impacted groups (Godinho, 2022; Hughes & Hoffmann, 2020; Kinol et al., 2023; Swanson, 2021; Hanke et al., 2023). When speaking about climate justice, is about the burdens and costs of climate impacts and climate actions that we are talking about (Kashwan, 2021). In fact, climate justice is progressively related to the intersectional analysis of existing systems, climate change impacts, and how those limit adaptive capacity or increase existing vulnerability (Amorim-Maia et al., 2022; Kinol et al., 2023).

However, the broad impacts of climate change and the repercussions of climate action made scholars reflect on the capacity of those definitions, expanding the three-dimensional climate justice framework. Due to the global scale of climate change and its impacts, as well as the long-term impacts that might be brought about, literature has inevitably started to raise questions about (1) intergenerational justice to ensure the liveability of the planet for future generations (Hughes & Hoffmann, 2020; Kinol et al., 2023; Wang & Lo, 2021), (2) interregional justice, to account for the impacts caused to third parties (Tamasiga et al., 2023), and (3) compensatory justice, to compensate those who can't fight against a crisis that they did not provoke (Lacey-Barnacle et al., 2020; Wang & Lo, 2021; Srivastava & Kumar, 2022).</td></tr>
<tr><td>What indicators or drivers can be used to assess justice?</td><td>Lit. Review; Interpretation</td></tr>
<tr><td colspan="2">Climate justice is not easy to measure or to assess. Several drivers can lead to achieving climate justice or creating unjust situations in a region. Some of those drivers are linked to structural societal conditions, while others are linked to the design of climate actions or politics, and others to socio-economic characteristics.

Structural conditions are linked to the societal system. Amorim-Maia et al., 2022 provide many drivers: colonial approaches to politics, racial and gendered capitalism, and increasing reliance on intergovernmental and private finance resources. Existent power relations (Mullen & Widener, 2022;</td></tr>
</table>

Owen, 2020), and institutional stability or corruption (Lacey-Barnacle et al., 2020) are also examples of those. Following those, certain approaches to politics might also define climate justice. Appliance of international laws in domestic courts (Colombo & Giadrossi, 2020), limited participation in decision-making or race-blind climate policies (Amorim-Maia et al., 2022; Kashwan, 2021; Roy et al., 2022; Swanson, 2021), applying reactive or proactive policies (Dwarkasing, 2023), providing housing security (Rao et al., 2023), ensuring equitable outcomes and safety (Swanson, 2021), investment balance between technology and social issues (Kinol et al., 2021) or mitigation costs (Jakob, 2021). Finally, the socioeconomic characteristics of the regions are also linked to justice. Characteristics like devaluation (Amorim-Maia et al., 2022), workers' skill (Godinho, 2022), economic disparity (Hughes & Hoffmann, 2020), educational level (Kinol et al., 2021), or accessibility to infrastructure and information (Kallis et al., 2021; Brisebois et al., 2022; Roy et al., 2022) fall into this type.	
How is justice related to vulnerability?	Lit. Review; Interpretation
Justice, equity, and vulnerability to climate change are closely linked. On the broader picture, the impacts of climate change have greater burdens on the most vulnerable communities (Hughes & Hoffmann, 2020; Kashwan, 2021). Moreover, those who felt most of the impacts of climate change are the ones who contributed less to it (Kato-Huerta & Geneletti, 2023) and have less capacity to face them (Lawrance et al., 2022). Climate impacts negatively affect accessibility to water, food, or health (Kinol et al., 2021). Being vulnerable to climate change poses a risk of creating or exacerbating more injustice. However, the relation also goes in the other direction. When looking at the local scale, drivers of justice or injustice can also increase or decrease vulnerability. Asymmetric power relations might influence distributional, procedural, and recognitional justice (Godinho, 2022; Kashwan, 2021; Owen, 2020), which are crucial for a fair distribution of climate action benefits. Unfair distribution of wealth and lack of recognition policies play an important role in certain demographic and socioeconomic groups' capability to face climate impacts (Garvey et al., 2022; Swanson, 2021; Swanson, 2023), as lack of equal opportunities for education does. Structural drivers of injustice, such as racism, misogynism, classism, or colonialism, are also drivers for the increased vulnerability of certain groups. Besides, unjust events and dynamics might make people who were not vulnerable fall into vulnerable groups. For example, these events might worsen the population's mental health (Lawrance et al., 2022), or a simple rise in rental or energy prices might make people fall into poverty and lose adaptive capacity.	
What are low-carbon lifestyles (LCL)?	D6.1
Reaching net zero won't only cut down emissions but also bring relevant changes to people's lifestyles. Lifestyle is defined as "the distinctive pattern and manner of living an individual or group use to meet their biological, economic, emotional, and social needs that typically reflect their attitudes, beliefs, and values" (Bell, 2014). Within the context of Europe, citizen's lifestyles are based on a high carbon footprint. Thus, when aiming to mitigate GHG emissions, those lifestyles will suffer several changes, which can be	

operationalised into six lifestyle domains, conceptualised as food, housing, transport, goods, leisure and services (Akenji et al., 2021). Several factors might facilitate the implementation of such changes, like time required, costs, or dependence on external infrastructure (Moreau, Vincent et al., 2017, p. 8; Lewis et al., 2021, pp. 111, 126 and Costa et al., 2021). Speaking from the individual perspective, those changes will also rely on their capacity and position. On the one hand, depending on their capacity, some population groups might be put under pressure when forced to adopt those changes. On the other hand, structural, socio-economic and cultural factors also pressure the adoption of those changes, leading to increased social vulnerability (Sharlamanov & Petreska, 2020, p. 26).	
How does LCL affect vulnerability and justice?	Lit. Review; Interpretation
Mitigation pathways might impact vulnerability and justice in several different ways, positive or negative, depending on the sector. When speaking about energy, infrastructure renovation has the potential to transform structural and systemic factors. Some benefits include job opportunities, health improvements, energy bill savings, wealth-building opportunities or increased resilience to power outrages (DeVar, 2021; Cai et al., 2022). However, action needs to be followed by fair, intersectoral and intentional policies (Amorim-Maia et al., 2022; DeVar, 2021). Including actions planned to account for distributional, procedural, and recognitional practices might bring health and wealth benefits to vulnerable communities (Kato-Huerta & Geneletti, 2023) and even increase the effectivity of those actions (IPCC WG II, 2022). Nonetheless, those actions and policies need a transdisciplinary approach since self-contained policies might offer a limited response detached from reality (Amorim-Maia et al., 2022; Kinol et al., 2021). In fact, when not accounting for justice, mitigation actions can even create or exacerbate vulnerability (Hughes & Hoffmann, 2020). According to the political ecology framework, mitigation actions can produce acts of enclosure – or capture of resources –, exclusion – or unfair planning practices –, encroachment – or producing environmental harms –, or entrenchment – or worsening inequality (Sovacool, 2021). All of them have a negative impact on vulnerability. For example, job creation might not be beneficial for local communities or marginalised groups or be permanent (Godinho, 2022; Wang & Lo, 2021), the transformation of the energy system might produce an energy price rise and induce social issues such as energy poverty to individuals (Zhou et al., 2023), not accounting for interregional justice might avoid the potential externalities of the extraction of raw materials to build new infrastructure (Srivastava & Kumar, 2022), and occupying land for implementing mitigation actions might retrain the land use for other purposes or harm the environment (Kalt & Tunn, 2022). Regarding the previous sections, mitigation actions might positively or negatively impact certain vulnerability or justice drivers. While in the case of impacted vulnerability drivers such as hazard exposure might be directly increased due to the capture of land, not accounting for justice might lead to perpetuate or exacerbate current systemic trends, such as producing unemployment in fossil-fuel dependent regions, including more people under the umbrella of vulnerable groups.	
What does Vulnerability to LCL mean?	Interpretation
Summing up the sections above, the term "vulnerability to low-carbon lifestyles" can be used when individuals suffer lifestyle alterations associated with the transition to net zero, creating or exacerbating their vulnerability to the effects of climate change.	

Vulnerability to LCL focuses not only on the vulnerable groups but also on the changes produced in vulnerability drivers that might lead to increased vulnerability. Thus, the analysis of vulnerability has two complementary factors:

1. Groups vulnerable to climate change are intrinsically vulnerable to low-carbon lifestyles. Thus, analysing climate-vulnerable groups is an essential dimension of vulnerability to LCL.
2. Implementing mitigation actions can change vulnerability drivers, which can impact population lifestyles. In doing so, groups not initially vulnerable to climate change impacts might become vulnerable to them. Thus, a second approach includes the analysis of potential variability of vulnerability drivers.

First, to assess vulnerability to low-carbon lifestyles, the vulnerability to climate change in each region needs to be mapped. This includes identifying vulnerable groups and any vulnerability drivers present in the region. The second step might have two alternative paths: (1) knowing the mitigation pathways that apply and listing the vulnerability drivers they are directly or indirectly impacting, or (2) defining the driver(s) relevant to the analysis and checking how the proposed mitigation pathways might impact vulnerability. The third step would be to analyse how vulnerability to climate change reshapes compared to the initial state. This difference is what can be called vulnerability to low-carbon lifestyles.

Narrowing down the approach: Energy poverty

What is energy poverty?	Lit. Review

European Union defines Energy poverty as "the inability of households to access basic energy services and products". And that it "is a multi-dimensional phenomenon considered to be caused by a combination of low income, high energy expenses, and poor energy efficiency in buildings". Details on the definition may vary from context to context, adding some % of the income to pay the energy bill or similar. In fact, it can be measured in different indicators depending on stakeholders' interests and perspectives (Lippert & Sareen, 2023).

Energy Poverty also greatly impacts equity and justice, being considered by some as a fundamental socio-political cause of injustice, hardly worsening equity, health, and well-being aspects (Hanke et al., 2023). Particularly in energy justice, addressing energy poverty might bring several benefits, being an allower factor to bring justice issues within the energy transition action (Lippert & Sareen, 2023).

What is energy justice?	Lit. Review

Energy justice analyses justice issues related to the deployment of energy systems and energy accessibility (Hughes & Hoffmann, 2020; Hanke et al., 2023; Kalt & Tunn, 2022) and their outcomes (Kinol et al., 2021). As energy poverty is one of the injustice drivers derived from the mentioned factors and a potential outcome resulting from non-equitable energy transitions (Kashwan, 2021), the energy justice framework fits into its analysis.

The framework to analyse energy justice resembles the three-dimensional approach to climate justice, including the distributional, procedural, and recognitional dimensions (Hanke et al., 2023; Boateng et

al., 2023; Lacey-Barnacle et al., 2020). However, recent literature highlighted the importance of the inclusion of restorative justice as a compensation method to remediate the already perceived energy injustices or potential injustices generated due to energy transition (Lacey-Barnacle et al., 2020; Srivastava & Kumar, 2022; Wang & Lo, 2021).	
What are the energy poverty and energy justice drivers?	Lit. Review
According to the literature review, 28 drivers might positively or negatively influence energy justice. The most common factors were energy accessibility (Kalt & Tunn, 2022; Lacey-Barnacle et al., 2020; Upham et al., 2022), decentralisation and diversification of resources (Wang & Lo, 2021; Garvey et al., 2022; Lacey-Barnacle et al., 2020), and energy affordability (Wang & Lo, 2021; Hanke et al., 2023; Upham et al., 2022). Besides those, several other different drivers were related to institutional capacity and governance, such as the dedication of funding and the type of government (Wang & Lo, 2021) or corruption (Lacey-Barnacle et al., 2020). However, most of the authors acknowledged the importance of distributive, procedural, and recognitional aspects, bringing into the discussion impacts on health and safety (Shelton & Eakin, 2022) and gender inequity and marginalised communities (Lacey-Barnacle et al., 2020). Some of those drivers are, indeed, pillars to assess energy poverty. This includes energy access (Hughes & Hoffmann, 2020; Lippert & Sareen, 2023) and energy costs (Hanke et al., 2023; Dwarkasing, 2023). Fifteen different drivers at higher scales have been detected in literature, such as inflation (Kashwan, 2021) or unequal control over resources (Hanke et al., 2023). However, the other twenty have been identified coming at the people scale, such as race or ethnicity (Hanke et al., 2023; Garvey et al., 2022; Lippert & Sareen, 2023), age (Hanke et al., 2023; Lippert & Sareen, 2023), gender (Hanke et al., 2023; Dwarkasing, 2023) or tenancy (Hanke et al., 2023; Lippert & Sareen, 2023). The fabric of drivers detected shows that energy poverty is not only worsened by energy aspects but also has an important socio-economic and demographic component.	
Which groups are vulnerable to energy poverty?	Lit. Review
From the people's perspective, most drivers are related to economic characteristics: low or unstable income, tenancy (Hanke et al., 2023; Lippert & Sareen, 2023) and poverty (Dwarkasing, 2023). When tackling the problem from the structural approach, economic characteristics are also important, including energy costs (Hanke et al., 2023; Dwarkasing, 2023), inflation (Kashwan, 2021) and resource control (Hanke et al., 2023). In fact, as mentioned before, the same definition of energy poverty has an economic approach. Thus, we can conclude the lower the income and the higher the life stability, the higher the risk of suffering energy poverty, especially when having increased energy prices and lack of energy accessibility in the region. However, the risk of suffering energy poverty might be exacerbated due to racism or ethnicity exclusion, advanced age, gender inequity, and marital status.	
How is energy justice related to other aspects of justice?	-

Answered before.	
How is Energy Poverty related to justice and equity?	-
Answered before.	
How is Energy Poverty related to Low-Carbon Lifestyles?	-
Answered before.	
How can vulnerability to Low-Carbon Lifestyles be assessed using energy poverty?	-
Answered before.	

Table 19: List of vulnerable households to energy poverty and low-carbon transition identified in the literature, with structural drivers causing it. Source: Authors.

Group	DOI	Continent	Main driver	Other drivers
Women	https://doi.org/10.1016/j.uclim.2021.101053	Europe	Gender	Sexual orientation
Women	https://doi.org/10.1080/09540261.2022.2128725	-	-	-
Women	https://doi.org/10.17645/up.v6i4.4536	Asia	-	-
Women	https://doi.org/10.1016/j.gloenvcha.2023.102638	America	-	-
Women	https://doi.org/10.1016/j.jclepro.2022.134354	-	-	-
Women	https://doi.org/10.3390/ijerph192417086	-	-	-
Women	https://doi.org/10.3389/fclim.2022.864292	Africa		
Ethnic minority	https://doi.org/10.1016/j.uclim.2021.101053	Europe	Race/ethnicity	Structural racism;Colonial legacy;Origin/Nationality/Indigeneity
Ethnic minority	https://doi.org/10.1080/09540261.2022.2128725	-	-	-
Poor	https://doi.org/10.1016/j.uclim.2021.101053	Europe	Income level	Access international climate funds;Access to clean energy;Access to food;Access to water;Availability of

				resources;Class;Financial loss;Financial support;Housing cost;Land-tenure;Unemployment
Poor	https://doi.org/10.1525/cse.2021.1125003	-	-	-
Poor	https://doi.org/10.1080/09540261.2022.2128725	-	-	-
Poor	https://doi.org/10.1002/wcc.858	-	-	-
Poor	https://doi.org/10.1016/j.worlddev.2023.106247	-	-	-
Poor	https://doi.org/10.17645/up.v6i4.4536	Asia	-	-
Poor	https://doi.org/10.1080/13549839.2023.2221431	Latin America	-	-
Poor	https://doi.org/10.1016/j.gloenvcha.2023.102638	America	-	-
Poor	https://doi.org/10.1080/14649357.2023.2189288	-	-	-
Poor	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Poor	https://doi.org/10.1088/1748-9326/ac7341	US, Australia, Europe	-	-
Poor	https://doi.org/10.3390/ijerph192417086	-	-	-
Poor	https://doi.org/10.1002/wcc.640	-	-	-
Poor	https://doi.org/10.3390/su151713036	Africa	-	-
Elderly	https://doi.org/10.1016/j.uclim.2021.101053	Europe	Age	Household level hierarchies;Traditional community/Cultural factors
Elderly	https://doi.org/10.17645/up.v6i4.4399	-	-	-
Elderly	https://doi.org/10.1016/j.gloenvcha.2023.102638	America	-	-
Elderly	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Elderly	https://doi.org/10.3390/ijerph192417086	-	-	-
Elderly	https://doi.org/10.1016/S2468-2667(22)00224-9	Asia	-	-
Disabled	https://doi.org/10.1016/j.uclim.2021.101053	Europe	Disabilities;Health conditions including mental health	Access to health

Disabled	https://doi.org/10.1080/13549839.2023.2221431	Latin America	-	-
Disabled	https://doi.org/10.1111/soc4.12954	America	-	-
Disabled	https://doi.org/10.1016/j.gloenvcha.2023.102638	America	-	-
Disabled	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Disabled	https://doi.org/10.1016/S2468-2667(22)00224-9	Asia	-	-
LGTBIQ+	https://doi.org/10.1016/j.uclim.2021.101053	Europe	Sexual orientation	Identity;Discrimination
Black	https://doi.org/10.1088/1748-9326/abe961	America	Race/ethnicity	Structural racism;Colonial legacy;Origin/Nationality/Indigeneity
Black	https://doi.org/10.1080/14693062.2021.1976095	-	-	-
Black	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Black	https://doi.org/10.1088/1748-9326/ac7341	US, Australia, Europe	-	-
Indigenous people	https://doi.org/10.1088/1748-9326/abe961	America	Race/ethnicity	Structural racism;Colonial legacy;Origin/Nationality/Indigeneity
Indigenous people	https://doi.org/10.1525/cse.2021.1125003	-	-	-
Indigenous people	https://doi.org/10.17645/up.v6i4.4536	Asia	-	-
Indigenous people	https://doi.org/10.1080/13549839.2023.2221431	Latin America	-	-
Indigenous people	https://doi.org/10.1016/j.esd.2020.01.010	-	-	-
Indigenous people	https://doi.org/10.1088/1748-9326/ac7341	US, Australia, Europe	-	-
Indigenous people	https://doi.org/10.1088/1748-9326/abc197	-	-	-
Other people of color	https://doi.org/10.1088/1748-9326/abe961	America	Race/ethnicity	Structural racism;Colonial legacy;Origin/Nationality/Indigeneity

Other people of color	https://doi.org/10.1088/1748-9326/ac7341	US, Australia, Europe	-	-
Other people of color	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Small landholders in rural areas/Rural communities	https://doi.org/10.5195/lawreview.2020.717	Asia	Land tenure;Region type	Access to food;Access to health;Access to information;Access to water;Availability of resources;Creation of substandard housing;Environmental factors;Financial support;Unemployment
Small landholders in rural areas/Rural communities	https://doi.org/10.1016/j.worlddev.2023.106247	-	-	-
Small landholders in rural areas/Rural communities	https://doi.org/10.1016/j.esd.2020.01.010	-	-	-
Small landholders in rural areas/Rural communities	https://doi.org/10.1088/1748-9326/ac7341	US, Australia, Europe	-	-
Small landholders in rural areas/Rural communities	https://doi.org/10.1088/1748-9326/abc197	-	-	-
Agricultural workers	https://doi.org/10.5195/lawreview.2020.717	Asia	Land tenure;Region type	Access to food;Access to health;Access to information;Access to water;Availability of resources;Creation of substandard housing;Environmental factors;Financial support;Unemployment
Racial minorities	https://doi.org/10.1002/wcc.640	-	Race/ethnicity	Structural racism;Colonial legacy;Origin/Nationality/Indigeneity
Racial minorities	https://doi.org/10.1080/14693062.2021.1976095	-	-	-
Marginalised minorities	https://doi.org/10.1002/wcc.640	-	Recognition of groups;Social capital/Exclusion	Historial marginalisation;Local participation and

				engagement;Politic, social, and economic relationships
Marginalised minorities	https://doi.org/10.1007/s10584-023-03486-4	-	-	-
Marginalised minorities	https://doi.org/10.1016/j.geoforum.2021.08.005	-	-	-
Marginalised minorities	https://doi.org/10.1080/14649357.2023.2189288	-	-	-
Marginalised minorities	https://doi.org/10.1016/j.erss.2023.102974	-	-	-
Marginalised minorities	https://doi.org/10.1016/j.cosust.2019.12.004	-	-	-
Domestic producers	https://doi.org/10.1016/j.oneear.2021.04.010	-	Unemployment	Availability of resources;Bureaucracy complexity;Common resources;Financial loss;Financial support;Income level;Institutional support and capacity;Tourism
Underdeveloped	https://doi.org/10.1525/cse.2021.1125003	-	-	Access to clean energy;Access to food;Access to health;Access to information;Access to water;Availability of resources;Donors interest;Financial support;Institutional support and capacity;
Homeless	https://doi.org/10.1525/cse.2021.1125003	-	Housing cost;Income level;Unemployment	Access to clean energy;Access to food;Access to health;Access to information;Access to water;Class;Creation of substandard housing;Gentrification;Income level;Institutional support and capacity;Land tenure;
Homeless	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Single moms	https://doi.org/10.1525/cse.2021.1125003	-	Gender;Marital status	Bureaucracy complexity;Financial support;Household level hierarchies;Institutional support and capacity;Social norms;Traditional community/Cultural factors;Threat or harm to self or loved ones

People with mental health conditions	https://doi.org/10.1080/09540261.2022.2128725	-	Health conditions including mental health	Access to health;Disabilities
Young/Children	https://doi.org/10.1080/09540261.2022.2128725	-	Age	Gender;Sexual orientation
Young/Children	https://doi.org/10.17645/up.v6i4.4399	-	-	-
Young/Children	https://doi.org/10.1016/j.worlddev.2023.106247	-	-	-
Young/Children	https://doi.org/10.17645/up.v6i4.4536	Asia	-	-
Young/Children	https://doi.org/10.1080/13549839.2023.2221431	Latin America	-	-
Young/Children	https://doi.org/10.1016/j.gloenvcha.2023.102638	America	-	-
Young/Children	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Young/Children	https://doi.org/10.1016/j.jclepro.2022.134354	-	-	-
Young/Children	https://doi.org/10.3390/ijerph192417086	-	-	-
Young/Children	https://doi.org/10.1136/bmjpo-2022-001518	-	-	-
Population with prior experiences of deprivation and occupation / displacement	https://doi.org/10.1080/09540261.2022.2128725	-	Evacuation;Financial loss	Damage to property;
Population with prior experiences of deprivation and occupation / displacement	https://doi.org/10.3390/ijerph192417086	-	-	-
Inmigrants	https://doi.org/10.1016/j.geoforum.2021.08.005	-	Race/ethnicity	Structural racism;Colonial legacy;Origin/Nationality/Indigeneity
Inmigrants	https://doi.org/10.1080/15568318.2022.2082343	-	-	-
Uneducated	https://doi.org/10.1016/j.worlddev.2023.106247	-	Education level	Fluency of languages
Uneducated	https://doi.org/10.1080/15568318.2022.2082343	-		
Orphans	https://doi.org/10.1016/j.worlddev.2023.106247	-		Age;Marital status;Threat or harm to self or loved ones

Widows	https://doi.org/10.1016/j.worlddev.2023.106247	-		Gender;Marital status;Threat or harm to self or loved ones
Asian	https://doi.org/10.1080/14693062.2021.1976095	-	Race/ethnicity	Structural racism;Colonial legacy;Origin/Nationality/Indigeneity
Unemployed	https://doi.org/10.1080/15568318.2022.2082343	-	Unemployment	Financial support;Housing cost;Land tenure
Unemployed	https://doi.org/10.3390/su151713036	Africa	-	-
No car owners	https://doi.org/10.1080/15568318.2022.2082343	-	Mobility	Collective autonomy and infrastructure
Nomadic	https://doi.org/10.1016/j.esd.2020.01.010	-	Land tenure	Access to clean energy;Access to food;Access to health;Access to information;Access to water
Underlying diseases	https://doi.org/10.1016/S2468-2667(22)00224-9	Asia	Health conditions including mental health	Access to health;Disabilities

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