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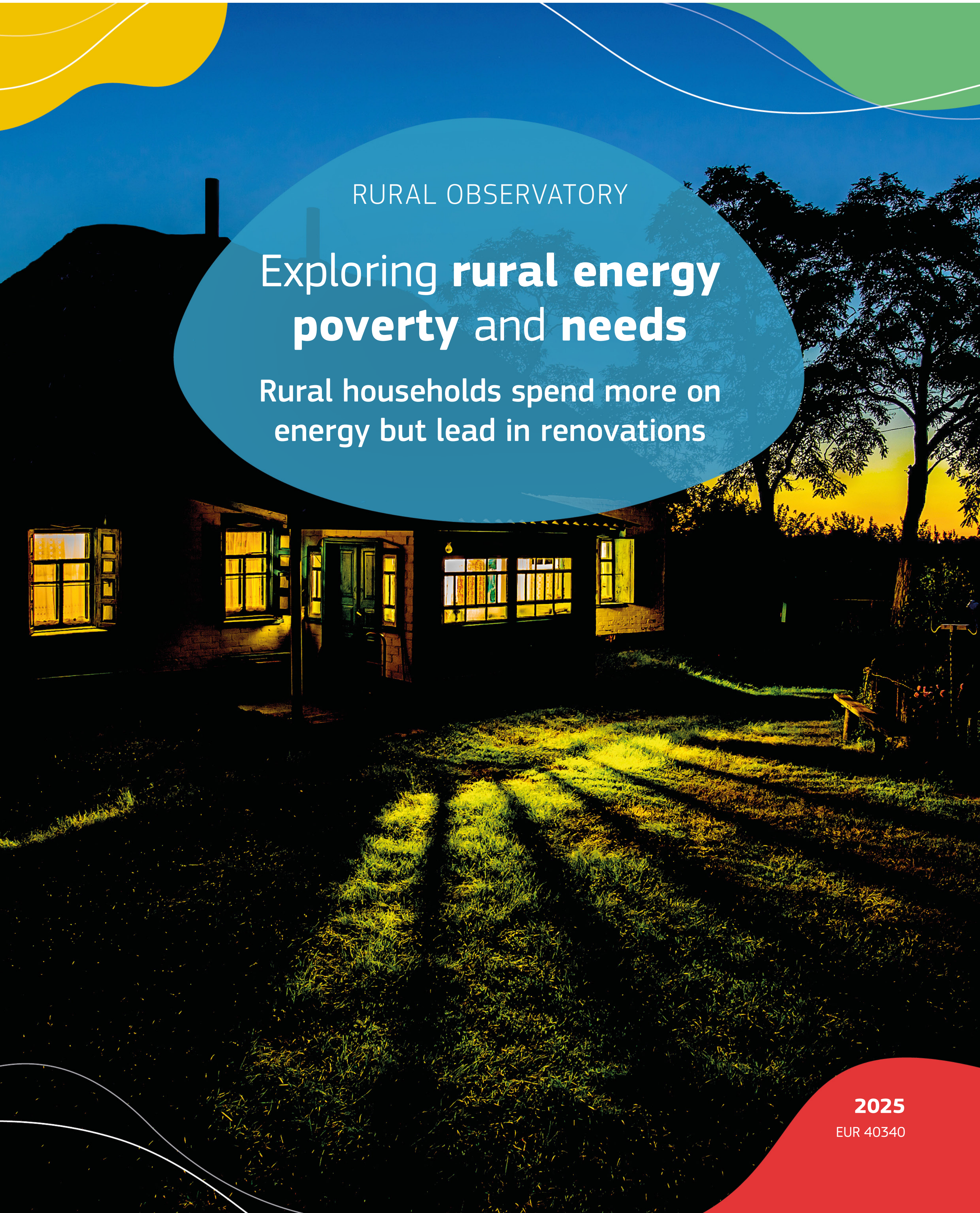

RURAL OBSERVATORY

Exploring **rural energy poverty** and **needs**

Rural households spend more on energy but lead in renovations

2025

EUR 40340

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Exploring **rural energy poverty** and **needs**

Rural households spend more on energy but lead in renovations

Hormigos Feliu, C., Florio, P., Dijkstra, L., Auteri, D., Bertozzi, C.

Contents

Abstract

In the context of the European path towards carbon neutrality and energy resilience, this report investigates energy poverty in EU households and energy need challenges in the EU's building stock, focusing on the vulnerabilities and opportunities for rural areas. Based on measures of consensual comfort levels, economic strain and dwelling energy efficiency from the Household Budget Survey and the EU Statistics on Income and Living Conditions, our results indicate that rural households could face higher levels of energy poverty. A high-resolution analysis of the building stock shows that rural areas feature higher residential building volumes per inhabitant and less compact shapes, which challenges their energy efficiency and increases heating needs. On the other hand, rural areas lead in energy efficiency improvements, and are particularly suited for the implementation of self-consumption renewable systems such as rooftop photovoltaics thanks to large roof areas per inhabitant and a high share of rural ownership (78% of owned dwellings). With rooftop PV, rural areas could potentially produce 2 200 kWh/inhabitant annually, 38% more than the average household electricity consumption in the EU.

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Executive summary

POLICY CONTEXT AND OBJECTIVES

The building sector plays a major role in energy use: **in 2021, energy use in buildings accounted for 40% of the EU's total energy consumption, and for 35% of its energy-related greenhouse gas emissions** (EEA, 2023 and 2024a; Eurostat, 2022a). With the European Green Deal, which aims to reduce greenhouse gas emissions by 55% by 2030 and to reach carbon-neutrality by 2050, the decarbonisation of the building sector has become a key European priority (EC, 2019).

In this context, **a Renovation Wave for Europe** has been put forward to **promote the decarbonisation of heating and cooling and to boost building renovations,** while he REPowerEU plan, which advocates for an energy-resilient union, envisions a massive scale up in renewable energy in the building sector (EC, 2020 and 2022b). Furthermore, the EU's Energy Performance in Buildings Directive was revised in 2024, updating the methodology for Member States to implement energy performance goals and targeting worse-performing buildings (EP, 2024). In rural areas, a larger, older and less compact building stock increases the importance of advancing in energy efficiency, a need which is reflected in the EU's Long-Term Vision for Rural Areas (EC, 2021a). In its initiative towards more resilient rural areas, it underlines the need to fund building renovation in rural areas, boost local renewable energy production and reduce energy poverty.

Energy poverty is closely related to the efficiency of the building stock. **In 2023, 48 million Europeans** (10.6% of the EU's population) **were estimated to be unable to heat their homes properly** (Eurostat, 2023a), a situation which could be alleviated by delivering more energy-efficient buildings with reduced energy bills. This link is highlighted in the Energy Efficiency Directive, revised in 2023, which requires Member States to include energy poverty reduction targets in their national building plans, as well as financial measures to facilitate building renovation in vulnerable households (EP, 2023). Energy poverty is, however, a complex multi-dimensional phenomenon. It is not only caused by a combination of low energy efficiency, low disposable income and high expenditure on energy, but is also driven by socio-economic and vulnerability factors. Local evidence suggests that rural areas could experience higher vulnerability towards energy poverty due to lower income levels, more widespread material deprivation, isolation, and older and bigger dwellings with less efficient heating systems.

Understanding local specificities in the path towards decarbonisation and energy resilience can help design place-based solutions that work best for citizens and their dwellings. This report aims to shed light on **energy poverty and energy efficiency and needs** with a territorial perspective, focusing on the **challenges and opportunities for the EU's rural areas.** To describe energy poverty at the European scale, two data collection efforts are employed: the **Household Budget Survey** (HBS), which provides household consumption expenditure data, and the **EU Statistics on Income and Living Conditions** (EU-SILC) framework, which contains information on household income, dwelling characteristics and energy sources, as well as perception-based indicators of energy poverty. In order to assess challenges in energy efficiency and needs in the EU's building stock, we analyse high spatial resolution and regional datasets on building characteristics (footprints, volumes and construction period), together with information on population, climate, and electricity production with rooftop photovoltaics. Limitations of this analysis include the lack of local information on Energy Performance Certificate ratings and renovation rates, currently not available at the territorial level as harmonised datasets.

KEY CONCLUSIONS

This analysis highlights how territories across the urban-rural continuum face different challenges in energy for housing: many rural areas could face higher levels of energy poverty and the energy efficiency of their building stock presents more challenges due to larger, less compact buildings. Rural dwellings, however, are best poised to host rooftop solar panels, and renovation rates for energy efficiency improvements are already higher in rural areas. Moving forward in the path towards building decarbonisation, EU-wide data with high spatial detail will become increasingly necessary to track progress and address challenges locally.

MAIN FINDINGS

Data on EU households shows that those in **rural areas dedicate a higher share of their total expenditure to electricity, gas and other fuels** (7.1% of total household expenditure) compared to towns and suburbs (6.2%) and cities (5%). Expenditure on energy reaches its highest levels in rural households of Bulgaria, Czechia and Slovakia (above 12%). Countries where the share of expenditure in energy is highest show the largest urban-rural disparities, suggesting that **high shares of expenditure on energy are associated with a deeper urban-rural divide,** with rural areas being most affected. Rural households also rely on diverse energy sources for heating, including gas, coal or oil, wood, electricity and renewables. On the other hand, **renovation rates for energy-efficiency measures are highest in rural areas,** with 29% of rural residents living in households that underwent improvements (improvement in thermal insulation, replacement of single-glazed windows for double- or triple-glazed windows, or the replacement of the heating system with a more efficient one) in the 5-year period prior to 2023.

Recognising the multi-factor nature of energy poverty and following recent developments in energy poverty assessments, a **composite indicator** was constructed by combining the share of household expenditure on energy with four relevant energy poverty indicators:

- the inability to keep a home adequately warm,
- the prevalence of arrears in utility bills,
- the share of households with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor,
- the at-risk-of-poverty rate, defined as the share of households where disposable income is below 60% of the country average.

The results indicate that r**ural areas experience higher levels of energy poverty,** especially in Bulgaria, Romania and Greece. In Member States **where energy poverty levels are above the EU average, rural areas** are generally the **most affected** territorial typology, while cities are always least affected.

Beyond urban-rural categories, we find that **income levels and household composition have a strong connection with energy poverty,** with low-income households and lone parents being most vulnerable. In households reporting an inability to keep their home adequately warm and/or arrears in utility bills, 62% fall in the last two income quintiles compared to 19% in the top two quintiles. More than 20% of households of lone parents with children report an inability to keep their home adequately warm and/or arrears in utility bills, a share which is 6pp above the EU average (14%).

When looking at the EU's building stock, our combined analysis of building characteristics, climate conditions and the implementation of rooftop photovoltaics at the local level shows that **rural areas could face more challenges in energy efficiency and needs** than towns and suburbs or cities. In some Member States (such as Latvia and Lithuania), these challenges coincide with high energy poverty markers, in particular high at-risk-of-poverty rates.

Differences across territorial typologies stem mainly from higher residential building volumes per inhabitant, less compact buildings and colder temperatures in rural areas, while variability between Member States originates mainly from differences in the age of the building stock, the implementation of rooftop PV systems and climate conditions. Each of these factors are analysed individually, leading to the following conclusions:

- The **EU's rural areas feature the highest residential building volumes per inhabitant** (565 m^3/inhabitant) and **the least compact buildings,** which negatively affects their energy efficiency and increases heating needs. Compared to rural areas, building volumes per inhabitant are 8% lower in towns and suburbs and 30% lower in cities. At the same time, building shape factors, which provide a measure of building compactness, show that buildings in cities and towns and suburbs are more compact by 23% and 18%, respectively, when compared to rural areas. Low building compactness in rural areas is in line with EU-SILC data on dwelling characteristics, which shows that **79% of**

rural dwellings are in detached or semi-detached houses. In cities and towns and suburbs, houses make up for only 24% and 55% of dwellings, respectively.

- In terms of the construction date of buildings, regional data shows that **the share of dwellings built after 2000** (generally best performing, thanks to the development of EU energy efficiency policies in recent decades) **is moderately lower in predominantly rural regions** (15% of dwellings), with higher shares (17%) in intermediate and predominantly urban regions. Predominantly rural regions show a modestly higher share of old dwellings (61% where built before 1980) compared to intermediate and predominantly urban regions (59% and 60%, respectively).
- On average in the EU, r**ural areas experience more heating needs due to climatic conditions** (2600 Heating Degree Days on average), when compared to towns and suburbs (2500 HDD, or 4% less) and cities (2300 HDD, 14% less). Climate pressure on cooling needs, on the other hand, is less pronounced in rural areas (85 CDD) than in other territorial typologies (102 and 87 CDD in towns and suburbs and cities, respectively). Effects of climate change are already observable in the EU, with **around 1.7 million people living in rural areas with high heat trends,** where extreme heat can pose important challenges for the health and wellbeing of households not equipped with cooling mechanisms.
- The implementation of renewable energy solutions such as rooftop photovoltaics can reduce household expenditure on energy through self-consumption. **Rural areas,** however, **are best poised to cover their electricity needs with rooftop photovoltaics,** thanks to larger available roof areas per inhabitant and a high share of dwelling ownership (78% of owned households), which facilitates the implementation of self-consumption systems. Rooftop photovoltaics in rural areas could potentially produce 2200 kWh/year per inhabitant, 25% more than in towns and suburbs (1800 kWh/year) and double than in cities (1100 kWh/year), and exceeding current individual electricity consumption (at 1600 kWh/inhabitant annually in the EU).

These results indicate that energy needs across the EU's territories can be best met with place-based policies. In rural areas, high levels of energy expenditure and energy poverty markers can be tackled by supporting rural households in implementing self-consumption systems, for which rural dwellings are especially suited (predominantly owned houses with large roof areas per inhabitant). Cities and towns and suburbs, on the other hand, are lagging behind in renovations improving energy efficiency and, already featuring buildings with more energy-efficient morphologies, would benefit from a boost in such improvements. We recommend EU efforts to collect and harmonise data on renovations and Energy Performance Certificates at high territorial detail in order to monitor progress at the local level and identify worse-performing dwellings, in line with the requirements of the most recent regulations (EP, 2024).

1

Introduction

The building sector is currently a major contributor to greenhouse gas (GHG) emissions, globally and in the EU. In 2021, **energy use in buildings accounted for 40% of the total energy consumed in the EU** and for 35% of its energy-related GHG emissions (EEA, 2023 and 2024a; Eurostat, 2022a). During the operational phase or use of a building, emissions result directly from the use of fossil fuels, such as oil and gas usage in boilers for heating, and indirectly from the production of electricity and heat later used in buildings (electricity consumed by water heaters, lighting, electrical devices, cooling systems, etc.) (EEA, 2023).(1)

As part of an ambitious climate agenda, the EU has proposed a **Renovation Wave for Europe,** which promotes the **decarbonisation of heating and cooling,** tackles **energy poverty** and aims to boost building renovations, starting from public and worse-performing buildings. With the New European Bauhaus, on the other hand, the EU aims to integrate sustainability, inclusivity and local innovation into rural housing development, supporting a green and fair transition (EC, 2021b). Furthermore, housing has recently risen to the top of the European agenda, with the new Commission announcing the development of a European Affordable Housing Plan and a pan-European investment platform to reinforce affordable energy-efficient and social housing (Von der Leyen, 2024). Up-to-date information and data on the EU's building stock can be found in the Building Stock Observatory(2), which supports the monitoring of EU energy policies and measures.

With the European Green Deal, the EU set out to reduce its **GHG emissions by 55%** (compared to 1990 levels) **by 2030** and to achieve **climate neutrality by 2050** – targets which have been enshrined in EU climate law (EC, 2019; EP, 2021). To achieve the 55% emission reduction target, it has been estimated that the EU should reduce buildings' GHG emissions by 60%, their final energy consumption by 14% and energy consumption for heating and cooling by 18% by 2030, compared to 2015 levels (EC, 2020). During the last decade, the EU's GHG emissions have decreased steadily, but as of 2021, a decrease in emissions by 53% in the building sector (and a reduction by 35% in total net emissions) is still needed in order to fulfil 2030 targets (see and Marinelli, 2025 for a comprehensive review of Green Deal targets and progress). Therefore, an accelerated building decarbonisation, to be completed by 2050, is essential to achieve EU climate targets. Through the Renovation Wave for Europe, the EU has set an agenda for the green transition of the building sector: it aims to at least double annual renovation rates for residential and non-residential buildings by 2030 and to foster deep energy renovations (EC, 2020). Energy renovation rates for residential buildings in the EU

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(1) Emissions from buildings are produced during their whole life cycle, which includes the operational phase, during which the building is used, as well as periods before the operational phase (production of materials, construction, transport, etc.) and after (deconstruction, disposal or re-use) (EP, 2024).

(2) https://energy.ec.europa.eu/eu-building-stock-observatory

are estimated to be at 1.0% annually (1.2% for non-residential buildings), while deep renovations (those with a significant impact on energy savings) are assessed to be only at 0.2% (0.3% for non-residential buildings) (DG ENER, 2019; Maduta et al., 2023). At the onset of the renovation wave, almost 75% of the EU's building stock was assessed to be energy inefficient, and more than 85% of buildings were likely to still be in use in 2050 (EC, 2020).

In order to achieve the building sector's climate goals, a rapid increase in renovation rates is paramount. In this context, the Energy Performance of Buildings Directive (EPBD), which has been recently revised, lays out the methodology for Member States to set national targets on energy performance standards, and specifies that more than 55% of the reductions in primary energy use must come from renovations in worst-performing buildings (EP, 2024). The recast EPBD also highlights the importance of considering the whole-life-cycle emission of buildings, promoting its assessment in national building plans and acknowledging that emissions are largely influenced by the design of buildings and the choice of materials for both construction and renovation. In this context, the use of low-carbon materials and research into corresponding technologies will be needed to accelerate the implementation of low-carbon buildings (Maduta et al., 2022, Röck et al., 2020). Furthermore, with the aim to secure energy independence, **the REPowerEU plan envisions a massive scale up in renewable energy in the building sector,** to be achieved as well through the European Solar Rooftops Initiative (EC, 2022a). As part of the EU Solar Strategy, the initiative introduces the obligation to install rooftop solar energy in large public and commercial buildings by 2027 and all new residential buildings by 2029 (EC, 2022b).

On the other hand, the newly recast Energy Efficiency Directive (EED) links the renovation of the building stock to the reduction of energy poverty (EP, 2023). The recast EED describes energy poverty as a multi-dimensional phenomenon, which hinges on the adequacy of the building stock as well as on socio-economic factors such as income and expenditure on energy. Acknowledging the uneven impact of climate and energy on different social groups, it stresses the need to combat energy poverty in order to ensure a fair and inclusive transition towards a climate-neutral Union. The directive requires Member States to include energy poverty reduction targets in their national building plans, as well as financial measures to facilitate building renovation in vulnerable households. **In 2023, 48 million Europeans (almost 11% of the EU's population) were estimated to be unable to afford heating their homes properly,** a situation which could be alleviated by delivering more energy-efficient buildings with reduced energy bills (Eurostat, 2023a). The Energy Poverty Advisory Hub (EPAH)(3) is the leading EU initiative aiming to combat energy poverty and accelerate a just energy transition of EU local governments. It acts as a platform of energy poverty expertise, providing support and evidence to local authorities and stakeholders, and collecting relevant national-level indicators on climate, housing, mobility and socio-economic data (Gouveia et al., 2023).

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(3) *https://energy-poverty.ec.europa.eu*

Across the urban-rural continuum of the EU's territories(4), buildings and households might face diverse challenges in view of the renovation wave. In its Long-Term Vision for Rural Areas, the European Commission identified the **support to rural municipalities and communities in the energy transition** as a flagship initiative towards more resilient rural areas (EC, 2021a). It also underlined the need to fund building renovation in rural areas as a key path to achieve Green Deal objectives by increasing energy efficiency, local renewable energy production and reducing energy poverty in the EU. Since housing presents different characteristics in rural areas than in urban contexts (for instance, in terms of dwelling types and tenancy status), understanding the characteristics of buildings and households at the local level and across the urban-rural continuum of the EU is crucial to efficiently deliver on the objectives of the Renovation Wave, the Green Deal and the Long-Term Vision for Rural Areas.

This report aims to provide a territorial perspective of housing and energy in the EU in view of these policy objectives, focusing on challenges and opportunities for rural areas. Leveraging a wide range of datasets that allow to characterise the EU's urban-rural continuum, two main areas are addressed: energy poverty in EU households, and patterns of energy efficiency and needs. In **Chapter 2,** energy poverty markers are derived based on data from the EU Statistics on Income and Living Conditions framework and the Household Budget Survey, assessing as well the overall risks towards energy poverty through a composite index. **Chapter 3** is devoted to an analysis of the EU's building stock at the local level, aimed at providing territorial insights on energy efficiency challenges. Making use of high spatial resolution data, we study physical properties of buildings (age, volume, compactness) together with climate patterns, demographic data and implementation of renewable solutions. Conclusions are discussed in **Chapter 4.**

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(4) To describe the urban-rural continuum, unless otherwise stated in this report we employ the definitions of the degree of urbanisation, which provides a standard methodology to identify cities, towns and suburbs, and rural areas (see *https://ec.europa.eu/eurostat/web/degree-of-urbanisation/methodology*).

2

EU households: **energy expenditure** and **energy poverty**

Energy poverty has been receiving increasing policy attention within the European Union in the last decades (see for instance Vandyck et. al., 2023). The Energy Efficiency Directive (EED), which was recast in 2023, describes energy poverty as a household's lack of access to essential energy services, where such services provide basic levels and decent standards of living and health (including adequate heating, hot water, cooling, lighting, and energy to power appliances). The causes of energy poverty are identified as a combination of factors, including at least non-affordability of energy carriers, insufficient household disposable income, high energy expenditure and poor energy efficiency of homes (EP, 2023). Cultural and environmental factors, age and disability have also been shown to affect vulnerability towards energy poverty (Simcock et al., 2017 and 2021; Robinson et al., 2019). Energy poverty is therefore recognised as a multi-dimensional phenomenon, linked both to socio-economic factors and to the energy performance of the building stock.

In the EU context, the Energy Poverty Advisory Hub (EPAH) leads the efforts to combat energy poverty and accelerate a just energy transition of EU local governments. It operates as a platform of energy poverty expertise, providing support and evidence to local authorities and stakeholders, and collecting relevant national-level indicators on climate, housing, mobility and socio-economic data (Gouveia et al., 2023). The EU is also engaged in the support of citizen-led renovation initiatives, with the aim to empower citizens to develop energy-saving renovation projects.(5) In this context, citizens' active participation in the shaping of their energy systems (also known as *energy citizenship*), has been put forward as a key element to ensure a fair energy transition (Della Valle et al., 2022). This is acknowledged in the recent EC recommendation on energy poverty, which highlights the importance of enabling energy-poor and vulnerable households to take their own steps to improve their ways of living in terms of energy efficiency and renewable energy (EC, 2023).

In measuring energy poverty, expenditure-based indicators can be used to evaluate a household's ability to tackle energy costs, while self-reported assessments of indoor housing conditions provide information on the perceived ability to attain decent levels of basic services. Information on dwelling conditions that indicate poor energy efficiency can be especially insightful to identify households which, with the aim to maintain or decrease energy spending,

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(5) *https://citizen-led-renovation.ec.europa.eu*

are pushed towards lower comfort levels through self-restriction. Indeed, energy efficiency improvement of homes at risk of energy poverty has been linked to important impacts on wellbeing and quality of life (Boemi et al., 2019).

Existing measurements of energy poverty at the EU scale are typically based on two data collection efforts carried out at the household level. The EU Household Budget Survey (HBS) is a collection of national surveys covering household consumption structure, and constitutes the main source for expenditure-based measures of energy poverty.(6) The EU Statistics on Income and Living conditions (EU-SILC) on the other hand, collects comparable cross-sectional and longitudinal data on household income, social conditions and dwelling properties, and is often used to derive consensual or perception-based indicators of energy poverty.(7) Due to the complex nature of energy poverty drivers, multi-indicator approaches are often employed to assess their combined effects (see for instance (Castaño-Rosa et al., 2019; Sokołowski et al., 2019; Lavecchia et al., 2024). An analysis of the challenges of data and indicators on energy poverty at the European scale can be found in (Thomson et al., 2017).

Previous quantitative studies have shown that energy poverty is strongly correlated with income distribution, while the connection between energy poverty and urbanisation levels in the EU remains less clear (Koukofikis et al., 2022; Igawa et al., 2022; Carfora et al., 2022; Chaudhuri et al., 2023). Local evidence, however, suggests that rural areas could experience higher energy poverty risks due to lower income and education levels, more widespread material deprivation and older and bigger dwellings with less efficient heating systems (Belaïd, 2016; Sokołowski et al., 2019; Simcock et al., 2021, Lavecchia et al., 2024; Dokupilová et al., 2024). Urban areas, on the other hand, can experience energy impacts due to heat island effects and high population densities (EEA, 2024b).

In this section, we aim to assess energy poverty in rural areas and across the EU's urban-rural continuum from data on expenditure, perceived levels of comfort and dwelling characteristics. In **Section 2.1,** we analyse household expenditure data from the Household Budget Survey, while **Section 2.2** is dedicated to energy poverty indicators identified by the Energy Efficiency Directive, and obtained from the EU Statistics on Income and Living Conditions framework. In **Section 2.3,** an energy poverty index is constructed, employing energy expenditure and energy poverty information. Selected indicators from the recent EU-SILC module on household energy efficiency are discussed in **Section 2.4,** and in **Section 2.5,** we analyse the characteristics of EU households (e.g. household type and income, dwelling type, tenure status) and their connection with energy poverty markers, focusing on differences across the urban-rural continuum. **Section 2.6** summarises the findings of this chapter.

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(6) *https://ec.europa.eu/eurostat/web/household-budget-surveys*

(7) *https://ec.europa.eu/eurostat/web/income-and-living-conditions*

2.1. HOUSEHOLD EXPENDITURE ON ENERGY

Expenditure patterns of households across territorial typologies can provide essential insight in the territorial incidence of energy poverty. High expenditure on energy is identified as one of the drivers of energy poverty in the EU's Energy Efficiency Directive, and the Energy Performance in Buildings Directive (recast in 2024) establishes the proportion of disposable household income spent on energy as a key indicator to track energy poverty (EP, 2023 and 2024).

In combination with a households' disposable income, energy expenditure provides a finance-based proxy of energy affordability and helps identify vulnerable areas. High expenditure on energy in households with high income might not impact wellbeing, and low expenditure on energy might be due to self-restriction in low-income situations. For these reasons, expenditure on energy is most insightful when analysed together with disposable income, see (Moore et al., 2012) for a detailed analysis.

Here, we analyse consumption expenditure patterns in the EU's Member States across the urban-rural continuum. The analysis is based on data from the Household Budget Survey, which provides detailed information on EU household consumption. The survey is carried out every 5 years, and delivers expenditure data on energy, transport, food, clothing, housing, durable goods, health and other services of all kinds. We analyse data from two relevant indicators provided by degree of urbanisation, namely:

(i) **total mean household consumption expenditure** (based on HBS dataset hbs_exp_t136);

(ii) **share of household consumption expenditure on electricity, gas and other fuels** (based HBS dataset hbs_str_t226).

Comparing these two indicators allows to identify relationships between total expenditure and expenditure dedicated to energy. At the EU level, the 2020 survey shows that total mean household consumption expenditure stood at around 26 600 Purchasing Power Standard (PPS) units, with household expenditure on electricity, gas and other fuels accounting for 6% of the total expenditure on average(8) (Eurostat, 2020a and 2020b).

Data for total mean household consumption expenditure in 2020 is available for all Member States (excluding Sweden), while expenditure on energy is reported for 24 Member States (additionally excluding Romania and Portugal).(9) We observe that, on average, the total mean household consumption expenditure in the EU does not vary substantially across the urban-rural continuum, with households spending slightly more in cities (27 000 PPS approx.) than in towns and suburbs (26 800 PPS) and rural areas (26 300 PPS).

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(8) Average of Member States with countries with available data (EU-27 countries except for Ireland, Portugal, Romania, Finland and Sweden).

(9) Data for rural areas in not available for Malta.

Within Member States, differences in total household expenditure across territorial typologies can be substantial, as shown in **Figure 1.** In 12 MS, total mean household expenditure is lower in rural areas than in cities and towns and suburbs, with the gap between rural areas and cities increasing with diminishing expenditure: in Bulgaria, Romania, Latvia and Lithuania, where total expenditure is lowest, households in rural areas spend at least 25% less than those in cities. On the other hand, total mean consumption expenditure is substantially higher than in cities (by more than 10%) in rural areas of Luxembourg, Austria, Germany, the Netherlands and Belgium, all countries where household expenditure is above the EU average.

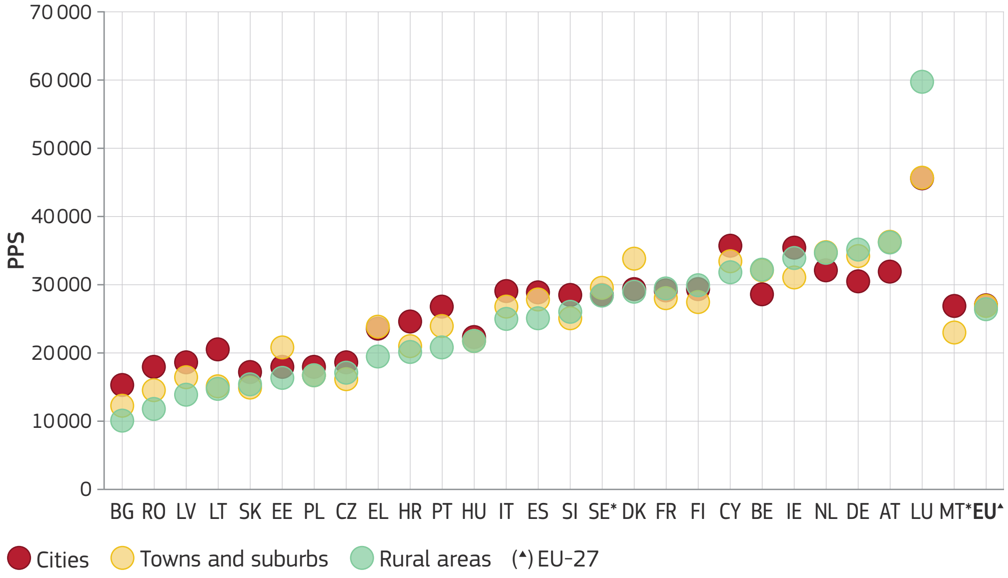


Figure 1. Mean household consumption expenditure in EU Member States by degree of urbanisation.

Note: (*) Sweden: values from 2015 are shown; Malta: information for rural areas unavailable.

Source: Eurostat, Household Budget Survey *(hbs_exp_t136).*

When it comes to the share of household expenditure on electricity, gas and other fuels, a clearer pattern arises: in 20 out of the 24 MS for which data is available, rural areas are the territorial typology with the highest shares, as shown in **Figure 2.** On average (MS mean), the share of energy expenditure amounts to 7.1% in rural areas, 6.2% in towns and suburbs and 5% in cities, reaching its highest levels (above 12%) in rural households of Bulgaria, Czechia and Slovakia.

In general, countries with larger urban-rural disparities (in percentage points) are those which experience higher shares of expenditure on electricity, gas and other fuels, as seen in **Figure 3.** These results suggest that high shares of expenditure are associated with a deeper urban-rural divide, with rural areas being most affected. The leading examples are Bulgaria, Czechia and Slovakia, where total expenditure on energy-related services is above 9%, and the urban-rural gap exceeds 4 pp. Poland constitutes a salient exception, where expenditure on energy is also above 9%, but the urban-rural gap is small (less than 1pp).

Figure 2. Share of household consumption expenditure on electricity, gas and other fuels in EU Member States by degree of urbanisation.

Note: (*) Sweden: values from 2015 are shown; Malta: information for rural areas unavailable.

Source: Eurostat, Household Budget Survey *(hbs_str_t226).*

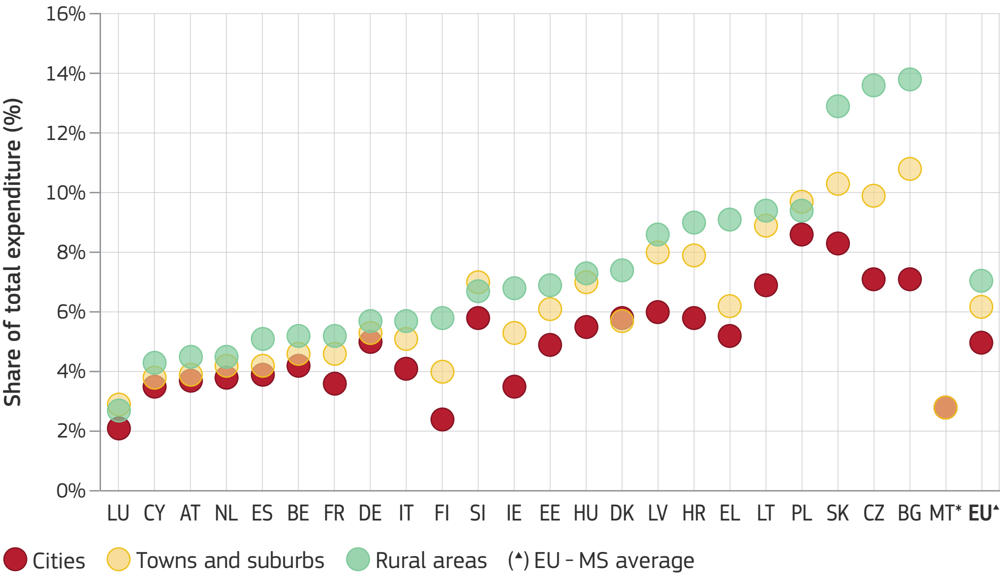
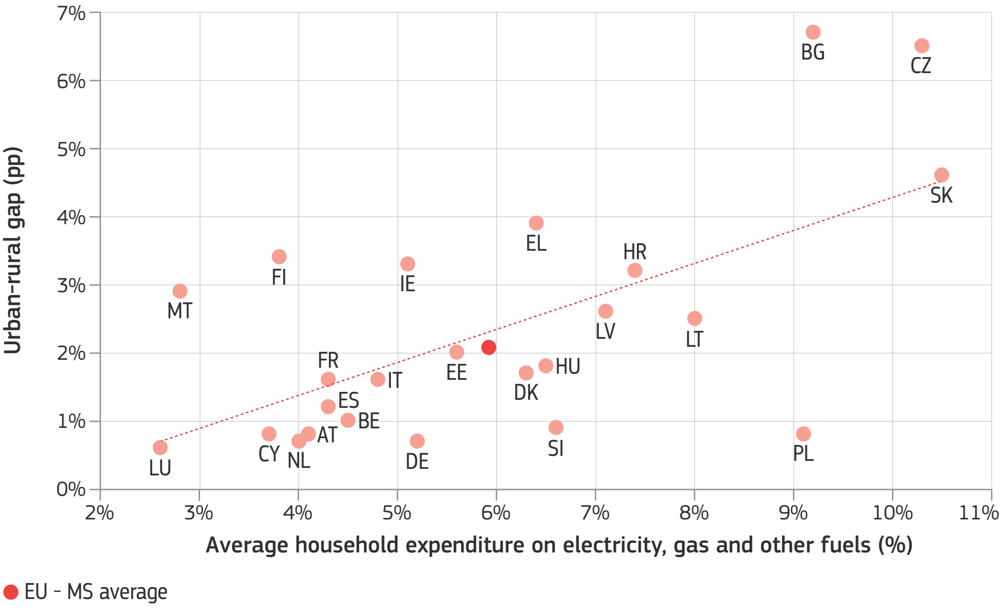


Figure 3. Urban-rural gap vs average household expenditure in expenditure on electricity, gas and other fuels.

Source: Own elaboration form Eurostat, Household Budget Survey 2020 *(hbs_str_t226 and hbs_str_t211).*



2.2. ENERGY POVERTY INDICATORS IN THE ENERGY EFFICIENCY DIRECTIVE

The recast Energy Efficiency Directive identifies several indicators for Member States to define energy poverty rates within their national context. These indicators, which reflect the physical as well as socio-economic dimensions of energy poverty, are gathered in the EU Statistics on Income and Living Conditions common framework. EU-SILC data contains information on income, household and dwelling characteristics, and includes as well the degree of urbanisation as a variable. The relevant indicators for energy poverty designated by the EED are the following:

(a) **inability to keep the home adequately warm** (EU-SILC code *ilc_mdes01*);

(b) **arrears on utility bills** (EU-SILC code *ilc_mdes07*);

(c) **total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floo**r (EU-SILC code *ilc_mdho01*);

(d) **at-risk-of-poverty rate** (EU-SILC code *ilc_li02*). The cut-off point of the indicator is at 60% of median equivalised income after social transfers.

Indicators (a) and (c) provide not only a self-reported assessment of a dwelling's energy efficiency, but also an indication of the level of comfort that households experience in winter. This can be useful to detect households that live under minimal warmth comfort conditions in order to avoid an increased financial burden. Indicators (b) and (d), on the other hand, reflect households' financial difficulties with regard to gas and electricity costs and their economic strain. In 2023, the rates of the above indicators stood at 7-16% of the EU's population (31 to 73 million Europeans), as shown in **Table 1.**

We note here that indicators (a)-(d) do not specifically target summer energy poverty. With the rise of global temperatures in recent years, exposure to excessive indoor temperatures and its effects on health, wellbeing and productivity is an increasingly relevant concern, especially in urban areas, where heatwaves can be particularly severe (Thomson et al., 2019; Torrego- Gómez et al., 2024). In 2012, EU-SILC results reported 19% of the EU population to be unable to keep their home adequately cool, a share which increased to 26% for households with low incomes. The indicator, however, is not regularly collected in the survey.(10)

In this section, we provide an analysis of the selected indicators by degree of urbanisation across Member States. Indicators (a), (b) and (c) are not publicly available by degree of urbanisation, but can be computed from the individual records of the survey. For this analysis, EU-SILC scientific files were requested and provided by Eurostat. The data contains around 210 000 cross-sectional household records for 2022 (most recent year available at the time of this study). Results are presented at the household level; further methodological details can be found in **Annex 1.**

For indicators (a) and (b) data is available by degree of urbanisation for 24 EU countries (excluding the Netherlands and Slovenia), while indicator (c) is available for 23 countries (additionally excluding Germany). Indicator (d) is already made available by degree of urbanisation by Eurostat, covering all MS by degree of urbanisation (Eurostat, 2023b). Indicator availability for each MS is summarised in **Table A1.1** of **Annex 1.**

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(10) The ad-hoc module on Energy Efficiency in the 2023 EU-SILC wave included an optional question on the inability to keep the dwelling comfortably cool during summer. The question specifically refers to the adequacy of the cooling system, excluding affordability barriers.

Table 1. Energy poverty indicators identified by the Energy Efficiency Directive.

Source: Eurostat, EU-SILC 2023.

ENERGY POVERTY INDICATORS – Share of total EU population, EU-SILC 2023

Inability to keep the home adequately warm **10.6%**	Arrears on utility bills **6.9%**
Dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor **15.5%**	At-risk-of-poverty rate **16.2%**

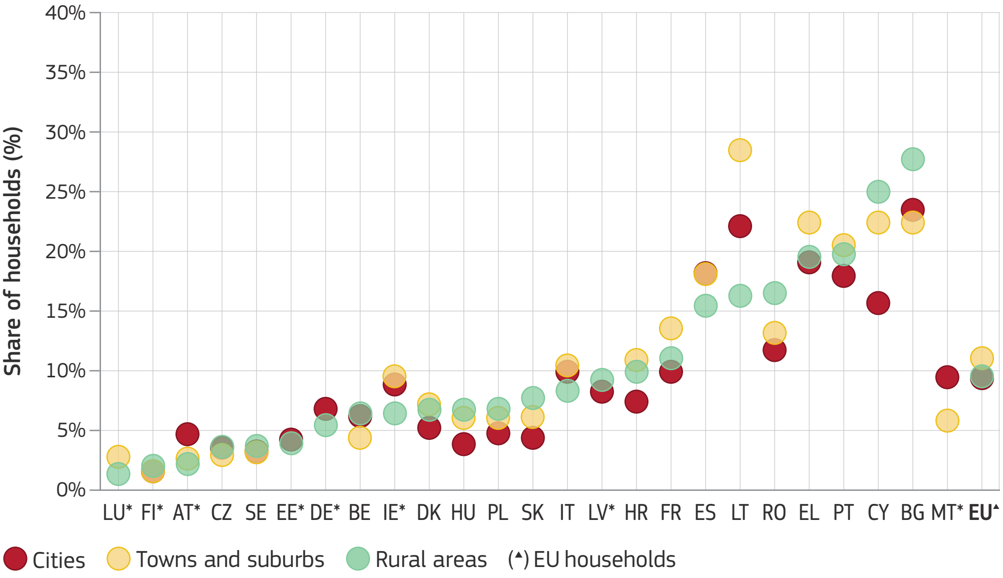
The inability to keep the home adequately warm provides a self-reported or consensual measure of comfort, and is therefore subject to subjective perceptions. At the EU level, we find that the share of households unable to keep their home adequately warm amounts to 11% in towns and suburbs, 10% in rural areas and 9% in cities (**Figure 4**). Shares are highest in Bulgaria, Cyprus, Portugal, Greece, Romania, Lithuania and Spain (above 15% in at least one category of the urban-rural continuum).

The distribution of the indicator by degree of urbanisation varies strongly within Member States: in Bulgaria, Cyprus and Romania rural areas show the largest share of households unable to keep their home adequately warm, while in Portugal, Greece and Lithuania the share is highest in towns and suburbs. In Spain, towns and suburbs and cities hold the largest shares. The Member States with the lowest rates are Luxembourg, Finland, Austria, Czechia and Sweden, where less than 5% of households report being unable to keep their home adequately warm across all territorial typologies.

Figure 4. Share of households unable to keep their home adequately warm in EU Member States by degree of urbanisation.

Note: (*) Malta (rural areas), Luxembourg (cities), Estonia, Germany, Latvia (towns and suburbs): insufficient/no data. Finland, Austria, Ireland, Luxembourg: limited record numbers (20-49) in some categories.

Source: Own elaboration from EU-SILC 2022, cross-sectional scientific files.



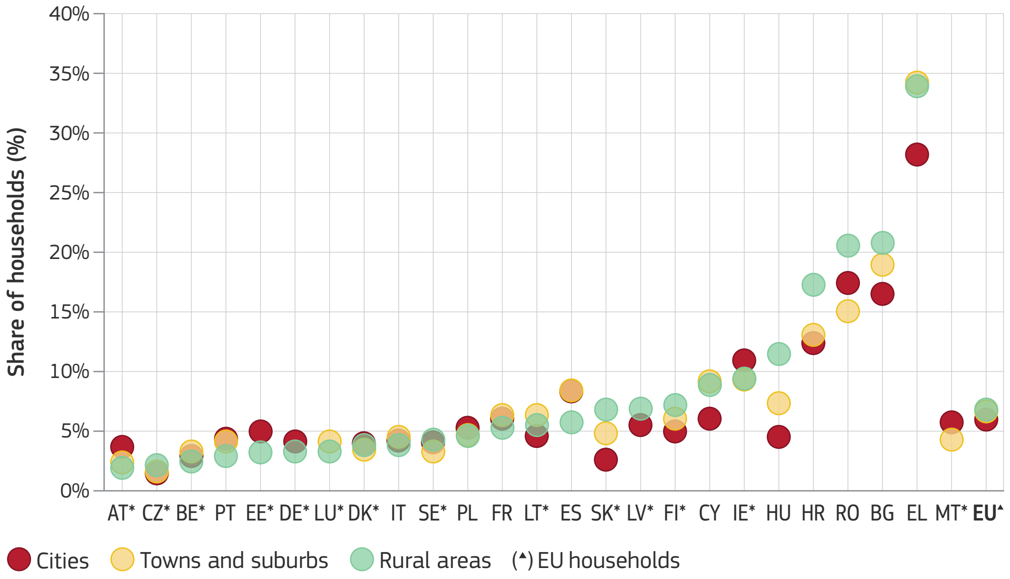


Figure 5. Share of households that have been in arrears on utility bills at least once in a year in EU Member States by degree of urbanisation.

Note: (*) Malta (rural areas), Luxembourg (cities), Germany, Estonia, Latvia (town and suburbs): insufficient/no data. Austria, Czechia, Belgium, Luxembourg, Lithuania, Slovakia, Ireland: limited record numbers (20-49) in some categories.

Source: Own elaboration from EU-SILC 2022, cross-sectional scientific files.

The prevalence of **arrears on utility bills** is computed as the share of households which report having been in arrears at least once in the past twelve months.[11] We find that, at the EU level, 7% of households in rural areas and towns and suburbs report arrears in utility bills, while the share amounts to 6% in cities (**Figure 5**). In Bulgaria, Romania and Croatia, the share of households reporting arrears in utility bills is above 15% in at least one territorial typology, with the highest shares being found in rural areas. Greece shows the highest levels of the indicator: 34% of households report arrears on utility bills in towns and suburbs and rural areas, and 28% in cities. Households are least likely to be in arrears in utility bills in Austria, Czechia and Belgium, where the share is below 4% across all territorial typologies.

The presence of a **leaking roof, damp walls, floors or foundation, or rot in window frames or floor** provides a measure of the condition of the dwelling, as dampness or rot indicates low energy efficiency and/or inadequate heating or ventilation. Previous analyses of EU-SILC longitudinal data have shown that the presence of leaks, damp or rot in the house is a persistent phenomenon when compared to other indicators, with 7% of residents having experienced these conditions in their household during least 3 years prior to the 2020 survey (Ozdemir et al., 2024). Based on 2020 cross-sectional EU-SILC data, we find that the share of households reporting such conditions is highest in rural areas (16%), followed by cities (15%) and towns and suburbs (14%), as shown in **Figure 6.**[12] The highest share of dwellings with leaking roofs, dampness or rot are found in Cyprus and Portugal, as well as rural areas of Hungary, Spain, Latvia and Italy (21% or above).

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(11) For this indicator arrears refer to all household bills, including water consumption. This might to overestimation of energy poverty if considered alone, however it provides an indication of financial difficulties with regard to household services (Thomson et al., 2013).

(12) EU-SILC collects information on dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor every three years. The latest data for this indicator available in the scientific files requested for this study is from 2020.

The **At-risk-of-poverty rate** (AROPE) reports the share of population with an equivalised disposable income (i.e. income after social transfers) below 60 % of the national median equivalised disposable income. As such, it provides a measure of low income in comparison to other residents in the country, which does not necessarily imply a low standard of living. However, it provides an indication of a household's potential vulnerability to high energy prices and expenditure, as well as reduced financial opportunities to invest in building renovation.

Previous analyses have shown that the at-risk-of poverty rate is a persistent indicator, estimating that 10-11% of the EU's population was at risk of poverty for at least three years (prior to each survey) during the 2013-2021 period (Ozdemir et al., 2024).

At the EU level, we find that highest at-risk-of-poverty rates are found in cities and rural areas (17%), with towns and suburbs showing the lowest rate (16%) (**Figure 7**). The highest AROPE rates are found in rural areas of Romania, Malta, Bulgaria, Latvia and Lithuania, as well as in towns and suburbs of Estonia, where more than 25% of the population is at risk of poverty.

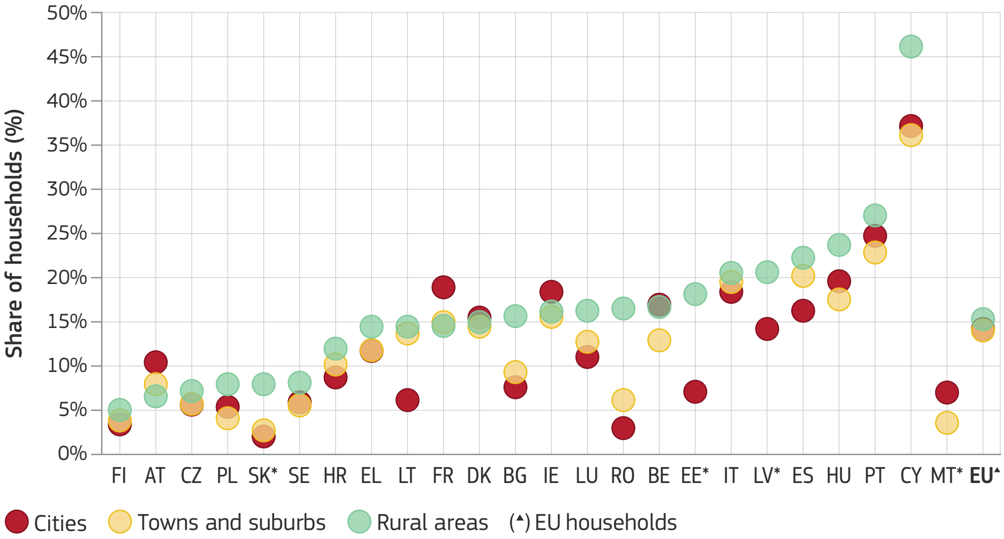

Figure 6. Share of households with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor in EU Member States by degree of urbanisation.

Note: (*) Latvia, Estonia (towns and suburbs), Malta (rural areas): insufficient/no data; Malta, Slovakia: limited record numbers (20-49) in some categories.

Source: own elaboration from EU-SILC 2020, cross-sectional scientific files.

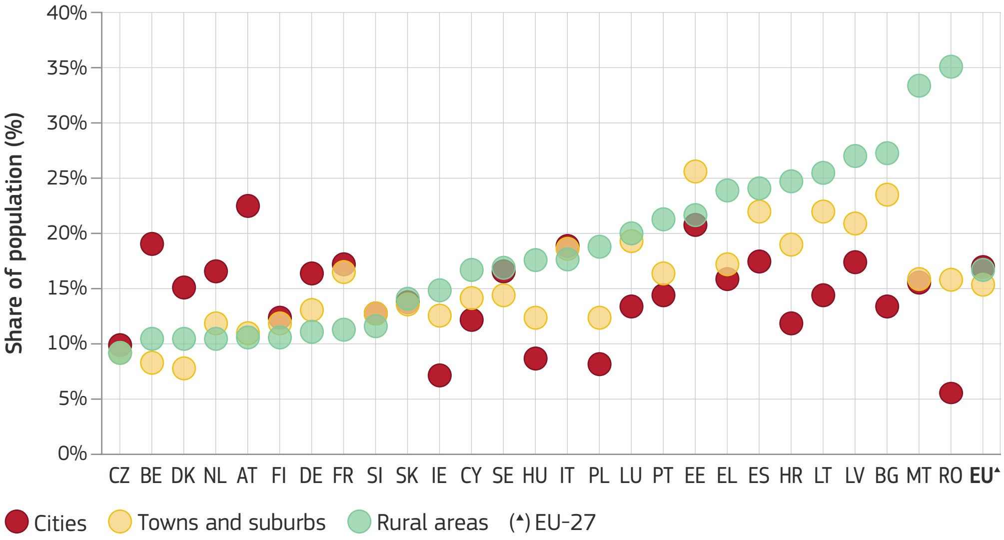

Figure 7. At-risk-of-poverty rate (share of population below 60% of median equivalised income after social transfers) in EU Member States by degree of urbanisation.

Source: Eurostat, EU-SILC 2023 *(ilc_li43).*

2.3. ENERGY POVERTY INDEX

Due to the multi-factor nature of energy poverty, composite measurements can help gain insight into the combined effects of energy poverty drivers. Building on recent developments in energy poverty assessments, we follow a multi-indicator approach to construct an energy poverty index. The index combines indicators (a), (b), (c) and (d), as well as the share of household consumption expenditure on electricity, gas and other fuels (indicator ii of **Section 2.1**) with equal weights. Therefore, it summarises information on household income and expenditure, dwelling conditions and consensual thermal comfort, in line with previous multi-indicator studies (Castaño-Rosa et al., 2019; Sokołowski et al., 2019; Lavecchia et al., 2024). In this case, the degree of urbanisation acts as a geographical dimension allowing to assess energy poverty across the urban-rural continuum.

The energy poverty index is constructed as the average of the five aforementioned indicators, previously standardised so that each variable follows a distribution centered at zero and with standard deviation equal to one.(13) The resulting index follows a normal distribution, where a zero value corresponds to the EU average across Member States and territorial typologies, and higher values indicate increased levels of energy poverty. In the cases where an indicator is available for a Member State for two territorial typologies only, the value for the missing typology is imputed as the country value. Extreme values and outliers falling above or below two standard deviations are assigned values of ±2.

At the EU level, we find that energy poverty markers are highest in rural areas (with an MS-average index of +0.13), with towns and suburbs falling close to the average (-0.075) and cities displaying a low score (-0.23) (**Figure 8**). The highest levels of the index (1.2 or above) are found in rural areas of Bulgaria, Romania and Greece, as well as in towns and suburbs of Bulgaria, which were home to more than 14 million people as of 2021 (Eurostat, 2023c).

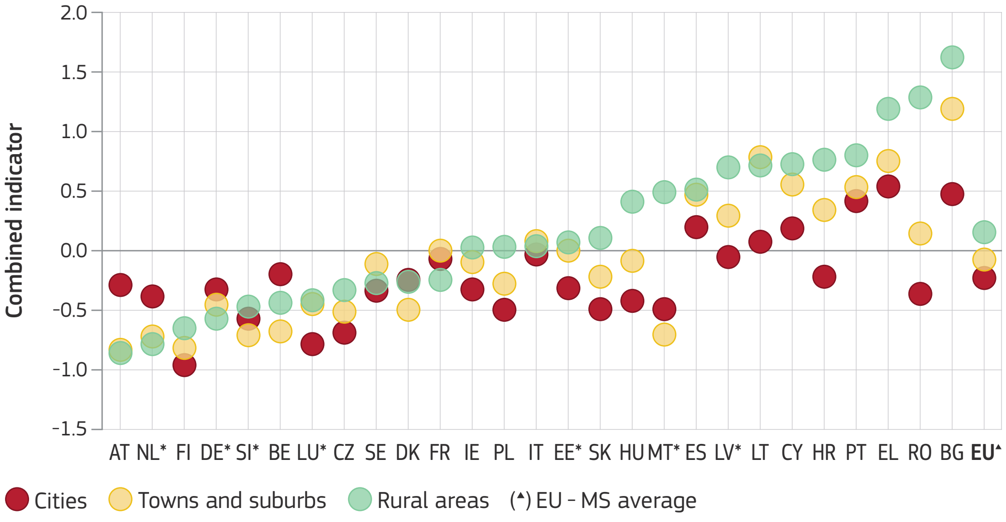

Figure 8. Energy poverty index in EU Member States by degree of urbanisation.

Note: The index combines indicators (a), (b), (c), (d) and (ii) of this section to assess risks of energy poverty. Values are normally distributed, with higher scores indicating higher risk of energy poverty, and a zero value being at the EU average across MS and territorial typologies.
(*) Slovenia, Netherlands: based only on two indicators; Estonia, Germany, Latvia (towns and suburbs), Malta (rural areas), Luxembourg (cities): imputed values in at least 2 indicators (see **Table A1.1** in **Annex 1**).

Source: own elaboration from HBS and EU-SILC data.

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(13) The choice of equal weights provides a meaningful index with a straightforward interpretation, given that all indicators are positively correlated (with the exception of a small negative correlation (p=-0.26) between household consumption expenditure and presence of leaks, rot or dampness in the dwelling).

2.4. EU-SILC: HOUSEHOLD ENERGY EFFICIENCY MODULE

In 2023, a new ad-hoc module on energy efficiency of dwellings was included in the EU-SILC questionnaire, responding to the need to provide indicators in this area. Two particularly relevant variables included in the new module are a households' number of renovations improving energy efficiency and the main energy source used by the heating system.

Renovations improving energy efficiency can refer to the improvement in thermal insulation, the replacement of single-glazed windows for double- or triple-glazed windows, or the replacement of the heating system with a more efficient one. The data indicates that, in the EU, 25.5% of people live in a household where energy efficiency has been improved in the last 5 years – a share that is highest for rural areas (29%), followed by towns and suburbs (25%) and cities (23%). Amongst households where owners live, more renovations improving energy efficiency have taken place in rural areas (29% of households) than in cities and towns and suburbs (25%).(14) A larger share of owner-occupied dwellings in rural areas together with an increased propensity of rural owners to renovate the dwellings they live in could be facilitating the rural lead in energy efficiency improvements.

As shown in **Figure 9,** the Netherlands and Estonia lead in renovation rates (above 40% of residents living in recently renovated dwellings across all territorial typologies), while these are lowest in Malta, Greece, Italy, Spain and Cyprus (below 20% across all territorial typologies). Coincidentally, these Member States are among those which experience the lowest number of Heating Degree Days (e.g. least climatic pressure on heating needs), as discussed in **Section 3.3.**

In terms of the **main energy source of heating systems,** we observe significant differences by degree of urbanisation (**Figure 10**). In rural areas, three energy sources are used approximately as frequently: gas (with 26% of the population living in households that use it as their main heating source), wood logs (25%) and oil or coal (23%). Electricity and renewables are least used (14% and 10%, respectively). On the other hand, in both cities and towns and suburbs more than half of the population lives in dwellings that use gas as their main heating source (56% and 54%, respectively). Electricity, oil or coal and renewables are, in this order, the most relevant sources of energy in both territorial typologies.

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(14) Based on 2023 household microdata from EU-SILC.

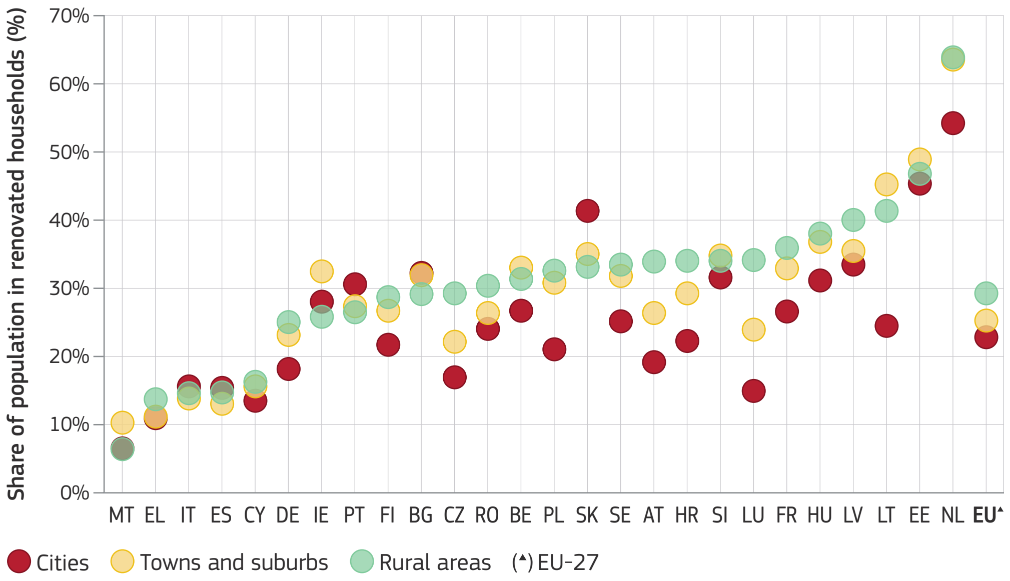

Figure 9. Percentage of population living in households that have undergone at least one renovation improving energy efficiency in the five years prior to the survey, by degree of urbanisation.

Source: own elaboration from Eurostat, EU-SILC 2023 *(ilc_lvhe09)*.

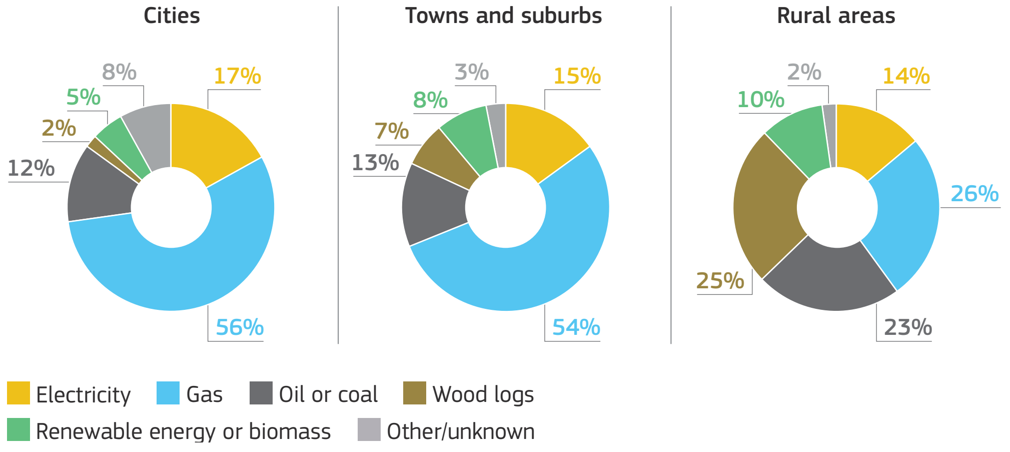

Figure 10. Main source of energy of the heating system used in households by degree of urbanisation, in percentage of population living in the households.

Source: own elaboration from Eurostat, EU-SILC 2023 *(ilc_lvhe02)*.

From 2023 EU-SILC cross-sectional microdata, we find that the main energy source used in heating is highly correlated with dwelling type (e.g. house or flat), and moderately correlated with educational attainment level, degree of urbanisation, tenure status and income quintile (see **Annex 1** and **Figure A1.2** for details). Renovations, on the other hand, are only moderately correlated with tenure status.

2.5. HOUSEHOLD CHARACTERISTICS AND ENERGY POVERTY

The EU-SILC scientific files allow to analyse household characteristics and correlate them with energy poverty indicators. Across all countries and territorial typologies, we find that 2% of EU households simultaneously report arrears on utility bills and inability to keep their home warm, while 14% report a positive response to at least one of these indicators.(15) In what follows, we refer to the latter category (households with positive response in arrears on utility bills and/or inability to keep their home warm) as households showing signs of energy poverty.

Households with signs of energy poverty are broken down by degree of urbanisation, by type of dwelling, by income quintile and by type of household (**Figure 11**). We find that 15% of households in towns and suburbs show signs of energy poverty, followed by rural areas (14%) and cities (13%). Therefore, the presence of arrears in utility bills and the inability to keep a home warm show small differences across the urban-rural continuum at the EU scale but, as discussed in **Section 2.2,** they can vary substantially within each Member State. A similar pattern emerges when analysing households by dwelling type – the share of households with signs of energy poverty falls within 1.5 percentage points of the EU average in all dwelling types (detached and semi-detached houses, apartment block above or below 10 dwellings or other dwelling types).

On the other hand, energy poverty indicators vary significantly with income level and household type. As shown in **Figure 11,** 22% of households in the lowest income quintile show signs of energy poverty, a share which decreases progressively with higher incomes (14%, 11%, 7% and 4% in the 4th, 3rd, 2nd and 1st income quintiles, respectively)(16). 62% of households unable to keep their home warm and/or in arrears on utility bills are in the two lowest income quintiles. These results are in line with previous studies based on EU-SILC data, where a strong association between income and energy poverty has been identified (Koukoufikis et al, 2022 and 2024).

When looking at household composition (referred to as household type), we find that households with lone parents are also more likely to show signs of energy poverty than any other household type, with the share reaching 24% for lone parents with at least a child aged less than 25, and 21% for lone parents with all children aged 25 or more. On the other hand, couples without children are least likely to experience signs of energy poverty (9% of households), followed by couples with at least one under-25 child (12%), one-person households and couples with all children aged 25 or above (15%). Women (15%) are more likely to suffer energy poverty than men (12%), while no major differences are found by age as all rates by 10-year age groups fall within 1.5 percentage points of the EU average.

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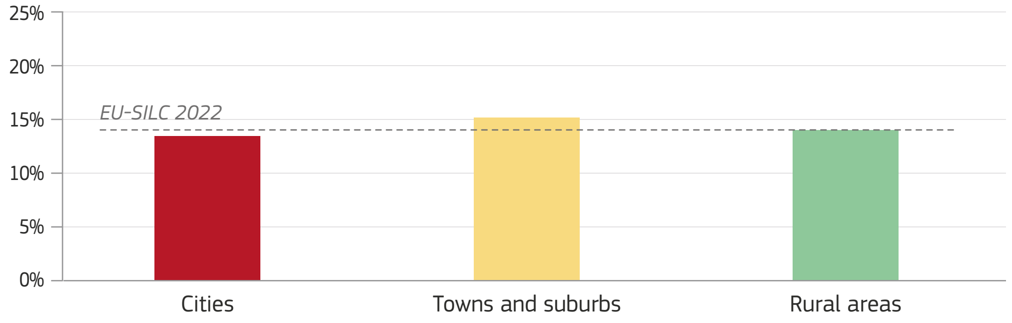
(15) We consider only households reporting degree of urbanisation.

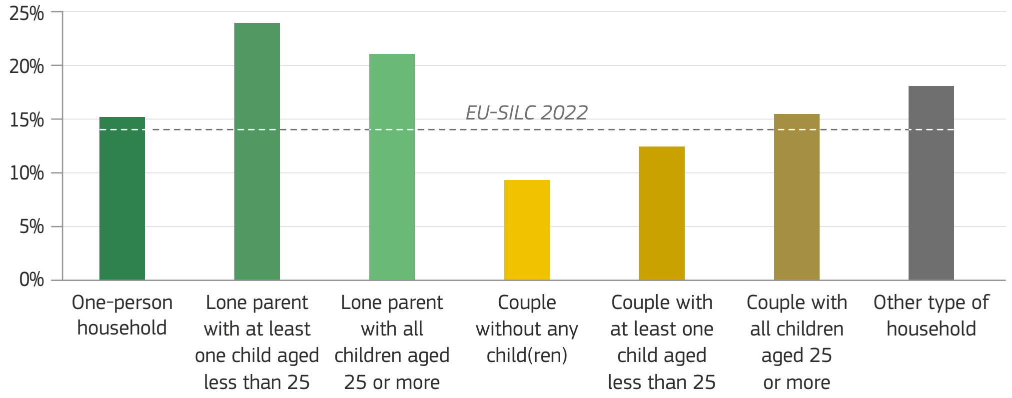
(16) Income data has been converted to PPS using power purchasing parities and yearly exchange rates from Eurostat (Eurostat, 2022b and 2022c).

Share of households unable to keep their home warm and/or in arrears on utility bills

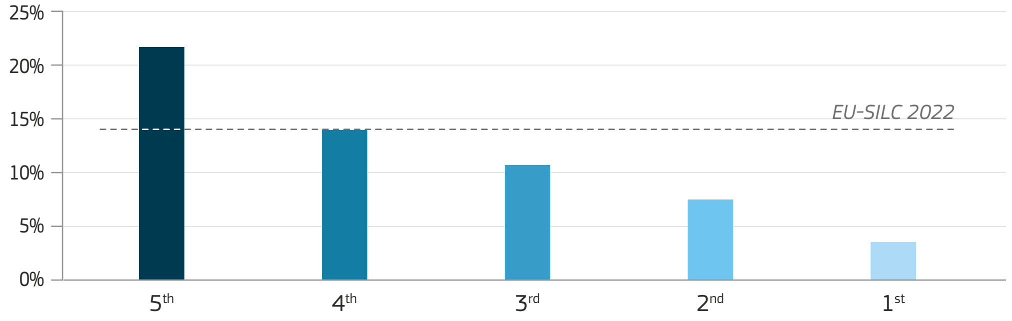
(a) Degree of urbanisation



(b) Household type



(c) Income quintile



(d) Dwelling type

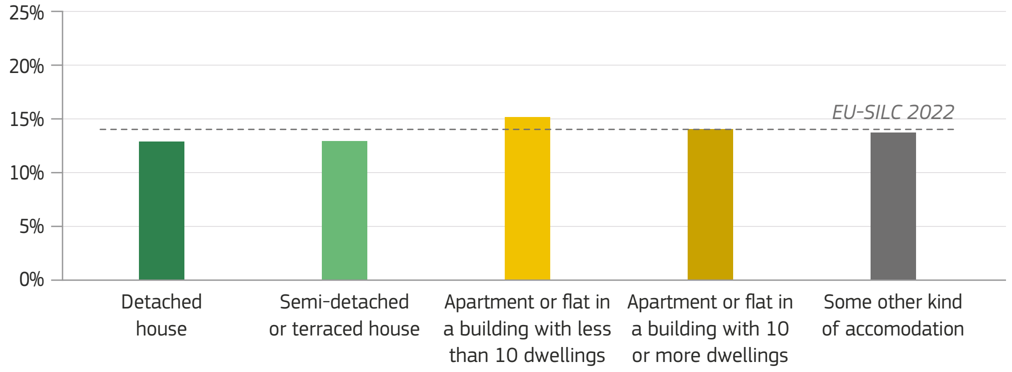


Figure 11. Share of households unable to keep their home warm and/or in arrears in utility bills by degree of urbanisation (a), household type (b), income quintile (disposable income in PPS)(c) and dwelling type (d).

Source: EU-SILC 2022, cross-sectional scientific files.

In order to assess the strength of the relationship between EU-SILC variables, a Chi squared-based statistical analysis was performed (see **Annex 1** for details). The results reveal that indeed the presence of arrears in utility bills and the inability to keep a home adequately warm show the highest association with income quintile and household type (low effect size), while correlations with all other analysed variables are negligible (see **Annex 1** and **Figure A1.1** for details). Statistically, we find that the degree of urbanisation shows the highest association with dwelling types (high effect size) and tenure status (low effect size).

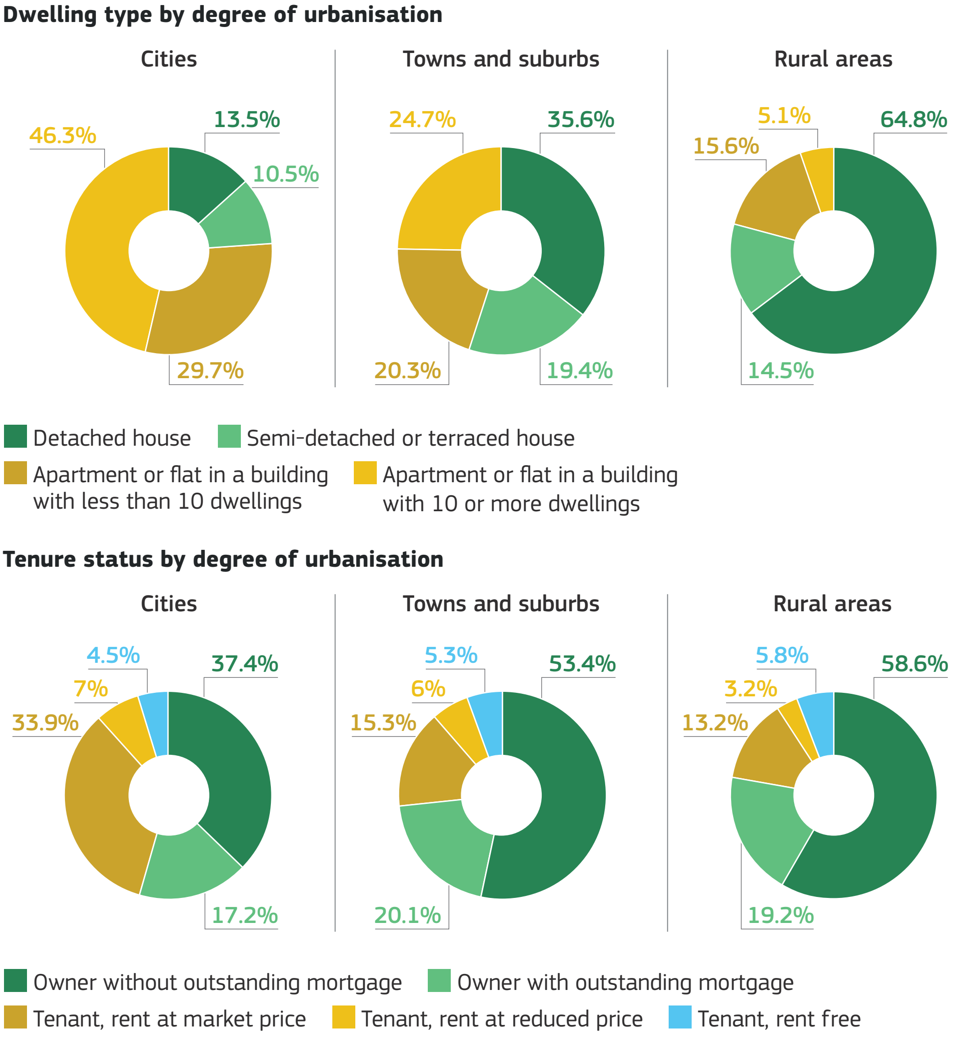


Figure 12. Dwelling type and tenure status by degree of urbanisation.

Source: EU-SILC 2022, cross-sectional scientific files.

EU-SILC data also allows us to identify the main characteristics of households by degree of urbanisation, regardless of their energy poverty status. Statistically, we find that the degree of urbanisation shows the highest correlation with dwelling types (high effect size) and tenure status (low effect size) (see **Annex 1** for details). We find that, in rural areas, 65% of dwellings are detached houses, followed by semi-detached houses (14%), apartments in buildings with less than 10 dwellings (16%) and apartments in buildings with more than 10 dwellings (5%) (**Figure 12,** top). Detached houses account for a smaller share of dwellings both in cities (14%) and towns and suburbs (36%). Therefore, the most prominent types of dwellings in rural areas are those which face more challenges in terms of energy efficiency: detached and semi-detached houses are usually less energy efficient due to their size and surface-to-volume ratio (see for example Florio et al., 2015 for experiences in France). This pattern is analysed in detail using high-spatial resolution data in **Chapter 3.**

Regarding tenure status, we find that in rural areas more than three quarters (78%) of households own their home, a share which is lower in towns and suburbs (73%) and cities (55%), (**Figure 12,** bottom). A high share of dwelling ownership can benefit rural areas in their path towards building energy efficiency, as it increases the opportunities and incentives for renovation and retrofitting and for the implementation of self-consumption energy systems.

2.6. SUMMARY

Energy poverty is a complex multi-dimensional phenomenon, linked both to socio-economic factors and to the energy performance of the building stock. As recognised in the EU's Energy Efficiency Directive, drivers of energy poverty include non-affordability, insufficient household disposable income, high energy expenditure and poor energy efficiency of homes. In this section, we analysed these factors by degree of urbanisation, focusing on the situation of rural areas.

HOUSEHOLD ENERGY EXPENDITURE

A household's share of household expenditure on energy services reflects the financial burden stemming from gas and electricity costs. Household Budget Survey data shows that **the share of household expenditure on electricity, gas and other fuels is higher in rural areas** (7.1% on average across MS), than in towns and suburbs (6.2%) or cities (5%). Highest energy expenditure shares are found in rural households of Bulgaria, Czechia and Slovakia (above 12%). Countries where the share of expenditure in electricity, gas and other fuels is highest show the largest urban-rural disparities, suggesting that **high shares of expenditure on energy are associated with a deeper urban-rural divide,** with rural areas being most affected.

ENERGY POVERTY INDICATORS

The share of **households reporting an inability to keep their home adequately warm** or **arrears in utility bills is similar across territorial typologies at the EU level,** although significant urban-rural gaps do exist within certain Member States. On average in the EU, the share of households reporting an inability to keep their home adequately warm reaches 11% in towns and suburbs, 10% in rural areas and 9% in cities. The countries with the highest shares are Bulgaria, Cyprus, Portugal, Greece, Romania, Lithuania and Spain, with rates above 15% in at least one territorial typology.

In rural areas, 7% of households report arrears in utility bills, while the share amounts to 6% in cities and towns and suburbs. In Greece, Bulgaria, Romania, Croatia and Hungary, more than 15% of households report arrears in utility bills in at least one territorial typology, with the highest shares in rural areas. In Greece, 34% of households in rural areas and towns and suburbs report arrears on utility bills. The share of households with **a leaking roof, damp walls, floors or foundation, or rot in window frames or floor is highest in rural areas** (16%), followed by cities (15%) and towns and suburbs (14%), while the **at-risk-of-poverty rate is highest in cities and rural areas** (17%), with towns and suburbs showing the lowest rate (16%).

Considering all households across the urban-rural continuum, we find that **income levels have a strong connection with energy poverty,** with 62% of households reporting an inability to keep their home adequately warm and/or arrears in utility bills being in the last two income quintiles. In terms of household composition, **lone parents with children also show increased energy poverty risks,** with more than 20% reporting inability to keep their home adequately warm and/or arrears in utility bills.

ENERGY POVERTY INDEX

Given the complex nature and variety of drivers of energy poverty, and following recent developments in energy poverty assessment, a multi-indicator index was constructed by combining the four relevant indicators identified by the Energy Efficiency Directive together with the share of household expenditure on energy. The resulting index, which summarises energy poverty risks in each Member State by degree of urbanisation, shows that **rural areas in most Member States have a higher risk of energy poverty,** with rural areas of Bulgaria, Romania and Greece being most at risk.

ENERGY EFFICIENCY AND HOUSEHOLD CHARACTERISTICS

A dedicated module of the EU-SILC framework shows that the main energy source of household heating systems varies substantially by degree of urbanisation: **gas, wood logs, oil/coal and renewables/electricity are each used approximately by 1 in 4 rural households,** while more than 50% of households in cities and towns and suburbs rely on gas. The same dataset shows **that rural areas are leading in renovations improving energy efficiency** (29% of residents live in households that underwent such renovations in a 5-year period), followed by towns and suburbs (25%) and cities (23%).

In rural areas, 79% of households are in detached or semi-detached houses, while only 21% are flats in apartment buildings. As detached and semi-detached houses are usually less energy-efficient due to their size and surface-to-volume ratio, rural areas could face more challenges in space heating than cities or towns and suburbs, where the share of houses is lower (55% and 24%, respectively). On the other hand, **dwelling ownership is high in rural areas, where 78% of dwellings are owned.** This can provide advantages for rural areas, as dwelling ownership increases the opportunities and incentives to invest in renovation, retrofitting, and self-consumption systems.

The forthcoming sections investigate more closely the energy efficiency dimension by analysing building characteristics, implementation of renewable solutions and climatic conditions at the local level.


N

3

Energy efficiency and needs: local indicators in the EU

Advancing towards an energy-efficient building stock is paramount to achieve the objectives of the European Green Deal, which aims to reach carbon neutrality in the EU by 2050. In this context, understanding challenges and opportunities in building energy efficiency and needs at the local level is key for an effective deployment of resources and renovation efforts. However, granular data on several relevant parameters for buildings in this context, such as Energy Performance Certificate (EPC) ratings or renovation rates, are not available at this time as EU-level harmonised datasets.

Regarding EPC ratings, MS may use their own calculation and labelling methodologies, which has led to important differences in evaluation schemes and data availability across MS, as well as an absence of comparable, EU-wide data (Zangheri et al, 2021; Maduta et al., 2023). Even if not fully comparable, available data for 14 MS shows that 50% of EPC receive a rating lower than D (BPIE, 2022). The recast EPBD takes some steps to tackle EPC rating comparability and availability, establishing that MS should set up databases on the energy performance of their national building stock and make publicly available aggregated or anonymised data on energy performance. Renovation rates also suffer from a severe lack of information, with harmonised data being available only at the MS level and based on an assessment for the period 2012-2016 (DG ENER, 2019). Energy saving rates are estimated at national level by the ODYSEE-MURE project, which places household energy savings in the EU in 2022 at 30% with respect to consumption levels in 2000 (ODYSEE-MURE, 2022).

Important efforts have been devoted to model energy consumption at the regional level and at high spatial resolution (Pezzutto et al., 2018; JRC, 2022; Hidalgo Gonzalez et al., 2023). Since EU-wide local or regional consumption data is currently not available, results of these studies are based on a disaggregation of national figures. Especially in the case of high-resolution studies, the results obtained when aggregating data within administrative units depend heavily on population distribution. This hinders the ability to provide insightful analyses based on these datasets in the full spectrum of the degree of urbanisation, including rural areas.

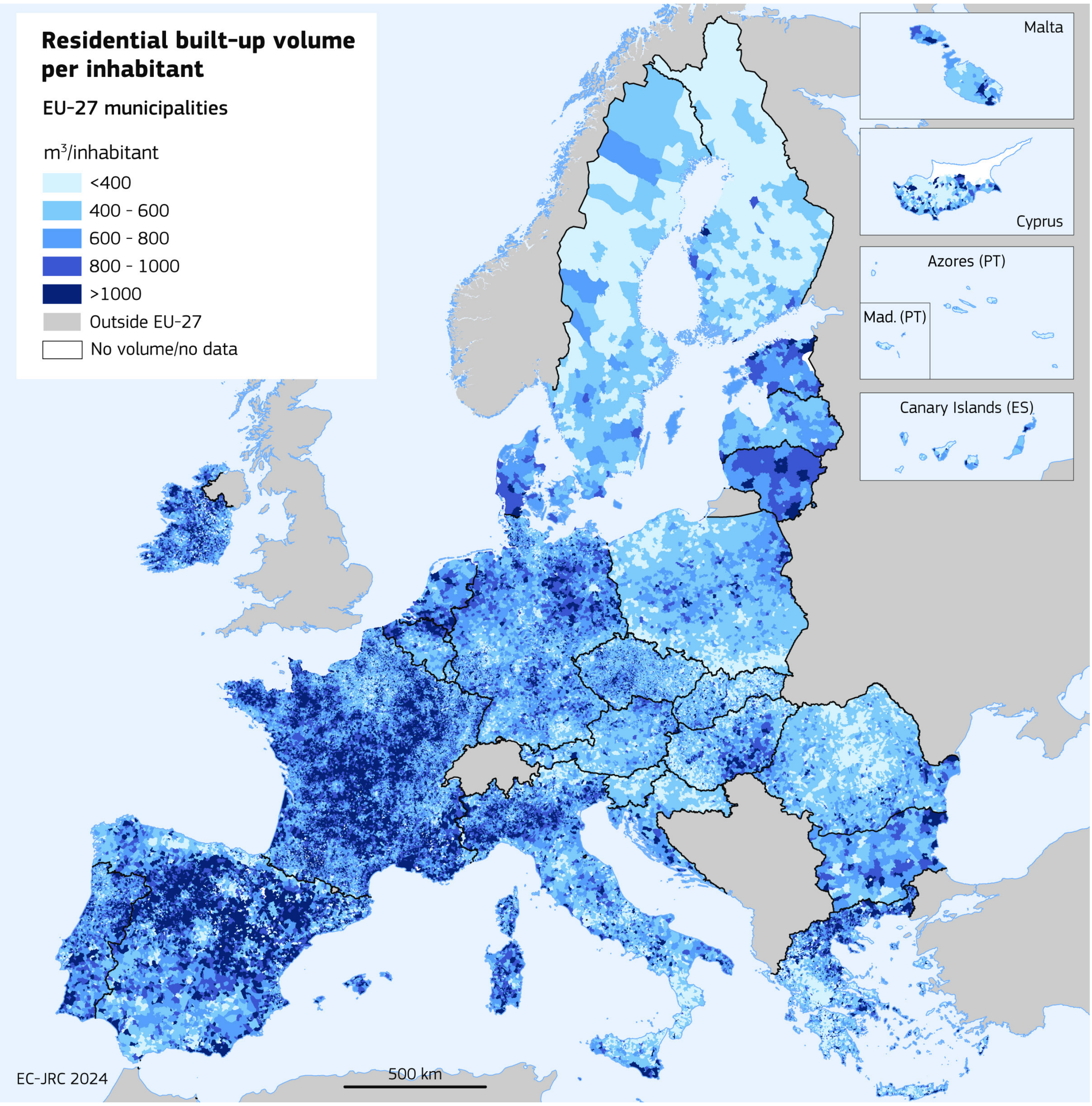
Here, we provide an analysis of indicators with an impact on building energy needs and energy efficiency which are available at high resolution and based on geospatial observations. These include characteristics of the building stock (residential building volumes, building compactness and building ages), implementation of renewable solutions (rooftop photovoltaic production) and climatic conditions. We then combine this information in a composite indicator at the municipality level, with the aim to identify local challenges in energy efficiency and needs across the EU. Our approach is in line with previous studies with a regional perspective (Baranzelli et al., 2015 and 2016; Zangheri et al., 2021), with an additional focus on the local level and urban-rural differences.

3.1. BUILDING VOLUME AND COMPACTNESS

In rural areas, 79% of households are detached or semi-detached houses, a share that is much lower in towns and suburbs (55%) and cities (24%), according to EU-SILC data (see **Figure 12**). Therefore, dwellings in rural areas are expected to be more scattered, less compact and larger, which makes them less efficient to heat.

Figure 13. Residential building volume per inhabitant in EU-27 municipalities.

Source: own elaboration from GHSL-BUILT-V and Eurostat 2021 population grid.



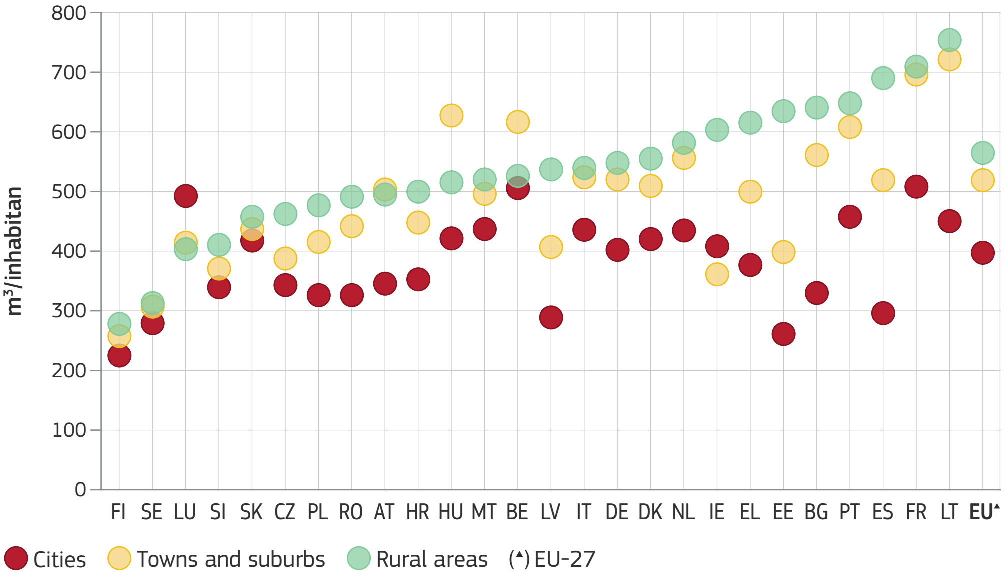
This is due to higher volumes and a larger building envelope exposed to the outdoors, leading to higher thermal losses, particularly for poorly insulated envelopes. In this section, we study the shapes of buildings by degree of urbanisation in order to quantify this effect, providing two indicators for the EU's municipalities: the average residential building volume per inhabitant and the average building shape factor, which measures building compactness.

Employing the residential built-up volume provided by the Global Human Settlement Layer (GHS-BUILT_V) (Pesaresi et al., 2023a), together with Eurostat's 2021 census population grid (Eurostat, 2023c), we obtain residential building volumes per inhabitant in the EU's municipalities (**Figure 13**). At the EU level, we find that rural areas feature the highest residential volumes per inhabitant (565 m^3/inhabitant), followed by towns and suburbs (519 m^3/inhabitant), and cities (398 m^3/inhabitant). The indicator is highest in rural areas and towns and suburbs of Lithuania and France, as well as in Spanish rural areas (above 650 m^3/inhabitant), while Finland and Sweden show the lowest residential volumes per inhabitant (below 320 m^3/inhabitant in all territorial typologies) (**Figure 14**).

Figure 14. Residential built-up volume per inhabitant in EU-27 Member States by degree of urbanisation.

Note: Cyprus: low reliability by territorial typology. Country value of 700 m^3/inhabitant.

Source: own elaboration from GHSL-BUILT-V and Eurostat 2021 population grid.



Shapes of buildings also impact their energy consumption (D'Amico et al., 2019). In particular, compact buildings (those with a small envelope surface area with respect to their volume) have been shown to experience reduced heat losses in cold climates (Depecker et al, 2001; Danielski et al., 2012)(17). In warm climates, minimizing the exposed external surface is also an effective strategy to reduce heat absorption in buildings (Cities Alliance, 2024). A useful parameter to quantify this effect is a building's shape factor, defined as the ratio of a building's envelope or outer surface (S) to its heated volume (V). The shape factor can be expressed as

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(17) Studies have not found effects of compactness in energy efficiency in temperatures above 11-14°C, depending on the thermal envelope performance of the building (Danielski et al., 2012).

$$sf = \frac{S}{V} = \frac{2}{h} + \frac{P}{A}$$

where *h, P* and are a building's height and perimeter respectively, and A represents floor area at the Level of Detail (LOD) 1 building approximation (simple footprint extrusion by its height). A small shape factor indicates a highly compact building, while less compact buildings display large shape factors. Differences in building compactness have been found to account for 10-20% of their final energy demand, and a shape factor of 0.8 m^2/m^3 or less is considered necessary to achieve high energy performance standards (Lylykangas, 2009; Danielski et al., 2012). In Florio et al. (2015), a case study for buildings in France allowed to estimate that a 10% change in compactness leads to a 7% change in energy demand.

In order to compute the shape factor of buildings across the EU, we employ the building footprints provided by the Digital Building Stock Model (DBSM), from which we derive building perimeters and floor areas (Florio et al., 2023).(18) We then use the GHSL Average Net Building Height (GHSL-ANBH) at 100 m spatial resolution to estimate building height at the grid level (Pesaresi et al., 2023b).(19) Shape factors are computed for each building footprint, and then aggregated by mean at 5 km spatial resolution (**Figure 15**) and at the municipality level. In this approximation, the building volume derived from the perimeter footprint and the GHSL-ANBH height is used to estimate heated volume. As certain building spaces such as garages, workshops, staircase space, etc. are not heated, this estimate should be considered as an upper bound for heated volume. Furthermore, other factors such as the orientation of buildings and the thermal insulation performance of the surface also have a direct influence on thermal exchange. A high-resolution evaluation of these factors is, however, beyond the scope of this work.

We find that, on average in the EU, buildings in rural areas are less compact (with an average shape factor of 1.2), followed by towns and suburbs (1.0) and cities (0.91). Across all Member States, rural areas are the territorial typology with the largest shape factors, ranging from a value of 1.09 in Malta up to values above 1.3 in Estonia (**Figure 16**). Moreover, rural areas show the least variation in terms of compactness across Member States (±0.05 in standard deviation), followed by towns and suburbs (±0.11) and cities (±0.14). This suggests that rural areas throughout Europe have similar building typologies, while cities and towns and suburbs feature more diversesity. This is in line with results from **Section 2.5,** where the majority of dwellings (65%) in rural areas were found to be detached houses, while dwelling typologies showed more diversity in towns and suburbs and cities.

For this assessment, all footprints in the DBSM database were analysed, including buildings which might not be used for residential purposes. Upper bounds on footprint size and information from additional high-resolution layers such as

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(18) In the case of France, DBSM building footprints are highly detailed. To enhance comparability of shape factors between Member States, building footprints in France have been merged for overlapping polygons.

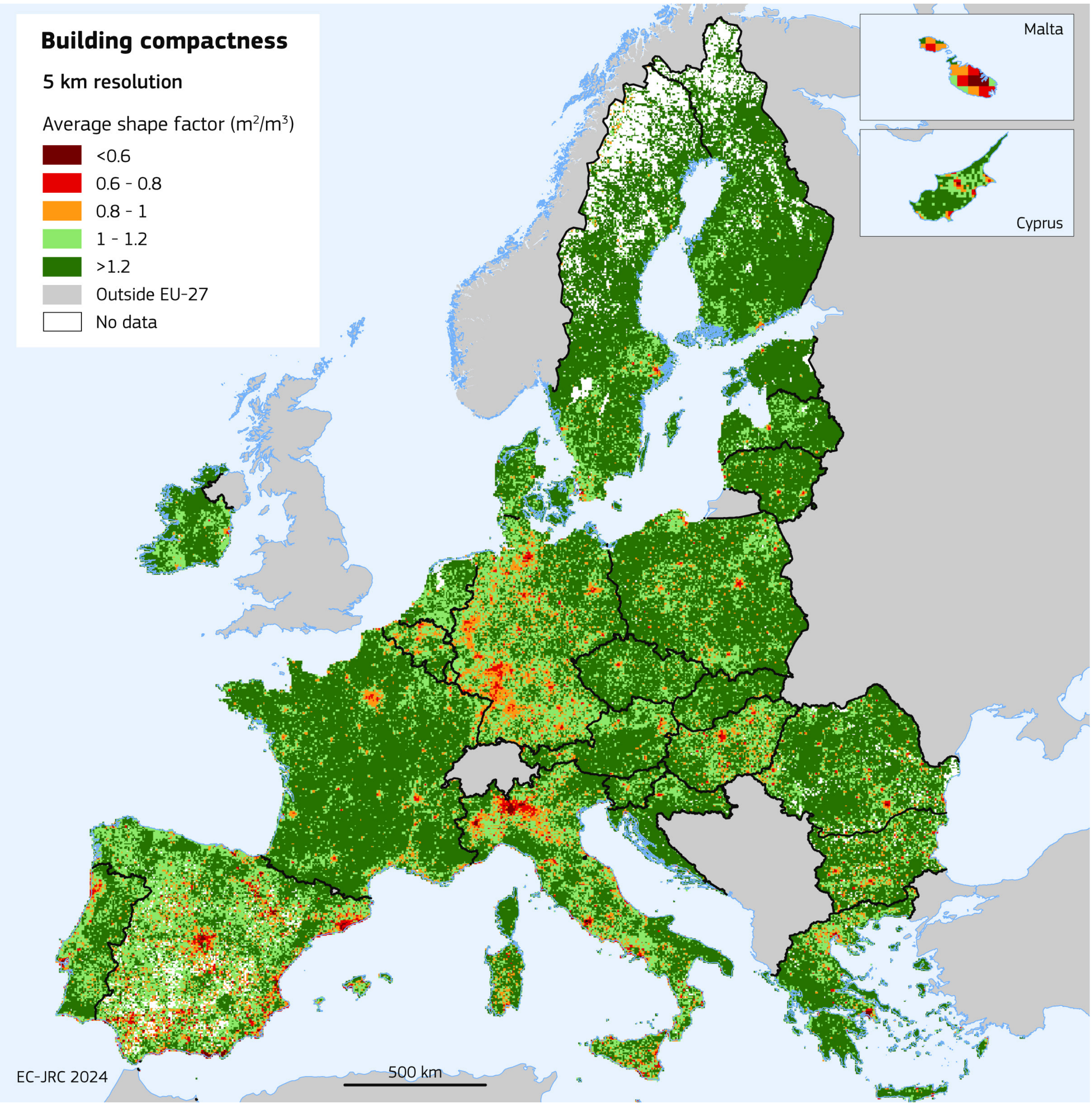
(19) In some cases, DBSM building footprints fall in areas where height values from the GHSL-ANBH dataset is zero. In these cases, the height from the 1 km GHSL-ANBH grid is used if nonzero, otherwise building height is set at 2.5 m, the minimum of the GHSL-ANBH grids.

GHSL-BUILT-V residential volumes (Pesaresi et al., 2023a) and the LUISA basemap (Pigaiani et al., 2021) can be used to distinguish between residential and non-residential DBSM footprints. A preliminary analysis using this methodology shows that shape factors of residential buildings could be larger, about 2% in cities and 1% in both towns and suburbs and rural areas, on average across MS. This indicates that residential buildings are, in general slightly less compact in all territorial typologies when compared to the full building stock. For these calculations, buildings with areas above 10 hectares were deemed non-residential and the EUBUCCO database was used to enrich residential footprints (Milojevic-Dupont et al., 2023). The classification of DBSM footprints with this methodology will be discussed in upcoming publications.

Figure 15. Average building shape factor in in the EU at 5 km resolution.

Note: Low shape factors indicate more compact buildings. 'No data' is used for unpopulated areas or areas without recorded building footprints. The Canary and Azores Islands and Madeira fall in the latter category.

Source: own elaboration from Digital Building Stock Model and GHSL height data.



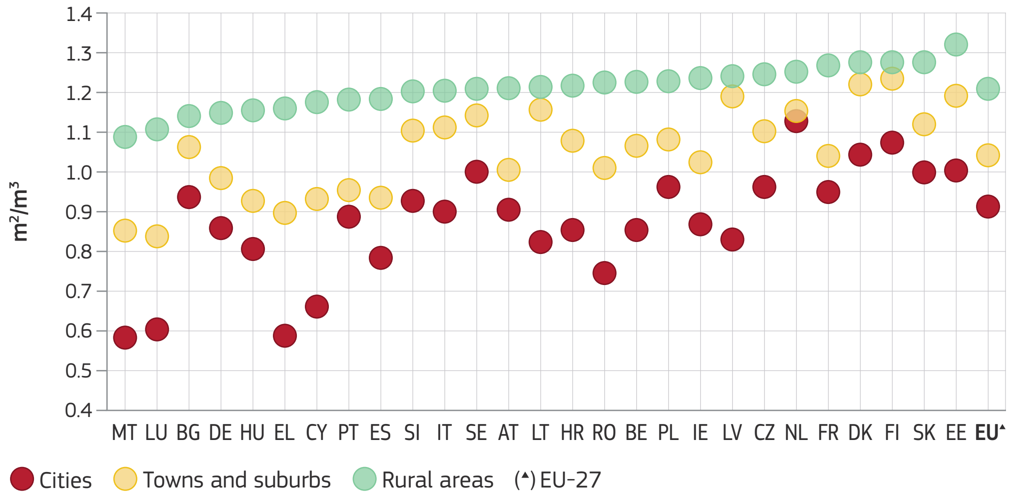


Figure 16. Average building shape factor by degree of urbanisation and Member State.

Source: own elaboration from Digital Building Stock Model and GHSL height data.

3.2. BUILDING CONSTRUCTION PERIOD

The energy efficiency of the building stock is directly influenced by the policies and regulations in place at the time of construction. The first EU policy efforts to promote energy savings began in the 1970s in response to the oil crisis, resulting in several Council recommendations with suggestions on how to increase the efficiency of heating systems, thermal insulation and electrical appliances (Economidou et. al., 2020). The SAVE Directive of 1993 represents the first comprehensive EU policy covering energy efficiency improvements for buildings, directly aiming at a reduction of CO_2 emissions in the building sector (CEC, 2023).

In 2002, the Energy Performance of Buildings Directive constituted a major step in EU energy efficiency policy. The directive set requirements for the calculation of the energy performance of buildings, for the energy performance of new buildings and large existing buildings undergoing major renovations, and for the inspection of boilers and heating/cooling systems (EP, 2002). With the subsequent recasting of the EPBD in 2010, 2018 and 2024, building energy efficiency policies were further developed.

Studies at the Member State level indeed show a strong dependence of energy performance on the construction epoch of buildings. The distribution of Energy Performance Certificate ratings in Denmark shows an increase of best-performing classes from the 1980s, with buildings built from 2007 onwards constituting more than 70% of buildings in classes A and B (Nykredit Group & MOE, 2023). In Italy, a higher building age has also been associated with lower energy performance and higher CO_2 emissions (Pagliaro et. al., 2021).

In this section, we present a complete dataset of dwelling construction epoch in the EU at the regional (NUTS 3) level, employing most recent available census data and the urban-rural typology classification based on the NUTS 2021 geometries(20). At the time of this report's elaboration, harmonised data from

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(20) See *https://observatory.rural-vision.europa.eu/what-is-rural* for a description of the urban-rural typology classification.

the 2021 census operation was available through the Census Hub (Eurostat, 2025) for 24 Member States (excluding Germany, Romania and Poland). For Germany, 2021 census data was retrieved from the National Statistical Office (Statistisches Bundesamt, 2024).(21) Lacking more recent information for Romania and Poland, data from the 2011 census was employed, available as well from the Census Hub.(22)

We find that, in the EU, approximately 60% of dwellings were constructed before 1980 (prior to the rollout of EU energy saving policies), 23% were built in the period 1980 – 2000, and 17% from 2001 on (mostly subject to the requirements of the first EPBD of 2002). These shares can vary substantially across regions and within the same territorial typology (**Figure 17**). For instance, the share of pre-1980 dwellings is above 85% in the regions of Charleroi (Belgium, predominantly urban region), Genova (Italy, predominantly urban), Teleorman and Caraş-Severin (Romania, predominantly rural)(23), while it is as low as 12% in Fuerteventura (Spain, intermediate), 21% in Guyane (France, intermediate) and 22% in Flevoland (Netherlands, predominantly urban).

At the EU level, predominantly rural regions show a modestly higher share of old dwellings (61% where built before 1980) compared to intermediate and predominantly urban regions (59% and 60%. respectively), as shown in **Figure 18.** Sweden and Denmark feature the oldest building stock, with a share of pre-1980 buildings of 70% or higher across territorial typologies. This share also reaches 70% in rural regions of Belgium, Bulgaria, and Latvia, as well as in predominantly urban regions of Belgium and Latvia and intermediate regions of Romania.

Newer dwellings (built after 2000) amount to 15% in predominantly rural regions, with slightly higher shares (17%) in intermediate and predominantly urban NUTS 3. The Member States with the newest building stock are Malta, Cyprus and Luxemburg (countries with only predominantly urban or intermediate regions), where more than 30% of dwellings were built after 2000. Predominantly urban regions of Ireland, Croatia and Finland, as well as intermediate regions of Spain and Portugal also feature high shares of new buildings (above 25%).

In order to estimate how the percentage of dwellings in each construction period could change when using the definition of rural areas (based on the degree of urbanisation, computed at municipality level) instead of the definition of predominantly rural regions (based on the urban-rural typology, computed for NUTS 3 regions), we employed data at both geographical levels for Germany, released by the Statistisches Bundesamt. We observed that construction period figures (percentage of dwellings built before 1980 and after 2000) differ by less than 2% when comparing values for rural areas and for predominantly rural regions in Germany (less than 4% across other territorial typologies). We note that, while Germany NUTS 3 regions are amongst the smallest in the EU, differences could be larger for other Member States.

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(21) For Germany, NUTS 3 codes were matched to region names in the Statistisches Bundesamt data.

(22) Data from the 2011 census was retrieved in NUTS 2010 version and mapped to NUTS 2021 geometries employing the NUTS converter tool with a regional area proxy (JRC, 2024).

(23) The share of buildings built before 1980 should be regarded as an upper bound for Romania, as results are based on the 2011 census.

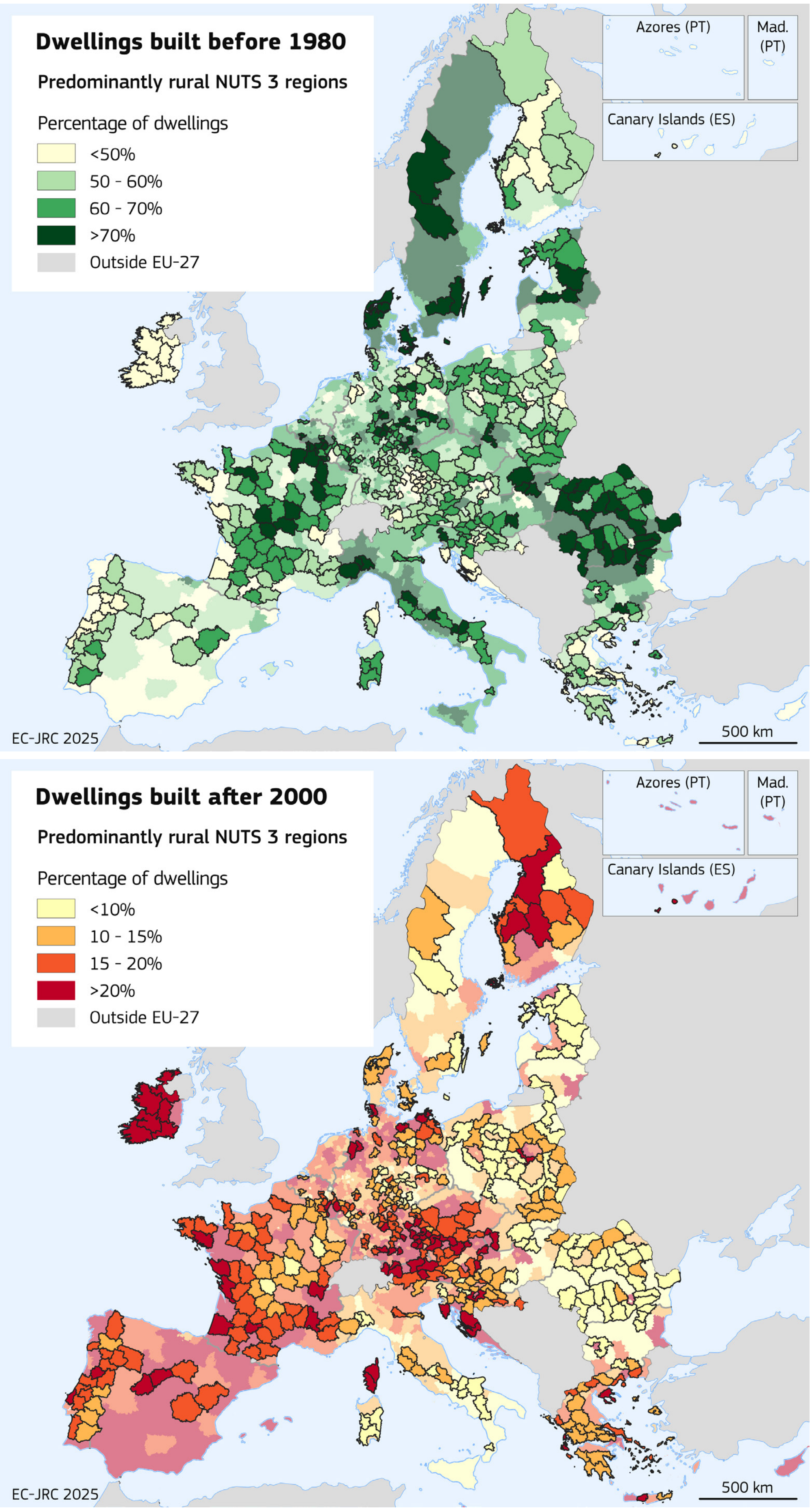


Figure 17. Percentage of dwellings built before 1980 (top) and after 2000 (bottom) in predominantly rural NUTS 3 regions.

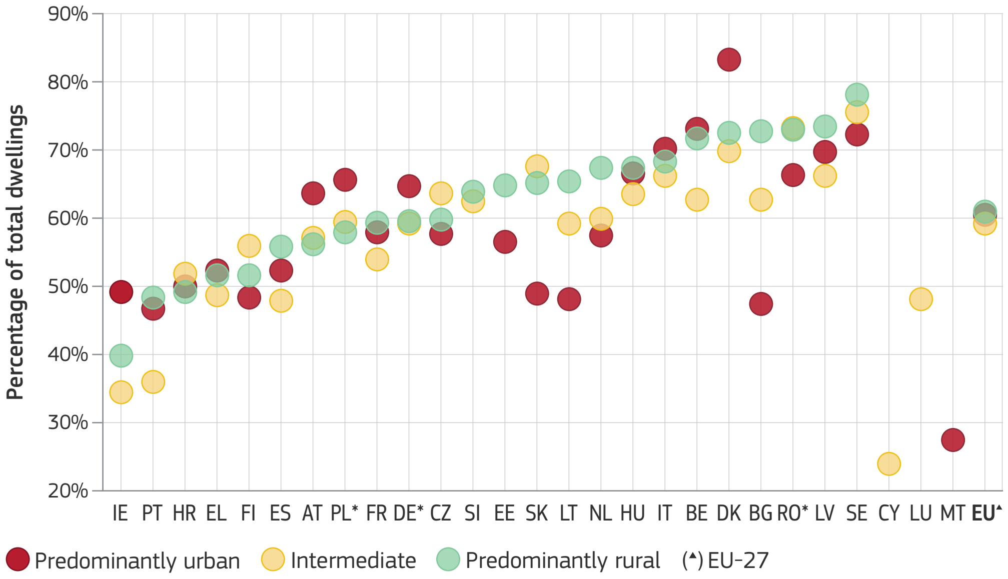
Note: Non-outlined regions correspond to intermediate and predominantly urban regions.

Source: own elaboration from Census Hub 2021 (24 MS), 2021 census data from National Statistical Offices (Germany), Census Hub 2011 (Poland and Romania).

Figure 18. Percentage of dwellings built before 1980 by urban-rural typology in the EU's Member States.

Note: (*) see **Figure 17** for country-specific data sources.

Source: own elaboration from census data.



3.3. HEATING AND COOLING DEGREE DAYS

In 2022, EU households spent 63.5% of their energy consumption in space heating and 14.9% in water heating, while only 0.6% of their energy consumption was dedicated to cooling (Eurostat, 2022d). These energy needs strongly depend on climatic conditions, which are best quantified in terms of heating degree days (HDD) and cooling degree days (CDD). These indices are designed to estimate the climate component of building energy requirements in terms of heating and cooling, respectively. In this section we assess HDD and CDD across the EU and its urban-rural continuum, calculating them in line with Eurostat methodology (Eurostat, 2024). Values correspond to the cumulative daily average deviation from a base temperature throughout the year (with base temperatures set at 18°C and 21°C for HDD and CDD, respectively). Deviations are only added if temperatures are below 15°C for HDD or above 24°C for CDD.

In **Figure 19** and **Figure 20** we show HDD and CDD values, respectively, across the EU and at high resolution (0.05 degrees or 5.4 km aprox.). Results stem from daily temperature data during the 2005 – 2023 period, and are based on ERA5 data processing with the Joint Research Centre's PVGIS tool (PVGIS, 2020; Gracia Amillo et al., 2021). The data shows that the EU's municipalities experience an average of 2 600 heating degree days, with highest values (more than 5 000 HDD) found in northern Finland and Sweden and high-altitude areas of the Alps, the Pyrenees and the Carpathian Mountains. HDD are also high in Estonia, Austria, Latvia and Lithuania, with municipality averages above 3 500. Lowest HDD values are found in Malta, Cyprus, Portugal, Greece and Spain (averages below 2 000 HDD). Alongside Italy and Croatia, these countries display the highest cooling degree day average (above 150 CDD in all these except for Portugal, where CDD are lower), while the average of the EU's municipalities stands at 88 CDD.

While HDD and CDD vary substantially between MS according to local climatic conditions, differences between territorial typologies are less prominent (**Figure 21**). On average in the EU, rural areas experience 2 600 HDD, a value which is lower by 4% (2 500 HDD) in towns and suburbs and by 14% (2 300 HDD) in cities. CDD, on the other hand, are on average lowest in rural areas (85), followed by cities (87) and towns and suburbs (102). Therefore, when compared to other territorial typologies the EU's rural areas experience higher climatic pressure on their energy needs for heating, while pressure on cooling needs is lower.

HDD and CDD values from this analysis indicate that building heating needs in the EU might be around 30 times higher than its cooling needs(24), and therefore pressure on energy consumption currently stems mainly from cold conditions.

However, the energy spent on space heating (63.5%) is 100 times higher than that used for cooling (0.6%). This may indicate that, while cooling needs exist, they are not being met with the current energy use in households, potentially signaling sub-comfort conditions in terms of cooling. Furthermore, climate change effects are expected to increase cooling needs for buildings, with assessments from Copernicus projecting a rise by approximately 18% in CDD in southern EU countries between 2024 and 2050 (C3S, 2025).(25) Assessing the risk of overheating inside dwellings, their adaptive capacity and sensitivity to health consequences from high temperatures is therefore becoming increasingly necessary to identify cooling vulnerabilities (Thomson et al., 2019; Torrego-Gómez et al., 2024).

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(24) Based on averages of the EU's municipalities.

(25) Spatially-averaged mean values for Spain, Portugal, Italy, Malta, Greece, Croatia and Cyprus in scenario SSP2-4.5 (intermediate reference scenario).

Figure 19. Heating degree days in the EU at high resolution.

Source: JRC-PVGIS.

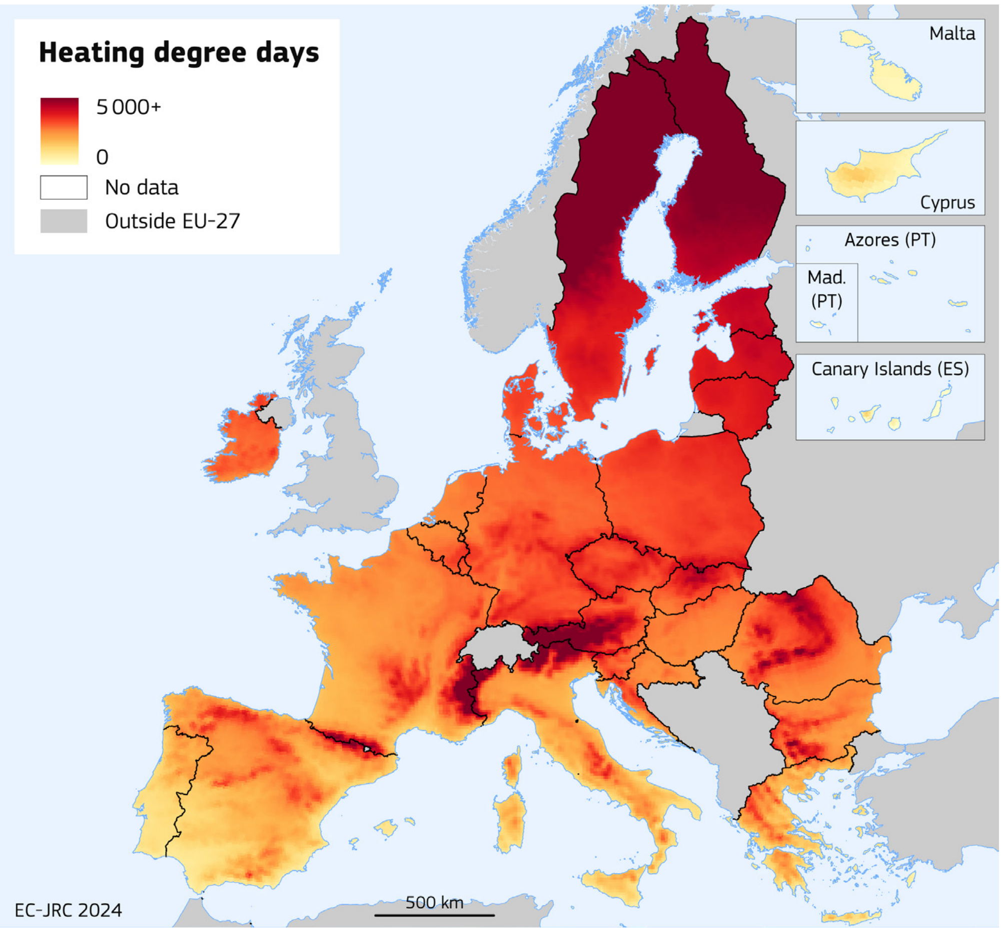
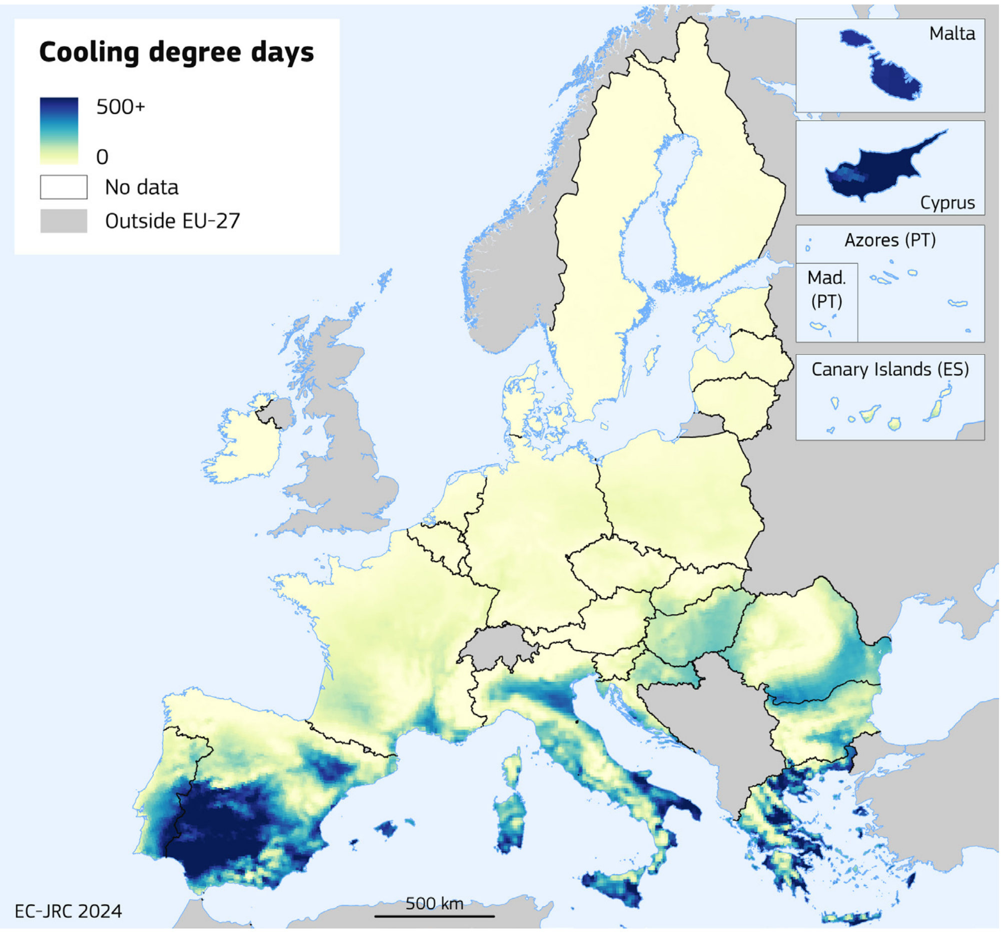


Figure 20. Cooling degree days in the EU at high resolution.

Source: JRC-PVGIS.



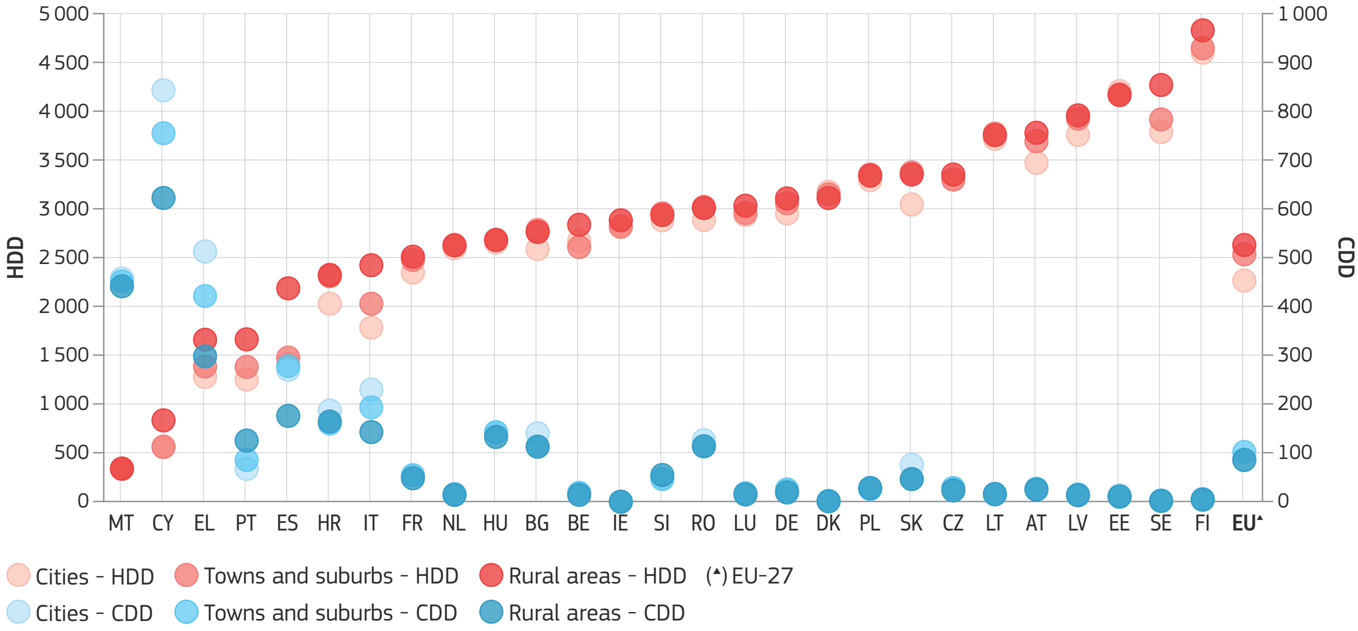


Figure 21. Heating Degree Days (HDD) and Cooling Degree Days (CDD) in the EU's Member States by degree of urbanisation.

Note: Values correspond to municipality averages. **Source:** own elaboration from JRC-PVGIS data.

3.4. A PERSPECTIVE IN VIEW OF CLIMATE CHANGE

Climate change will likely affect heating and cooling needs in Europe. By looking at the Universal Thermal Climate Index (UTCI), a measure of the human physiological response to meteorological conditions, trends of overheating are already observable: compared to 1950, today there are at least 3 additional days per year of strong physiological heat stress on average in the EU, with huge disparities among Member States (more than 20 additional days in Malta, Italy, Spain and Cyprus, vs less than one additional day in Finland, Denmark and Sweden), see **Figure 22** (right).

INDICATOR	CRITERION
Number of hot days (above 30 °C of maximum temperature)	> 30 days per year
Number of tropical nights (above 20 °C of minimum temperature)	> 30 nights per year
Number of heatwave days (exceeding the 99th percentile of the daily maximum temperatures of the May to September season in a reference period)	> 7 days per year
Number of high UTCI days (causing strong physiological heat stress)	> 28 days per year
Additional high UTCI days between 1950s and 2020s	> 20 days per year

Table 2. Indicators from the Copernicus Climate Data Store (C3S, 2025) delineating high heat trend areas.

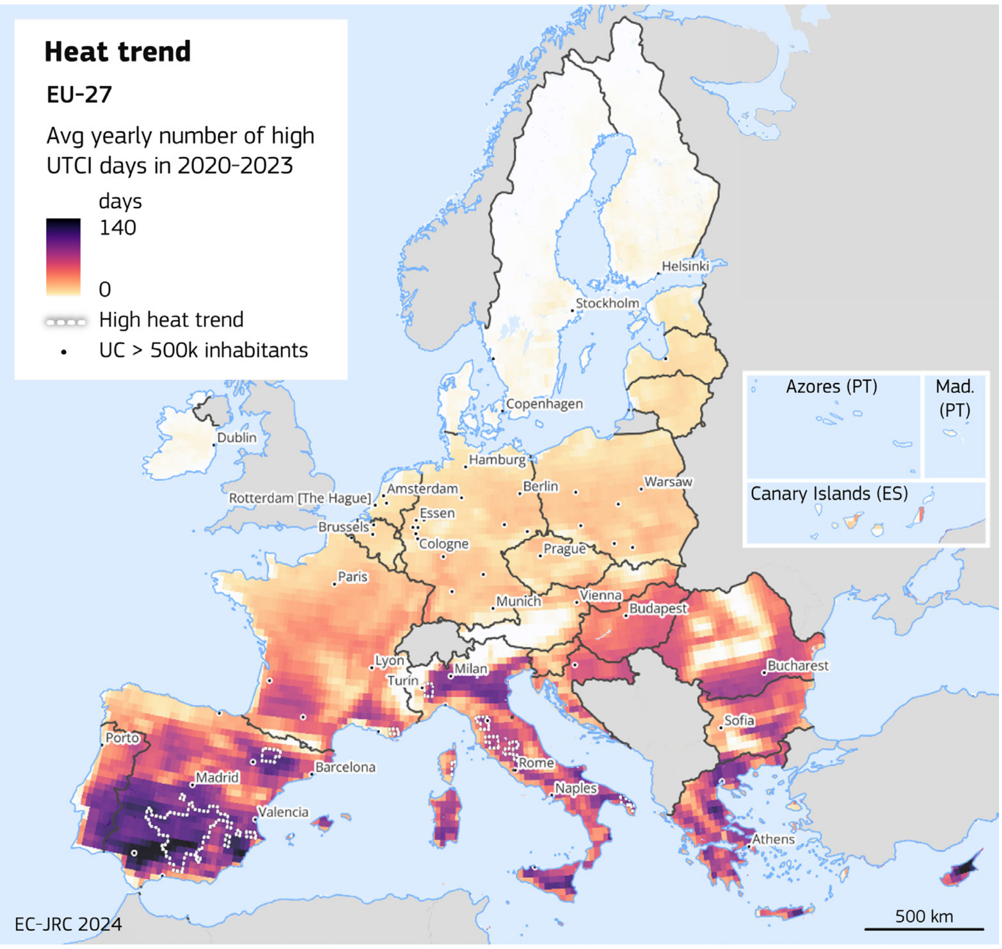
In some locations, denoted as high heat trend areas, heat strikes with particular intensity, giving rise to an elevated occurrence of hot days, tropical nights, heatwave days and UTCI days (C3S, 2025), see **Table 2**[26]. On a yearly average in the 2020-2023 period, high heat trend areas experienced many hot days (more than 30 days above 30 °C of maximum temperature), which were not compensated by fresh nights that allow buildings to cool off (experiencing instead more than 30 nights above 20 °C of minimum temperature, denoted as tropical nights). Many heatwave days (more than 7 days of maximum temperatures exceeding 99% highest typical summer temperatures) occur in high heat trend areas during unbearable summers with more than 4 weeks of strong physiological heat stress days, which grew by more than 20 days since the 1950s. High heat trend areas are located mainly in Spain and Italy, with small areas in France and Cyprus (see **Figure 22,** left), and host a population of 5.3 million people in 2025, of which one third (33%) live in rural areas, 46% in towns and suburban areas and 21% in urban areas of cities. In coming years, projected temperature rise over the continent may make this population increase.

With the current ageing trends in Europe, this situation risks affecting health and wellbeing of many vulnerable households, without leaving trace in the energy demand patterns, as many households are not equipped with air conditioners. This phenomenon is known as summer energy poverty (Cornelis, 2025).

Figure 22. Heat trends in the EU-27.

Note: The color ramp indicates the average number of days for which the Universal Thermal Climate Index (UTCI) remains above 32 °C, indicating physiologically strong heat stress, for the period 2020-2023. High heat trend areas are highlighted, and Urban Centres hosting more than 500 thousand inhabitants are shown. The table shows the average number of additional high UTCI days per country, between 1950s and 2020s.

Source: JRC analysis from Copernicus Climate Change Service datasets.



Member state	Average additional yearly number of high UTCI days, 2020s vs 1950s
MT	30
IT	24
ES	23
CY	22
PT	18
HR	18
FR	17
EL	15
HU	14
SI	13
SK	12
RO	10
BG	10
PL	9
DE	9
CZ	9
BE	8
LT	7
LU	7
LV	7
NL	6
AT	5
EE	5
IE	1
FI	1
DK	1
SE	1

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[26] Climate indicators for Europe from 1940 to 2100 derived from reanalysis and climate projections.

3.5. ROOFTOP PHOTOVOLTAICS

The presence of renewable energy installations in buildings can alleviate energy expenditure of households by providing energy for self-consumption. Furthermore, it reduces the carbon footprint of the associated building's energy use and increases resilience in view of supply shortages. In terms of technologies, rooftop photovoltaics (PV) are a growing renewable solution for buildings which is becoming increasingly accessible: the cost of crystalline solar PV modules in Europe reportedly declined by 91% between 2009 and 2022 (IRENA, 2023).

The development of rooftop PV is supported by the EU Solar Rooftops Initiative as part of the EU Solar Strategy, put forward by the EC in 2022 (EC, 2022b). The initiative highlights the ability of solar installations to be rapidly rolled out and to grant citizens the autonomy to produce their own energy, and introduces the obligation to install rooftop solar energy in all new residential buildings by 2029. The 2024 recast EPBD implements solar-ready requirements as well, for both new and existing buildings, with the purpose to facilitate the cost-effective installation of solar technologies.

In this section, we evaluate the implementation of rooftop PV as well as the untapped potential for this technology across the EU's municipalities and by degree of urbanisation. Results are based on annual electricity generation figures (in GWh) from Perpiñá Castillo et al. (2024), where rooftop PV production was assessed at the municipality level using the location and panel area of small PV installations (with a capacity under 20 kW), built-up distribution and local solar irradiation conditions (**Figure 23**). Rooftop PV potential figures are based on (Bódis et al., 2019; Perpiñá Castillo et al., 2024). Open-source statistical and satellite data were combined to estimate building rooftop areas, and the PVGIS tool was then employed to calculate PV energy yields. Per each municipality, 26% of rooftop areas was assumed as available for PV installations, while the rest was estimated to be unsuitable due to poor orientation and/or inclination, air-conditioning units and chimneys, shading from other constructions, or walkways for maintenance.

At the Member State level, Austria, Belgium and Malta lead in rooftop PV electricity generation, producing more than 380 kWh per inhabitant annually with this technology, while Latvia, Finland, Cyprus, Lithuania and Poland produce least (below 3 kWh/inhabitant per year). By degree of urbanisation, the highest annual production is found in towns and suburbs of the EU (180 kWh/inhabitant), followed by rural areas (70 kWh/inhabitant) and cities (60 kWh/inhabitant), as shown in **Figure 24.** Towns and suburbs of Austria, Belgium and Malta show the highest production per inhabitant (above 600 kWh annually). Rural areas and cities of Austria and towns and suburbs of Italy, the Netherlands and Hungary also generate high amounts of electricity with rooftop PV (more than 200 kWh per inhabitant annually).

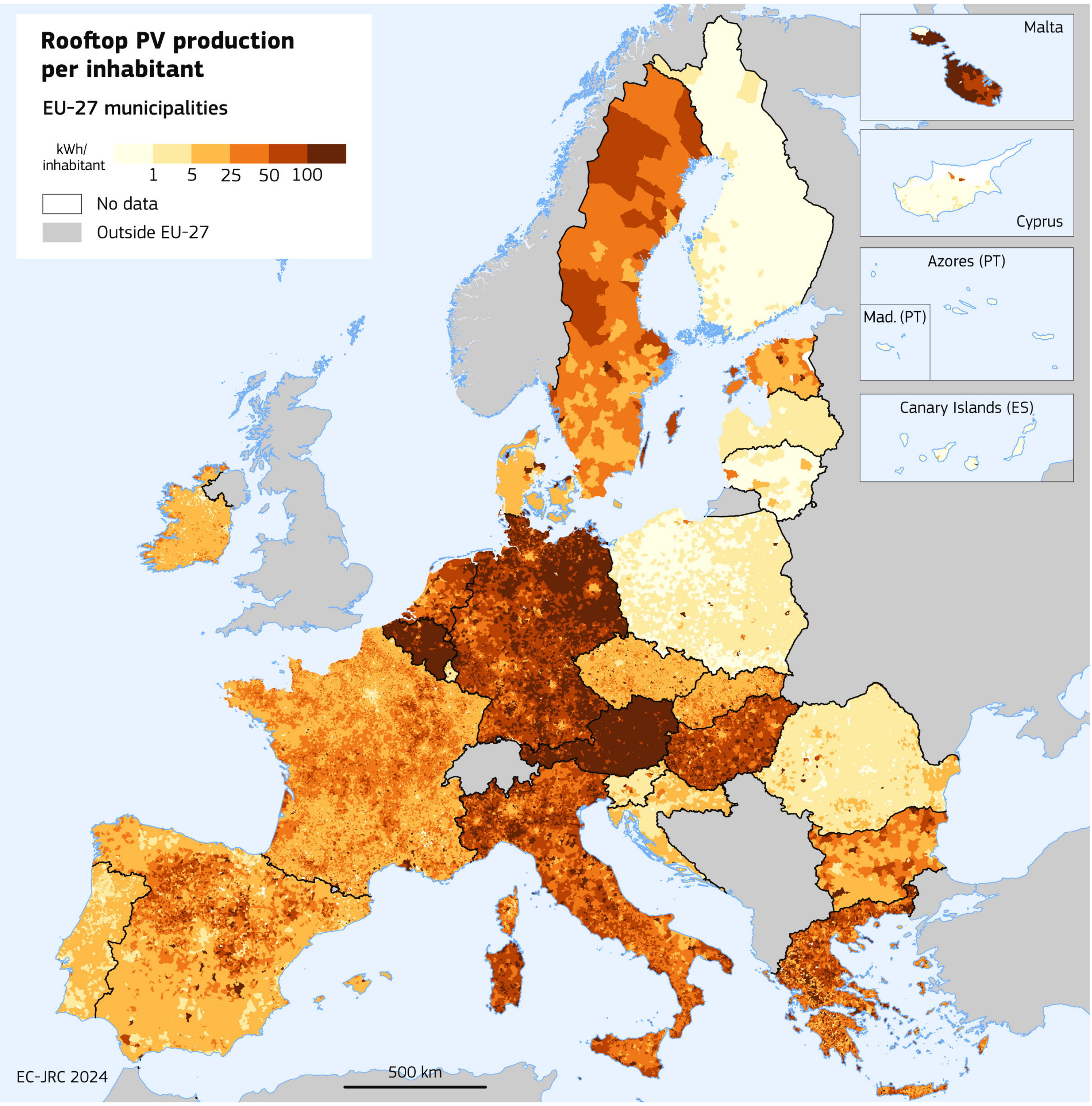

Figure 23. Annual electricity production with rooftop photovoltaics per inhabitant in EU-27 municipalities.

Source: own elaboration from JRC assessment of renewable energy production (2023) and Eurostat 2021 population grid.

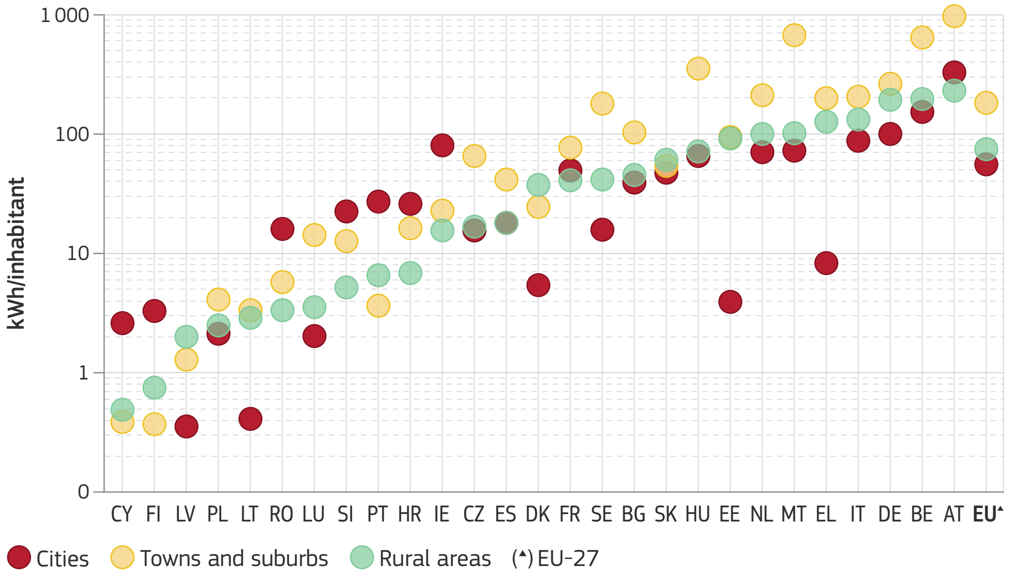

Figure 24. Annual electricity production with rooftop photovoltaics per inhabitant in EU Member States by degree of urbanisation.

Source: own elaboration from JRC assessment of renewable energy production (2023) and Eurostat 2021 population grid.

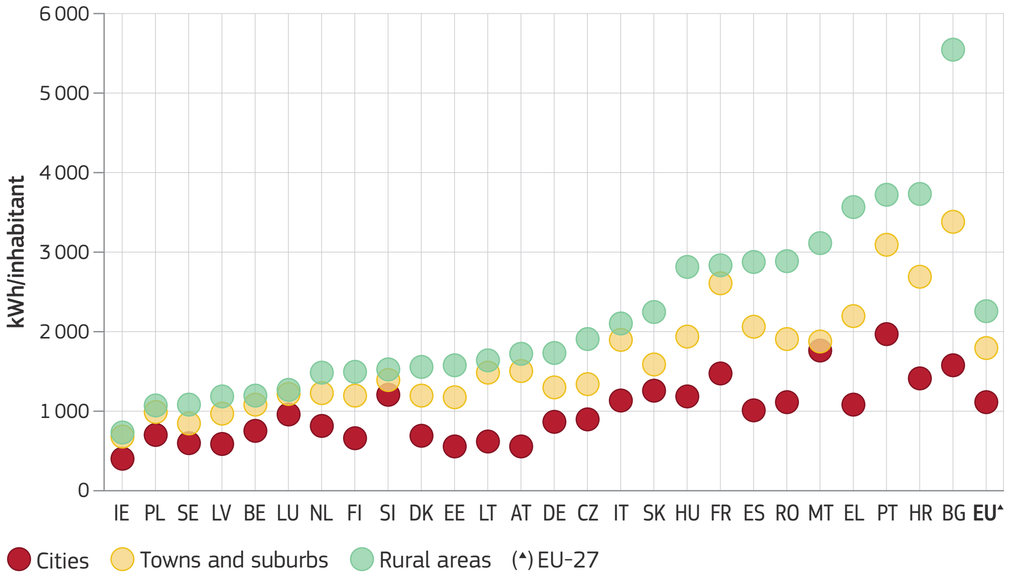

Figure 25. Technical potential for annual electricity production with rooftop photovoltaics per inhabitant in EU Member States by degree of urbanisation.

Source: own elaboration from JRC assessment of renewable energy production (2023) and Eurostat 2021 population grid.

When looking at technical potential, electricity production per inhabitant with rooftop PV could reach 2 200 kWh/year in the EU's rural areas, 25% more than in towns and suburbs (1 800 kWh/year per inhabitant) and double than in cities (1 100 kWh/year) (**Figure 25**).(27) Both in rural areas and towns and suburbs, this potential production would exceed current electricity consumption from the household sector, which stood at 1 600 kWh/inhabitant annually in the EU in 2022 (Eurostat, 2022e). Across Member States, rooftop potential per capita is highest in rural areas of Bulgaria, Croatia, Portugal and Greece, as well as in Cyprus(28) (above 3 500 kWh/year per inhabitant).

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(27) Source variability and storage capacity needs should be further assessed to fully exploit generation of electricity from rooftop PV systems, see for instance Gomez-Exposito et. al., 2020 for an evaluation of these factors in the case of Spain.

(28) Cyprus: low reliability by territorial typology. Estimate country value of 5 800 kWh/inhabitant per year.

The high potential of rooftop PV production per inhabitant in rural areas is due to the characteristics of the residential building stock: as seen in **Section 2.5,** 79% of rural dwellings are detached or semi-detached houses, which are less compact and contain more volume per inhabitant. Although these characteristics pose challenges in terms of thermal isolation and space heating, they provide better opportunities for electricity production with rooftop installations. Furthermore, homes in rural areas are mostly owned (78%, see **Section 2.5**) which facilitates the rollout of new PV installations by residents for their own consumption. Therefore, rural areas are well poised to cover a substantial part of their housing energy needs through rooftop PV.

3.6. CHALLENGES IN ENERGY EFFICIENCY AND NEEDS ACROSS THE EU'S TERRITORIES

Throughout this chapter we have analysed different factors that impact energy efficiency and needs across the EU's buildings, covering the characteristics of the building stock, climate conditions and the implementation of renewable solutions. In order to provide an overview of the strength of challenges faced at the local level and in rural areas, in this section we develop a composite indicator based on available data. By merging all information into a single indicator, the combined effect and spatial confluence of factors impacting energy efficiency and needs can be better understood. In building this indicator, we consider the following variables:

- Residential built-up volume per inhabitant (*vol*)
- Average building shape factor (*sf*)
- Building construction period: percentage of dwellings built before 1980 (age_{1980}) and after 2000 (age_{2000})
- Rooftop photovoltaic electricity production per inhabitant (*PV*)
- Average heating and cooling degree days (*HDD* and *CDD*)

All variables are computed at the municipality level[29] and standardised (values are rescaled so that each variable follows a distribution centered at zero and with standard deviation equal to one). In order to avoid excessive influence from large values and outliers, points falling above or below two standard deviations are assigned values of ±2.

A composite indicator is then designed to signal more challenges in energy efficiency and needs with larger positive values. The residential volume per inhabitant and average shape factor of each municipality are included with a positive sign, as increased values are associated with lower energy efficiency. Building construction epoch is included as the difference between the percentage of dwellings built before 1980 (typically less efficient to heat) and those built after 2000 (subject to recent regulations and likely to display high energy efficiency).

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[29] In the case of building construction period, data at NUTS 3 level (see **Section 3.2**) is used to assign values for each municipality.

Heating and cooling degree days are given a combined weight equal to the other indicators, with individual weights (ω_H and ω_D) determined for each municipality according to a share-based approach.(30) The implementation of rooftop photovoltaics is included with a negative sign, as it provides a positive effect on energy efficiency. The composite indicator (ci) is then computed as follows:

$$ci = (vol + sf + (age_{1980} - age_{2000})/2 + \omega_H HDD + \omega_C HDD - PV)/5$$

At the EU level, we find that combined challenges are higher in rural areas (ci = +0.05) than in towns and suburbs (-0.07) and cities (-0.21). This stems manly from larger residential building volumes per inhabitant, less compact buildings and more heating degree days in rural areas compared to other territorial typologies. In 24 EU countries (excluding Denmark, Cyprus and Belgium), rural areas face more challenges than cities or towns and suburbs (see **Figure 26** and **Figure 27** for indicator values at the national and municipal level, respectively).

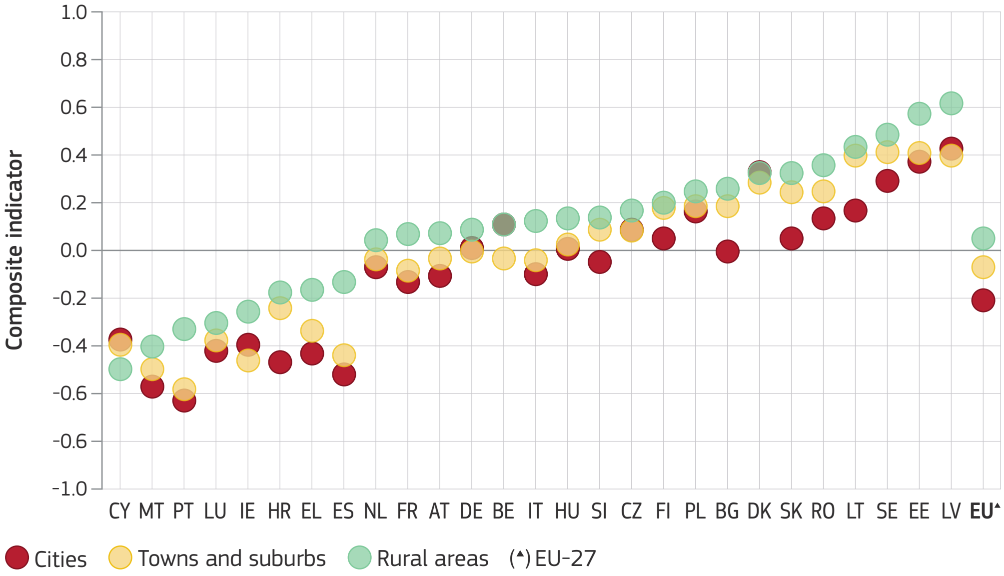

Figure 26. Composite indicator quantifying challenges in energy efficiency and needs in EU Member States by degree of urbanisation.

Source: own elaboration.

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(30) The weights ω_H and ω_D are computed as the rate of heating or cooling degree days, respectively, with respect to the sum of heating and cooling degree days in each municipality. At the EU level, heating accounts for 99% of the energy consumption for space temperature regulation. This share is above 97% in all MS except for Malta (58%), Cyprus (78%) and Greece (94%) (Eurostat, 2022d).

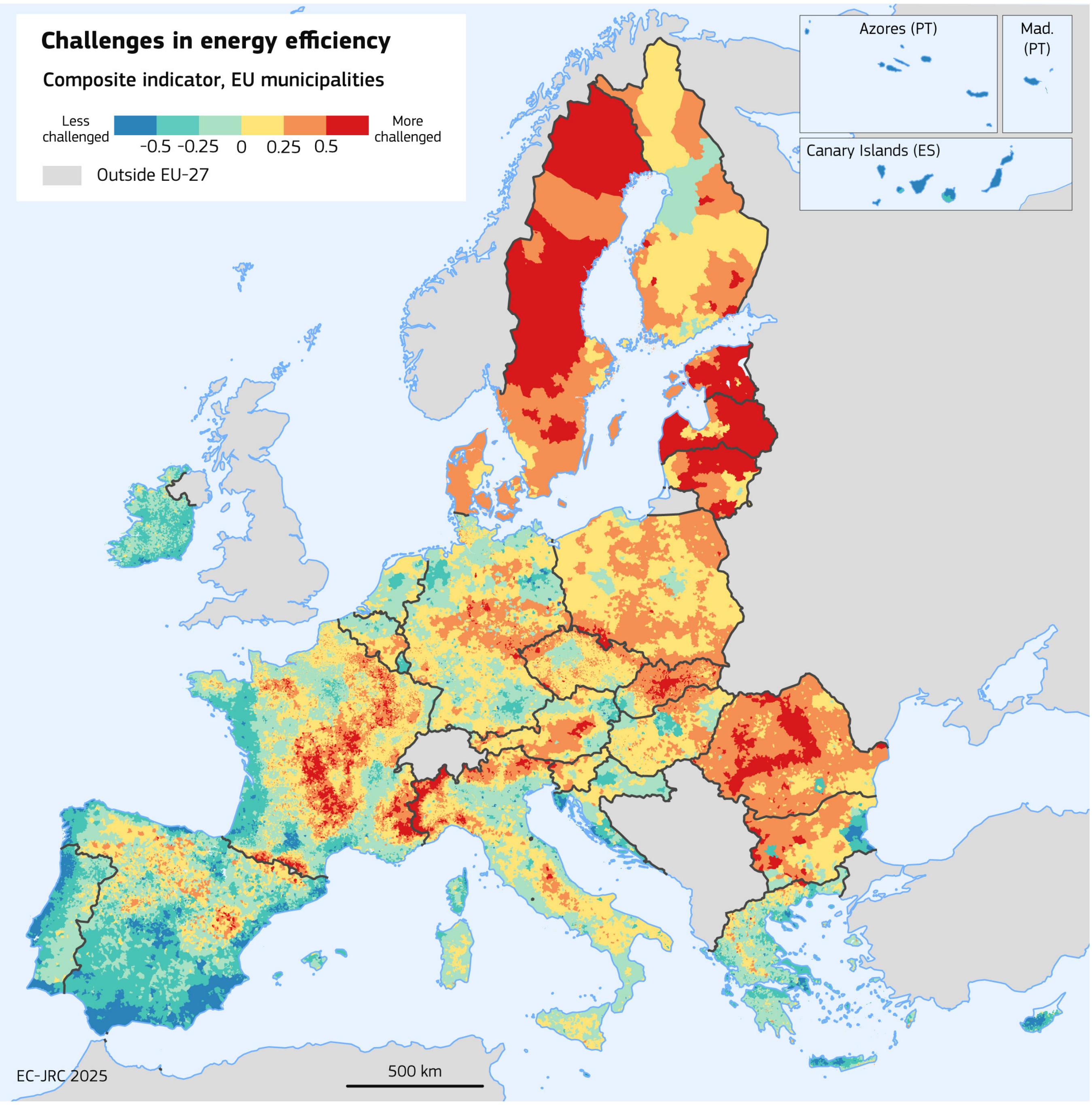

Figure 27. Composite indicator quantifying challenges in energy efficiency and needs in EU-27 municipalities.

Source: own elaboration.

Across Member States, Latvia, Estonia, Sweden and Lithuania display the highest values of the composite indicator, mainly due to the combination of extremely cold temperatures and an old building stock (see **Figure 28** for the most relevant challenge for each municipality). In Latvia and Lithuania, this situation is aggravated by high energy poverty markers, especially the at-risk-of-poverty rate, which is above 20% in their rural areas and towns and suburbs (see **Figure 7**).

By contrast, other MS with a high number of Heating Degree Days such as Finland and Austria face less challenges, thanks to a newer building stock in both countries and a highly developed rooftop photovoltaic infrastructure in the case of Austria. With warm temperatures and the newest dwelling stock in the EU, Cyprus and Malta display the least combined challenges, aided as well by a substantial rollout of rooftop PV in the case of Malta.

In large areas of Spain, France and Ireland, less compact buildings with high residential volumes per inhabitant pose the main challenge for energy efficiency and needs, while Bulgaria, Romania, Denmark and Sweden are especially affected by an old building stock (**Figure 28**). In many municipalities of Spain and Greece high numbers of Cooling Degree Days represent the most prominent challenge.

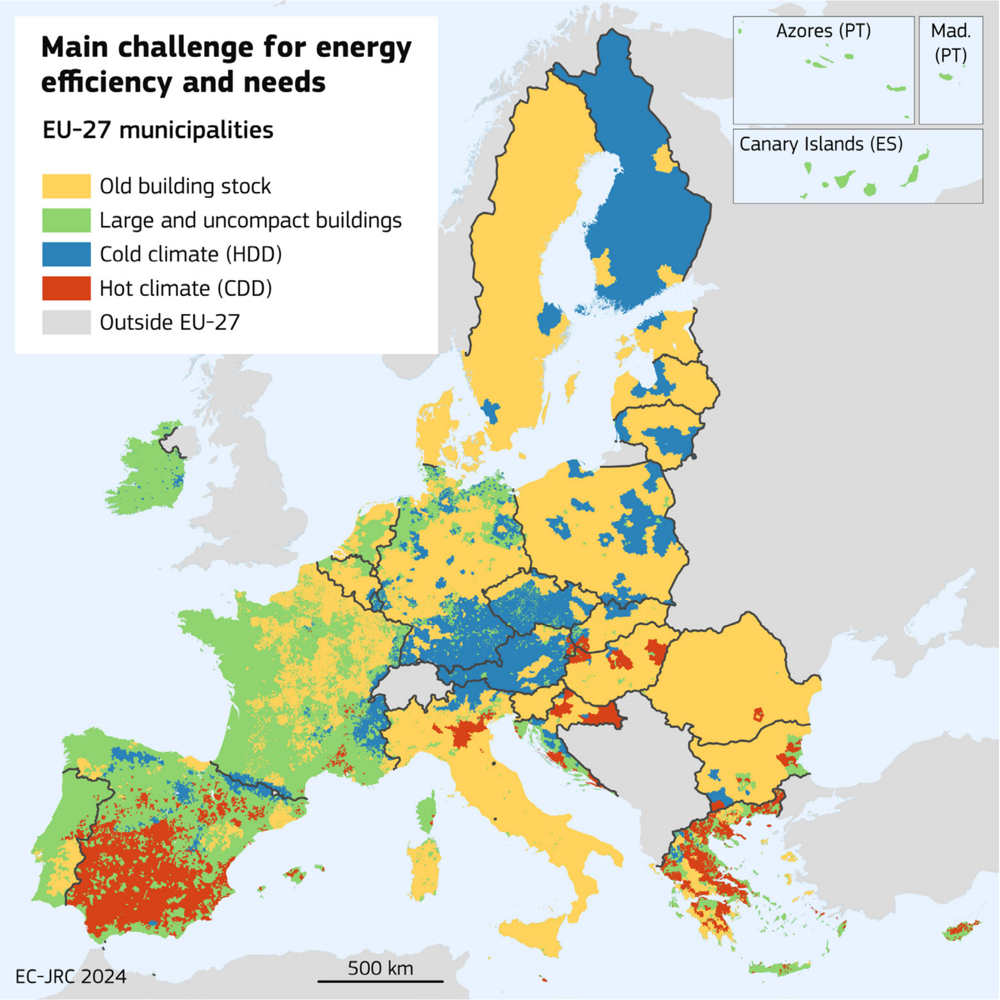

Figure 28. Main challenge in energy efficiency and needs in EU-27 municipalities.

Note: The main challenge is identified as the maximum between the following standardised indicators: residential volume per inhabitant, building shape factor (*Large and uncompact buildings*), average of heating and cooling degree days (*Cold climate* for areas with more HDD, *Warm climate* for areas with more CDD), half of difference between share of buildings built before 1980 and buildings built after 2000 (*Old building stock*).

Source: own elaboration.

3.7. SUMMARY

In this section, indicators with an impact on energy efficiency and operational energy needs in buildings were evaluated for the EU's municipalities and by degree of urbanisation (by urban-rural typology in case of building construction period). Results are based on high spatial resolution data on building footprints and volumes, population, climate and electricity production with rooftop photovoltaics, and regional data on building construction period.

BUILDING CHARACTERISTICS

The **EU's rural areas feature the highest residential building volumes per inhabitant** (565 m³/inhabitant) and the least compact buildings (shape factor of 1.2), which negatively impacts their energy efficiency. Compared to rural areas, building volumes per inhabitant are 8% lower in towns and suburbs and 30% lower in cities, while building shape factors are also lower in these territorial typologies (by 24% and 14% cities and towns and suburbs, respectively), indicating more compact buildings.

Buildings in rural areas show similar levels of compactness across Member States, which suggests **that rural buildings have similar typologies across the EU.** This is in line with the results shown in **Section 2.5,** where 79% of dwellings in rural areas were found to be detached or semi-detached houses, which typically have a similar structure. Residential volume per inhabitant, on the other hand, shows more variation between rural areas of Member States. It is highest in rural areas of Lithuania, France and Spain (above 650 m³/inhabitant), while Finland and Sweden show the lowest values of the indicator (below 320 m³/inhabitant in all territorial typologies).

In terms of construction period, newer dwellings in the EU are typically more energy efficient, especially those subject to the progressive regulations of the Energy Performance in Buildings Directive, developed during the 2000s and 2010s. We find that **the share of newer dwellings** (built after 2000) **is moderately lower in predominantly rural regions** (15% of dwellings), with higher shares (17%) in intermediate and predominantly urban NUTS 3. The Member States with the newest building stock are Malta, Cyprus and Luxemburg (countries with only predominantly urban or intermediate regions), where more than 30% of dwellings were built after 2000. **Predominantly rural regions show a modestly higher share of old dwellings** (61% where built before 1980) compared to intermediate and predominantly urban regions (59% and 60%, respectively). Sweden and Denmark feature the oldest building stock, with a share of pre-1980 buildings of 70% or higher across territorial typologies.

CLIMATE CONDITIONS

The climate component of building energy requirements in terms of heating and cooling was assessed through the Heating and Cooling Degree Days indicators, computed at high spatial resolution. These vary according to local climate conditions and show large variations across MS, while differences between territorial typologies are less prominent (see **Figure 21**). On average in the EU, rural areas experience 2 600 HDD, a value which is lower by 4% (2 500 HDD) in towns and suburbs and by 14% (2 300 HDD) cities, while CDD are slightly lower in rural areas (85 CDD) than in other territorial typologies (102 and 87 CDD in towns and suburbs and cities, respectively). Therefore, when compared to other territorial typologies **the EU's rural areas experience higher climatic pressure on their energy consumption for heating,** while pressure on cooling needs is lower. Effects of climate change are already observable in the EU, with **around 1.7 million people living in rural areas with high heat trends,** where the wellbeing of households not equipped with cooling mechanisms is challenged.

ROOFTOP PHOTOVOLTAICS

Implementing renewable energy solutions such as rooftop photovoltaics can reduce household expenditure on energy through self-consumption. This analysis showed that **rural areas are best poised to cover a substantial part of their electricity needs with rooftop photovoltaics:** they could potentially produce 2 200 kWh/year, 25 % more than towns and suburbs (1 800 kWh/year per inhabitant) and double than cities (1 100 kWh/year), and exceeding current household electricity consumption (at 1 600 kWh/inhabitant annually in the EU in 2022). This is due to low population densities and larger, less compact buildings, which provide rural municipalities with sizable roof areas per inhabitant to install photovoltaic panels. Furthermore, a larger share of rural ownership in (78% of owned dwellings) reduces practical obstacles in implementing self-consumption systems.

COMBINED CHALLENGES

In order to assess the combined spatial patterns of the different factors impacting energy efficiency and needs analysed in this chapter, a composite indicator was built to quantify the strength of challenges faced at the local level. The indicator summarises data on building stock characteristics, climate and production of electricity with rooftop PV. We find that, at the EU level, **combined challenges in energy efficiency and needs are higher in rural areas** (ci = +0.05) than in towns and suburbs (-0.07) and cities (-0.21) (**Figure 26**). These differences across territorial typologies stem mainly from larger residential building volumes per inhabitant, less compact buildings and more heating degree days in rural areas compared to towns and suburbs and cities. On the other hand, variability between Member States stems mostly from the age of the building stock, the implementation of rooftop PV systems and climate conditions.

4

Conclusions

This report investigated **challenges and opportunities for the EU's rural areas to tackle their energy needs, in the context of building decarbonisation and energy resilience EU goals.** Energy poverty indicators in rural households were assessed based on the Household Budget Survey and the EU Statistics on Income and Living conditions framework (**Chapter 2**). High spatial resolution data sources were also leveraged to characterise the EU's building stock and its possible challenges in energy efficiency and needs, with datasets including local data on building shapes and volumes, population, climatic conditions and implementation of renewable solutions for self-consumption, as well as regional data on the construction period of buildings (**Chapter 3**).

To assess energy poverty levels in rural areas, a multi-indicator index taking into account non-affordability of energy services, insufficient household disposable income, high energy expenditure and poor energy efficiency of homes was constructed (**Figure 8**). Results show that **rural areas could face higher levels of energy poverty,** especially in Bulgaria, Romania and Greece. In Member States where the energy poverty index is above the EU average, rural areas are generally the most affected territorial typology, while cities are always least affected.

Rural households spend more on electricity, gas and other fuels (7.1% of total household expenditure on average across MS) than towns and suburbs (6.2%) or cities (5%). Countries where the share of expenditure in electricity, gas and other fuels is highest show the largest urban-rural disparities, suggesting that **high shares of expenditure on energy are associated with a deeper urban-rural divide,** with rural areas being most affected. Rural households rely on diverse energy sources for heating, including gas, coal or oil, wood, electricity and renewables.

A combined analysis of the spatial patterns of building stock characteristics, climate conditions and implementation of rooftop photovoltaics (composite indicator) at the local level shows that **challenges in energy efficiency and needs are higher in rural areas** than in towns and suburbs and cities (**Figure 26**). Differences across territorial typologies stem mainly from higher residential building volumes per inhabitant, less compact buildings and more heating degree days in rural areas, while variability between Member States is due to the age of the building stock, the implementation of rooftop PV systems and climate conditions.

Rural areas are especially well suited to benefit from rooftop photovoltaics, thanks to large roof areas per inhabitant and a high share of rural ownership (78%), which can facilitate the implementation of self-consumption systems. Potential production with this technology could reach 2 200 kWh per inhabitant annually, more than current household electricity consumption. **Rural areas are already seeing a higher implementation of energy-efficiency improvements,**

with 29% of households having undergone such renovations in the five years prior to 2023. This share is lower in town and suburbs (25%) and cities (23%).

Limitations of this analysis include the lack of information on Energy Performance Certificate ratings and renovation rates, currently not available at the territorial level as harmonised datasets. Furthermore, our analysis of the EU building stock focused on challenges and opportunities during the operational phase of buildings. Further analyses covering the whole-life-cycle of buildings will become increasingly important as their energy efficiency increases.

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List of abbreviations

ANBH	Average Net Building Height
CDD	Cooling Degree Days
DBSM	Digital Building Stock Model
EC	European Commission
EED	Energy Efficiency Directive
EPAH	Energy Poverty Advisory Hub
EPBD	Energy Performance in Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
GHG	Greenhouse gas
GHSL	Global Human Settlement Layer
HDD	Cooling Degree Days
HBS	Household Budget Survey
kWh	Kilowatt hour
LOD	Level of Detail
MS	Member State
PPS	Purchasing Power Standard
PV	Photovoltaics
EU-SILC	EU Statistics on Income and Living Conditions
UTCI	Universal Thermal Climate Index

List of figures

List of tables

1

Annex 1. **EU-SILC microdata:** methodology and statistical analysis

In **Table A1.1**, the Member State availability of data by degree of urbanisation for energy poverty indicators analysed in **Section 2.2** is shown. Indicator values were computed using cross-sectional household weights (DB090). Data at the person level (e.g. sex and age) corresponds to the survey respondent, and disposable income quintiles have also been computed using household weights.

Table A1.1. Availability of data by degree of urbanisation for energy poverty indicators.

Note: (1) Limited number of records (20-49) in some categories. (r) Insufficient/no data for rural areas. (t) Insufficient/no data for towns and suburbs. (c) Insufficient/no data for cities.

Member State	**Inability to keep home adequately warm** (EU-SILC 2022, microdata)	**Arrears on utility bills** (EU-SILC 2022, microdata)	**Dwellings with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor** (EU-SILC 2020, microdata)	**At-risk-of-poverty rate** (EU-SILC 2023)	**Consumption expenditure on electricity, gas and other fuels** (HBS 2020)
AT	x (1)	x (1)	x	x	x
BE	x	x (1)	x	x	x
BG	x	x	x	x	x
CY	x	x	x	x	x
CZ	x	x (1)	x	x	x
DE	x (t)	x (t)		x	x
DK	x	x (1)	x	x	x
EE	x (t)	x (t)	x (t)	x	x
EL	x	x	x	x	x
ES	x	x	x	x	x
FI	x (1)	x	x	x	x
FR	x	x	x	x	x
HR	x	x	x	x	x
HU	x	x	x	x	x
IE	x (1)	x (1)	x	x	x
IT	x	x	x	x	x
LT	x	x (1)	x	x	x
LU	x (c,1)	x (c,1)	x	x	x
LV	x (t)	x (t)	x (t)	x	x
MT	x (r)	x (r)	x (r,1)	x	x
NL				x	x
PL	x	x	x	x	x
PT	x	x	x	x	
RO	x	x	x	x	
SI				x	x
SE	x	x	x	x	
SK	x	x	x (1)	x	x

A statistical analysis on the strength of the relationship between the EU-SILC variables was performed in order to identify patterns in household characteristics and their connection to energy poverty indicators. The effect size was computed through Cohen's ω statistic, calculated as

$$\omega_{ij} = \sqrt{\frac{X_{ij}^2}{N}}$$

where *N* is the sample size and x^2 is Pearson's Chi-squared. Values above 0.1, 0.3 and 0.5 are considered to indicate low, medium and high strength of a relationship between variables *i* and *j*, respectively. The results for EU-SILC variables are shown in **Figure A1.1** for 2022 cross-sectional data, and in **Figure A1.2** for 2023 data. Respondent age has been divided into the following groups: under 30, 30 - under 40, 40 – under 50, 50 – under 60, 60 – under 70, 70 and over. Education attainment level is assessed in terms of ISCED levels (1 – 8).

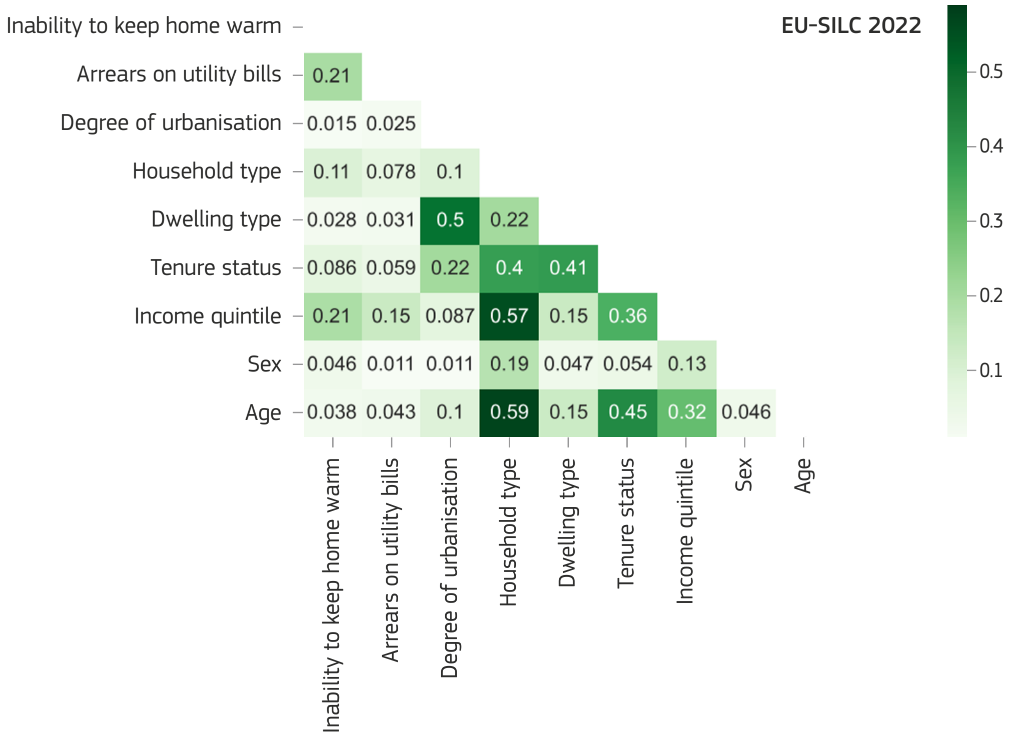
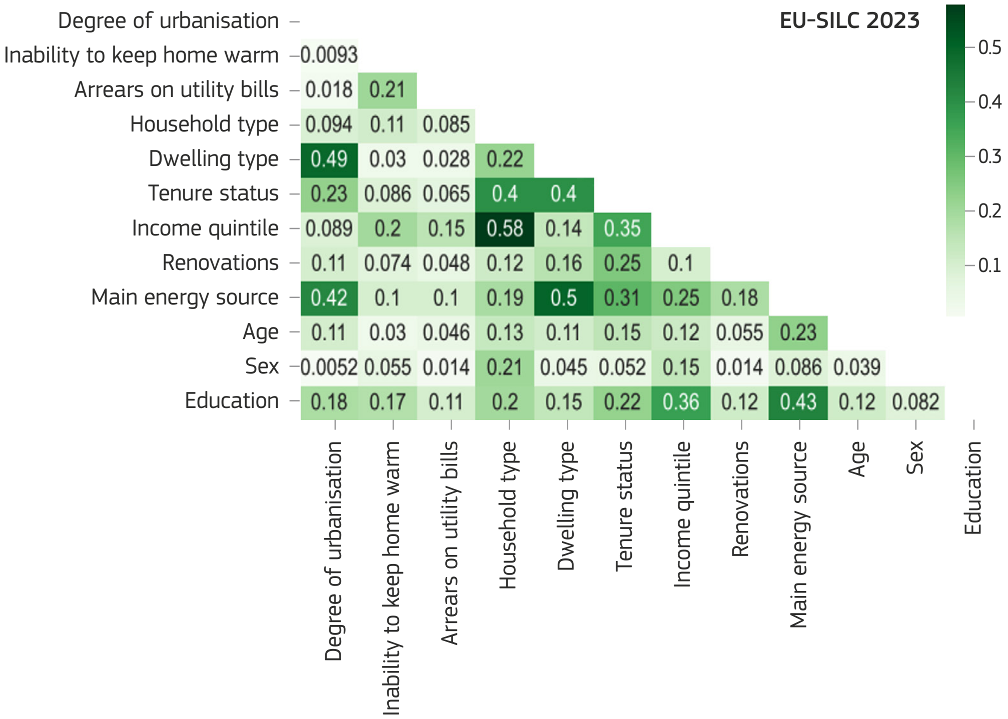


Figure A1.1. Effect size between EU-SILC variables, measured through Cohen's ω.

Note: Values above 0.1, 0.3 and 0.5 are considered to indicate a low, medium and high strength of the relationship between two variables, respectively.

Source: EU-SILC 2022 cross-sectional data.



	Degree of urbanisation	Inability to keep home warm	Arrears on utility bills	Household type	Dwelling type	Tenure status	Income quintile	Renovations	Main energy source	Age	Sex	Education
Degree of urbanisation												
Inability to keep home warm	0.0093											
Arrears on utility bills	0.018	0.21										
Household type	0.094	0.11	0.085									
Dwelling type	0.49	0.03	0.028	0.22								
Tenure status	0.23	0.086	0.065	0.4	0.4							
Income quintile	0.089	0.2	0.15	0.58	0.14	0.35						
Renovations	0.11	0.074	0.048	0.12	0.16	0.25	0.1					
Main energy source	0.42	0.1	0.1	0.19	0.5	0.31	0.25	0.18				
Age	0.11	0.03	0.046	0.13	0.11	0.15	0.12	0.055	0.23			
Sex	0.0052	0.055	0.014	0.21	0.045	0.052	0.15	0.014	0.086	0.039		
Education	0.18	0.17	0.11	0.2	0.15	0.22	0.36	0.12	0.43	0.12	0.082	

Figure A1.2. Effect size between EU-SILC variables, measured through Cohen's ω.

Note: comments in **Figure A1.1** apply.

Source: EU-SILC 2023 cross-sectional data.

In **Figure A1.3** we provide additional information on the characteristics of households which report inability to keep their home warm and/or arrears in utility bills. A breakdown is shown by degree of urbanisation, type of dwelling, income quintile and type of household. We observe that 47% of the households with signs of energy poverty are located in cities, followed by towns and suburbs (28%) and rural areas (25%), a distribution which does not differ substantially when compared to the household location of the full survey sample (differences under 10%). Significant differences are observed regarding disposable income: 62% of households unable to keep their home warm and/or in arrears on utility bills are in the two lowest income quintiles, while only 19%, 13% and 6% of the households of the households with sings of energy poverty are in the third, second and first income quintiles, respectively.

Households unable to keep their home warm and/or in arrears on utility bills

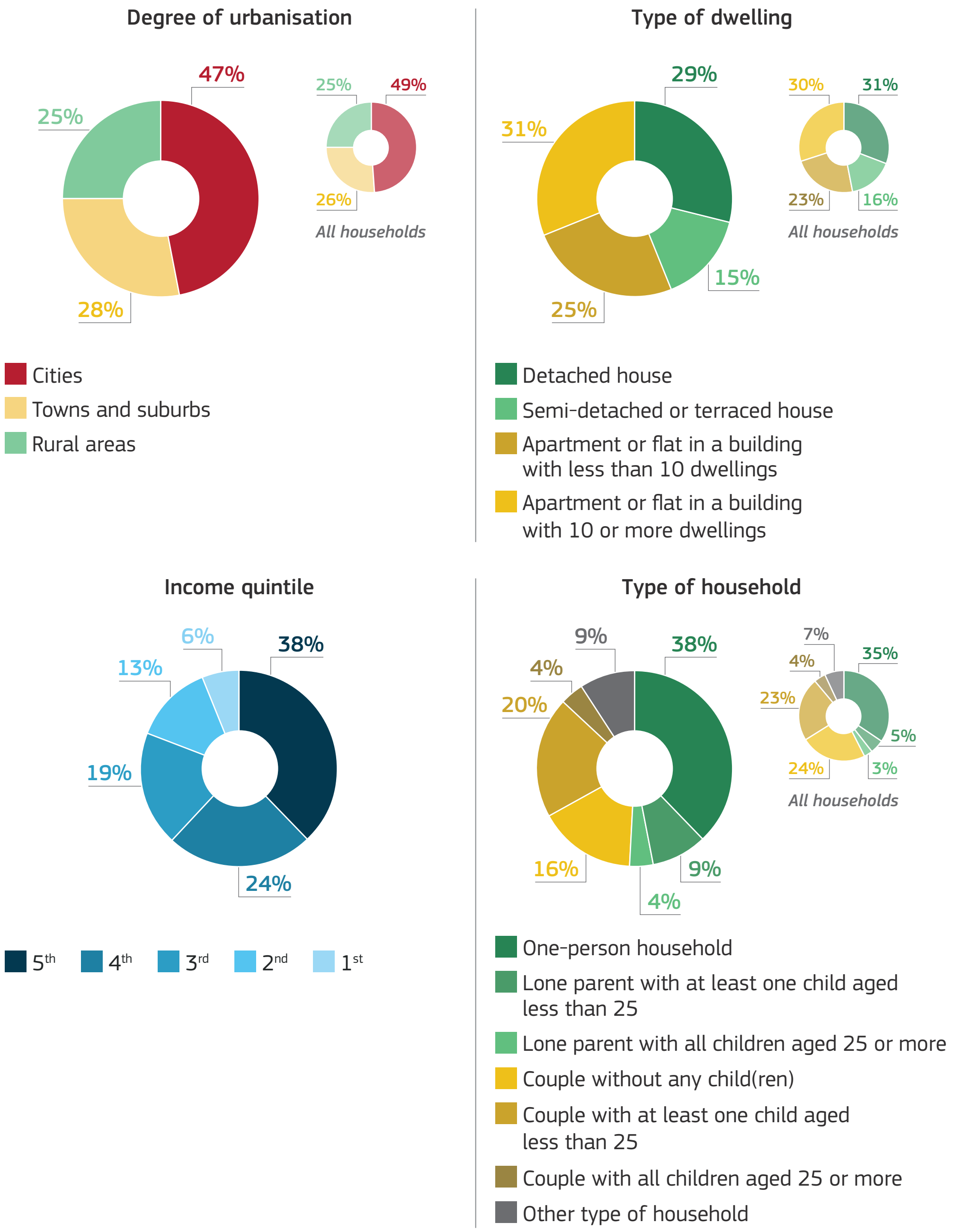


Figure A1.3. Characteristics of households unable to keep their home warm and/or in arrears in utility bills.

Note: The profiles of all households in the survey sample are also shown for comparison.

Source: Source: EU-SILC 2022, cross-sectional scientific files.

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