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Veni, vidi, vixi: Heterogeneities in residential floor space and energy consumption across households in Italy

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ABSTRACT

Floor space is an important housing indicator closely linked to both service levels and energy consumption. Floor space levels have been commonly related to income, yet heterogeneities across housing and household groups, including gender and age, are mostly overlooked. An improved understanding of how floor space relates to household and housing characteristics and energy consumption is needed to better support policies related to energy poverty, sufficiency, and access to decent living standards.

We use national household microdata and statistical analysis to investigate the distribution and heterogeneities of residential floor space and energy consumption across the population of Italy, a relevant case study due to ageing, ownership patterns, and regional and other disparities. Although per capita floor space is positively associated with expenditure levels, our empirical findings indicate that household composition and size are even stronger predictors. Per capita floor space is three times larger for singles compared to couples with two children or more, and even higher for elderly singles. Households living below two per capita floor space thresholds (15 m^2/cap and 30 m^2/cap) exhibit distinct characteristics, with significant overlaps with difficult economic conditions for the lower threshold. Per capita natural gas energy consumption exhibits similar heterogeneities across household types, sizes, and expediture deciles, while energy consumption intensity per unit of floor space decreases with increasing floor space. This study highlights the importance of considering household heterogeneity in floor space and energy consumption analyses to improve the understanding and modelling of living conditions and to inform sufficiency policies.

1. Introduction

The buildings sector is facing increasing pressure to reduce its direct and indirect energy consumption and related greenhouse gas (GHG) emissions to contribute to climate targets [1]. Despite gradual progress in energy efficiency improvements over the last decades, total energy consumption in buildings has not declined due to growing building stocks and increasing service demand [2]. Floor space is an important indicator of building stock size and service levels in buildings [3,4]. Floor space is tightly linked to total energy consumption of buildings, as energy requirements generally increase with the size of heated or cooled space [5–7]. At the same time, sufficient floor space is an important constituent of Decent Living Standards (DLS), which represent a set of minimum material requirements necessary to support human wellbeing [8].

The importance of avoiding overcrowding in homes is broadly recognized as an element of DLS for shelter, together with building durability and home comfort, helping to reduce physical and mental health risks and improve access to wellbeing. Rao and Min [8] use recommended minimum living space standards from Taiwan and Korea, alongside middle-class home sizes in India and China, as guidelines to propose 30 m^2 per home plus a minimum of 10 m^2 per member of the household. Several follow-up global studies have adopted this same definition [9,10], while others have used direct scaling rates per capita without accounting for current household size distributions, often opting for 15 m^2/cap [11–13] to represent the minimum floor space considered necessary for human wellbeing.

While one side of the spectrum focuses on minimum floor space to support human activities, low occupancy rates and excess floor space are becoming causes for concern in several world regions, indicating

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overconsumption of energy and resources [14]. In the European Union (EU), 34% of the population lives in underoccupied homes, offering an untapped potential for optimizing the use and reuse of existing buildings [15]. Yet, most of the existing building policies narrowly focus on carbon and energy intensity reductions, while overlooking inequalities and housing shortage [15].

Sufficiency is a selection of strategies that aim to reduce energy and material demands through shifts in consumption behaviour and lifestyles, such as absolute service reduction, modal shifts, longevity, and sharing to address both overconsumption and deprivation [16–23]. Sufficiency has been increasingly designated as a key pillar of mitigation strategies, together with efficiency and consistency, and plays a key role in achieving low demand-based carbon neutrality and energy security across Europe [24,25]. An emission reduction potential of 19% for the Europe and Eurasia region has been estimated for sufficiency strategies in buildings [1]. Per capita floor space reduction is at the core of sufficiency for the residential sector, as reuse or more intensive use of vacant or underoccupied buildings can improve the efficiency of existing resources while reducing the need for new construction [26,27]. Detailed analysis of the potential for emission reduction through sufficiency, however, has been limited by the lack of detailed data on floor space [28]. An improved understanding of floor space heterogeneities across housing and household types is critical to further assess sufficiency strategies while ensuring basic service levels [4]. Conversely, an accurate representation of current floor space deprivation is crucial to avoid wrongly ascribing mitigation potential to households that already live in smaller living spaces.

A large body of empirical research has investigated buildings' energy consumption and its determinants related to building characteristics and socio-demographic, using microdata and field survey [5,29–31]. Conditional demand analysis (CDA) is commonly used to decompose aggregate household energy consumption into end-use–specific demands, conditional on appliance ownership, dwelling characteristics, and household attributes [32–35]. In contrast, the literature on empirical floor space analysis and mapping with socio-demographic characteristics in residential buildings is surprisingly sparse. In national and global studies, per capita floor space is usually differentiated by region, location (urban and rural), and housing type [36–38]. Floor space has been commonly related to income levels, expenditure levels, or gross domestic product (GDP) [39,40]. More detailed analysis of the distribution of residential floor space across building types and income levels was only found at the urban and city level [41,42]. Thus, there is a critical research gap and limited understanding of how floor space varies across socio-demographic and household characteristics, particularly household composition and size, and how these patterns relate to energy consumption at the national level. This study addresses this gap by investigating heterogeneities in floor space across a broad set of housing and household characteristics. It aims to improve understanding of how service levels relate to energy consumption and support policies that can simultaneously promote minimum service provision and reduce excessive floor space toward climate and sustainable development goals.

To this end, we provide a novel empirical analysis of residential floor space across building and household characteristics and its relationship with energy consumption at the national level in Italy. We carry out an exploratory analysis based on detailed household microdata, and run regression analyses to quantify the relationship between floor space and a set of explanatory variables, including socio-demographics (household composition, expenditure levels, tenure, and age and sex of household members) and housing characteristics (housing type and period of construction). We analyse inequalities in the distribution of floor space and the characteristics of households below different thresholds of per capita floor space. Finally, we examine natural gas energy consumption using a CDA model and compare it with floor space to identify joint patterns across household groups. We focus on the national residential stock of Italy, providing an interesting case study due to significant heterogeneities in both housing and household characteristics, as well as a relative high share of the elderly population, specific ownership patterns, and regional and other disparities. Detailed microdata for Italy are available from the Italian National Institute of Statistics (ISTAT) [43], providing a comprehensive dataset for our analysis. We further discuss the application of a similar methodology to other countries with a minimum dataset. This study could help target policies on the provision of basic living standards and the reduction of overconsumption. The analysis and data provided by this study can support improved modelling of policy scenarios focused on floor space and energy consumption reductions, targeting specific household and housing types, beyond the current practice of applying uniform interventions across the entire stock.

2. Methods

2.1. Survey microdata

We use the microdata for public use of the Household Budget Survey run by ISTAT [43] for the year 2019, chosen to avoid the more recent COVID years. The yearly sample is of 28,000 households, representative of the Italian population. Table 1 reports the variables used in the analysis, covering geographical context, socio-demographics, housing, and energy consumption. Housing size is reported as useful floor space per dwelling unit (m^2). In this paper, we only consider floor space for primary homes while secondary homes are not included. We calculate per capita floor space by dividing housing floor space by household size. We identify ten relevant household types by combining information on household size, household reference person, including age and gender, and relationship to the reference person of other household members (see next section for more details on household grouping). In the absence of income data, households are ranked by equivalized per capita consumption expenditure and grouped into deciles, following common practice in welfare and inequality analysis [44,45]. Consumption expenditure is widely used as a welfare measure in household surveys when income data are not available, forming the basis for distributional results across household groups [46]. While expenditure has been indicated as a more appropriate measure of the standard of living and material wellbeing than income [47–49], using expenditure deciles can result in lower inequality estimates compared with income deciles [46,50]. We calculate equivalised expenditure deciles by dividing the total household expenditures by the weighted number of members and ranking the results. The weights correspond to 1 for the reference person, 0.5 for other adult members, and 0.3 for minors [43,51]. Other household-related variables include tenure and household size. A more detailed accounting of income and wealth conditions will be part of future work.

Housing variables include housing type and period of construction. We estimate natural gas energy consumption (hereafter "gas consumption") from household survey expenditures, using information from the Italian national energy authority (ARERA) on price structures, including fixed and variable components and regionally differentiated costs and taxes [52] (see Supplementary Information, section 3.1). Results are expressed per unit of floor space (kWh/m^2/yr) and per capita (kWh/cap/yr). We select natural gas as the most common energy carrier for space heating, domestic hot water, and cooking in Italy and used data from households with natural gas connection. We include the five NUTS1 regions in the floor space analysis to account for regional differences and the twenty NUTS2 regions in the gas consumption analysis to better reflect different climate and contextual conditions.

2.2. Household grouping

We group households based on household type and expenditure deciles. To enhance comparability and policy relevance, we adopt predefined household types rather than empirical groupings, aligned with Eurostat standards [53]. We identify relevant household types in

Table 1
Overview of the variables selected for the analysis.

Dimension	Variable	Type	Units and values	Notes
Floor space	Floor space	Original	m^2/dwelling	Primary residence only. Assumed as floor space per household.
	Floor space per capita	Derived	m^2/cap	Derived based on total floor space per dwelling and household size
Socio-demographics	Household type	Derived	Single, single female with children, couple without children, couple with one child, couple with two children, couple with three or more children, elderly single, elderly couple, elderly other, other	Based on household size and combination of age of the household head, sex of the household head, and relationship with the household head of the household members
	Household size	Original	1,2,3,4,5,6 or more	
	Tenure	Original	Owning, Renting, Other (including usufruct)	
	Total expenses	Original	EUR/household/yr	
	Deciles	Derived	1 to 10	Derived based on equivalized yearly expenditures
Housing	Housing type	Derived	Single Family House (SFH), Multi-Family House (MFH), Apartment block (ABL)	Aggregated to three categories based on original data
	Period of construction	Original	<1900; 1900–49; 1950–59; 1960–69; 1970–79; 1980–89; 1990–99; 2000–09; >2009	
Context	Region	Original	NUTS1 (5 regions): Northwest, Northeast, Center, South, and Insular Italy.	
Energy consumption	Natural gas expenditure	Original	EUR/household/yr	
	Natural gas energy consumption	Derived	kWh/household/yr	Derived based on total natural gas expenditure per household and gas price and tariffs.
	Natural gas energy consumption per capita	Derived	kWh/cap/yr	Derived based on total natural gas consumption and household size.
	Natural gas energy consumption per unit of floor space	Derived	kWh/m^2/yr	Derived based on total natural gas consumption per household and floor space.

subsequent steps (see Supplementary Information, section 1, for detailed analysis and intermediate results). First, we adopt existing household types as reported in the European household composition statistics [53], including single adults, single adults with children, and family with children by number of children. We consider dependent children aged 0–17 years. We expand the set of household types by introducing an age-based distinction between elderly and non-elderly households, defined based on the household reference person in the survey. This distinction reflects the significant share of elderly households in Italy and their distinct housing characteristics, such as larger-than-needed dwelling size [54,55]. We add further differentiation by gender for singles with and without children, as female face different conditions and are often more affected by housing challenges, such as energy poverty [56]. Second, we examine differences in per capita floor space across these pre-defined household groups using weighted analysis of variance (ANOVA) [57] and assess statistical significance of group differences using design-corrected F-tests. Following the overall ANOVA, we conduct post-hoc pairwise comparisons of group means using estimated marginal means with Tukey-adjusted p-values [58]. Third, we refine and confirm the household grouping based on the results of the ANOVA and pairwise comparisons, sample size, and characteristics of specific household types. As part of this step, we merge the *single male with children* household type with the *others* group, due to a small share of total households (0.7%). Similarly, we merge *single male* and *single female* households into the *single* group (both for non-elderly and elderly) due to statistically insignificant per capita floor space differences. Fourth, we perform a second round of ANOVA and pairwise comparison on the final household grouping as a validation and robustness check. Fifth, we conduct Oaxaca–Blinder decompositions [59] to further characterize the differences in per capita floor space across household types and complement this with exploratory clustering analysis using latent class analysis (LCA) [60,61] to check the robustness of the set of identified household types.

Fig. 1 shows the distribution of the selected household types by expenditure decile and total households. While the different household types are present in all deciles, some differences in their relative share can be noted. In particular, the share of single-person households and couple without children increases in higher deciles, while single female with children, family with two, three or more children, and other households are more represented in lower deciles.

2.3. *Microdata exploration*

We process the survey microdata using the software R [62] and relevant packages for statistical analysis. For data exploration, we systematically examine patterns and potential relationships in the dataset using data visualization. First, we map households and housing characteristics by exploring the relationship between household types and expenditure deciles with housing type, tenure, and period of construction. Then, we analyse the distribution of per capita floor space across potential explanatory variables, including housing type, tenure, region, period of construction, household type, household size, and expenditure deciles. For gas consumption, we explore distributions both in per capita terms, to enable comparison with the corresponding per capita floor space analysis, and per unit of floor space, to better understand energy consumption intensities related to housing conditions and operation.

2.4. *Regression analysis*

Linear regression models are widely used to investigate the relationship between housing characteristics and residential energy consumption. We develop five regression models to estimate residential per capita floor space (*Floor*) using different sets of explanatory variables. The explanatory variables include per capita expenditures (*Expenditures*), household type, household size, housing type, period of construction tenure, region (NUTS1 level), and household type. We

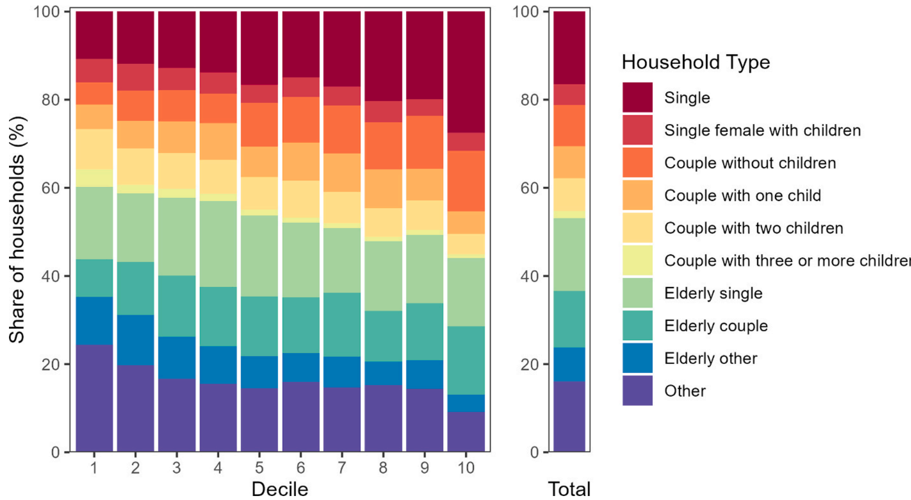

Fig. 1. Shares of household types by expenditure deciles and total.

introduce household type and household size one at a time due to detected collinearity (see Supplementary Information, Section 2.2 for full diagnostics). To enhance the models, we use logarithmic transformations for per capita floor space, per capita expenditures, and household size. Because both expenditures and household size, as well as the dependent variable per capita floor space, were log-transformed, the corresponding regression coefficients can be interpreted as elasticities. The equations underlying the five models are the following:

$$\text{Model F1}: Log(Floor) = \beta_0 + \beta_1 \cdot Log(Expenditures) + \sum_i \beta_i \cdot Household\ type + \sum_j \beta_j \cdot Housing\ type + \sum_k \beta_k \cdot Period\ of\ construction + \sum_l \beta_l \cdot Tenure + \sum_m \beta_m \cdot Region\ (NUTS1) + \varepsilon \quad (1)$$

$$\text{Model F2}: Log(Floor) = \beta_0 + \beta_1 \cdot Log(Expenditures) + \beta_2 \cdot Log(Householdsize) + \sum_j \beta_j \cdot Housingtype + \sum_k \beta_k \cdot Periodofconstruction + \sum_l \beta_l \cdot Tenure + \sum_m \beta_m \cdot Region(NUTS1) + \varepsilon \quad (2)$$

$$\text{Model F3}: Log(Floor) = \beta_0 + \beta_1 \cdot Log(Expenditures) + \sum_i \beta_i \cdot Householdtype + \sum_j \beta_j \cdot Housingtype + \varepsilon \quad (3)$$

$$\text{Model F4}: Log(Floor) = \beta_0 + \beta_1 \cdot Log(Expenditures) + \beta_2 \cdot \log(Householdsize) + \sum_i \beta_i \cdot Housingtype + \varepsilon \quad (4)$$

$$\text{Model F5}: Log(Floor) = \beta_0 + \beta_1 \cdot Log(Expenditures) + \varepsilon \quad (5)$$

Model F1 and F2 include the full set of selected explanatory variables with either household type or household size. With model F3 and F4, we consider a limited set of variables, namely expenditures, either household size or household type, and housing type, that are more easily retrievable for other countries and can explain a large share of the variation in results. Finally, model F5 tests the predictive power using equivalised expenditures only. Diagnostics and additional analyses with models introducing only household size or household types are in the Supplementary Information, section 2.

We use CDA [32–35] to estimate end-use specific gas consumption as a function of socio-economic, structural, and contextual factors. Gas consumption is decomposed into a baseline component associated with cooking, common to almost all gas-using households, and additional components attributable to domestic hot water and space heating. Similar to other studies [5,63], we model these end uses within a linear regression framework that relates gas consumption per capita or per unit of floor space to household composition and housing characteristics, while controlling for structural differences across dwellings. Regional fixed effects are included to capture climatic and geographic heterogeneity affecting heating demand, consistent with previous studies [64,65]. This approach is complementary to other studies on energy consumption in Italy that used bottom-up analysis [66] or energy expenditures [67]. We develop two sets of models to estimate gas consumption (Gas) per capita (models G1, G2) or per unit of floor space (models G3, G4) based on a set of household, housing, and contextual characteristics, introducing alternatively household size (model G1, G3) and detailed household types (model G2, G4):

$$Log(Gas) = \beta_0 + \beta_1 \cdot DHW + \beta_2 \cdot Space\ heating + \beta_3 \cdot Log(Expenditures) + \beta_4 \cdot Log(Floor\ total) + \sum_i \beta_i \cdot Household\ type + \sum_j \beta_j \cdot Housing\ type + \sum_k \beta_k \cdot Period\ of\ construction + \sum_l \beta_l \cdot Tenure + \sum_m \beta_m \cdot Region\ (NUTS2) + \varepsilon \quad (6)$$

$$Log(Gas) = \beta_0 + \beta_1 \cdot DHW + \beta_2 \cdot Spaceheating + \beta_3 \cdot Log(Expenditures) + \beta_4 \cdot Log(Floortotal) + \beta_2 \cdot Log(Householdsize) + \sum_j \beta_j \cdot Housingtype + \sum_k \beta_k \cdot Periodofconstruction + \sum_l \beta_l \cdot Tenure + \sum_m \beta_m \cdot Region(NUTS2) + \varepsilon \quad (7)$$

Where *DHW* indicates the use of gas for domestic hot water (yes or no), *Space heating* the use of gas for space heating (yes or no), and *Floor total* the dwelling floor space. Differently from floor space, we consider here the twenty Italian regions (NUTS2 level) to fully account for differences in climate and context. Model diagnostics are reported in the Supplementary Information, section 3.2.

2.5. Floor space distribution and decent living analysis

We analyse the distribution of per capita floor space at the national level and fit a parametric distribution by testing different alternative functions with the R package "fitdistrplus" [68]. The Gini coefficient [69] is a measure of statistical dispersion commonly used to estimate inequality. It varies between 0 and 1, with 0 corresponding to perfect equality and 1 to perfect inequality. It is broadly used to represent income inequality and, by extension, energy and resources inequality [10,70,71]. Here, we use the Gini coefficient as one indicator to describe inequality in per capita floor space distributions.

We finally investigate the characteristics of households with low per capita floor space below two different thresholds (below 15 m^2/cap and below 30 m^2/cap) and the intersection with qualitative self-assessed economic resources and absolute poverty. The latter is defined as the condition of a household with consumption expenditures below the value of a basket of essential goods and services needed to avoid social exclusion [43]. The lower value of 15 m^2/cap represents a minimum value in line with DLS requirements, broadly supported by the existing literature [11–13]. With per capita floor space at higher levels in developed countries, we investigate an additional threshold of 30 m^2/cap aligned with floor space sufficiency values proposed for Europe [24,72] (see Introduction for additional information on the theoretical foundation of the adopted thresholds). We further explore additional thresholds (10 and 20 m^2/cap) in the Supplementary Information, section 5.3 as a sensitivity analysis.

3. Results

3.1. Mapping households and housing characteristics

Mapping households and housing characteristics is essential for understanding the distribution of floor space and energy consumption. We investigate how households are distributed across housing types, tenure, and building construction periods by household type and expenditure decile (Fig. 2). The results show clear differences in housing type composition across household types, with higher shares of singles, couples without children, and elderly singles living in apartment blocks (ABL), compared with couples with children and other household types. Moving from lower to higher expenditure levels, the share of ABL

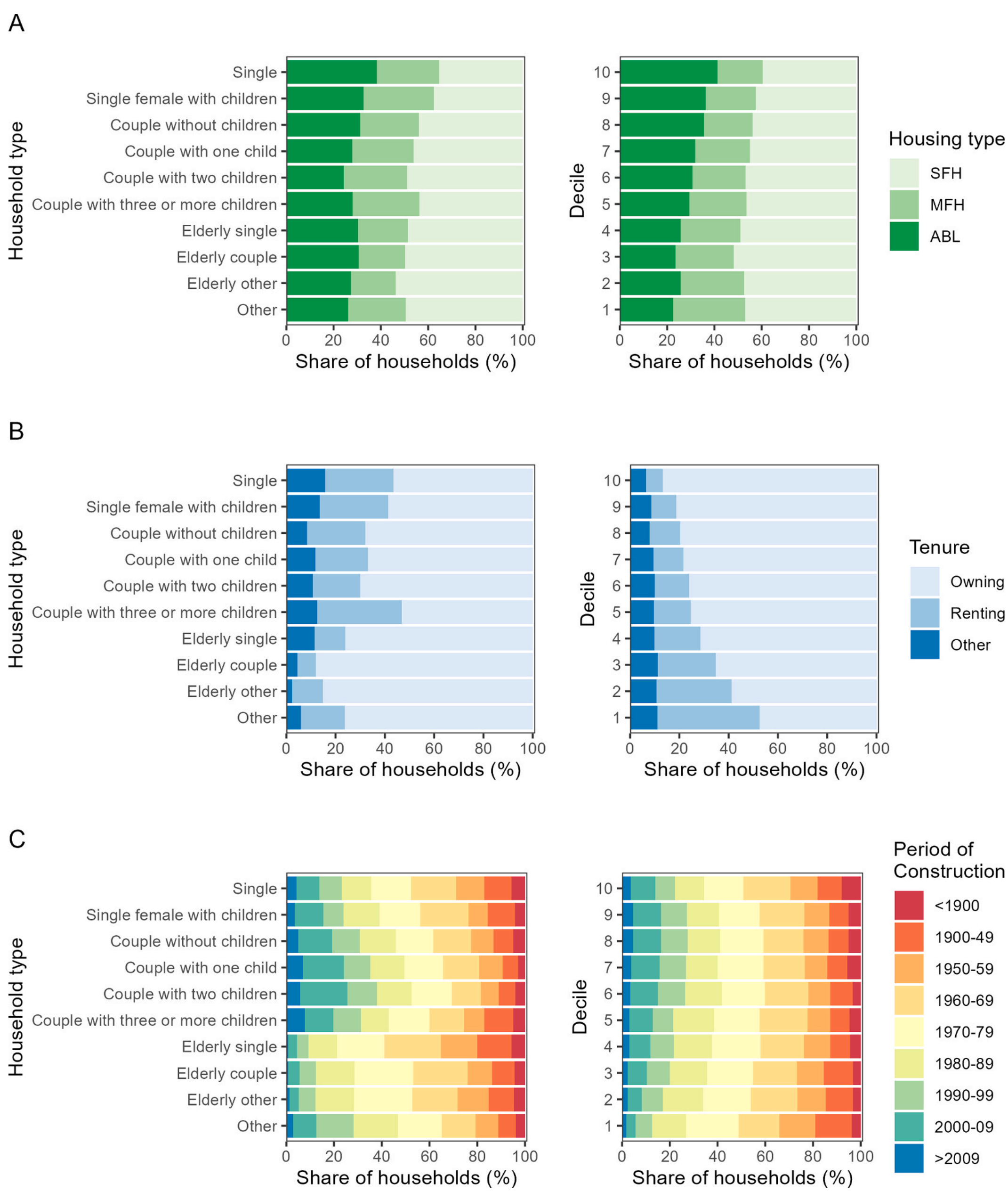

Fig. 2. Mapping of household types and expenditure deciles with housing types (A), tenure (B), and periods of construction (C).

increases, while the share of multi-family houses (MFH) decreases, likely indicating a larger share of households living in urban contexts (Fig. 2A). Regarding tenure (Fig. 2B), singles and couples without children have higher share of renting, while ownership is generally higher for couples with children and elderly households, but not for couples with three or more children. The period of construction of buildings largely differs across household types and expenditure deciles (Fig. 2C). Singles and single females with children have higher share living in older buildings (built before 1970) and lower share in newer buildings (built after 2000) compared to couples with children. Almost 60% of the elderly singles live in buildings built before 1970 while the share living in recent buildings (built after 2020) is lower than 5%. Similarly, the share of other elderly households living in buildings built before 1970 is above 40%. These results highlight a major divergence between elderly households and other households in terms of the age of the buildings they live in. Differences are also evident across expenditure levels, where households in higher deciles tend to live in newer buildings and those in lower deciles in older and potentially lower-quality buildings. However, the share of older buildings (before 1950) is higher for the top expenditure decile, likely indicating residences with higher historical value.

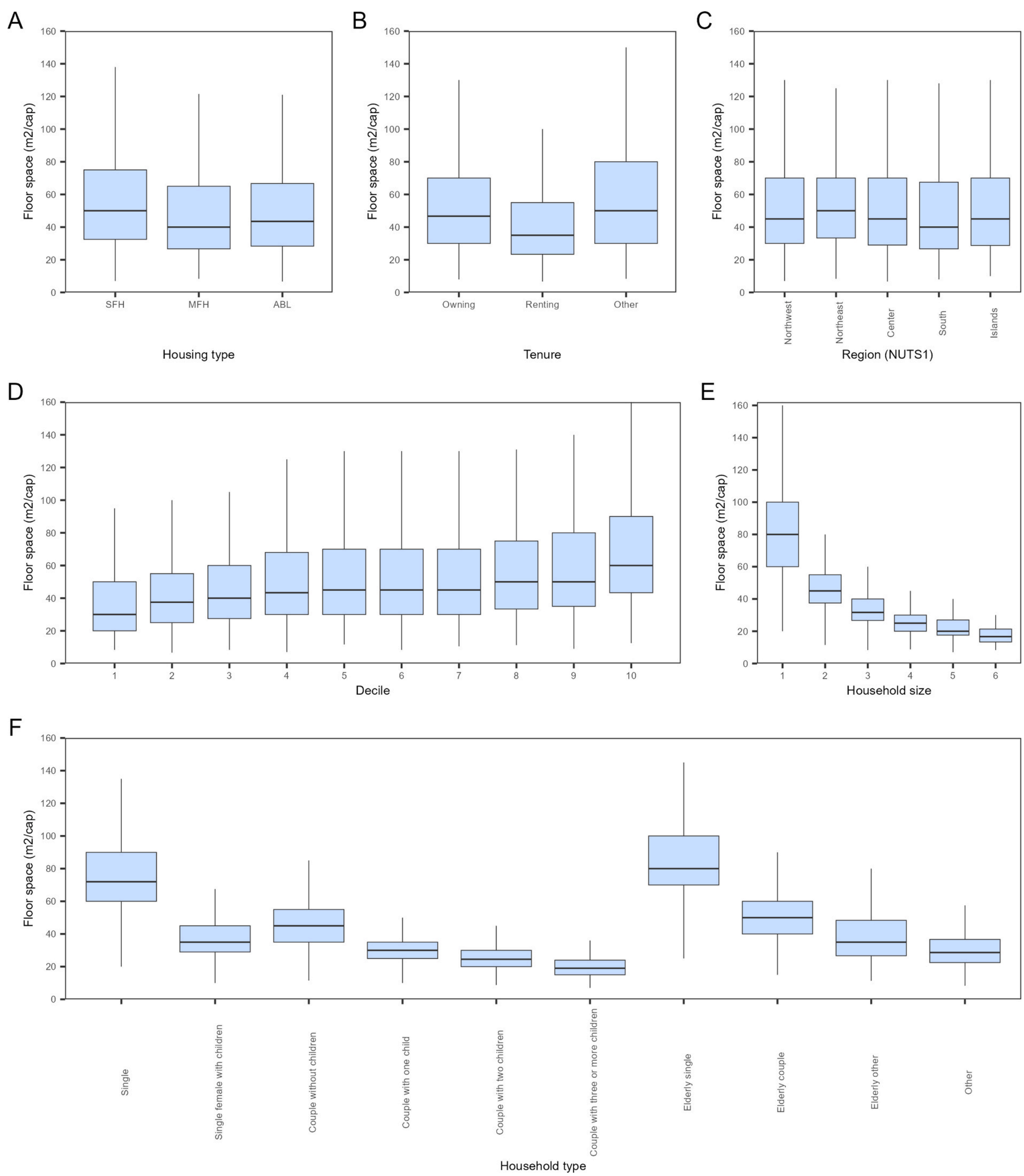

Fig. 3. Distribution of per capita floor space across different housing and household types: by housing type (A), by tenure (B), by region NUTS1 (C), by expenditure deciles (D), by household size (E), and by housing type (F).

3.2. Floor space heterogeneities and distributions

3.2.1. Exploring heterogeneities

We explore here the distribution of per capita floor space across key housing and socio-demographic dimensions, including housing type, tenure, region, expenditure decile, and household type (Fig. 3). Additional results on the distribution of total dwelling floor space on a per-household basis are reported in the Supplementary Information, section 4. The results confirm that per capita floor space is higher in SFH (median 50 m^2/cap) than MFH (median 40 m^2/cap) and ABL (median 44 m^2/cap). Rented dwellings have generally lower per capita floor space than owned and other dwellings. Regional differences are smaller, but dwelling space is larger in the Northwest and smaller in the South. Per capita floor space increases with expenditure levels, from a median 30 m^2/cap for the first decile to more than 60 m^2/cap for the tenth decile. Yet, the largest differences in per capita floor space are across household types and sizes. Single-person households have the highest per capita floor space, with median values of 75 m^2/cap for non-elderly households, corresponding to three times the median values of couples with two children (25 m^2/cap), and almost four times the median values of the couple with three or more children (19 m^2/cap). Elderly single households have even higher per capita floor space, with median 85 m^2/cap. Per capita floor space diminishes with household size, where couples with three or more children have the lowest values.

Fig. 4 provides an overview of average per capita floor space values by expenditure decile and household type. The heatmaps reveal three patterns. First, household size is a strong predictor of per capita floor space. The difference between the average per capita floor space between the singles and the couples with three or more children is remarkable and consistent across expenditure deciles (ranging from 44 m^2/cap in the first decile to 63 m^2/cap in the tenth decile). Second, higher expenditure levels are associated with increased per capita floor space across all household types, and especially for single-person households. For instance, the difference between the floor space of the highest decile and the lowest decile is 34 m^2/cap for singles compared to 12 to 15 m^2/cap for couples. Third, across different expenditure levels and household sizes, elderly people show consistently higher per capita floor space than non-elderly households. In particular, elderly singles live in spaces that are 7 to 21 m^2/cap larger space than those of non-elderly singles. The combination of these three effects leads to a difference of up to 94 m^2/cap (or factor 6) between the minimum per capita floor space (17 m^2/cap, for couples with three or more children in the first decile) and the highest (111 m^2/cap, for elderly singles in the tenth decile).

3.2.2. Regression results

Table 2 shows the results of the five estimated regression models for per capita floor space (see Supplementary Information, section 2 for model diagnostics and additional analyses). Models F1 and F2 include the broadest set of variables with either household type (model F1) or household size (model F2) included. Most variables were found to be significant, with the exception of the region Center and specific periods of construction (1960–69, >2009 and, for model F1, 2000–09). The two models can explain a significant share of the variability in per capita floor space, with R^2 values of 0.675 and 0.705 respectively. As observed in the data exploration, expenditures correlate positively with per capita floor space, while household size (model F2) is negatively correlated. All household types were found to be significant in model F1, with the regression coefficients reflecting the differences highlighted in the data exploration. The coefficients for MFH and ABL are negative as they have lower floor space levels relative to the reference SFH housing type. Periods of construction and regions show relatively small coefficients, indicating more limited variation compared to the other categorical variables in the model. The effect of tenure relative to owning (reference value) is negative for both renting and other categories. In models F3 and F4, a limited number of variables, namely expenditures, either household type or household size, and housing type, and can still explain a large part of the variability with an R^2 value of 0.656 and 0.680 respectively. While models F3 and F4 are similar in their performance, only model F3 can account for differences in floor space between age and gender groups with the same number of household members, e.g. elderly single, or single female with children. On the other hand, introducing only expenditures as a predictor of per capita floor space in model F5 results in a very low R^2 of 0.068, showing that additional variables, in particular household size or household type, are essential to explain the variability within the data. Relative importance measures computed using the LMG (Shapley–Owen) decomposition of R^2 are reported in Table 3. The results show that household size or household type alone can explain the largest variance share with values of around 85% in models F1 and F2 and more than 87% in models F3 and F4. Expenditures exhibit a much lower share of variance between 6.6% and 8.6%, followed by housing type at 3–4% across models F1-F4.

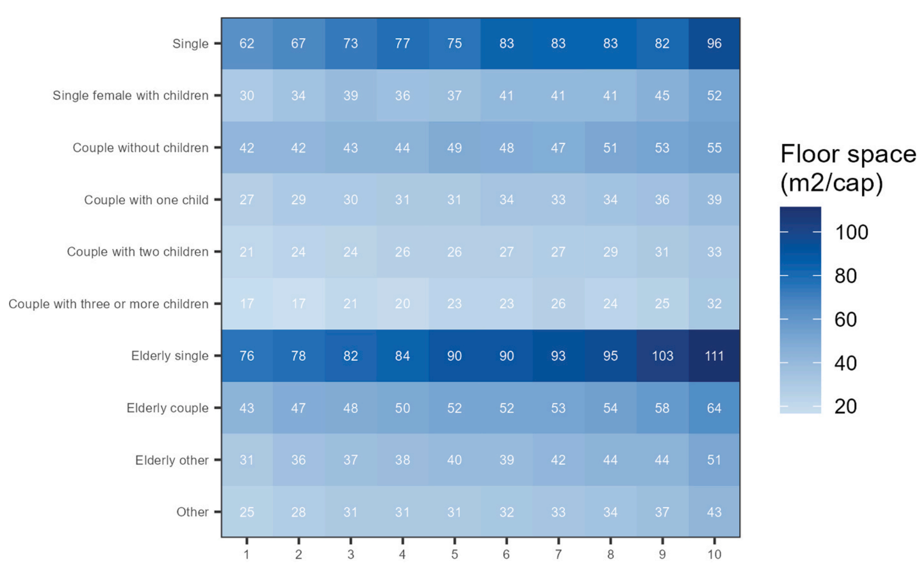

Fig. 4. Average values of per capita floor space by household types and expenditure deciles.

Table 2
Results of the regression analysis for five different models of per capita floor space. The independent variable is represented by the log of per capita floor space in m^2/cap. Reference values for categorical variables are: "single" for household type; "SFH" for housing type;"<1900" for period of construction; "owning" for tenure; and "Northwest" for region (NUTS1),

Group	Variable	Model F1	Model F2	Model F3	Model F4	Model F5
	Intercept	3.014*** (0.038)	3.255*** (0.036)	2.845*** (0.033)	3.097*** (0.031)	1.918*** (0.052)
Expenditures	log(Expenditures)	0.196*** (0.005)	0.171*** (0.004)	0.216*** (0.004)	0.192*** (0.004)	0.263*** (0.007)
Household size	log(Household size)		−0.816*** (0.004)		−0.800*** (0.004)	
Household type	Single female with children	−0.692*** (0.013)		−0.685*** (0.013)		
	Couple without children	−0.538*** (0.010)		−0.520*** (0.010)		
	Couple with one child	−0.910*** (0.011)		−0.892*** (0.011)		
	Couple with two children	−1.107*** (0.011)		−1.079*** (0.011)		
	Couple with three or more children	−1.281*** (0.020)		−1.268*** (0.020)		
	Elderly single	0.105*** (0.008)		0.130*** (0.009)		
	Elderly couple	−0.466*** (0.009)		−0.420*** (0.009)		
	Elderly other	−0.748*** (0.010)		−0.705*** (0.010)		
	Other	−0.950*** (0.009)		−0.912*** (0.009)		
Housing type	MFH	−0.154*** (0.006)	−0.166*** (0.006)	−0.174*** (0.006)	−0.191*** (0.006)	
	ABL	−0.195*** (0.006)	−0.203*** (0.006)	−0.227*** (0.006)	−0.240*** (0.005)	
Period of construction	1900–49	−0.056*** (0.013)	−0.059*** (0.012)			
	1950–59	−0.054*** (0.013)	−0.062*** (0.012)			
	1960–69	−0.018 (0.012)	−0.014 (0.011)			
	1970–79	0.038** (0.012)	0.045*** (0.011)			
	1980–89	0.038** (0.012)	0.042*** (0.012)			
	1990–99	0.027* (0.013)	0.027* (0.012)			
	2000–09	−0.015 (0.013)	−0.034** (0.012)			
	>2009	−0.010 (0.017)	−0.031+ (0.016)			
Tenure	Renting	−0.157*** (0.007)	−0.178*** (0.006)			
	Other	−0.103*** (0.009)	−0.129*** (0.008)			
Region (NUTS1)	Northeast	0.031*** (0.007)	0.037*** (0.007)			
	Center	−0.013+ (0.007)	−0.004 (0.007)			
	South	0.054*** (0.007)	0.064*** (0.007)			
	Islands	0.073*** (0.009)	0.077*** (0.009)			
	R^2	0.675	0.705	0.656	0.680	0.068
	R^2 Adj.	0.674	0.704	0.656	0.680	0.068
	AIC	153500.5	151688.6	154512.7	153165.5	173107.6
	BIC	153719.9	151845.3	154622.4	153212.5	173131.1
	F-statistic	1488.306	2472.546	2967.902	9910.888	1364.02
	p-value	$<2.2 \cdot 10^{-16}$	$<2.2 \cdot 10^{-16}$	$<2.2 \cdot 10^{-16}$	$<2.2 \cdot 10^{-16}$	$<2.2 \cdot 10^{-16}$
	RMSE	0.32	0.30	0.33	0.32	0.54

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 '' 1.

3.2.3. *Floor space distribution and decent living standards*

Per capita floor space follows a right-skewed distribution across the sample of the Italian population, with a long tail of high values (Fig. 5). A lognormal function with mean 3.823 and standard deviation 0.572 of the natural logarithm of the data provided the best fit for this distribution relative to gamma, Weibull, and logistic functions (Supplementary Information, section 5.2). This floor space distribution is associated with a Gini coefficient of 0.32, similar to levels of income inequality in Italy [73], but much lower than wealth inequality [74]. While international data on floor space inequality are extremely sparse, the calculated Gini coefficient lies within the range reported in the literature for residential buildings in different world regions (see Supplementary Information,

Table 3
Results of variance decomposition analysis for four different models of per capita floor space.

Variable	Share of explained variance (%)			
	Model F1	Model F2	Model F3	Model F4
log(Expenditures)	7.5	6.6	8.6	7.6
log(Household size)		84.9		87.9
Household type	84.4		87.1	
Housing type	3.4	3.4	4.3	4.5
Period of construction	1.1	1.1		
Tenure	3.2	3.4		
Region (NUTS1)	0.5	0.5		

section 5.1). This level of inequality is plausible because per capita floor space reflects households' economic resources, shaped by both disposable income and wealth, yet it captures only a subset of total wealth. In particular, housing constitutes only one physical asset, while wealth inequality is amplified by the much stronger upper-tail concentration of financial and business assets. In addition, because we consider only primary residences, the estimated floor space Gini is likely conservative; including secondary homes would likely increase it, since second-home ownership is more concentrated among wealthier households.

To further explore the characteristics of the households with low per capita floor space values, we investigate two different thresholds (15 m^2/cap and 30 m^2/cap). We find that 28.2% of the households live on less than 30 m^2/cap and 2.1% live under 15 m^2/cap (Fig. 5). Significant shares of the households below the 15 m^2/cap threshold experience challenging economic conditions, with 35% living in absolute poverty and 67% assessing their economic resources as insufficient or scarce. The economic situation improves significantly when considering the group of households below the higher 30 m^2/cap threshold, which includes a much larger share of the population. In this group, 12% of the households are in absolute poverty conditions, and 42% report their economic resources as insufficient to scarce. Household characteristics vary when assuming different per capita floor space thresholds, but some patterns are consistent across groups. The households below these thresholds are mostly families with children, with almost 50% and 40% of the households below 15 m^2/cap and 30 m^2/cap respectively being families with at least two children. Households in the other and other elderly groups also account for substantial shares. While moving to the higher per capita floor space threshold broadens the range of expenditure levels represented, the three lower deciles are consistently prominent and represent 73% and 44% of the households below the 15 and 30

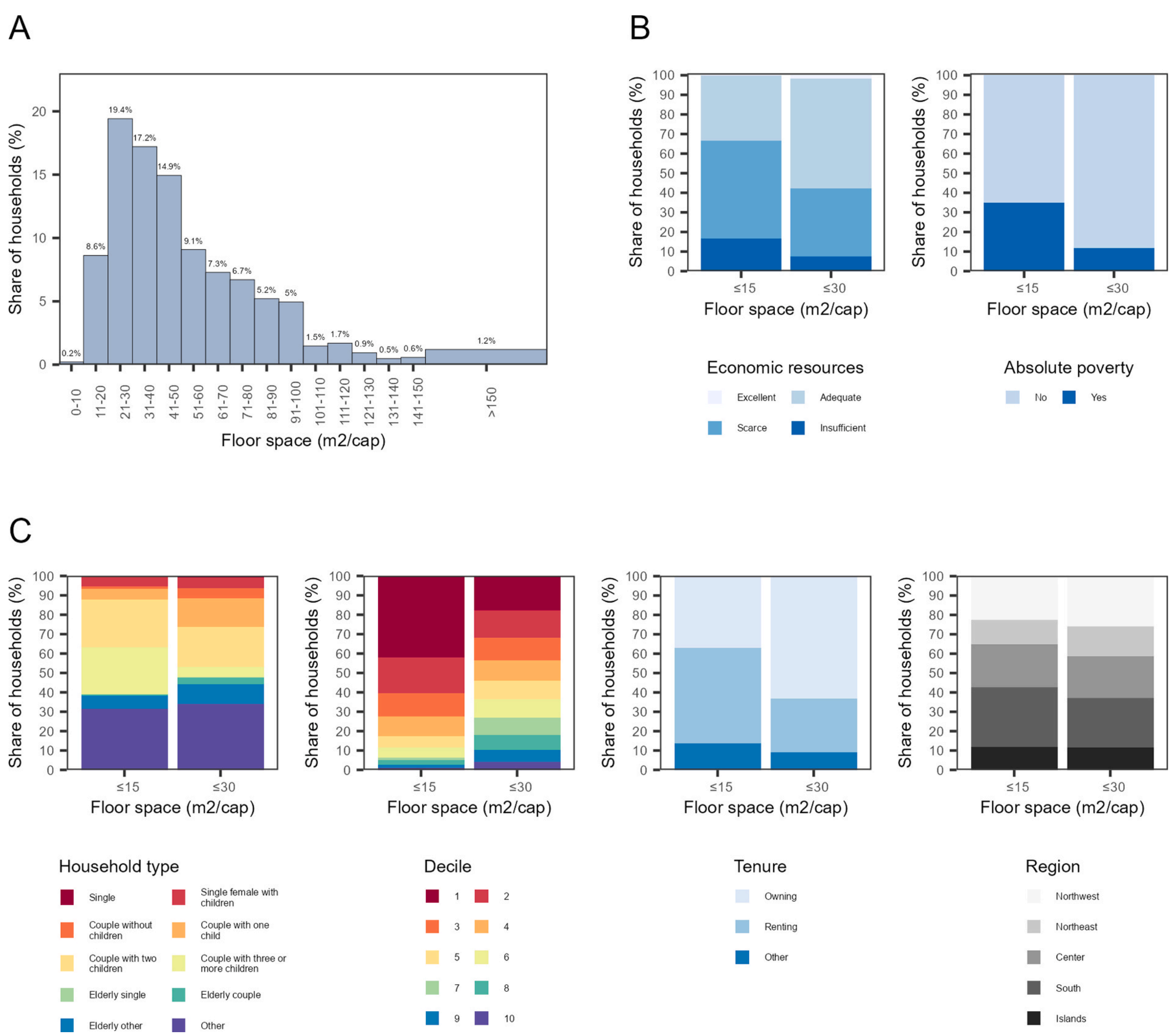

Fig. 5. Distribution of households by per capita floor space (A). Note that the last three bins have different size compared to the others. Share of households below two different per capita floor space thresholds (15 and 30 m2/cap) by economic status, including economic resources and absolute poverty (B), and household characteristics, including household type, expenditure decile, tenure, and region (C).

m^2/cap thresholds respectively. Almost half of the households below 15 m^2/cap (49%) live in rented dwellings, while the proportion of owners significantly increases with higher floor space thresholds. Important differences exist across regions, with large shares of households below the thresholds living in Southern Italy, up to 31% of the households below 10 m^2/cap and 26% of the households below 30 m^2/cap. Similar results are observed across a broader range of floor space thresholds (10, 20, and 30 m^2/cap) (see Supplementary Information, section 5.3). In particular, the findings indicate a gradual improvement in economic conditions as higher thresholds are applied, capturing an increasingly larger share of households.

3.3. Gas consumption heterogeneities

3.3.1. Exploring heterogeneities

Fig. 6 presents the distribution of gas consumption across different household and housing groups. Per capita and per m^2 results reveal different patterns. Per capita gas consumption gradually increases with higher per capita floor space, confirming the tight relationship with floor space. In contrast, energy intensity per unit of floor space decreases, probably due to larger shares of unheated rooms in larger dwellings. Gas consumption increases across expenditure deciles both in per capita and per m^2 terms. However, differences in per m^2 consumption across expenditure levels are comparatively smaller, plateauing at medium-to-

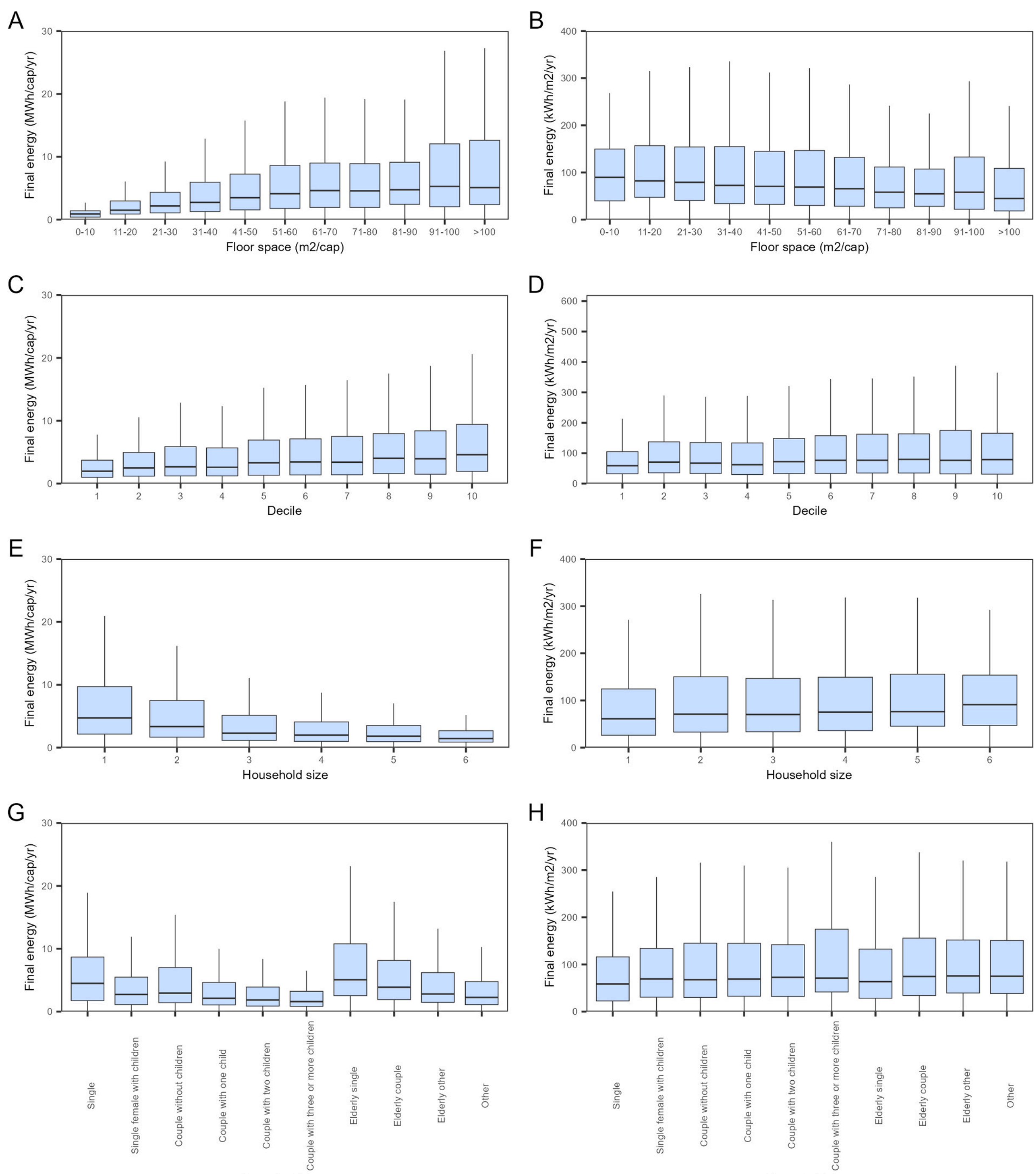

Fig. 6. Distribution of gas consumption per capita (MWh/cap/yr)(panels A,C,E,G) and per unit of floor space (kWh/m^2/yr) (panels B,D,F,H) across different housing and household groups: per capita floor space bins (A,B), expenditure deciles (C,D), household sizes (E,F), and household types (G,H).

high expenditure levels. This pattern may be related to several aspects. Higher expenditure deciles include a larger share of single-person households, likely using heating less intensively during the day. They also predominantly reside in MFH and ABL housing types, which typically exhibit lower heat losses due to more favourable surface-to-volume ratios compared to SFH. In addition, these groups have a higher share of recently constructed buildings (Fig. 2), which generally require less heating due to better insulation. At the same time, the highest decile also shows a relatively large share of older buildings (pre-1970), likely suggesting a higher prevalence of renovations and more efficient energy systems. The analysis of per capita gas consumption by household size and household type reveals similar patterns as those observed for per capita floor space distribution, namely high consumption for single-person households and lower consumption as the household size increases. In contrast, gas consumption per m^2 increases with household size, even though differences are relatively smaller. Elderly households exhibit higher per capita consumption compared to the corresponding non-elderly households both in per capita and per m^2 terms. This could be explained by the higher share of older buildings for elderly households (Fig. 2) and higher thermal comfort needs. Additional results on the distribution of gas consumption on a per-household basis are reported in the Supplementary Information, section 4.

3.3.2. Regression results

This section reports the results of the CDA for gas consumption using four models, assuming either gas consumption per capita (models G1 and G2) or per unit of floor space (models G3 and G4) as dependent variable (Table 4). Additional model diagnostics are reported in the Supplementary Information, section 3.2. All models include a broad set of variables related to the end-uses of gas, context, housing, and household characteristics, with either household type (models G1 and G3) or the log of household size (models G2 and G4). The four models can explain a lower share of variability compared to floor space regression models, with the two models on per capita basis reporting R^2 values of 0.298 (model G1) and 0.306 (model G2), and the per m^2 models exhibiting smaller R^2 values of 0.123 and 0.118.

The results show that hot water and space heating have statistically significant positive coefficients relative to the base cooking end-use in all estimated models. Household expenditure coefficients are statistically significant and positively correlated with gas consumption in all models, confirming the data exploration results. Both household size and household type–related variables are statistically significant and exhibit opposite effects when gas consumption is expressed in per capita versus per-m^2 terms. Household size is negatively associated with gas consumption in per capita models and positively associated in per-m^2 models. Similarly, per capita floor space has a negative coefficient in models G1–G2 and a positive coefficient in models G3–G4, consistent with the trends observed in the exploratory data analysis. While both tenure and housing type are statistically significant across all model specifications, with both MFH and ABL exhibiting lower values relative to SFH, the period of construction is generally not significant, except for the most recent construction period (post-2009) relative to the base period (pre-1900). This finding is consistent with the results of a previous regression analysis on energy expenditures in Italy [67] and may be partly attributable to differences in renovation levels and occupant behaviour, leading to uncertainty in the estimates. Most of the regional estimates are statistically significant, with only a few exceptions, broadly reflecting climate and context-related differences.

We use the LMG (Shapley–Owen) decomposition of R^2 to assess the relative importance of explanatory variables across the four models (Table 5). Three main insights emerge. First, household type and household size explain the largest share of variance in models G1 and G2, respectively, while per capita floor space is the most important variable in models G3–G4, reflecting the different unit bases of the two model groups (per capita versus per m^2). Second, the regional dummy variables account for a substantial share of the explained variance in all models, particularly in the per m^2 specifications (above 30%), highlighting the role of climatic and contextual heterogeneity in gas consumption. Third, expenditures exhibit relatively large contributions across all models, exceeding 11% in models G1–G2 and around 8% in models G3–G4. Overall, the results underscore the relevance of household-related variables (household composition and expenditures) in explaining per capita gas consumption, and of structural (floor space) and contextual (region) factors in per m^2 gas consumption.

3.3.3. Comparing floor space and gas consumption results

Comparing differences across household types and deciles relative to average per capita floor space and average gas consumption (per capita and per unit of floor space) enables the identification of joint patterns (Fig. 7). Across household types, percentage differences from average values for per capita floor space and per capita gas consumption are similar in magnitude. Non-elderly and elderly single groups show the largest positive differences relative to the average values, up to +74% for floor space and +70% for gas consumption for elderly single households. In contrast, couples with children present the largest negative differences, up to –61% for floor space and –57% for gas consumption for couples with three or more children. Per m^2 gas consumption differences from the average are smaller, indicating less heterogenous patterns of energy intensities, and mostly exhibit opposite values in relation to per capita values. Singles have lower than average values, while the groups with lower floor space consistently have higher per m^2 gas consumption. A notable exception is represented by the group of single females with children with both 30% lower-than-average per capita floor space and lower gas consumption, revealing potentially lower energy use than other groups with similar average per capita floor space.

Different patterns emerge across expenditure deciles, with deviations from the average being larger for per capita gas consumption than for per capita floor space. This reflects higher energy use in the top decile (+52%), driven by both larger floor space and higher energy intensity per unit of floor space, and lower energy use in the bottom decile (−53%), due to both smaller floor space and lower energy intensity (Fig. 6). The analysis of per m^2 gas consumption exhibits lower differences with average values, but significant disparities between the top and bottom deciles. While the tenth decile has per m^2 gas consumption that is 11% higher than average, the first decile has per m^2 gas consumption that is 26% lower than average, suggesting the possibility of thermal comfort deprivation.

4. Discussion and conclusions

Floor space is a key dimension of housing, serving both as an indicator of service levels and a determinant of energy demand. By examining floor space heterogeneities across key housing and household dimensions and their relationship with energy consumptions in Italy, this study contributes to bridging a critical gap in the literature on housing and energy demand analysis and modelling, where such relationships are mostly overlooked or over-simplified with a narrow focus on income.

We show that household size and composition are strong predictors of per capita floor space, with an increasing number of household members systematically related to lower per capita floor space. The difference in floor space between single-person and multi-person households is found at all expenditure deciles and it is even more pronounced at higher expenditure levels. While increasing expenditure levels are associated with higher per capita floor space across all household types, expenditure alone can only explain a limited part of the variability in floor space, with household type, size and housing type being stronger predictors. Further examination of socio-demographic characteristics reveals that age plays a crucial role, with elderly singles living in larger dwellings than other age groups, for a given household size. At the other end of the spectrum, large overlaps exist

Table 4

Results of the conditional demand analysis (CDA) of gas consumption. The independent variable is represented by the log of per capita gas consumption in kWh/cap/yr for models G1-G2 and by the log of gas consumption per unit of floor space in kWh/m^2/yr for model G1-G2. Reference values for categorical variables are: "single" for household type; "SFH" for housing type;"<1900" for period of construction; "owning" for tenure; and "Lombardia" for region (NUTS2),

Group	Variable	Model G1	Model G2	Model G3	Model G4
Independent variable		Log(per cap gas consumption)	Log(per cap gas consumption)	Log(per m^2 gas consumption)	Log(per m^2 gas consumption)
	Intercept	5.683***	5.894***	5.700***	5.894***
		(0.174)	(0.170)	(0.172)	(0.170)
End-uses	Domestic hot water	0.090***	0.093***	0.090***	0.093***
		(0.022)	(0.022)	(0.022)	(0.022)
	Space heating	0.273***	0.270***	0.267***	0.270***
		(0.043)	(0.043)	(0.043)	(0.043)
Expenditures	log(Expenditures)	0.288***	0.225***	0.247***	0.225***
		(0.018)	(0.018)	(0.018)	(0.018)
Household size	log(Household size)		−0.814***		0.186***
			(0.016)		(0.016)
Household type	Single female with children	−0.648***		0.218***	
		(0.044)		(0.044)	
	Couple without children	−0.533***		0.146***	
		(0.035)		(0.034)	
	Couple with one child	−0.872***		0.209***	
		(0.037)		(0.037)	
	Couple with two children	−1.061***		0.296***	
		(0.038)		(0.037)	
	Couple with three or more children	−1.172***		0.430***	
		(0.066)		(0.066)	
	Elderly single	0.196***		0.182***	
		(0.031)		(0.031)	
	Elderly couple	−0.365***		0.305***	
		(0.033)		(0.033)	
	Elderly other	−0.655***		0.368***	
		(0.038)		(0.038)	
	Other	−0.864***		0.364***	
		(0.031)		(0.031)	
Dwelling size	Log(Floorspace)	0.221***	0.304***	−0.714***	−0.696***
		(0.028)	(0.027)	(0.027)	(0.027)
Housing type	MFH	−0.085***	−0.087***	−0.078***	−0.087***
		(0.021)	(0.021)	(0.021)	(0.021)
	ABL	−0.162***	−0.154***	−0.152***	−0.154***
		(0.022)	(0.022)	(0.022)	(0.022)
Period of construction	1900–49	−0.000	−0.000	−0.004	−0.000
		(0.046)	(0.046)	(0.046)	(0.046)
	1950–59	0.039	0.036	0.030	0.036
		(0.045)	(0.045)	(0.045)	(0.045)
	1960–69	−0.011	−0.013	−0.018	−0.013
		(0.043)	(0.043)	(0.042)	(0.043)
	1970–79	−0.018	−0.009	−0.014	−0.009
		(0.043)	(0.042)	(0.042)	(0.042)
	1980–89	0.012	0.012	0.015	0.012
		(0.043)	(0.043)	(0.043)	(0.043)
	1990–99	−0.059	−0.067	−0.045	−0.067
		(0.045)	(0.044)	(0.044)	(0.044)
	2000–09	−0.045	−0.085+	−0.048	−0.085+
		(0.045)	(0.044)	(0.044)	(0.044)
	>2009	−0.247***	−0.282***	−0.229***	−0.282***
		(0.061)	(0.060)	(0.061)	(0.060)
Tenure	Renting	0.072**	0.044+	0.081***	0.044+

(*continued on next page*)

Table 4 (*continued*)

Group	Variable	Model G1	Model G2	Model G3	Model G4
		(0.024)	(0.024)	(0.024)	(0.024)
	Other	0.085**	0.056+	0.080*	0.056+
		(0.033)	(0.032)	(0.033)	(0.032)
Region (NUTS2)	Abruzzo	−0.218***	−0.216***	−0.213***	−0.216***
		(0.051)	(0.051)	(0.050)	(0.051)
	Basilicata	−0.153+	−0.151+	−0.148+	−0.151+
		(0.085)	(0.084)	(0.084)	(0.084)
	Calabria	−0.407***	−0.409***	−0.402***	−0.409***
		(0.062)	(0.062)	(0.061)	(0.062)
	Campania	−0.588***	−0.558***	−0.550***	−0.558***
		(0.037)	(0.036)	(0.036)	(0.036)
	Emilia-Romagna	−0.140***	−0.146***	−0.144***	−0.146***
		(0.033)	(0.033)	(0.033)	(0.033)
	Friuli-Venezia Giulia	−0.014	−0.002	0.002	−0.002
		(0.058)	(0.058)	(0.058)	(0.058)
	Lazio	−0.354***	−0.366***	−0.359***	−0.366***
		(0.033)	(0.033)	(0.033)	(0.033)
	Liguria	−0.209***	−0.220***	−0.218***	−0.220***
		(0.055)	(0.054)	(0.054)	(0.054)
	Marche	−0.143**	−0.128**	−0.131**	−0.128**
		(0.049)	(0.048)	(0.048)	(0.048)
	Molise	−0.292**	−0.302**	−0.290**	−0.302**
		(0.110)	(0.109)	(0.109)	(0.109)
	Piemonte	−0.078*	−0.089*	−0.086*	−0.089*
		(0.038)	(0.038)	(0.038)	(0.038)
	Puglia	−0.294***	−0.285***	−0.282***	−0.285***
		(0.035)	(0.035)	(0.035)	(0.035)
	Sardegna	−0.234	−0.236	−0.217	−0.236
		(0.180)	(0.179)	(0.178)	(0.179)
	Sicilia	−0.140**	−0.140***	−0.134**	−0.140***
		(0.043)	(0.042)	(0.042)	(0.042)
	Toscana	−0.198***	−0.178***	−0.181***	−0.178***
		(0.036)	(0.036)	(0.036)	(0.036)
	Trentino-Alto Adige	−0.192*	−0.186*	−0.189*	−0.186*
		(0.079)	(0.079)	(0.078)	(0.079)
	Umbria	−0.267***	−0.271***	−0.266***	−0.271***
		(0.063)	(0.063)	(0.063)	(0.063)
	Valle d'Aosta	0.130	0.122	0.131	0.122
		(0.253)	(0.251)	(0.251)	(0.251)
	Veneto	−0.072*	−0.069*	−0.067*	−0.069*
		(0.032)	(0.032)	(0.032)	(0.032)
	R^2	0.298	0.306	0.123	0.118
	R^2 Adj.	0.295	0.304	0.119	0.115
	AIC	186441.4	186315.9	112608.8	112647.9
	BIC	186771.5	186588.6	112938.9	112920.6
	F-statistic	92.931	118.021	30.714	35.836
	p-value	<2.2·10-16	<2.2·10-16	<2.2·10-16	<2.2·10-16
	RMSE	0.80	0.80	0.80	0.80

Table 5
Results of variance decomposition analysis for different models of gas consumption.

Variable	Share of explained variance (%)			
	Model G1	Model G2	Model G3	Model G4
Domestic hot water	0.3	0.3	0.8	0.8
Space heating	1.4	1.3	3.6	3.7
log(Expenditures)	12.9	11.4	8.2	7.8
log(Household size)		66.7		3.9
Household type	65.2		6.3	
Log(Floor space)	1.6	2.4	42.7	43.3
Housing type	2.4	2.4	2.4	2.6
Period of construction	2.7	2.8	3.3	4
Tenure	0.7	0.6	2.5	2.3
Region (NUTS2)	12.8	12.1	30.2	31.7

between low per capita floor space levels and poverty conditions. Per capita gas consumption reveals similar patterns, while gas consumption per unit of floor space increases as per capita floor space decreases and household size increases. The analysis in this study is correlational in nature and does not aim to establish causal relationships.

4.1. Wellbeing and sufficiency implications

Human wellbeing is strongly multidimensional and most conceptions of wellbeing include housing or shelter as one of its core dimensions [75]. Even so, the connection between living conditions and human wellbeing is not straightforward and insufficiently studied [76]. A few elements are clear in the literature. One of those is that small living spaces and overcrowding can be correlated with lower health-related quality of life, for instance due to mental health issues [77–79], with living space being a key factor in housing choice. Many European countries therefore have regulations in place determining minimum floor space requirements [80]. While existing studies determine DLS achievement around the world [9,81], their analysis is focused on housing requirements in the Global South, which gives little guidance on wellbeing-oriented sufficiency policies in a country like Italy.

Crucially, our study's empirical findings show that household size and composition are strong predictors of per capita floor space, highlighting their importance for improving the assessment and modelling of DLS. An additional hint lies in the economic data responses. Most of the households living below the 30 m^2/cap floor space threshold (58%) report at least adequate economic resource conditions, which may suggest a deliberate choice to live in such spaces that may meet their needs, rather than a forced situation. The data also reveal that a per capita floor space range of 0–15 m^2/cap (2.1% of the households) is associated with a high prevalence of poverty and economic hardship. By revealing the interrelationships between household socio-demographics, housing characteristics, and energy expenditures, the analysis in this study can also support improved assessments of energy poverty, accounting for the key dimensions of heterogeneity. It should be noted that living space and gas consumption are not the only living condition indicators of relevance to wellbeing. Future work can also consider further elements such as the number of people per room and more detailed gender and age structures of households, as well as housing conditions, including mould, leaks, and general structural issues and upkeep, These factors could help refine the understanding of how needs and deprivations vary across populations. When paired with human wellbeing indicators, such as life satisfaction, this analysis could help in identifying at what levels of provisioning needs are satisfied.

By providing detailed distributions of floor space in relation to household characteristics, this study can also inform sufficiency policies targeting under-occupied or oversized homes. Critically, this study shows that household size and composition are key predictors of per capita floor space and should be better incorporated in the assessment of sufficiency strategies for the housing sector. As the demographic projections for a country like Italy show constant decrease in fertility rates, rapidly aging population, and shrinking household size, the question of equitable access to sufficient floor space will become even more central in the sustainable housing discourse. This requires a shift to prioritizing better utilization and valorisation of the existing housing stock over new constructions to meet housing demand, considering strategies to balance occupancy levels and promote reuse, adaptation, and sharing of living spaces [15]. While reducing the consumption of resources, co-housing and collective forms of living also offer an opportunity for improved social interactions, health, and wellbeing [82,83]. The analysis in this study could support the development of policies promoting these and other sufficiency strategies while accounting for both infrastructural and socio-behavioural aspects.

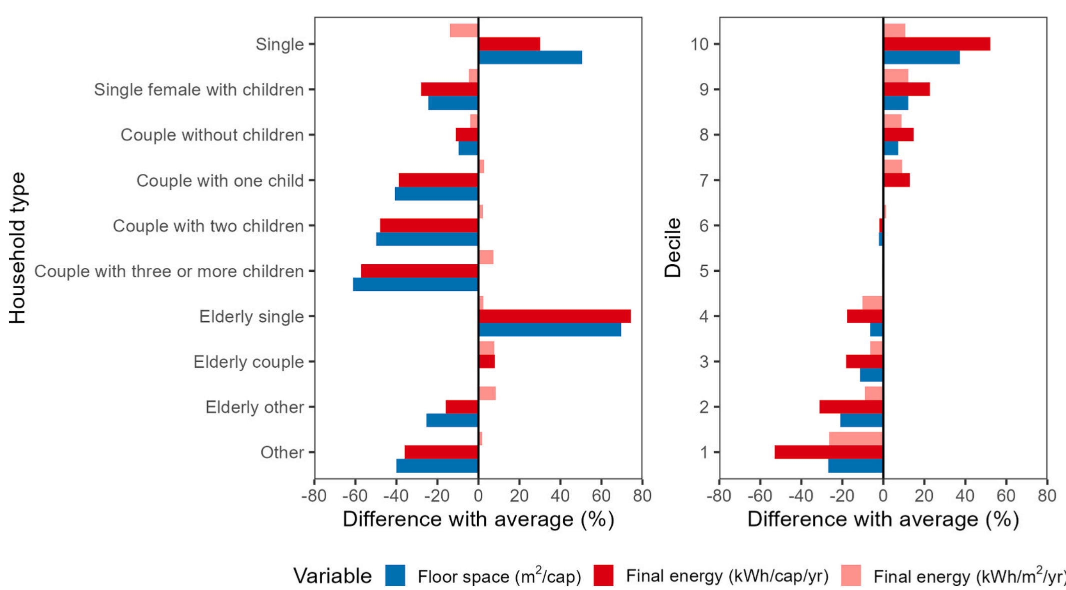

Fig. 7. Percentage differences of per capita floor space and gas consumption (per capita and per m^2), with relative to population-weighted averages, by household type (left panel) and expenditure decile (right panel).

4.2. Support to scenario modelling

Quantitative scenario modelling for the building sector is an important tool for supporting effective decision making. However, critical heterogeneities and distributions in housing, such as those in floor space, are largely overlooked in current building sector models. This limits the representation of socio-demographic dynamics that are key to sustainable transitions and highlights the need for additional empirical evidence and model improvements [4]. The detailed floor space estimations provided in this study inform key heterogeneities that can be incorporated in detailed bottom-up building model to enhance the representation of the status quo by mapping housing and household characteristics. Moreover, the regression models developed in this study could be integrated in future modelling exercises for Italy, or countries with similar housing conditions, to inform the relationship between floor space, households, and housing characteristics. Incorporating such information in building scenario modelling at the national level improves the accounting of floor space heterogeneities, distributions, and deprivations that are critical for the assessment of sufficiency, energy poverty, and decent living standards. Such information, combined with data on future socio-demographic development and enabling conditions, can support an enhanced representation of policies targeting specific housing and household groups while accounting for distributional aspects, service levels, and their linkage to energy use and GHG emissions. These improvements could represent a step change in comparison with the current practice, which mostly overlooks such aspects, enabling the representation of a broader set of policies reconciling climate and sustainable development considerations.

4.3. Limitations and future developments

The use of survey microdata has some limitations in the availability of relevant variables, for which we use proxy variables. For example, gas consumption is calculated based on household expenditures data, with potential bias due to the unavailability of more detailed data on energy price and tariffs. Other potentially relevant dimensions, such as urban and rural locations, where not analysed due to their unavailability in the public version of the survey. Future analysis could account for additional dimensions, such as urban density, housing prices, and household preferences, supported by additional and novel data sources. For instance, remote sensing data could inform more detailed and spatially explicit floor space estimates [84,85], improving the explanation of heterogeneities through spatially explicit information. Additional data collected at the micro level, e.g. using social media or citizen science methods, could further shed light on the diverse preferences of households in floor space and housing as well as related levels of subjective wellbeing. Our analysis only includes primary homes. Considering secondary homes would have implications on the results, especially on the floor space of higher expenditure deciles. Further analysis on larger households accounting for multigenerational living and for the age of children and other household members, could contribute to a better understanding of the mapping between housing and household characteristics and access to sufficient floor space. We only focus here on a snapshot of the building stock for a specific year (2019). Timeseries and panel analyses could reveal trends and dynamics of floor space and related inequalities over time. Further analysis on timeseries and secondary homes will be the subject of future work.

The results of this study are valid for Italy and generalizability to other countries might be limited to those with similar socio-economic and housing characteristics, including ownership structures. For instance, specific age characteristics and wealth distribution are expected to play a major role in Italy, with elderly people owning a larger fraction of the wealth, and a relevant portion of this wealth being constituted precisely by housing properties. Comparisons with other countries could help in understanding similarities and specificities in different contexts in view of further results generalisation. While this study focuses on the analysis of the status quo, future work will make use of the newly generated data to support the quantitative assessment of policies targeting sufficiency, energy poverty, decent living standards in combination with climate goals.

CRediT authorship contribution statement

Alessio Mastrucci: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Gianluca Maracchini:** Writing – review & editing, Validation, Conceptualization. **Jarmo Kikstra:** Writing – original draft. **Tommaso Zaini:** Writing – original draft. **Bas van Ruijven:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enbuild.2026.117745.

Data availability

The code and data generated for this manuscript can be shared upon reasonable request to the authors.

References

[1] L.F. Cabeza, Q. Bai, P. Bertoldi, J. Kihila, A.F.P. Lucena, É. Mata, S. Mirasgedis, A. Novikova, Y. Saheb, Chapter 9: Buildings., in: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, 2022.

[2] UNEP, Global Status Report for Buildings and Construction 2024/2025, United Nations Environment Programme, & Global Alliance for Buildings and Construction, 2025. https://wedocs.unep.org/20.500.11822/47214.

[3] H. Li, T. Hong, S.H. Lee, M. Sofos, System-level key performance indicators for building performance evaluation, Energ. Buildings 209 (2020) 109703, https://doi.org/10.1016/j.enbuild.2019.109703.

[4] A. Mastrucci, L. Niamir, B. Boza-Kiss, N. Bento, D. Wiedenhofer, J. Streeck, S. Pachauri, C. Wilson, S. Chatterjee, F. Creutzig, S. Dukkipati, W. Feng, A. Grubler, J. Jupesta, P. Kumar, G. Marangoni, Y. Saheb, Y. Shimoda, B. Shoai-Tehrani, Y. Yamaguchi, B. Van Ruijven, Modeling low energy demand futures for buildings: current state and research needs, Annu. Rev. Environ. Resour. 48 (2023) 761–792, https://doi.org/10.1146/annurev-environ-112321-102921.

[5] O. Guerra Santin, L. Itard, H. Visscher, The effect of occupancy and building characteristics on energy use for space and water heating in dutch residential stock, Energ. Buildings 41 (2009) 1223–1232, https://doi.org/10.1016/j.enbuild.2009.07.002.
[6] S. Clune, J. Morrissey, T. Moore, Size matters: house size and thermal efficiency as policy strategies to reduce net emissions of new developments, Energy Policy 48 (2012) 657–667, https://doi.org/10.1016/j.enpol.2012.05.072.
[7] A. Stephan, R.H. Crawford, The relationship between house size and life cycle energy demand: Implications for energy efficiency regulations for buildings, Energy 116 (2016) 1158–1171, https://doi.org/10.1016/j.energy.2016.10.038.
[8] N.D. Rao, J. Min, Decent living standards: material prerequisites for human wellbeing, Soc. Indic. Res. 138 (2018) 225–244, https://doi.org/10.1007/s11205-017-1650-0.
[9] J.S. Kikstra, A. Mastrucci, J. Min, K. Riahi, N.D. Rao, Decent living gaps and energy needs around the world, Environ. Res. Lett. 16 (2021) 095006, https://doi.org/10.1088/1748-9326/ac1c27.
[10] J.S. Kikstra, V. Daioglou, J. Min, F. Sferra, B. Soergel, E. Kriegler, H. Lee, A. Mastrucci, S. Pachauri, N. Rao, S. Rauner, D. Van Vuuren, K. Riahi, B. Van Ruijven, J. Rogelj, Closing decent living gaps in energy and emissions scenarios: introducing DESIRE, Environ. Res. Lett. 20 (2025) 054038, https://doi.org/10.1088/1748-9326/adc3ad.
[11] J. Millward-Hopkins, J.K. Steinberger, N.D. Rao, Y. Oswald, Providing decent living with minimum energy: a global scenario, Glob. Environ. Chang. 65 (2020) 102168, https://doi.org/10.1016/j.gloenvcha.2020.102168.
[12] C.F. Rammelt, J. Gupta, D. Liverman, J. Scholtens, D. Ciobanu, J.F. Abrams, X. Bai, L. Gifford, C. Gordon, M. Hurlbert, C.Y.A. Inoue, L. Jacobson, S.J. Lade, T. M. Lenton, D.I.A. McKay, N. Nakicenovic, C. Okereke, I.M. Otto, L.M. Pereira, K. Prodani, J. Rockström, B. Stewart-Koster, P.H. Verburg, C. Zimm, Impacts of meeting minimum access on critical earth systems amidst the Great Inequality, Nat Sustain 6 (2022) 212–221, https://doi.org/10.1038/s41893-022-00995-5.
[13] J.A. Vélez-Henao, S. Pauliuk, Material Requirements of decent living Standards, Environ. Sci. Technol. 57 (2023) 14206–14217, https://doi.org/10.1021/acs.est.3c03957.
[14] D. Ness, Growth in floor area: the blind spot in cutting carbon, EOR 1 (2023), https://doi.org/10.1108/eor-05-2023-0002.
[15] BPIE, Prioritising Existing Buildings for People and Climate., Buildings Performance Institute Europe (BPIE), 2024. https://www.bpie.eu/ publication/prioritising-existing-buildings-for-people-and-climate/.
[16] A. Baumgartner, F.C. Krysiak, F. Kuhlmey, Sufficiency without regret, Ecol. Econ. 200 (2022) 107545, https://doi.org/10.1016/j.ecolecon.2022.107545.
[17] F. Cellina, T. Gerosa, P. Granato, E. Lobsiger-Kägi, D. Wemyss, P. Kienast, Can app-based communities support energy sufficiency in households? Evidence from a one-year quasi-experiment in switzerland, Sustain. Cit. Soc. 114 (2024) 105771, https://doi.org/10.1016/j.scs.2024.105771.
[18] N. Golinucci, M.V. Rocco, M.G. Prina, F. Beltrami, L. Rinaldi, E.M. Schau, W. Sparber, The role of sufficiency measures in a decarbonizing Europe, Ecol. Econ. 235 (2025) 108645, https://doi.org/10.1016/j.ecolecon.2025.108645.
[19] J. Lage, Sufficiency and transformation–A semi-systematic literature review of notions of social change in different concepts of sufficiency, Front. Sustain. 3 (2022), https://doi.org/10.3389/frsus.2022.954660.
[20] T. Princen, The Logic of Sufficiency, MIT Press, Cambridge, MA, 2005.
[21] M. Rudolf, M. Schmidt, Efficiency, sufficiency and consistency in sustainable development: reassessing strategies for reaching overarching goals, Ecol. Econ. 227 (2025) 108426, https://doi.org/10.1016/j.ecolecon.2024.108426.
[22] M. Sandberg, Sufficiency transitions: a review of consumption changes for environmental sustainability, J. Clean. Prod. 293 (2021) 126097, https://doi.org/10.1016/j.jclepro.2021.126097.
[23] C. Zell-Ziegler, J. Thema, B. Best, F. Wiese, J. Lage, A. Schmidt, E. Toulouse, S. Stagl, Enough? The role of sufficiency in european energy and climate plans, Energy Policy 157 (2021) 112483, https://doi.org/10.1016/j.enpol.2021.112483.
[24] A. Bierwirth, S. Thomas, Estimating the sufficiency potential in buildings: the space between underdimensioned and oversized, (2019). https://d-nb.info/1189206773/34.
[25] F. Wiese, N. Taillard, E. Balembois, B. Best, S. Bourgeois, J. Campos, L. Cordroch, M. Djelali, A. Gabert, A. Jacob, E. Johnson, S. Meyer, B. Munkácsy, L. Pagliano, S. Quoilin, A. Roscetti, J. Thema, P. Thiran, A. Toledano, B. Vogel, C. Zell-Ziegler, Y. Marignac, The key role of sufficiency for low demand-based carbon neutrality and energy security across Europe, Nat. Commun. 15 (2024) 9043, https://doi.org/10.1038/s41467-024-53393-0.
[26] S. Thomas, J. Thema, L.-A. Brischke, L. Leuser, M. Kopatz, M. Spitzner, Energy sufficiency policy for residential electricity use and per-capita dwelling size, Energ. Effi. 12 (2019) 1123–1149, https://doi.org/10.1007/s12053-018-9727-4.
[27] A. Mastrucci, B. Boza-Kiss, B. Van Ruijven, Towards net-zero emissions in global residential heating and cooling: a global scenario analysis, Clim. Change 178 (2025) 85, https://doi.org/10.1007/s10584-025-03923-6.
[28] M. Ma, S. Zhang, J. Liu, R. Yan, W. Cai, N. Zhou, J. Yan, Building floorspace and stock measurement: a review of global efforts, knowledge gaps, and research priorities, Nexus 2 (2025) 100075, https://doi.org/10.1016/j.ynexs.2025.100075.
[29] C.A. Balaras, E.G. Dascalaki, K.G. Droutsa, S. Kontoyiannidis, Empirical assessment of calculated and actual heating energy use in Hellenic residential buildings, Appl. Energy 164 (2016) 115–132, https://doi.org/10.1016/j.apenergy.2015.11.027.
[30] F. Belaïd, T. Garcia, Understanding the spectrum of residential energy-saving behaviours: French evidence using disaggregated data, Energy Econ. 57 (2016) 204–214, https://doi.org/10.1016/j.eneco.2016.05.006.
[31] G. Ruellan, S. Attia, G. Haesbroeck, Clustering of archetypal building-inhabitant pairs to improve energy efficiency: the case of the Walloon region in Belgium, Energy Build. 335 (2025) 115549, https://doi.org/10.1016/j.enbuild.2025.115549.
[32] M. Parti, C. Parti, The total and appliance-specific conditional demand for electricity in the household sector, Bell J. Econ. 11 (1980) 309–321, https://doi.org/10.2307/3003415.
[33] M. Papineau, K. Yassin, G. Newsham, S. Brice, Conditional demand analysis as a tool to evaluate energy policy options on the path to grid decarbonization, Renew. Sustain. Energy Rev. 149 (2021) 111300, https://doi.org/10.1016/j.rser.2021.111300.
[34] D.J. Aigner, C. Sorooshian, P. Kerwin, Conditional demand analysis for estimating residential end-use load profiles, Energy J. 5 (1984) 81–98, https://doi.org/10.5547/ISSN0195-6574-EJ-Vol5-No3-6.
[35] J.A. Dubin, D.L. McFadden, An econometric analysis of residential electric appliance holdings and consumption, Econometrica 52 (1984) 345, https://doi.org/10.2307/1911493.
[36] T. Loga, B. Stein, N. Diefenbach, TABULA building typologies in 20 European countries—Making energy-related features of residential building stocks comparable, Energ. Buildings 132 (2016) 4–12, https://doi.org/10.1016/j.enbuild.2016.06.094.
[37] S. Marinova, S. Deetman, E. van der Voet, V. Daioglou, Global construction materials database and stock analysis of residential buildings between 1970-2050, J. Clean. Prod. 247 (2020) 119146, https://doi.org/10.1016/j.jclepro.2019.119146.
[38] A. Mastrucci, B. van Ruijven, E. Byers, M. Poblete-Cazenave, S. Pachauri, Global scenarios of residential heating and cooling energy demand and CO2 emissions, Clim. Change 168 (2021) 14, https://doi.org/10.1007/s10584-021-03229-3.
[39] V. Daioglou, B.J. Van Ruijven, D.P. Van Vuuren, Model projections for household energy use in developing countries, Energy 37 (2012) 601–615, https://doi.org/10.1016/j.energy.2011.10.044.
[40] M.C.P. Moura, S.J. Smith, D.B. Belzer, 120 Years of U.S. residential housing stock and floor space, PLoS One 10 (2015) e0134135, https://doi.org/10.1371/journal.pone.0134135.
[41] L.T. Bolton, Space ratio: a measure of density potentials in the built environment, Sustain. Cities Soc. 75 (2021) 103356, https://doi.org/10.1016/j.scs.2021.103356.
[42] M. Santamouris, K. Kapsis, D. Korres, I. Livada, C. Pavlou, M.N. Assimakopoulos, On the relation between the energy and social characteristics of the residential sector, Energy Build. 39 (2007) 893–905, https://doi.org/10.1016/j.enbuild.2006.11.001.
[43] ISTAT, Household Budget Survey, (2025). https://www.istat.it/en/microdata/household-budget-survey-2/.
[44] J. Foster, S. Seth, M. Lokshin, Z. Sajaia, A unified approach to measuring poverty and inequality: theory and practice, The World Bank (2013), https://doi.org/10.1596/978-0-8213-8461-9.
[45] OECD, OECD Handbook on the Compilation of Household Distributional Results on Income, Consumption and Saving in Line with National Accounts Totals, OECD Publishing, 2024. https://doi.org/10.1787/5a3b9119-en.
[46] C. Balestra, F. Oehler, Measuring the joint distribution of household income, consumption and wealth at the micro level, 2023. https://doi.org/10.1787/f9d85db6-en.
[47] M. Brewer, C. O'Dea, Measuring living standards with income and consumption: evidence from the UK, IFS Working Papers (2012). https://ideas.repec.org//p/ifs/ifsewp/12-12.html (accessed January 26, 2026).
[48] H.-H. Noll, Consumption, Income and Living Standards. A review of related recent research activities., (2007).
[49] European Commission. Statistical Office of the European Union., Statistical matching of European Union statistics on income and living conditions (EU-SILC) and the household budget survey: 2017 edition., Publications Office, LU, 2017. https://doi.org/10.2785/933460.
[50] S. Sadaf, Income and consumption inequality trends: a comparative analysis between paid employees and the self-employed, J Labour Market Res 58 (2024) 13, https://doi.org/10.1186/s12651-024-00372-z.
[51] Eurostat, Glossary:Equivalised disposable income, (2025). https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Equivalised_disposable_income (accessed January 26, 2026).
[52] ARERA, Relazione annuale. Volume 1 - Stato dei servizi 2019., Autorità di Regolazione per Energia Reti e Ambiente (ARERA), 2020. https://www.arera.it/chi-siamo/relazione-annuale/relazione-annuale-2020.
[53] Eurostat, Household composition statistics, (2025). https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics.
[54] C. Reynaud, S. Miccoli, F. Lagona, Population Ageing in Italy: an Empirical Analysis of Change in the Ageing Index across Space and Time, Spat Demogr 6 (2018) 235–251, https://doi.org/10.1007/s40980-018-0043-6.
[55] C. Reynaud, S. Miccoli, Population ageing in Italy after the 2008 economic crisis: A demographic approach, Futures 105 (2019) 17–26. https://doi.org/10.1016/j.futures.2018.07.011.
[56] European Economic and Social Committee., Study on gender-disaggregated data on energy poverty: final study report., Publications Office, LU, 2024. https://data.europa.eu/doi/10.2864/44780 (accessed July 21, 2025).
[57] A. Field, J. Miles, Zoë, Field, Discovering statistics using R, Sage, London, 2012.
[58] R.V. Lenth, Least-squares means: the r package lsmeans, J. Stat. Soft. 69 (2016). https://doi.org/10.18637/jss.v069.i01.
[59] B. Jann, The Blinder–Oaxaca Decomposition for Linear Regression Models, The Stata Journal: Promoting Communications on Statistics and Stata 8 (2008) 453–479. https://doi.org/10.1177/1536867X0800800401.
[60] P.F. Lazarsfeld, N.W. Henry, Latent Structure Analysis, Houghton, Mifflin, 1968.

[61] L.M. Collins, S.T. Lanza, Latent Class and Latent Transition Analysis: With Applications in the Social, Behavioral, and Health Sciences, 1st ed., Wiley, 2009. https://doi.org/10.1002/9780470567333.
[62] R Core Team, R: A language and environment for statistical ## computing., (2021). https://www.R-project.org/.
[63] D. Brounen, N. Kok, J.M. Quigley, Residential energy use and conservation: Economics and demographics, Eur. Econ. Rev. 56 (2012) 931–945, https://doi.org/10.1016/j.euroecorev.2012.02.007.
[64] P.C. Reiss, M.W. White, Household electricity demand, Revisited, Rev Econ Studies 72 (2005) 853–883, https://doi.org/10.1111/0034-6527.00354.
[65] A. Alberini, W. Gans, D. Velez-Lopez, Residential consumption of gas and electricity in the U.S.: the role of prices and income, Energy Econ. 33 (2011) 870–881, https://doi.org/10.1016/j.eneco.2011.01.015.
[66] G. Besagni, M. Borgarello, L. Premoli Vilà, B. Najafi, F. Rinaldi, MOIRAE – bottom-up MOdel to compute the energy consumption of the Italian REsidential sector: Model design, validation and evaluation of electrification pathways, Energy 211 (2020) 118674, https://doi.org/10.1016/j.energy.2020.118674.
[67] G. Besagni, M. Borgarello, The determinants of residential energy expenditure in Italy, Energy 165 (2018) 369–386, https://doi.org/10.1016/j.energy.2018.09.108.
[68] M.-L. Delignette-Muller, C. Dutang, fitdistrplus: Help to Fit of a Parametric Distribution to Non-Censored or Censored Data. R package., (2025). https://CRAN.R-project.org/package=fitdistrplus.
[69] R. Dorfman, A formula for the gini coefficient, Rev. Econ. Stat. 61 (1979) 146, https://doi.org/10.2307/1924845.
[70] A. Jacobson, A.D. Milman, D.M. Kammen, Letting the (energy) Gini out of the bottle: Lorenz curves of cumulative electricity consumption and Gini coefficients as metrics of energy distribution and equity, Energy Policy 33 (2005) 1825–1832, https://doi.org/10.1016/j.enpol.2004.02.017.
[71] A. Druckman, T. Jackson, Measuring resource inequalities: the concepts and methodology for an area-based Gini coefficient, Ecol. Econ. 65 (2008) 242–252, https://doi.org/10.1016/j.ecolecon.2007.12.013.
[72] A. Gaspard, L. Chateau, C. Laruelle, B. Lafitte, P. Léonardon, Q. Minier, K. Motamedi, L. Ougier, A. Pineau, S. Thiriot, Introducing sufficiency in the building sector in net-zero scenarios for France, Energ. Buildings 278 (2023) 112590, https://doi.org/10.1016/j.enbuild.2022.112590.
[73] World Bank, World Bank Open Data, (2025). https://data.worldbank.org/.
[74] UBS, Global Wealth Report 2025, 2025. https://www.ubs.com/us/en/wealth-management/insights/global-wealth-report.html.
[75] S. Alkire, Dimensions of human development, World Dev. 30 (2002) 181–205, https://doi.org/10.1016/S0305-750X(01)00109-7.
[76] K. Čermáková, E. Hromada, Change in the affordability of owner-occupied housing in the context of rising energy prices, Energies 15 (2022) 1281, https://doi.org/10.3390/en15041281.
[77] C.Y. Chan, R.Y.S. Lai, B. Hoi, M.Y.Y. Li, J.H.Y. Chan, H.H.F. Sin, E.S.K. Chung, R.T. Y. Cheung, E.L.Y. Wong, The effect of dwelling size on the mental health and quality of life of female caregivers living in informal tiny homes in Hong Kong, BMC Public Health 24 (2024) 2578, https://doi.org/10.1186/s12889-024-19915-7.
[78] A. Riva, A. Rebecchi, S. Capolongo, M. Gola, Can homes affect well-being? A scoping review among housing conditions, indoor environmental quality, and mental health outcomes, IJERPH 19 (2022) 15975, https://doi.org/10.3390/ijerph192315975.
[79] J. Ruiz-Tagle, I. Urria, Household overcrowding trajectories and mental well-being, Soc. Sci. Med. 296 (2022) 114051, https://doi.org/10.1016/j.socscimed.2021.114051.
[80] L. Appolloni, D. D'Alessandro, Housing Spaces in Nine European Countries: a Comparison of Dimensional Requirements, IJERPH 18 (2021) 4278, https://doi.org/10.3390/ijerph18084278.
[81] R. Hoffmann, O. Patange, C. Zimm, S. Pachauri, C. Belmin, S. Pelz, E. Brutschin, J. S. Kikstra, M. Kuhn, J. Min, R. Muttarak, K. Riahi, T. Schinko, K. Mintz-Woo, Subnational survey data reveal persistent gaps in living standards across 75 low and middle-income countries, Nat. Commun. 16 (2025) 4986, https://doi.org/10.1038/s41467-025-60195-5.
[82] R. McClatchey, K. McClymont, E. Griffin, L. Carmichael, Community led housing, health and wellbeing: a comprehensive literature review, Int. J. Hous. Policy 25 (2025) 18–55, https://doi.org/10.1080/19491247.2023.2232200.
[83] D. Van Gasse, B. Wyninckx, Social support exchange in shared living arrangements with older adults—exploring the benefits of intergenerational living for older adults, Population Ageing 17 (2024) 277–295, https://doi.org/10.1007/s12062-023-09427-4.
[84] J.H. Arehart, F. Pomponi, B. D'Amico, W.V. Srubar, A new estimate of building floor space in North America, Environ. Sci. Technol. 55 (2021) 5161–5170, https://doi.org/10.1021/acs.est.0c05081.
[85] A. Foong, S. Svintsov, T. Seydewitz, A. Holsten, B.K. Reck, A global spatialized approach to estimate residential building floor area and material stocks, Resour. Conserv. Recycl. 221 (2025) 108398, https://doi.org/10.1016/j.resconrec.2025.108398.