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Abstract

Accurate projections of residential energy consumption are crucial for achieving decarbonization targets; however, most models overlook demographic dynamics, particularly changes in household composition, which significantly impact energy demand. This study addresses this gap by integrating demographic projections into bottom-up energy forecasts for Spain's residential sector from 2021 to 2039. By disaggregating households into nine types based on size and age structure, the model captures heterogeneous energy use patterns and their evolution over time. The results reveal a counterintuitive outcome: although projections indicate significant reductions in per-person and per-household energy consumption, total residential energy consumption is expected to increase by 0.80% over the 2024–2039 period. This is a direct consequence of the composition effect driven by sustained demographic change, specifically, the growing prevalence of smaller, higher-per-capita-use single-person and elderly households, which reduces economies of scale. These structural shifts effectively offset technical efficiency gains and behavioural changes, preventing an overall decline in energy demand. To meet Spain's target of a 1.69% annual reduction in residential energy use by 2030, per-household consumption must decrease by more than 3.4% annually, more than twice the historical rate. This research underscores the need to align housing and energy policies with demographic trends. Targeted strategies, such as promoting smaller, energy-efficient dwellings and accelerating building retrofits, are essential for achieving climate goals in an aging and increasingly fragmented society.

Keywords: Households, residential energy consumption, household type distribution, energy consumption scenarios, ageing, behavioral changes
JEL codes: D10, I31, J11, Q41, Q57

1. Introduction

The global energy transition underway in most countries hinges not only on the successful deployment of renewable energy, essential for decarbonization, but also on accurate projections of future energy consumption. These projections must reflect the expected evolution of economic activity, population, consumption patterns, and external shocks. Together, they are fundamental to defining realistic energy scenarios and policy targets. However, in many instances, public policy goals are overly ambitious and challenging to achieve, particularly in the residential sector.

Although it is widely recognized that demographic factors, such as aging populations, shrinking household sizes, and changing family structures, significantly shape residential energy demand, most energy forecasting models — primarily top-down and engineering-based approaches — still fail to incorporate these variables. The absence of household composition and age-related dynamics in current models results in projections that do not accurately reflect future consumption patterns, thereby undermining the precision and relevance of policy responses (1,2). Relying on historical energy use trends without accounting for demographic transformation can lead to systematic underestimation of future demand, as such models often assume static, homogeneous household structures (3,4). This modeling gap is reflected in policy design: despite empirical evidence showing that household characteristics substantially influence energy use (5,6), few energy policies are tailored to the diverse needs of households differentiated by size, age, or composition, thereby limiting both their effectiveness and equity.

This research, analyzing the case of Spain, argues that a key reason for the disconnect between policy goals and achievable outcomes lies in the neglect of demographic dynamics—specifically, changes in household composition—when projecting residential energy consumption. This is a critical oversight, particularly given that the residential sector accounts for a significant share of final energy consumption in many countries, with 17.85% in Spain in 2023 (7).

The relevance of this issue is underscored by the European Union's evolving climate policy. Since December 2019, the EU has committed to reducing greenhouse gas (GHG) emissions by 55% by 2030 compared to 1990 levels. In line with this, the European Commission introduced the "Fit for 55" legislative package in 2021, followed by the REPowerEU plan in 2022, both of which aimed to accelerate the energy transition in response to geopolitical shocks, including Russia's invasion of Ukraine (8).

Spain's national energy targets are outlined in its Integrated National Energy and Climate Plan (PNIEC). Following the revision of energy efficiency targets in EU Directive 2023/1791, Spain's updated PNIEC establishes cumulative energy savings of 53,593 ktoe from 2021 to 2030, of which 7,323.6 ktoe (13.7%) are expected from the residential sector. Within this, 4,979.4 ktoe (or 68%) is expected to result from improved energy efficiency in residential buildings, and 1,745.2 ktoe (or 23.8%) from the renovation of residential equipment (8). Given a residential energy consumption of 14,705.6 ktoe in 2021, and a target of 12,609 ktoe in 2030, this implies an annual reduction rate of 1.69% in residential energy consumption. PNIEC also sets the goal of reducing primary energy consumption per square meter in residential buildings by 16% by 2030 compared to 2020, implying the renovation of 1.37 million dwellings by 2030.

In Spain, the DENIO model—a dynamic econometric neo-Keynesian input-output model—has been used to evaluate the impact of energy policies. This model integrates input-output econometrics with computable general equilibrium (CGE) modeling, and is fed with projections from the TIMES-SINERGIA model developed by the Subdirectorate General of Energy Forecasting and Statistics (9). TIMES projects residential energy demand based on household numbers and elasticities, distinguishing among energy uses (heating, cooling, lighting, etc.) and housing types (single-family homes, multi-family dwellings with collective or individual systems). However, a critical limitation remains: while TIMES accounts for the number of households, it does not consider changes in the *distribution* of household types.

This problem is also shared by other recent studies (10), which employ the newly developed TIMES-Europe energy system model to investigate the contribution of the residential sector to achieving the EU's ambitious energy savings goals within the broader Fit-for-55 policy framework. Despite progress in energy systems modeling, which increasingly incorporates previously underrepresented elements of social-ecological systems, such as land use, water consumption, and human time allocation (11), analyses of the household sector often treat it as a single, aggregated entity. This approach overlooks disaggregation into specific household types, thereby limiting a more detailed understanding of how various household structures influence overall energy consumption patterns. The same issue is also observed in other studies analyzing residential energy consumption that focus on household spending (12,13).

We address this gap by employing a novel approach that integrates demographic variables, specifically the evolution of household types, into residential energy projections (14). This method facilitates the identification of distinct energy consumption patterns across household types and quantifies the substantial impact of shifts in household distribution on projected residential energy demand between 2021 and 2039. By isolating demographic drivers, specifically the growth in total household numbers and changes in their structural composition, the analysis distinguishes these effects from variations resulting from energy efficiency improvements and behavioral modifications; the latter may be influenced by price fluctuations or other exogenous factors that remain outside the scope of this research.

By doing so, the article aims to demonstrate how incorporating changes in household composition over time leads to more accurate projections of energy consumption for the residential sector, thereby allowing building more robust scenarios that may help tailor policies to mitigate the environmental impact of household energy consumption and achieve policy targets related to decarbonization and climate policies.

2. Related literature

Modeling future residential energy consumption has become increasingly complex as scholars strive to integrate an ever-growing number of determinants into forecasting tools. A substantial body of literature emphasizes the importance of demographic and household structural variables in shaping energy demand, yet these factors are often underrepresented in the predominant modeling approaches. Literature distinguishes between top-down and bottom-up modeling frameworks, each with unique advantages and limitations. Top-down models, as reported in the literature (15,16,17), provide valuable macroeconomic insights by capturing relationships between energy demand and broad economic or climatic variables, such as GDP per capita or heating degree days, which is particularly beneficial for understanding structural trends at national or regional scales. These models are well-suited to simulating large-scale scenarios, including the long-term effects of global warming and population growth. Their reliance on aggregate data makes them relatively easy to apply across countries or regions, especially when detailed household-level data is scarce. However, they struggle to capture the micro-level heterogeneity of household behavior and structure, which limits their ability to incorporate demographic transitions, such as population aging and household fragmentation (2).

In contrast, bottom-up models start from disaggregated data on individual households, buildings, and end-use appliances. This allows for more nuanced representations of residential energy consumption. Some research indicates that, with economic development and demographic change, the share of energy allocated to space heating, cooling, and appliances increases significantly (18). Other models demonstrate a strong correlation between residential electricity demand and the timing of active dwelling occupancy, generating occupancy profiles from time-use surveys (19). Other bottom-up approaches use stochastic simulation models to estimate electricity demand from appliance usage reported in time-use surveys, thereby identifying appliance-use time profiles that inform demand-side management policies (20). The ability to incorporate physical and behavioral heterogeneity makes bottom-up models more appropriate for assessing the effects of changing household structures, although they are data-intensive and computationally demanding.

Empirical studies have demonstrated that demographic and household structural changes are among the most significant drivers of residential energy consumption. Aging populations tend to increase energy use due to more extended periods of home occupancy, greater sensitivity to thermal conditions, and behavioral preferences for comfort. Early evidence (21,22) suggests that elderly households have higher occupancy rates and more extended periods of in-home activity, resulting in greater energy demand. Adult presence, rather than the number of children, is more strongly correlated with household energy consumption (23). These findings have been corroborated across different regions. This pattern has been confirmed to persist in the US even after controlling for income, climate, and housing type (24). Similar conclusions have been reached in Europe (25) and Japan (26).

Household composition—particularly the decline in average household size—has also emerged as a significant factor in residential energy dynamics. As fertility rates decline and longevity increases, households are becoming smaller and more often composed of single individuals. This trend undermines the economies of scale associated with shared energy use. An analysis of Chinese households found that reducing the number of household members by one increases per capita electricity consumption by 17.0–23.6% (27). In Japan, a 5% decrease in average household size was associated with a 3.5% increase in energy demand (28). The expansion of single-person households, particularly among the elderly, is especially noteworthy. Recent research indicates that solo living is becoming increasingly prevalent in high-income countries, particularly among elderly women, driven by gendered differences in life expectancy (29,30).

Socioeconomic variables introduce additional complexity to residential energy modeling. Income is one of the most robust predictors of energy consumption, as wealthier households tend to occupy larger homes, purchase more energy-consuming appliances, and maintain higher standards of thermal comfort. Research has found that income is closely linked to electricity use, even when controlling for building characteristics (5). The intersection of income and age further complicates this dynamic. While elderly households often have lower incomes, which could constrain energy use, they simultaneously spend more time at home and may underinvest in energy-saving technologies due to short expected payback periods or behavioral inertia (3). In Spain, research has found that retirees' longer periods of home occupancy are associated with higher energy expenditures, despite limited financial resources (13).

Urbanization and spatial distribution are also critical components of residential energy modeling. While the energy ladder hypothesis posits that urbanization leads to cleaner and more efficient energy use (31), the evidence is mixed. A transition in Chinese urban households from biomass to electricity and gas has been documented (32), as also observed during Spain's urbanization in the mid-20th century (33). However, per capita electricity use in Chinese urban areas has increased, driven by greater access to appliances and higher comfort expectations (34). In Spain, rural households consume more electricity on average than urban ones, partly due to housing typology, such as detached homes that require more energy (35). Urban sprawl also contributes to higher energy use, since it is correlated with increased electricity consumption, particularly among affluent households (36).

3. Methods and data

3.1. Classification of household types

Previous studies have demonstrated that economies of scale exist in household energy consumption. As the number of household members increases, total energy consumption also rises, but at a decreasing rate (26,27,28,37,38). Additionally, the age composition of household members significantly influences energy use. Numerous studies have shown that children generally consume less energy than adults, whereas older adults tend to consume more than the working-age population (3,26,39,40).

Building on these findings, this study classifies households into nine types based on size and composition:

Type 1. Working-age single-person households

Type 2. Senior single-person households

Type 3. Two-person households consisting solely of working-age persons

Type 4. Two-person households including at least one senior person

Type 5. Two-person households comprised of one adult and one child

Type 6. Three-person households consisting solely of adults

Type 7. Three-person households including at least one minor

Type 8. Four or more-person households comprised exclusively of adults

Type 9. Four or more-person households including at least one minor

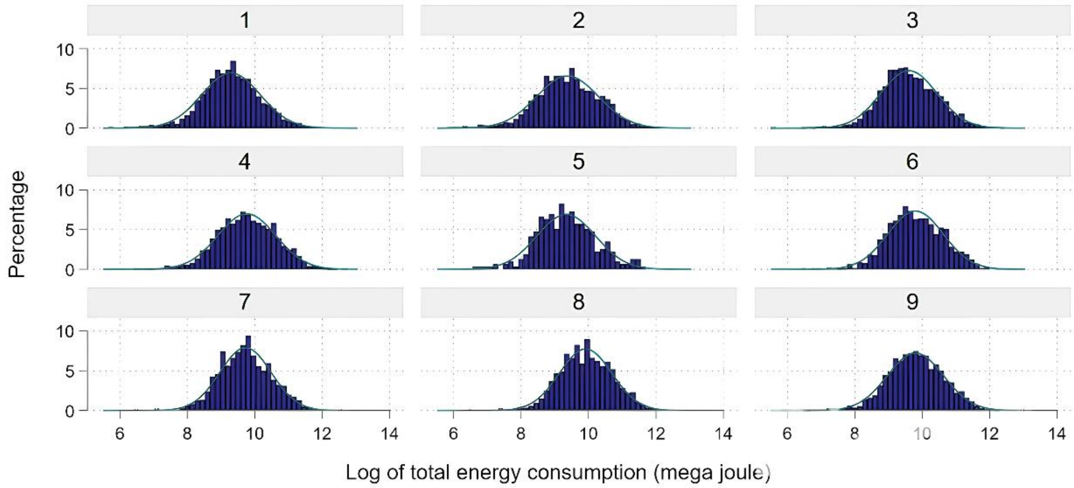
3.2. Energy consumption patterns by household type

To project changes in energy consumption by household type, this study utilizes data from the Household Budget Survey (41). The survey is conducted annually across Spain and collects detailed information on household expenditures for a wide range of goods and services, with approximately 20,000 households surveyed each year. To ensure data consistency, this study focuses on the period from 2006 to 2023. Microdata at the household level are available for download from the INE website.

Regarding energy, the survey reports both expenditure amounts and consumption levels by energy type in physical units. In this study, we focus on residential energy consumption, specifically electricity, natural gas, liquefied gas, and liquefied fuels. Hence, solid fuels such as firewood and transportation fuels (e.g., gasoline) are excluded from the analysis.[1] Additionally, because many households in Spain own secondary residences, their energy consumption is also accounted for in the calculation.

[1] The Household Budget Survey also collects information on household consumption of solid fuels, including coal, coke, coal agglomerates, wood, firewood, charcoal, and peat. In the 2023 survey, which included a sample of 20,707 households, 524 reported expenditures on coal and 1,574 reported expenditures on other solid fuels. These figures indicate that the proportion of households purchasing solid fuels is relatively low. Moreover, except for a minimal subset of households, reported expenditure amounts are minimal. Additionally, the number of households with accurately recorded quantities of solid fuel usage is minimal, making it challenging to estimate average household solid fuel consumption reliably. Given these limitations, solid fuels were excluded from the present analysis. Based on data from households that provided both expenditure and consumption records, the annual solid fuel energy consumption in fiscal year 2023 is estimated to be approximately 3,100 megajoules (MJ). Accordingly, the omission of solid fuels may result in an underestimation of average household energy consumption by approximately 13%.

Fig 1. Histogram of annual energy consumption by household type (2023)

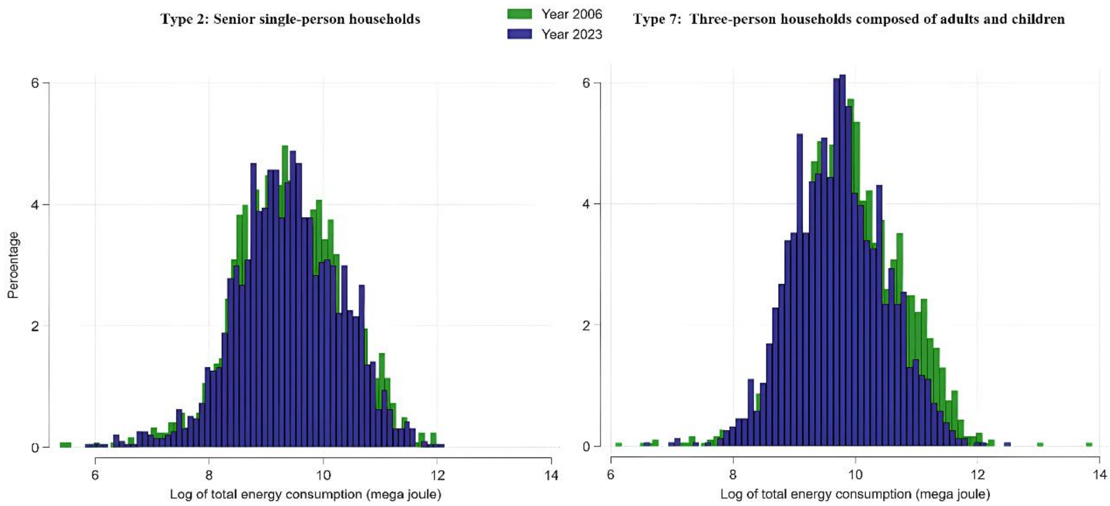


For this analysis, the consumption of the four selected energy types is standardized to standard units (megajoules, MJ), and total household energy consumption is calculated accordingly. The detailed calculation process is provided in Appendix 1.

Figure 1 illustrates the distributions of total annual energy consumption (MJ) by household type in 2023. The horizontal axis is presented on a logarithmic scale to enhance visualization. The solid curve represents an approximation using a normal distribution, which closely aligns with the shape of the histogram. This suggests that total annual household energy consumption itself follows a log-normal distribution.

This study aims to forecast future household energy consumption patterns by analyzing historical trends in energy consumption. Figure 2 illustrates the evolution of these patterns between 2006 and 2023. The left panel represents Type 2 senior single-person households, whereas the right panel corresponds to Type 7 three-person households composed of adults and children. Comparing the two figures reveals that changes in energy consumption patterns differ by household type.

Fig 2. Time series changes in energy consumption patterns



The energy consumption pattern in senior single-person households has remained relatively stable over time. In contrast, three-person households with adults and children have shown a downward trend in average energy consumption, indicating a broader shift toward reduced energy use attributable to energy-efficiency improvements or behavioral changes.

These results suggest that the potential for energy savings varies by household type, emphasizing the importance of policy approaches tailored to specific household types.

As noted earlier, annual household energy consumption, measured in MJ, tends to follow a lognormal distribution. Table 1 illustrates the evolution of this distribution over time. When considering all households, the average annual energy consumption declined from 30,086 MJ to 23,346 MJ, representing an average annual reduction rate of approximately 1.48%. It should be noted, however, that this decline was not uniform over time, as it was influenced by external factors, including the global financial crisis and the COVID-19 pandemic. For changes in energy consumption over the entire survey period, refer to Appendix 2.

Further analysis by household type reveals that average energy consumption decreased across all categories during the survey period, indicating overall progress in household energy conservation. However, the rate of decline varied considerably by household type. As shown in Table 1, larger households achieved larger reductions in energy use, whereas smaller households exhibited only modest decreases.

Additionally, Table 1 indicates a decrease in the standard deviation of energy consumption, suggesting that household energy usage patterns are becoming increasingly similar over time.

Table 1. Changes in the energy consumption distribution function

	year	Observations	Skewness	mean (MJ)	Change (%)	std. dev. (MJ)	Change (%)	Median	Change (%)
Type 1	2006	1,419	7.4	18,881		25,970		10,951	
	2023	2,596	3.1	16,165	-0.91%	16,444	-2.65%	11,179	2.08%
Type 2	2006	1,227	2.6	18,206		18,508		11,642	
	2023	1,903	2.7	18,680	0.15%	18,582	0.02%	12,574	8.00%
Type 3	2006	3,258	14.7	26,811		33,695		18,229	
	2023	3,745	3.0	22,010	-1.15%	21,565	-2.59%	14,869	-18.43%
Type 4	2006	2,102	5.8	28,901		34,959		19,177	
	2023	2,673	3.7	27,236	-0.35%	25,956	-1.74%	19,320	0.75%
Type 5	2006	171	5.5	21,322		30,718		12,168	
	2023	316	2.7	17,017	-1.32%	17,849	-3.14%	11,241	-7.62%
Type 6	2006	2,852	2.9	32,042		29,517		23,102	
	2023	2,586	2.6	26,504	-1.11%	24,160	-1.17%	18,710	-19.01%
Type 7	2006	1,849	13.0	30,662		36,736		21,127	
	2023	1,532	3.2	23,007	-1.68%	20,307	-3.43%	17,001	-19.53%
Type 8	2006	1,638	16.9	38,010		48,368		27,150	
	2023	1,274	2.0	28,706	-1.64%	23,194	-4.23%	21,600	-20.44%
Type 9	2006	4,478	5.3	35,785		36,294		25,270	
	2023	3,432	3.8	26,159	-1.83%	24,518	-2.28%	18,613	-26.34%
All households	2006	18,994	10.3	30,086		34,927		20,785	
	2023	20,057	3.2	23,346	-1.48%	22,565	-2.54%	16,196	-22.08%

Type 1. Working-age single-person households; Type 2. Senior single-person households; Type 3. Households consisting of two working-age persons; Type 4. Two-adult households including at least one senior person; Type 5. Two-person households comprised of one adult and one child, Type 6. Three-person households consisting solely of adults; Type 7. Three-person households including at least one minor, Type 8. Four or more-person households consisting solely of adults; Type 9. Four or more-person households including at least one minor

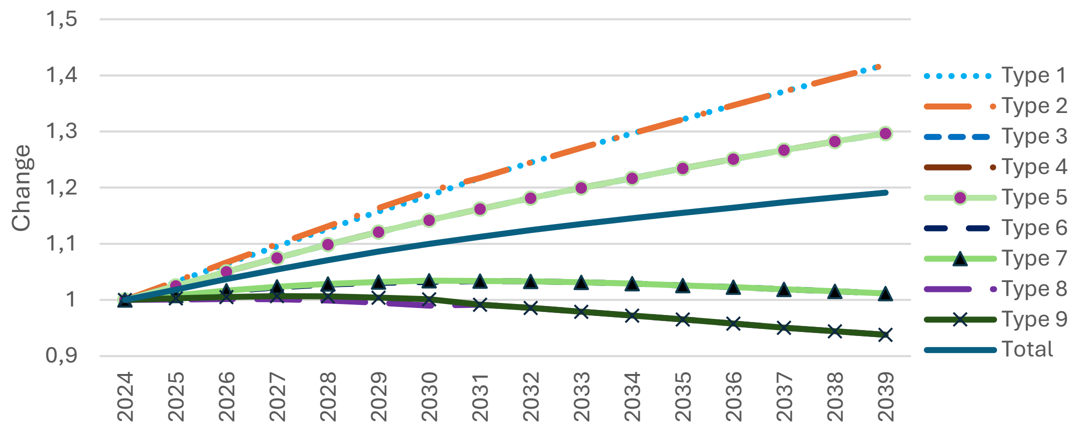
3.3. Future estimates of household composition

Accurate estimation of household energy consumption requires well-founded assumptions about future trends in household numbers, household composition, and energy-use patterns. In this study, we estimated the number of households across nine household types using projections of household size published by the National Institute of Statistics (42), which extend through 2039. The detailed methodology for these estimates is provided in Appendix 3, and the resulting figures are presented in Table

A.1. In the subsequent analysis, the number and composition of households are assumed to follow the projections outlined in this table.

Figure 3 shows the changes in the number of households (by type) from 2024 to 2039. According to INE projections, the total number of households is expected to increase by approximately 10% between 2024 and 2030. It is shown with a bold solid line in Figure 3; however, the growth rate varies significantly by household type. The number of Type 1 (working-age single-person households) and Type 2 (elderly single-person households) is projected to increase by approximately 19%. In contrast, the number of three-person households is expected to grow by only approximately 3%, whereas the number of households with four or more members is projected to remain nearly unchanged. These results indicate that household sizes in Spain will continue to shrink.

Fig 3. Household growth rate (base = 2024)



3.4. Extraction of energy consumption patterns by household type

Due to the presence of a relatively small number of households with disproportionately high energy consumption, the distribution of household energy use exhibits a long-tailed pattern. A log-normal distribution can reasonably approximate this distribution. Although it is technically feasible to conduct simulation analyses directly using the log-normal distribution, assuming a constant rate of change over time, such time-series transformations are often complex to interpret both intuitively and visually. Moreover, conducting simulations under this framework requires consideration of an extensive range of potential energy consumption values.

For these reasons, in the subsequent analysis, residential energy consumption is logarithmically transformed and approximated by a normal distribution, which is then employed for simulation purposes. Over time, the mean of the residential energy consumption distribution is observed to decline, and the standard deviation tends to decrease in most instances. The reduction in the mean can largely be attributed to improvements in energy efficiency and behavioral changes. At the same time, the decline in the standard deviation is likely a result of the widespread adoption of energy-saving technologies and behavioral changes, leading to a more uniform implementation of efficiency measures across households.

The energy consumption $c_{k,t}$ of k-type households in the year t is assumed to follow the following log-normal distribution,

$$f(c_{k,t}; \mu_{k,t}, \sigma_{k,t}^2) = \frac{1}{\sqrt{2\pi(\sigma_{k,t})^2} c_{k,t}} exp\left(-\frac{(\ln c_{k,t} - \mu_{k,t})^2}{2(\sigma_{k,t})^2}\right) \qquad 0 < c_{k,t} < \infty \quad [1]$$

where $\mu_{k,t}$ and $\sigma_{k,t}^2$ are mean and variance. Furthermore, we assume that the mean and standard deviation change at constant rates, but at different rates.

$$\frac{\mu_{k,t+1}}{\mu_{k,t}} = \theta \cdot r_k^{\mu}, \qquad [2]$$

$$\frac{\sigma_{k,t+1}}{\sigma_{k,t}} = \theta \cdot r_k^{\sigma}. \qquad [3]$$

In this context, r denotes the historical rate of change in energy consumption observed between 2006 and 2023, while θ represents the acceleration rate—an indicator that quantifies the extent to which future energy efficiency improvements and behavioral changes outpace historical trends. Over time, average household energy consumption declines, and variation in energy consumption across households also diminishes. The parameter θ determines the speed at which this trend unfolds.

In the baseline analysis, it is assumed that the rate of change from 2006 to 2023 will continue unchanged; accordingly, θ is set to 1. Under this assumption, the expected energy consumption of k-type households is

$$E[c_{k,t}] = exp\left(\mu_{k,t} + \frac{(\sigma_{k,t})^2}{2}\right). \qquad [4]$$

Then, the "total" energy consumption of k-type households in the year t is

$$E[TC_{k,t}] = H_{k,t} \cdot E[c_{k,t}]. \qquad [5]$$

where $H_{k,t}$ is the number of k-type households. The total energy consumption of the household sector is calculated by adding up the energy consumption of nine types of households,

$$E[TC_t] = \sum_k E[TC_{k,t}]. \qquad [6]$$

4. Analyzing residential energy consumption scenarios in Spain

4.1. Model 1: Analysis not considering household composition

This model aggregates data across all household types, using pooled data. It is assumed that household energy consumption will continue to decline, consistent with historical trends, while the number of households will increase in line with projections. Specifically, household energy consumption is assumed to decrease at the rate reported in Table 1, whereas the number of households is assumed to increase at the rate shown in Table 2.

The estimates suggest that if the current rate of energy savings continues, final energy consumption in the household sector will increase by approximately 0.78%, from 450,352 TJ in 2024 to 453,854 TJ in 2030, driven by an increase in the number of households. However, over time, the impact of energy efficiency improvements and behavioral changes is projected to exceed that of household growth, resulting in a 4.16% decrease in energy consumption by 2039 relative to 2024.[2]

The table illustrates changes in energy consumption per household and per capita, both of which decline. However, the rate of decrease in per capita energy consumption is lower than that observed for per-household energy consumption. This discrepancy suggests that a reduction in average household size is offsetting a portion of the energy efficiency gains.

Table 2. Estimation of total energy consumption

	2024	2030		2039	
Demographic projection: INE (2023)			Δ		Δ
Population (person)	48,610,458	51,876,064	6.72%	53,747,905	10.57%
Households (number)	19,310,776	21,244,779	10.02%	23,001,927	19.11%
Model 1: Pooled data estimate					
Expected total energy consumption (TJ) $E[TC_t]$	450,352	453,854	0.78%	431,596	-4.16%
Energy consumption per person (MJ)	9,265	8,749	-5.57%	8,030	-13.33%
Energy consumption per household (MJ)	23,321	21,363	-8.40%	18,763	-19.54%
Model 2: Disaggregated data estimate					
Expected total energy consumption (TJ) $E[TC_t]$	422,566	432,626	2.38%	425,933	0.80%
Energy consumption per person (MJ)	8,693	8,340	-4.06%	7,925	-8.84%
Energy consumption per household (MJ)	21,882	20,364	-6.94%	18,517	-15.38%

4.2. Model 2: Analysis considering household composition

This model disaggregates households into nine types and projects energy consumption for each type. As in Model 1, we assume that household energy consumption will

[2] Since future population projection data have been available since 2024, the fiscal year 2024 projections are used as the baseline.

continue to decline in the future based on past trends (Table 1). In contrast, the number of households will increase in accordance with future projections (Table 2).

Table 3 presents the projected changes in the number of households by household type, along with corresponding energy consumption patterns. The central column of the table reports changes in per-household energy consumption, reflecting anticipated reductions attributable to technological advancements and behavioral changes. Time-series changes in energy consumption by household type are calculated as the product of changes in the number of households in each category and changes in per-household energy consumption. The resulting estimates are presented in the "Expected energy consumption" column.

Table 3. Estimation of energy consumption by household type (The percentage change with respect to 2024 is shown in parentheses.)

	Household number projected, $H_{k,t}$ (number)			Energy consumption per household, $E[c_{k,t}]$ (MJ)			Expected energy consumption, $E[TC_{k,t}]$ (TJ)		
	2024	2030	2039	2024	2030	2039	2024	2030	2039
Type 1	3,160,310	3,759,011	4,483,355	15,710	15,047	14,217	49,648	56,560	63,740
		(18.9%)	(41.9%)		(-4.2%)	(-9.5%)		(13.9%)	(28.4%)
Type 2	2,273,659	2,704,390	3,225,514	18,005	17,932	17,824	40,937	48,496	57,491
		(18.9%)	(41.9%)		(-0.4%)	(-1.0%)		(18.5%)	(40.4%)
Type 3	2,433,878	2,780,013	3,156,131	20,717	19,289	17,350	50,424	53,624	54,758
		(14.2%)	(29.7%)		(-6.9%)	(-16.3%)		(6.3%)	(8.6%)
Type 4	2,693,969	3,077,092	3,493,404	25,088	24,337	23,312	67,586	74,888	81,439
		(14.2%)	(29.7%)		(-3.0%)	(-7.1%)		(10.8%)	(20.5%)
Type 5	426,323	486,953	552,835	16,456	15,386	13,944	7,016	7,492	7,709
		(14.2%)	(29.7%)		(-6.5%)	(-15.3%)		(6.8%)	(9.9%)
Type 6	2,438,133	2,518,873	2,466,078	25,021	23,414	21,213	61,005	58,977	52,313
		(3.3%)	(1.1%)		(-6.4%)	(-15.2%)		(-3.3%)	(-14.2%)
Type 7	1,429,109	1,476,436	1,445,490	21,999	19,942	17,269	31,439	29,443	24,963
		(3.3%)	(1.1%)		(-9.4%)	(-21.5%)		(-6.3%)	(-20.6%)
Type 8	1,615,478	1,610,625	1,515,304	26,934	24,584	21,479	43,512	39,596	32,547
		(-0.3%)	(-6.2%)		(-8.7%)	(-20.3%)		(-9.0%)	(-25.2%)
Type 9	2,839,916	2,831,386	2,663,816	25,001	22,445	19,136	71,000	63,550	50,974
		(-0.3%)	(-6.2%)		(-10.2%)	(-23.5%)		(-10.5%)	(-28.2%)

Type 1. Working-age single-person households; Type 2. Senior single-person households; Type 3. Households consisting of two working-age persons; Type 4. Two-adult households including at least one senior person; Type 5. Two-person households comprised of one adult and one child, Type 6. Three-person households consisting solely of adults; Type 7. Three-person households including at least one minor, Type 8. Four or more-person households consisting solely of adults; Type 9. Four or more-person households including at least one minor

While energy consumption per household is projected to decline across all household types, the magnitude of these reductions varies. According to projections, energy consumption is expected to decrease by approximately 15–23% for three-person households (Types 6-7) and those with four or more members (Types 8-9) between 2024 and 2039. In contrast, the reduction is projected to be considerably smaller for single-person (Types 1-2) and two-person households (Types 4-5). For instance, energy consumption among single-person senior households (Type 2) is expected to decrease by only about 1%. Furthermore, shifts in household composition also differ by type. Consequently, total expected energy consumption is projected to decrease substantially for households with three or more persons. In contrast, an increase is expected for single-person and two-person households, given their growing prevalence.

The aggregated results for all households, derived by summing the outcomes for each household type presented in Table 3, are reported in Model 2, located in the lower section of Table 2. When these results are compared with those from Model 1 in the upper section of the table, it is evident that although both models exhibit similar overall trends, Model 2 yields a more conservative estimate of the effectiveness of energy efficiency improvements and behavioral changes. For instance, the projected reduction in per capita energy consumption between 2024 and 2039 is 13.33% in Model 1, whereas it is only 8.84% in Model 2. Similarly, the reduction in per-household energy consumption is 19.54% in Model 1, compared to 15.38% in Model 2.

The divergence among these modelling approaches yields substantially different projections of total energy consumption. While Model 1, which assumes a uniform rate of energy conservation across all categories, anticipates a 4.16% decrease in total household energy consumption by 2039, Model 2, a disaggregated approach that allows for variation across different household types, projects a slight increase of 0.80%. This discrepancy underscores the critical impact of demographic dynamics, which are frequently overlooked in standard energy forecasts. Crucially, although projections indicate significant reductions in both energy consumption per person and per household during the 2024–2039 period, the expected total energy consumption unexpectedly increases by 0.80%. This counterintuitive outcome is a direct consequence of the composition effect driven by sustained demographic change, namely the growing prevalence of smaller household sizes that are less efficient due to reduced economies of scale. These structural shifts in household formation effectively offset technical efficiency gains and behavioral changes, thus preventing an overall decline in household energy demand.

5. Energy Conservation in Households and Society: Can Spain Achieve Its Energy Conservation Targets for the Residential Sector?

As previously noted, the Spanish government has set an ambitious target to reduce final energy consumption in the residential sector by 1.69% annually. However, given that energy consumption in this sector has declined at an average annual rate of only 1.48% over the past 17 years, achieving the stated target presents a considerable challenge. Compounding this difficulty is the demographic shift: the average household size has already decreased, and the relative contribution of large households, which have historically played a significant role in reducing energy consumption, is expected to diminish further. Conversely, the number of small households, particularly those with one or two persons, is projected to increase substantially. This trend is likely to erode the benefits of economies of scale in residential energy consumption, further complicating efforts to meet energy conservation targets.

The analysis in the previous section projects future residential energy consumption under the assumption that the historical rate of energy savings continues. However, should more proactive and comprehensive energy conservation policies be implemented, it may be possible to accelerate the rate of improvement. This section examines the extent of additional effort required to meet the targets set by the Spanish government.

When evaluating energy conservation in the context of demographic changes, such as growth in household numbers and shifts in household composition, it is crucial to distinguish between energy conservation at the societal and household levels. The total societal rate of reduction in energy consumption does not correspond to the per-household consumption rate. As the number of households increases and average household size declines, overall energy conservation in the residential sector tends to decrease. Therefore, to offset the negative impact of these demographic trends, household-level energy conservation efforts must exceed the societal-level reduction targets. This discrepancy is clearly illustrated in Table 4, which highlights the divergence between the required energy conservation at the aggregate and household levels.

Table 4. Energy conservation at home and in society

	2021	2030						
Number of households	18,083,690	21,244,779						
Acceleration rate (θ)		1.00	1.25	1.50	1.75	2.00	2.25	2.50
Model 1								
Total energy consumption (TJ)	488,517	453,854	442,462	431,387	420,619	410,150	399,970	390,070
Rate of reduction		-0.81%	-1.09%	-1.37%	-1.65%	-1.92%	-2.20%	-2.47%
Energy use per household (MJ)	27,014	21,363	20,827	20,306	19,799	19,306	18,827	18,361
Rate of reduction		-2.57%	-2.85%	-3.12%	-3.39%	-3.66%	-3.93%	-4.20%
Model 2								
Total energy consumption (TJ)	461,360	432,626	425,079	417,746	410,620	403,693	396,960	390,414
Rate of reduction		-0.71%	-0.91%	-1.10%	-1.29%	-1.47%	-1.66%	-1.84%
Energy use per household (MJ)	25,512	20,364	20,009	19,663	19,328	19,002	18,685	18,377
Rate of reduction		-2.47%	-2.66%	-2.85%	-3.04%	-3.22%	-3.40%	-3.58%

In 2021, there were 18,083,690 households in Spain. According to estimates from the Household Budget Survey, total energy consumption in the residential sector amounted to 488,517 TJ, corresponding to an average household energy consumption of 27,014 MJ. The number of households is projected to increase to 21,244,779 by 2030. Based on projections from Model 1, if energy efficiency improvements continue at the historical rate, total energy consumption is expected to decline to 453,854 TJ by 2030. It is worth noting that energy consumption in 2021 was higher than in other years, likely due to the impact of the COVID-19 pandemic. Under this scenario, the implied annual rate of energy conservation at the societal level is approximately 0.81%.

The acceleration rate (θ) defined in Equations 2 and 3 in Section 3.3 measures the extent to which energy conservation efforts exceed historical trends. The subsequent column in Table 4 reports projections under a scenario in which the acceleration rate is set to 1.25 times the historical rate; under Model 1, this corresponds to a 1.09% annual reduction in total societal energy consumption. However, when accounting for the increase in the number of households, achieving this level of energy savings would require a 2.85% annual reduction in energy consumption per household.

By contrast, projections based on Model 2, which incorporate changes in household composition, indicate that achieving the same overall reduction would require a 2.66% annual decrease in energy consumption per household. The same interpretive framework applies to the remaining acceleration-rate scenarios.

To assess the feasibility of the target set by the Spanish government, it is necessary to examine the additional efforts required. In Model 1, total household energy consumption in 2021 is estimated at 488,517 TJ. To meet the governmental target, energy consumption must decline to 419,043 TJ by 2030. Achieving this reduction requires an acceleration rate exceeding 1.75, corresponding to an annual decrease in per-household energy consumption of more than 3.39%.

In contrast, Model 2 estimates total household energy consumption at 461,360 TJ in 2021. To achieve the 2030 target of 395,748 TJ, an acceleration rate exceeding 2.25 is required. This implies that per-household energy consumption must decrease at an annual rate exceeding 3.40%.

These findings indicate that, regardless of the model, achieving a 1.69% annual reduction in residential energy consumption at the societal level will require a household-level annual decrease of more than 3.40%. This highlights the significant challenge posed by demographic shifts, particularly the rise in the number of smaller households, and underscores the need for more rigorous and comprehensive energy conservation measures to meet national targets.

6. Discussion and conclusions

This study examined the impact of changes in household composition on national residential energy consumption, highlighting a potential obstacle to achieving official energy conservation targets. Among the various findings, three results stand out as particularly significant. First, the projected growth of small households, particularly among elderly and single-person households, will significantly alter the composition of energy demand, presenting challenges for per-capita efficiency. Second, historical energy reductions have been more substantial in larger households; however, their declining share of the population reduces their impact on future savings. Third, achieving national energy conservation goals will require a sustained and accelerated decline in per-household energy use, more than twice the historical rate, underscoring the urgency for policy interventions tailored to evolving household demographics.

The analysis of residential energy consumption in Spain highlights demographic dynamics that align with broader findings in the literature on household structure and energy demand. Between 2024 and 2030, the total number of households in Spain is projected to grow by nearly 10%, rising from 19.31 million to 21.24 million. Increases in single-person households primarily drive this expansion, with both working-age and elderly households expected to grow by approximately 19%. Such demographic shifts toward smaller households have been observed across high-income countries (30,43). In Spain, the rising prevalence of elderly-headed and single-occupancy households has been documented starting in the 1980s (12). As fertility rates decline and longevity increases, the decline in average household size undermines economies of scale in shared energy use (27,28), a trend that our projections confirm for Spain.

In recent decades, the pace of this demographic shift has been tempered by a substantial influx of immigrants, primarily of working age and with higher fertility rates than the native population. Without this migration, which accounted for a significant share of household growth, Spain's demographic structure would have trended more sharply toward an older population. Specifically, between 2001 and 2011, the foreign-national population rose from 1.54 million (3.79% of the total) to 5.24 million (11.20%). Furthermore, while 65% of Spanish nationals were of working age in 2011, this figure was 79.8% among foreign residents, indicating a relatively higher proportion of the foreign-born in the labor force. These trends remained stable through 2021, with foreign residents totaling 5.4 million (11.4% of the population), 75.7% of whom were of working age.

In 2023, household energy consumption exhibited a log-normal distribution across all nine household types, with larger households consuming more energy on average but also displaying greater variance. Specifically, the mean annual consumption ranged from approximately 16,165 MJ for working-age single-person households to 38,010 MJ for households with four or more adults. This pattern of higher energy requirements for larger households aligns with findings that adult presence correlates more strongly with energy use than the number of children (23) and that larger dwellings and appliance stocks drive consumption (5).

Historical trends from 2006 to 2023 show that average energy consumption per household in Spain decreased from 30,086 MJ to 23,346 MJ—an annual decline of 1.48%—while the standard deviation of consumption fell by 2.54% per year. Larger households experienced even steeper reductions (up to –1.83% per year in mean consumption), suggesting that economies of scale and the widespread adoption of efficiency measures and behavioral changes have a greater impact when absolute consumption is higher, as observed in the literature (5,13). In contrast, elderly single-person households exhibited a slight increase in average consumption (+0.15% per year), consistent with empirical evidence that aging populations tend to increase energy use due to more extended occupancy and greater sensitivity to thermal comfort (24,44).

When examining energy consumption by household type, the analysis underscores divergent trajectories. Three- and four-plus-person households (Types 6–9) are projected to achieve substantial reductions in average consumption, ranging from 15% to 23% between 2024 and 2039, due to both efficiency gains and behavioral changes, as well as slower growth in household numbers. This finding is consistent with evidence suggesting that larger households benefit more from energy-saving measures and economies of scale (5,13). In contrast, single-person and two-person households (Types 1–5), particularly elderly single-person households (Type 2), experience only modest per-household declines—about 1% for Type 2—while their aggregate consumption rises because these household types expand more rapidly. This result is consistent with previous research (30), which notes that the increase in solo living, especially among elderly women, increases energy intensity per dwelling, even if per-capita electricity use remains variable (5,30).

Comparing the two modelling approaches underscores how neglecting demographic dynamics can lead to overly optimistic energy forecasts. By 2039, Model 1, which omits household composition, projects a 4.16% reduction in total residential energy use relative to 2024. In contrast, the disaggregated Model 2 forecasts a slight increase of 0.80%. This discrepancy arises even though both models predict significant reductions in per-household and per-capita consumption: 19.54% and 13.33%, respectively, in Model 1, compared to 15.38% and 8.84% in Model 2. This counterintuitive outcome is a direct consequence of the composition effect driven by sustained demographic change, specifically the growing prevalence of smaller household sizes. These discrepancies, which amount to nearly one-fourth of the projected values, align with established literature suggesting that models omitting demographic variables systematically underestimate future energy demand (1,2). Ultimately, these structural shifts in household formation effectively offset technical efficiency gains and behavioral changes, preventing an overall decline in residential demand. These findings underscore the critical need to integrate demographic trends into energy policy and decarbonization strategies.

Analysis of energy conservation requirements between 2021 and 2030, as required to meet the official targets set by the PNIEC, further reinforces the central role of demographics in achieving these targets. In 2021, total residential consumption stood at 488,517 TJ across 18.08 million households (27,014 MJ/household). Under the historical conservation rate ($\theta = 1$), Model 1 forecasts a reduction to 453,854 TJ by 2030 (0.81% annual societal reduction; 2.57% yearly household reduction), while Model 2 yields 432,626 TJ (0.71% societal; 2.47% yearly household). To meet the government's target of a 1.69% annual societal reduction—translating to 419,043 TJ in Model 1 or 395,748 TJ in Model 2 by 2030—θ must exceed 1.75 in Model 1 (requiring > 3.39% yearly household reduction) and 2.25 in Model 2 (> 3.40% yearly household reduction). These requirements vastly exceed historical rates, demonstrating that demographic shifts toward smaller households make policy targets more challenging. This aligns with the literature, which highlights that demographic blind spots in modeling lead to overly optimistic decarbonization pathways (3).

Based on these findings, two primary policy directions emerge: reducing the average dwelling size and significantly scaling up energy-efficient home renovations and retrofits.

First, aligning new housing supply with demographic shifts requires promoting smaller, more compact homes, especially in urban areas, and prioritizing vertical housing (e.g., apartments) over detached or semi-detached houses. Detached housing, often associated with higher energy consumption, remains prevalent in low-density areas, where floor area per capita is higher, and energy demand is elevated (35). This policy aligns with international literature indicating that floor area is a significant predictor of household electricity use (45,46,47,48,49) and residential energy consumption (44). In Spain, urban sprawl, particularly in high-income and coastal areas, is correlated with increased electricity consumption (36), underscoring the need for compact urban development strategies. Research in coastal Spain has also found that the higher the number of dwellings per building, the lower the energy consumption per dwelling (50). Therefore, in Spain, where 41.2% of total residential energy use in 2022 was accounted for by heating (51), the potential savings from smaller dwellings would be enormous.

Second, to meet the PNIEC's target of reducing residential energy consumption per square meter by 16% by 2030, Spain must retrofit at least 1.37 million dwellings. However, as of April 2025, the Professional College of Property Managers estimates that only 285,000 renovations will be completed by that date, far below the target (52). This represents less than a quarter of the target and reflects the broader trend of underperformance in residential-sector energy conservation. This underscores the urgent need to accelerate the implementation of the Long-Term Strategy for Energy Rehabilitation in the Building Sector, which aims to achieve a zero-emission housing stock by 2050 (53), and which already includes tax incentives and lump-sum subsidies. Efforts should prioritize the oldest and most energy-inefficient buildings, frequently inhabited by low-income and elderly residents, by streamlining administrative processes, enhancing financial instruments such as green loans and subsidies, and providing robust technical support.

These two policy priorities—downsizing dwellings and massively scaling up retrofits—are interdependent and mutually reinforcing. Smaller, energy-efficient homes not only align better with demographic realities but also offer a more cost-effective path to meeting Spain's energy targets. Without these structural transformations, the growing number of small households will offset much of the expected energy savings from efficiency improvements. Future residential energy policy must therefore be spatially and demographically aware, ensuring that the housing system evolves in line with the social and environmental demands of the coming decades.

The primary limitation of this research resides in the divergent treatment of demographic dynamics between the two analytical frameworks employed. Model 1 utilizes an aggregate approach that prioritizes total consumption volume over internal household structure. By relying on pooled data across all household types, it implicitly assumes a static, homogeneous household structure over time. This model adopts a uniformity assumption, projecting a consistent rate of energy conservation across the residential sector regardless of the inhabitants' age or household size. In contrast, Model 2 employs a disaggregated framework to capture heterogeneous demographic shifts. While this model accounts for the trend toward shrinking household sizes and aging populations, its results are constrained by specific assumptions regarding the impact of reduced economies of scale. Based on empirical data for 2006-2023, the analysis assumes that as households become smaller and more fragmented, they inevitably become less efficient, thereby offsetting expected technological gains and behavioral changes. Furthermore, the model assumes that energy conservation potential is intrinsically tied to specific household types. Moreover, cohort effects are not considered. Given that previous studies have shown that future energy consumption patterns are shaped by changes in population structure and the overlap of generational profiles[3], the estimation results presented in this paper may be biased by the omission of cohort effects.

The study's results would likely shift significantly if alternative demographic or behavioral assumptions were applied to the residential energy models. Regarding the tension between behavioral adaptation and structural inertia, if the models assumed that smaller or elderly households could adopt high-efficiency behavioral changes, such as smart home automation or communal living arrangements, the efficiency penalty associated with fragmentation might be less severe than Model 2 suggests. Furthermore, while the current model assumes that energy conservation rates follow historical trends (r) or fixed acceleration rates (θ), a rapid breakthrough in affordable, small-scale retrofit technology could cause the modest reduction rates projected for senior households to be substantially exceeded. Finally, alternative migration or urbanization trends could alter projected outcomes, as the study currently relies on projections assuming a continued rise in single-person units. Should economic factors or social policies encourage a return to multi-generational living, the economies of scale currently being lost would reappear, making national energy targets significantly easier to achieve without the drastic 3.4% annual per-household reduction that the model identifies as necessary.

Future research should prioritize disaggregated modeling of energy behavior and technology adoption among elderly and single-person households. It could also examine in more detail differences in energy consumption patterns between immigrant and non-immigrant households. Longitudinal studies are needed to understand how aging impacts energy use over time. It would be helpful if the Household Budget Survey, for instance, retained the same households in the sample for more than two periods, as it currently does, so that following households' behavior over their life cycle and as they age would provide valuable information for policy design. In the meantime, as suggested by one of the reviewers, we may create a pseudo-panel using Household Budget Survey data as an alternative to tracking families over time.

Appendix 1. Calculation of total energy consumption

In the Household Budget Survey, energy consumption is reported in different units: electricity in kWh, city and natural gas in m^3, liquefied gas in kg, and liquid fuel in liters. To ensure comparability, we convert these values into megajoules (MJ) using standard conversion factors from the OECD and International Energy Agency (54). The

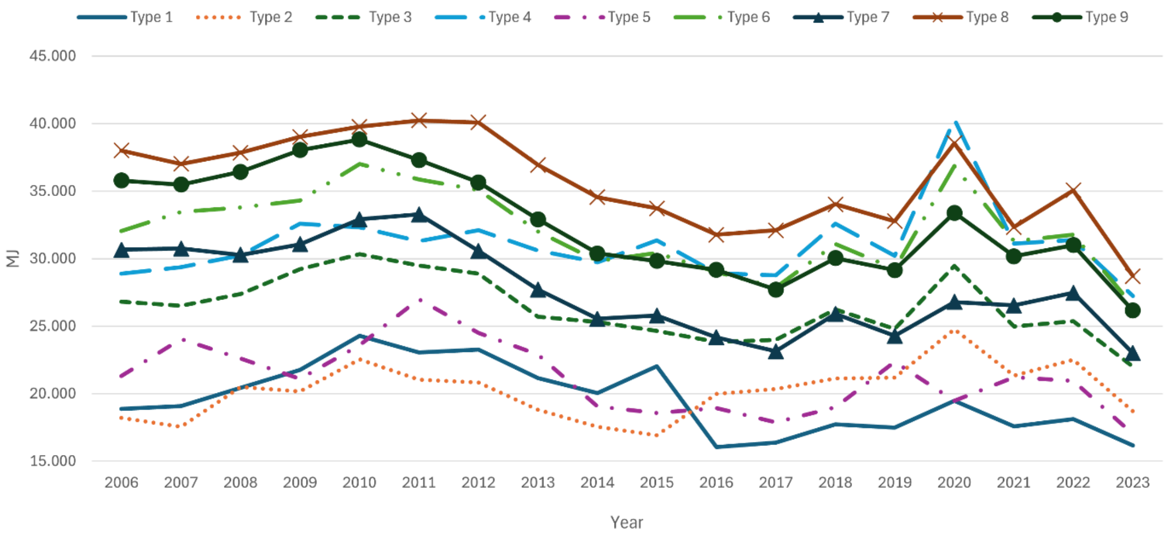
[3] Bardazzi and Pazienza (56) analysed electricity and natural gas consumption patterns among Italian households, finding that younger generations consume more energy than older households. They suggest that this pattern may reflect the influence of living environments experienced during the formative stages of life. In contrast, Inoue et al. (26) examined total energy consumption—including electricity, natural gas, and kerosene—among Japanese households and found that older generations consume more energy than younger generations. They attribute this difference to changes in energy source choices and the downsizing of housing over the life course.

conversion factors are as follows: City and natural gas: 33.9 MJ/m³, Liquid gas: 46.2 MJ/kg, Liquid fuel: 34.8 MJ/L.

Appendix 2. Changes in average energy consumption over the entire survey period

Figure A1 illustrates changes in average energy consumption over the entire survey period by household type. The figure indicates that average energy consumption declined for all household types except single elderly households. It also shows temporary increases in energy consumption during the Global Financial Crisis and the COVID-19 pandemic. The increase during the former period is attributed to higher unemployment, while the growth during the latter period is attributed to infection risks that compelled individuals to remain at home as well as to legal confinements set by authorities. To mitigate the influence of these exceptional circumstances, this study focuses on comparing energy consumption patterns from 2006 to 2023.

Fig A1. Household growth rate (base = 2024)



Appendix 3. Estimation of the number of households

The INE's population estimates provide data on the number of households by size. However, we aim to estimate the number of households by both size and type. To achieve this, we calculated the proportion of each household type within specific household-size categories, using historical census data as the reference.

Table A1. Estimated number of households

	Total	single-person		two-persons			three-persons		four-persons	
		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Year		working-age	senior	working-age only	at least one senior	with one minor	adult only	with minors	adult only	with minors
2024	19,310,776	3,160,310	2,273,659	2,433,878	2,693,969	426,323	2,438,133	1,429,109	1,615,478	2,839,916
2025	19,671,198	3,263,531	2,347,920	2,495,866	2,762,580	437,181	2,458,232	1,440,890	1,618,960	2,846,038
2026	20,026,547	3,366,934	2,422,314	2,556,712	2,829,929	447,839	2,477,212	1,452,016	1,622,076	2,851,515
2027	20,364,411	3,467,381	2,494,579	2,616,209	2,895,784	458,261	2,493,675	1,461,665	1,623,260	2,853,597
2028	20,681,965	3,566,828	2,566,125	2,673,867	2,959,603	468,360	2,506,032	1,468,908	1,621,586	2,850,655
2029	20,977,839	3,665,969	2,637,452	2,728,598	3,020,183	477,947	2,514,285	1,473,746	1,617,024	2,842,634
2030	21,244,779	3,759,011	2,704,390	2,780,013	3,077,092	486,953	2,518,873	1,476,436	1,610,625	2,831,386
2031	21,487,754	3,847,295	2,767,905	2,828,912	3,131,217	495,518	2,520,294	1,477,269	1,602,406	2,816,937
2032	21,712,140	3,932,954	2,829,531	2,875,460	3,182,739	503,672	2,518,754	1,476,366	1,592,733	2,799,931
2033	21,922,903	4,017,406	2,890,290	2,920,024	3,232,065	511,478	2,514,691	1,473,984	1,581,964	2,781,001
2034	22,118,643	4,098,116	2,948,357	2,962,225	3,278,776	518,870	2,508,909	1,470,595	1,571,025	2,761,770
2035	22,307,244	4,177,654	3,005,579	3,003,981	3,324,995	526,184	2,501,833	1,466,447	1,559,341	2,741,230
2036	22,489,804	4,256,359	3,062,203	3,044,542	3,369,890	533,289	2,493,712	1,461,687	1,547,575	2,720,547
2037	22,667,026	4,333,845	3,117,950	3,083,976	3,413,537	540,196	2,484,860	1,456,498	1,535,987	2,700,177
2038	22,838,031	4,409,972	3,172,719	3,121,065	3,454,590	546,693	2,475,569	1,451,052	1,525,185	2,681,187
2039	23,001,927	4,483,355	3,225,514	3,156,131	3,493,404	552,835	2,466,078	1,445,490	1,515,304	2,663,816

For this analysis, we assume that household composition in 2030 will remain consistent with that of INE's Population and Housing Census (55). Specifically, 58% of single-person households will consist of working-age individuals, while 42% will consist of elderly individuals. Among two-person households, 44% are assumed to include only working-age individuals, 49% to include at least one person aged 65 or older, and the remaining 7% to be single-parent households with one child. Three-person and four-or-more-person households are classified based on the presence of children: it is assumed that 37% of three-person households and 64% of larger households will include children.

The projected number of households under these assumptions is shown in Table A.1. Using the attached program, it is possible to adjust assumptions about demographic trends and generate predictions for energy consumption.

References

1. Nacht T, Pratter R, Ganglbauer J, Schibline A, Aguayo A, Fragkos P, et al. Modeling Approaches for Residential Energy Consumption: A Literature Review. Climate. 2023 Sep;11(9):184.
2. Salami H, Okpara K, Choochuay C, Kuaanan T, Akeju D, Shitta M. Domestic

energy consumption, theories, and policies: a systematic review. Environ Dev Sustain. 2023 Dec;
3. Bardazzi R, Pazienza MG. Demographic Shifts, Household Energy Needs and Vulnerability. In: Bardazzi R, Pazienza MG, editors. Vulnerable Households in the Energy Transition. Cham: Springer; 2023. p. 29–55.
4. Chen L, Luo J, Cai G, Xia L, Wang Y, Xu L. The impact of energy metabolic pattern on household carbon emissions: a spatio-temporal perspective in Guangdong-Hong Kong-Macao Greater Bay Area. Sustain Cities Soc [Internet]. 2024 Dec;106094. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2210670724009168
5. Brounen D, Kok N, Quigley JM. Residential energy use and conservation: Economics and demographics. Eur Econ Rev. 2012 Jul;56(5):931–45.
6. Huang WH. Nonlinear relationship between household composition and electricity consumption: optimal threshold models. Optim Eng. 2022 Dec;23(4):2261–92.
7. MITECO. Balance Energético de España 1990-2023. Madrid; 2024.
8. MITECO. Plan Nacional Integrado de Energía y Clima. Actualización 2023-2030. Madrid; 2024.
9. Arto I, Kratena K, García-Muros X, Cazcarro I, González-Eguino M. Modelo DENIO: modelo Dinámico Econométrico Neokeynesiano Input-Output para España. Papeles de Energía. 2021;12:23–31.
10. Salim SS, Luxembourg SL, Dalla Longa F, van der Zwaan B. Decarbonisation scenarios for the European residential sector. Build Environ. 2025 Feb;269:112408.
11. Di Felice LJ, Pérez-Sánchez L, Manfroni M, Giampietro M. Towards nexus thinking in energy systems modelling: A multi-scale, embodied perspective. Energy Policy. 2024 Apr;187:114052.
12. Aldás J, Solaz M. Patrones de consumo de los hogares españoles: Evolución histórica [1973-2017] e impacto de la crisis de 2007. Madrid: Fundación Ramón Areces; 2019. 129 p.
13. Labandeira X, Labeaga JM, Rodríguez M. A Residential Energy Demand System for Spain. Energy J. 2006 Apr;27(2):87–112.
14. Ramos-Martín J, Matsumoto S. Impact of changes in the distribution of household types on residential energy consumption in Spain, 2006-2023 [Internet]. 2025. (UHE-UAB Working Paper). Report No.: 2025_01. Available from: https://ddd.uab.cat/pub/worpap/2025/309169/2025_01.pdf
15. Blázquez L, Boogen N, Filippini M. Residential electricity demand in Spain: New empirical evidence using aggregate data. Energy Econ. 2013;36:648–57.
16. Bianco V, Marchitto A, Scarpa F, Tagliafico LA. Forecasting Energy Consumption in the EU Residential Sector. Int J Environ Res Public Health. 2020 Mar;17(7):2259.
17. Frontuto V. Forecasting household consumption of fuels: A multiple discrete-continuous approach. Appl Energy. 2019 Apr;240:205–14.
18. Daioglou V, van Ruijven BJ, van Vuuren DP. Model projections for household energy use in developing countries. Energy. 2012 Jan;37(1):601–15.
19. López-Rodríguez MA, Santiago I, Trillo-Montero D, Torriti J, Moreno-Munoz

A. Analysis and modeling of active occupancy of the residential sector in Spain: An indicator of residential electricity consumption. Energy Policy. 2013 Nov;62:742–51.
20. Escobar P, Martínez E, Saenz-Díez JC, Jiménez E, Blanco J. Modeling and analysis of the electricity consumption profile of the residential sector in Spain. Energy Build. 2020 Jan;207:109629.
21. Baker P, Blundell R, Micklewright J. Modelling Household Energy Expenditures Using Micro-Data. Econ J. 1989 Sep;99(397):720.
22. Van Raaij WF, Verhallen TMM. A behavioral model of residential energy use. J Econ Psychol. 1983 Jan;3(1):39–63.
23. Hirst E, Goeltz R, Carney J. Residential energy use. Energy Econ. 1982 Apr;4(2):74–82.
24. Estiri H, Zagheni E. Age matters: Ageing and household energy demand in the United States. Energy Res Soc Sci. 2019 Sep;55:62–70.
25. Deuster C, Kajander N, Muench S, Natale F, Nedee A, Scapolo F, et al. Demography and climate change. EUR 31512. Luxembourg: Publications Office of the European Union; 2023. 96 p.
26. Inoue N, Matsumoto S, Mayumi K. Household energy consumption pattern changes in an aging society: the case of Japan between 1989 and 2014 in retrospect. Int J Econ Policy Stud [Internet]. 2022 Feb 21;16(1):67–83. Available from: https://link.springer.com/10.1007/s42495-021-00069-y
27. Wu W, Kanamori Y, Zhang R, Zhou Q, Takahashi K, Masui T. Implications of declining household economies of scale on electricity consumption and sustainability in China. Ecol Econ. 2021 Jun;184:106981.
28. Schröder C, Rehdanz K, Narita D, Okubo T. The decline in average family size and its implications for the average benefits of within-household sharing. Oxf Econ Pap. 2015 Jul;67(3):760–80.
29. Esteve A, Reher DS, Treviño R, Zueras P, Turu A. Living Alone over the Life Course: Cross-National Variations on an Emerging Issue. Popul Dev Rev. 2020 Mar;46(1):169–89.
30. Esteve A, Reher DS. Trends in Living Arrangements Around the World. Popul Dev Rev. 2024 Mar;50(1):211–32.
31. Grubler A, Hogan CM. Energy transitions. In: The Encyclopedia of Earth. Cutler J. 2013.
32. Chen L, Xu L, Velasco-Fernández R, Giampietro M, Yang Z. Residential energy metabolic patterns in China: A study of the urbanization process. Energy. 2021 Jan;215:119021.
33. Bartolomé Rodríguez MI, Gutiérrez-González P. Residential energy consumption in Spain during the 1960s. Butane and the precariousness of developmentalism. Rev Hist Ind — Ind Hist Rev. 2024 Dec;
34. Nie Y, Zhang G, Zhong L, Su B, Xi X. Urban–rural disparities in household energy and electricity consumption under the influence of electricity price reform policies. Energy Policy. 2024 Jan;184:113868.
35. Lasarte Navamuel E, Rubiera Morollón F, Moreno Cuartas B. Energy consumption and urban sprawl: Evidence for the Spanish case. J Clean Prod. 2018 Jan;172:3479–86.

36. Cartone A, Díaz-Dapena A, Langarita R, Rubiera-Morollón F. Where the city lights shine? Measuring the effect of sprawl on electricity consumption in Spain. Land use policy. 2021 Jun;105:105425.
37. Ironmonger DS, Aitken CK, Erbas B. Economies of scale in energy use in adult-only households. Energy Econ. 1995 Oct;17(4):301–10.
38. Andor MA, Bernstein DH, Sommer S. Determining the efficiency of residential electricity consumption. Empir Econ. 2021 Jun;60(6):2897–923.
39. Liao HC, Chang TF. Space-heating and water-heating energy demands of the aged in the US. Energy Econ. 2002 May;24(3):267–84.
40. Bardazzi R, Pazienza MG. Switch off the light, please! Energy use, aging population and consumption habits. Energy Econ. 2017 Jun;65:161–71.
41. INE. Household Budget Survey. Household Budget Survey. 2023.
42. INE. Proyecciones de población. Años 2024-2039. Madrid; 2024.
43. Esteve A, Pohl M, Becca F, Fang H, Galeano J, García-Román J, et al. A global perspective on household size and composition, 1970–2020. Genus. 2024 Jan;80(1):2.
44. O'Neill BC, Chen BS. Demographic Determinants of Household Energy Use in the United States. Popul Dev Rev. 2002;28(Supplement):53–88.
45. Ellsworth-Krebs K. Implications of declining household sizes and expectations of home comfort for domestic energy demand. Nat Energy. 2019 Dec;5(1):20–5.
46. Bogin D, Dorman M, Kissinger M, Erell E. Beyond efficiency: Evaluation of the electricity saving potential of green residential buildings. Energy Build. 2024 Oct;320:114627.
47. Esmaeilimoakher P, Urmee T, Pryor T, Baverstock G. Identifying the determinants of residential electricity consumption for social housing in Perth, Western Australia. Energy Build. 2016 Dec;133:403–13.
48. Kavousian A, Rajagopal R, Fischer M. Determinants of residential electricity consumption: Using smart meter data to examine the effect of climate, building characteristics, appliance stock, and occupants' behavior. Energy. 2013 Jun;55:184–94.
49. Lee SJ, Song SY. Determinants of residential end-use energy: Effects of buildings, sociodemographics, and household appliances. Energy Build. 2022 Feb;257:111782.
50. Martínez-Llorens AM, Taltavull de La Paz P, Mora-Garcia RT. Effect of The Physical Characteristics of a Dwelling on Energy Consumption and Emissions: The Case of Castellón And Valencia (Spain). Sustainability. 2020;12:9747.
51. IDAE. Informe anual de consumos por usos del sector residencial. Madrid; 2024.
52. Lara D. España solo rehabilitará a este ritmo una cuarta parte de las viviendas que planeaba para 2030. Infolibre. 2025;1.
53. MITMA. Actualización 2020 de la Estrategia a largo plazo para la rehabilitación energética en el sector de la edificación en España. Madrid; 2020.
54. IEA. Energy Statistics Manual. Paris; 2004.
55. INE. Population and Housing Census. Population and Housing Census. 2021.
56. Bardazzi R, Pazienza MG. When I was your age: Generational effects on long-run residential energy consumption in Italy. Energy Res Soc Sci. 2020 Dec;70:101611.