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Analyzing Energy Consumption Behavior in an Aging Society using the NTA Methodology*

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Abstract

Purpose: This study investigates how population aging and household structure influence residential energy consumption patterns. The goal is to identify energy consumption behaviors that are specific to different age groups and energy sources, moving beyond traditional household-level analyses. **Research design, data and methodology:** Using the National Transfer Accounts (NTA) framework, we transform household-level energy consumption data from the Household Energy Panel Survey into individual-level estimates. We apply age-weighted allocation and smoothing techniques to create age profiles for electricity, city gas, district heating, and petroleum-based fuels. This enables meaningful comparisons across various life stages and household types. **Results:** Electricity consumption increases with age and remains high in later life, reflecting persistent needs for comfort and safety. District heating shows no clear age-related trend. In contrast, city gas consumption follows an inverted U-shaped pattern. Petroleum-based fuels remain essential for elderly and single-person households, particularly in detached homes. Single-person households exhibit the highest per capita energy use across all ages, indicating limited economies of scale. **Conclusions:** Population aging constitutes a structural driver of residential energy demand. Energy policies and forecasting models should incorporate age and household composition to improve precision. The age-specific profiles developed here provide empirical foundations for targeted energy welfare, efficiency enhancement, and sustainable policy design in aging societies.

Keywords: Population aging, National Transfer Accounts (NTA), Age profiles, Energy use, Energy policy

JEL Classification Code: J11, Q40

1. Introduction

The global trends of low fertility and population aging have accelerated in recent decades, resulting in profound demographic transformations that influence not only residential environments and lifestyles but also the structural dynamics of energy consumption (Yamasaki & Tominaga, 1997). In particular, advanced economies, including South Korea (hereafter referred to as Korea), are experiencing an unprecedented pace of population aging, accompanied by structural challenges such as slowing economic growth, declining labor forces, and rising healthcare and welfare

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expenditures (Kim & Park, 2014). These demographic changes extend beyond socioeconomic dimensions; they have also reshaped household structures through changes in housing types, declining household sizes, and a growing share of elderly households (Ota et al., 2018; Yagita & Iwafune, 2021). Consequently, household lifestyles and following patterns of energy consumption have gradually evolved, generating significant implications for the design and implementation of national energy demand management policies (Kim & Park, 2014).

In general, the effects of population aging on energy demand can be attributed to several micro-level mechanisms. First, older adults tend to spend more time indoors than younger cohorts, allocating a larger share of their energy use to maintenance-related needs such as heating, cooling, lighting, and hot water (Han et al., 2022; Yamasaki & Tominaga, 1997). Second, as individuals age, their dependence on electricity-based services related to safety, healthcare, and convenience tends to rise (Yagita & Iwafune, 2021; Sanquist et al., 2012; Guo et al., 2018). Third, changes in household composition alter the degree of “shareability” in energy use, thereby affecting economies of scale. In single-person households, basic loads such as refrigerators, lighting, and standby power cannot be shared, leading to higher per capita energy consumption even within the same living space. Taken together, these factors suggest that total energy demand, as well as temporal, seasonal, and fuel-specific energy consumption patterns, are likely to respond heterogeneously to changes in the population’s age structure (Kim & Park, 2014; Ota et al., 2018; Han et al., 2022).

Nevertheless, empirical studies in Korea have reported mixed and sometimes contradictory results. Some studies suggest that population aging leads to a modest decline in residential electricity demand, with more pronounced effects in the short term (Won, 2012; Jo et al., 2020; Ryu et al., 2021). In contrast, some studies suggest that integrating age-specific consumption structures with the inter-industry linkages of the energy sector may lead to an increase in total energy use and associated emissions over the medium term (Kim & Park, 2014). These inconsistencies may arise from differences in analytical units (household vs. individual), the level of age-specific identification, variations in fuel sensitivity, and heterogeneity across housing type, climatic conditions, and regional distributions. More fundamentally, many existing studies rely on aggregated analytical frameworks that link “household head’s age” to “total household consumption,” thereby limiting their ability to capture heterogeneous consumption behaviors among individuals within the same household (Sanquist et al., 2012; Guo et al., 2018; Ota et al., 2018; Bardazzi & Pazienza, 2017; Yagita & Iwafune, 2021).

Many studies on energy consumption have estimated electricity demand functions separately for industrial and residential sectors, analyzing variations according to factors such as income, price, and housing type (Won, 2012; Kim et al., 2019). Studies focusing on household-level behavior have also examined how electricity and overall energy consumption differ across income levels, dwelling types, educational attainment, and lifestyle characteristics (Sanquist et al., 2012; Guo et al., 2018). Some studies have further incorporated population aging as an explanatory variable, identifying heterogeneous effects across different energy sources such as electricity and city gas (Ota et al., 2018; Bardazzi & Pazienza, 2017; Yagita & Iwafune, 2021). However, because the unit of analysis in most cases remains at the “entire household” level, these studies face inherent limitations in capturing intra-household age heterogeneity or directly identifying individual-level consumption behaviors.

Recent studies have increasingly acknowledged these limitations and highlighted the importance of analyzing detailed energy consumption behaviors based on the age of individual household members (Han et al., 2022; Zou et al., 2025; Yamasaki & Tominaga, 1997). These studies demonstrate that energy use behaviors and preferences vary substantially across age groups. Older adults tend to spend more time indoors and use heating and cooling appliances more frequently. In contrast, younger individuals exhibit higher usage frequencies of electronic devices such as home appliances and computers. Such behavioral differences are challenging to capture through aggregated household-level analyses, underscoring the need for age-specific, individual-level approaches to more accurately identify distinct patterns of energy consumption.

To address the limitations of previous studies and conduct a more precise analysis of age-specific energy consumption, this study applies the National Transfer Accounts (NTA) methodology. Specifically, we allocate household-level energy consumption to individual household members according to their age, and then use the resulting individual-level estimates to construct age profiles of energy consumption. The NTA framework, as outlined in the United Nations manual, provides a systematic approach to disaggregating household-level data into individual-level estimates based on age composition. This methodology has proven particularly useful in studies related to population aging and low fertility. In this study, we employ NTA-based allocation to calculate age-weighted average energy consumption for individuals and apply smoothing techniques to construct reliable age profiles of energy consumption.

This study offers several important academic and policy implications. First, the age profiles of energy consumption constructed for disaggregated energy sources provide a more precise foundation for predicting and responding to the long-term effects of population aging on energy demand.

This approach can enhance the accuracy of future energy demand forecasting models and strengthen the effectiveness of policy responses. Second, by identifying detailed patterns of energy consumption at the individual level, the findings enable policymakers and relevant institutions to design more targeted and effective energy management strategies. In particular, the results are expected to serve as valuable policy input for improving energy efficiency among older populations and addressing issues of energy poverty. Finally, the age-specific energy consumption profiles developed in this study can function as essential baseline data for subsequent analyses. As population aging continues to accelerate, these empirical findings provide a robust evidence base for formulating sustainable and demographically responsive energy policies.

The remainder of this paper is structured as follows. The next section outlines the data and research methodology. Section 3 presents the empirical results, focusing on the age-specific profiles of energy consumption by source. Finally, Section 4 summarizes the key findings and discusses their policy implications.

2. Data and Methodology

2.1. Overview of the Household Energy Panel Survey (HEPS)

The Household Energy Panel Survey (HEPS) is an annual longitudinal survey designed to monitor household energy consumption behaviors by repeatedly observing the same households or dwellings over time.[2] Following a pilot survey of 1,500 households in 2009 and a trial survey in 2010, the first HEPS, which is approved as official statistics based on data for 2010, was launched in 2011, with approximately 2,500 participating households. As of 2025, the survey has been conducted annually through its 14th wave, which is based on data for 2024.

In 2019, a new survey panel was established, expanding the sample coverage to approximately 8,300 households. Since 2020, approximately 1,000 households identified as renewable energy users have been excluded from the sample. Since then, the survey has been conducted annually, involving approximately 7,400 households in total. Notably, beginning in 2020, the Energy Census ceased to collect separate data for the residential sector. Consequently, the HEPS now serves as the only longitudinal dataset in Korea that provides time-series information on household energy consumption by household and housing characteristics. It thus plays a crucial role as a foundational data source for formulating national energy policies and for related academic and policy-oriented research.

The primary objective of the HEPS is to identify household- and individual-level patterns and structures of energy consumption that cannot be captured through conventional energy supply and demand statistics. To achieve this, the HEPS collects detailed information not only on household-level energy consumption by source but also on the demographic and socioeconomic characteristics of household members that influence energy use. Specifically, the survey is organized into several thematic components, including: housing characteristics; heating, cooling, and cooking; monthly energy consumption by source; ownership and usage of home appliances; energy-related behaviors and perceptions; and household and individual characteristics. Because the HEPS simultaneously collects information at both the household and individual levels, it provides a uniquely valuable dataset for research fields in which individual-level demographic information – such as in studies on low fertility and population aging – is essential.

2.2. Data

This study employs data from the 11th wave (2020) of the Household Energy Panel Survey (HEPS) for empirical analysis. The 11th wave of HEPS records monthly household energy consumption by source, including electricity, off-peak (midnight) electricity, district heating, city gas, and petroleum-based fuels. Considering that household energy use may vary substantially across seasons, this study constructs annual energy consumption values by aggregating the monthly data and uses these annualized figures for the analysis.

To identify household composition by generation, this study also utilize the individual-level component of the HEPS dataset, which provides detailed information on each household member's year of birth, relationship to the household head, employment status, telecommuting status, and nationality. Each household member's age as of 2020 is calculated based on the reported year of birth. Households containing members with missing birth-year information or consisting solely of individuals under age 20 are excluded from the sample.

Households are further classified according to household composition using the "relationship to household head"

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[2] From 2011 to 2018, the survey was conducted under the official title "Household Energy Consumption Survey" (approved statistical name) and the research title "Household Energy Standing Survey (HESS)."

variable.[3] To ensure demographic balance within multi-generation households, two-generation households in which all members are aged 70 or older, and three-generation households in which all members are either older than 50 or younger than 40, are excluded from the sample. As a result, the final analytical sample comprises 5,660 households and 14,818 individuals.[4] Among these individuals, 1,034 belong to single-person households, 3,420 to one-generation households, 9,643 to two-generation households, and 721 to households with three or more generations.

2.3. Methodology for Constructing Age Profiles

To examine the effects of population aging on energy consumption, this study first converts household-level energy consumption data into individual-level data using the National Transfer Accounts (NTA) framework. In practice, because individual-level microdata on private consumption are not available in Korea, household-level consumption data – such as those from the Household Income and Expenditure Survey conducted by the Ministry of Data and Statistics – are transformed into individual-level estimates following the procedures outlined in the NTA Manual in order to construct the Korean National Transfer Accounts data, including age profiles of private consumption.

Applying a similar approach, this study transforms household-level energy consumption data from the Household Energy Panel Survey (HEPS), which reports household energy use by source, into individual-level consumption data. Specifically, the allocation methodology described in the NTA Manual is adapted to distribute household energy consumption among household members, thereby generating a dataset of individual-level energy consumption.

For each energy source, $\gamma(a)$ is estimated using the regression model specified in equation (1), which relates the household-level energy consumption (Energy_{ih}) to the number of household members by age ($M_h(a)$). The estimated coefficients, $\hat{\gamma}(a)$, are then substituted into the relationship defined in equation (2) to calculate energy consumption per household member (Energy_{ihj}).

Considering data availability, all individuals aged 85 and older are grouped into a single age category, defining the age range as 0 to 85 and above. Following the procedures described in the NTA Manual, the regression estimation in equation (1) and the subsequent allocation in equation (2) are performed sequentially for each age group to generate individual-level energy consumption data for each energy source.

$$\text{Energy}_{ih} = \sum_{a=0}^{85} \gamma(a) M_h(a) + \epsilon_h \tag{1}$$

where Energy_{ih} denotes the total household consumption of energy source i by household h, and $M_k(a)$ represents the number of household members in household h who are age a. Energy sources (i) include electricity, off-peak electricity, total electricity (the sum of electricity and off-peak electricity), district heating, city gas, petroleum-based fuels, and total energy consumption. The variable a represents the age range of household members (from 0 to 85+)

$$\begin{gathered} \hat{e}_{ihj} = \sum_{a=0}^{85} \{ I[\hat{\gamma}(a) > 0] \times \hat{\gamma}(a) \times D_{hj}[a, M] \} \\ \text{Energy}_{ihj} = \text{Energy}_{ih} \times \frac{\hat{e}_{ijh}}{\sum_j \hat{e}_{ihj}} \end{gathered} \tag{2}$$

where $\hat{e}_{ijh}$ indicates the average consumption of energy source i by an individual of age j within household h. $I[\hat{\gamma}(a) > 0]$ is a dummy variable that equals 1 if $\hat{\gamma}(a)$ is positive and 0 otherwise.[5] $D_{hj}[a, M]$ is a dummy variable

[3] Specifically, a household composed solely of one member—the household head—is classified as a single-person household. Among households with two or more members, those consisting only of the household head together with a spouse and/or siblings (and their spouses) are categorized as one-generation households. Households composed only of the household head (and spouse) together with their parents, or only with their children (and their spouses) or siblings' children (and their spouses), are classified as two-generation households. All remaining households that do not fall into the single-person, one-generation, or two-generation households are classified as households with three or more generation.

[4] Out of the 6,320 households surveyed in the 11th wave of the HEPS in 2020, a total of 5,660 households were retained for the final analysis after excluding the following cases: 648 households with at least one member missing birth year information, 6 households composed entirely of members under the age of 20, 4 two-generation households in which all members were aged 70 or older, and 2 three-generation households in which all members were either younger than 40 or older than 50.

[5] During the conversion of household-level energy consumption data from the Household Energy Panel Survey (HEPS) into individual-level data using the regression model (1) and allocation equation (2), some estimated coefficients $\hat{\gamma}(a)$ may yield negative individual consumption values (Energy_{ihj}). Consequently, when calculating age-averaged energy consumption profiles, negative values may occasionally appear.

that equals 1 if individual j in household h is age a, and 0 otherwise. In addition, Energy_{ihj} denotes the individual-level consumption of energy source i by member j in household h.

Following the procedure described above, we generate individual-level energy consumption data by energy source. Then, we construct age profiles of individual-level energy consumption by energy source using individual-level energy consumption data. Specifically, for each energy source, we calculate age-specific averages of individual household members' energy consumption, applying cross-sectional sampling weights to produce per capita (single-person equivalent) age profiles. As recommended in the National Transfer Accounts (NTA) Manual, we also then apply a locally weighted scatterplot smoothing (LOWESS) procedure to the age profiles to minimize the influence of outliers that may result from imbalances in the number of observations across age groups. This process yields the final smoothed age profiles of per capita energy consumption for each energy source.[6]

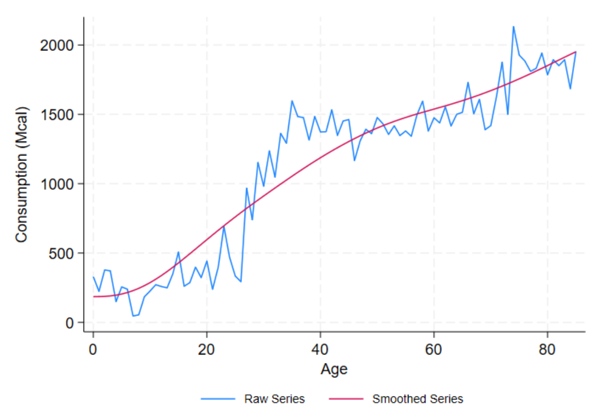
3. Results: Construction of Age Profiles

This section presents the age profiles of energy consumption by energy source, constructed using the National Transfer Accounts (NTA) methodology. The profiles are derived from individual-level energy consumption data of household members, aggregated into age-specific weighted averages and subsequently smoothed using the locally weighted scatterplot smoothing (LOWESS) procedure, as explained earlier. The interpretation of the results focuses on three key aspects: (1) heterogeneity across all households and by household type; (2) differences across energy sources; and (3) robustness of the estimated age profiles.

3.1. Age Profile of Electricity Consumption

The age profile of electricity consumption reveals a distinct life-cycle pattern. Electricity use increases sharply from the late 20s to the late 30s, corresponding to the stage of household formation. After this period, the rate of increase slightly moderates, showing a gradual upward trend through the 40s and beyond. Notably, this upward trend persists even into the 70s, indicating that essential demands for comfort and safety – such as heating, hot water, and lighting – continue to sustain or slightly increase electricity consumption among older adults (see Figure 1-a). Overall, the results demonstrate a typical life-cycle trajectory of electricity use: low consumption at younger ages → a steep rise during household formation → a gradual plateau throughout middle and later adulthood.

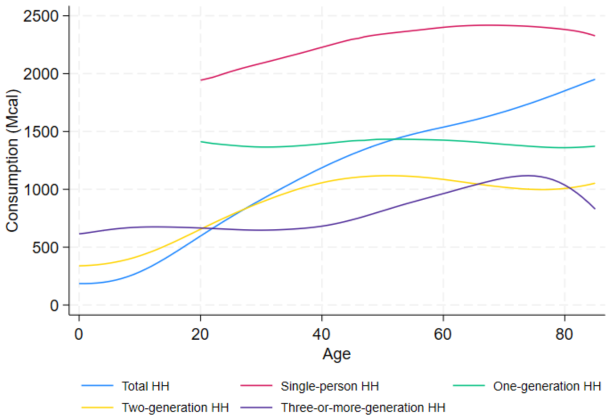
When examining electricity consumption by household type, distinct differences emerge across age groups. As illustrated in Figure 1-b, per capita electricity consumption in two-generation and three-or-more-generation households is significantly lower than that observed in one-generation and single-person households of the same age. This pattern can largely be attributed to economies of scale resulting from the shared use of heating, cooking, lighting, and electrical appliances among multiple household members. Moreover, in multi-generational households, the peak in per capita electricity use tends to occur at later ages. In contrast, single-person households consistently exhibit higher levels of electricity consumption across all age groups. Their electricity use declines modestly after the age of 70, primarily due to a reduction in physical activity and mobility. However, the decline remains limited, as basic needs related to heating, lighting, safety, and health continue to sustain electricity demand among older adults. Overall, these findings suggest that two opposing mechanisms operate simultaneously among older adults: a growing propensity toward energy saving with age, and increased time spent at home, which in turn raises electricity consumption.



(a) Raw and Smoothed Series

Following the correction procedure recommended in the National Transfer Accounts (NTA) methodology, any negative coefficient values ($\hat{y}(a) < 0$) are replaced with zero to ensure that the resulting age profiles of energy consumption contain no negative values.

6 The smoothed series were multiplicatively scaled so that the mean of the smoothed data matched the mean of the original unsmoothed data, ensuring consistency between the smoothed and raw series.

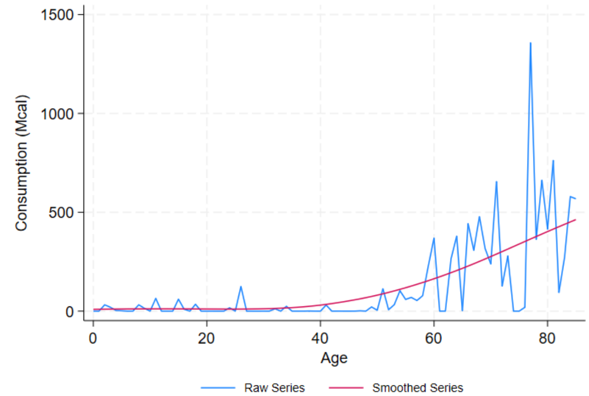


(b) Smoothed Series by Household Type

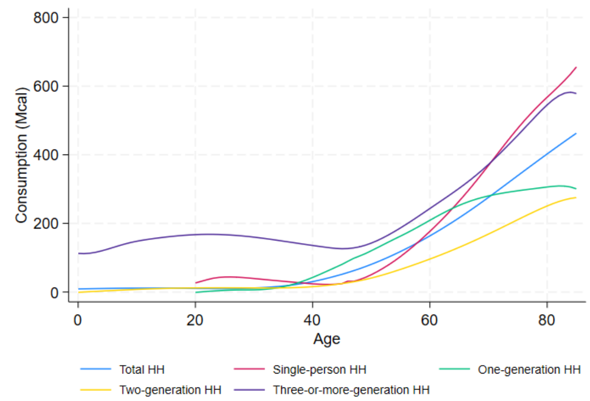
Figure 1: Age-specific Electricity Consumption

In contrast to the general pattern of electricity consumption described earlier, the age-specific profile of off-peak electricity use exhibits distinct characteristics. Among individuals under mid-30s, off-peak electricity consumption remains very low. However, it begins to increase gradually from the 40s onward, with the rate of increase becoming more pronounced at older ages (see Figure 2-a). Because the introduction of new off-peak electricity contracts for general households (excluding welfare facilities) was discontinued after 2010 (Kim & Park, 2015), the observed increase in off-peak electricity use among older age groups likely reflects a combination of factors: reduced nighttime outdoor activities among the elderly and the continued use of existing off-peak contracts and storage-type heating systems. Taken together, these factors indicate an incremental upward trend in off-peak electricity consumption driven primarily by nighttime heating and hot-water usage.

When examining off-peak electricity consumption by household type, it is observed that per capita usage is slightly higher in households with three or more generations, even though single-person households show a marked increase in off-peak electricity consumption after the age of 50 (see Figure 2-b). This pattern can be interpreted as the combined outcome of demographic and structural factors. Even after the discontinuation of new off-peak electricity installations for general households in 2010, existing off-peak boilers – predominantly installed in detached houses and rural areas – have continued to operate. The demographic composition of these residual users tends to overlap more with older and multi-generational households (Kim & Park, 2015). Moreover, because heating and hot water usage allow for only limited potential for energy savings through shared use, economies of scale are relatively weak for these end uses compared with lighting or general household appliances. This structural characteristic helps explain why per capita off-peak electricity consumption remains relatively high in multi-generational households.



(a) Raw and Smoothed Series



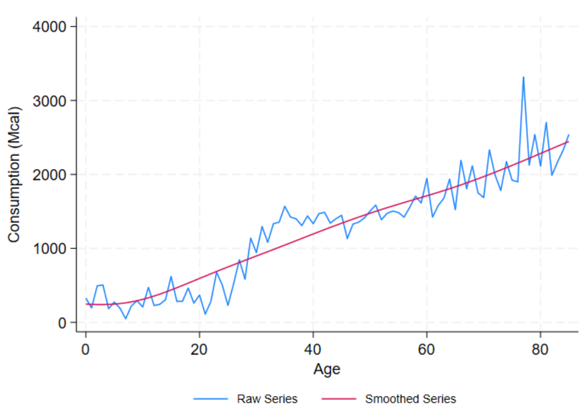
(b) Smoothed Series by Household Type

Figure 2: Age-specific Off-peak Electricity Consumption

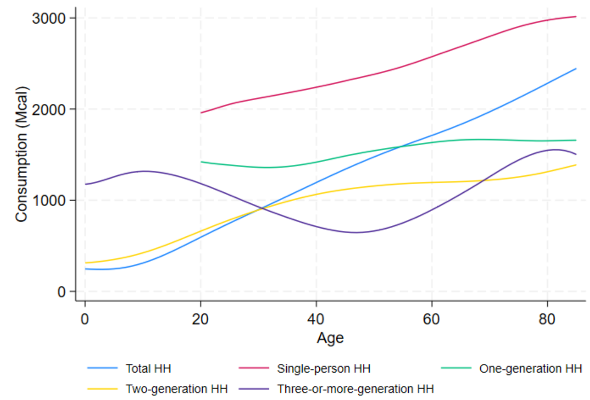
Figure 3 presents the total electricity consumption, which combines general electricity use with off-peak (nighttime) electricity consumption. As shown in Figure 3-a, the inclusion of off-peak electricity – mainly used for nighttime heating and hot water demand by remaining subscribers – leads to a gradual increase in total electricity consumption among older age groups after the age of 60. This pattern suggests that general electricity use, which primarily reflects daytime activities and appliance operation, and off-peak electricity, which is mainly driven by nighttime heating and hot water demand, complement each other in terms of time and function.

When total electricity consumption is disaggregated by household type, single-person households consistently exhibit higher consumption across nearly all age groups compared to other household types (Figure 3-b). This occurs largely because single-person households cannot share basic electrical loads such as refrigerators, lighting, and standby power with other household members. The consumption gap between single-person households and others widens further in older age groups, reflecting the combined effects of essential comfort and safety needs (such as heating, hot water, and lighting) and residual off-peak electricity usage. Similarly, one-generation households also show relatively higher total electricity consumption than two-generation and three-or-more-generation households, as their opportunities for sharing base electrical loads are limited. In contrast, two-generation and three-or-more-generation households – where children typically live with parents – exhibit substantially lower per capita total electricity use, since appliances, cooking, and heating are shared among household members. Consequently, their age profile curves are considerably flatter.

Among all household types, three-or-more-generation households record the lowest and most stable per capita total electricity consumption, reflecting the most potent effects of shared energy use. Even though off-peak electricity consumption tends to increase among older adults, the sharing and efficiency effects within two- and three-or-more-generation households – common living arrangements for the elderly – offset this increase, thereby maintaining a relatively low and stable level of total electricity consumption in later life.



(a) Raw and Smoothed Series



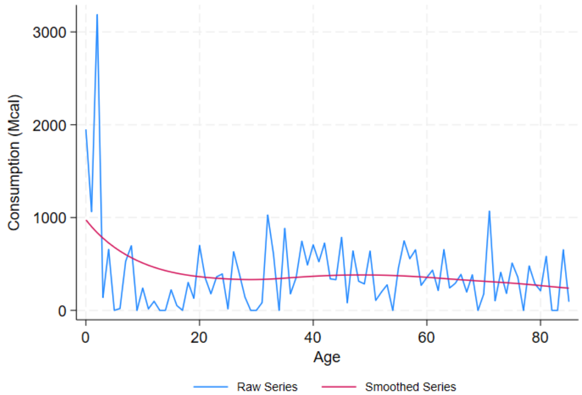
(b) Smoothed Series by Household Type

Figure 3: Age-specific Total Electricity Consumption (General + Off-peak)

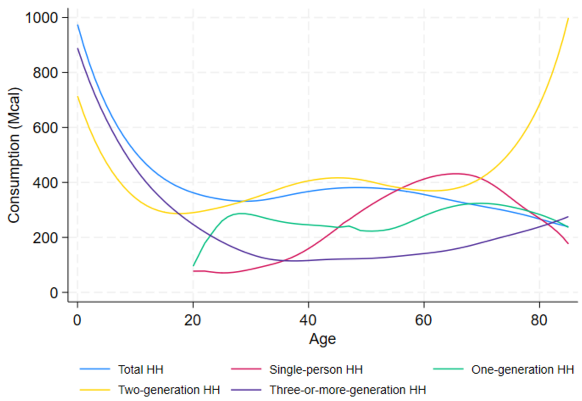
3.2. Age Profile of District Heating Consumption

In the case of district heating, consumption appears to be slightly higher among children under the age of 5; however, overall, it remains relatively stable across most age groups, showing only minor variations. This gently sloping and low-level age pattern indicates that individual annual consumption of district heating is relatively uniform and that age-related changes exert only a limited influence on total district heating usage (see Figure 4-a). When district heating consumption is analyzed by household type, more apparent differences emerge compared with the age-based pattern (Figure 4-b). Among single-person and one-generation households, district heating consumption tends to decline after age 70. In contrast, among two-generation and three-or-more-generation households, consumption in the same older age groups tends to increase.

This contrast can be explained by two factors. First, the distribution of district heating systems is often concentrated in specific housing types and construction periods, which are associated with particular age groups and household types. Second, households with more members maintain a minimum level of heating demand – for example, for shared spaces and hot water supply – which sustains relatively stable consumption levels regardless of individual aging.



(a) Raw and Smoothed Series



(b) Smoothed Series by Household Type

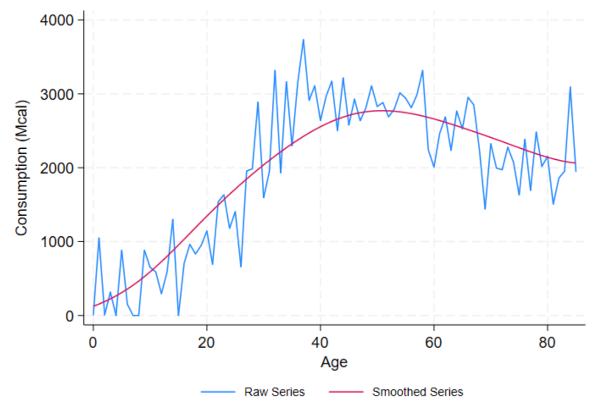
Figure 4: Age-specific District Heating Consumption

3.3. Age Profile of City Gas Consumption

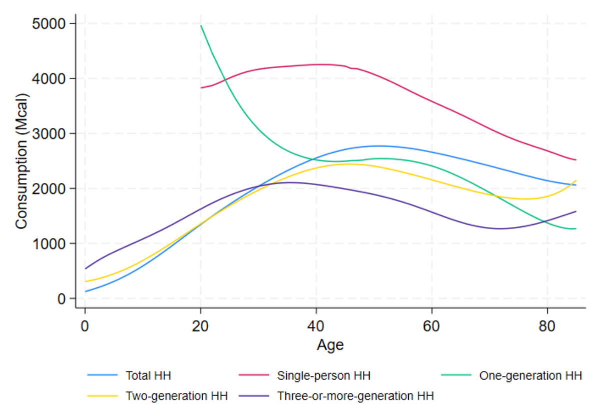
City gas serves as a primary energy source for heating and hot water in the residential sector. The age profile of city gas consumption reveals a gradual increase in usage up to the late 40s, corresponding to the household formation and expansion stage, followed by a moderate decline after the age of 50, forming an inverted U-shaped pattern (see Figure 5-a).

This pattern can be interpreted as follows. Individuals in their 20s tend to exhibit relatively low city gas consumption because they are less likely to engage in household responsibilities such as cooking or childcare. As individuals enter their 30s and 40s, they typically form and expand households, which entails larger living spaces, more frequent use of hot water through gas boilers, and increased cooking activity. These factors collectively contribute to higher per capita city gas consumption during this period. After the 50s, consumption begins to decline gradually, reflecting reduced physical activity levels among older adults, although minimum heating and hot water needs persist.

When examining city gas consumption by household type, per capita usage is generally higher among single-person and one-generation households across all age groups. In contrast, individuals in two-generation and three-or-more-generation households exhibit relatively lower levels of consumption due to economies of scale (see Figure 5-b). In particular, single-person households maintain relatively high levels of city gas consumption throughout young and middle adulthood, followed by only a modest decline in later life. Conversely, individuals in three-or-more-generation households show consistently lower consumption from their 30s onward, reflecting more efficient sharing of heating and cooking energy within larger family structures.



(a) Raw and Smoothed Series



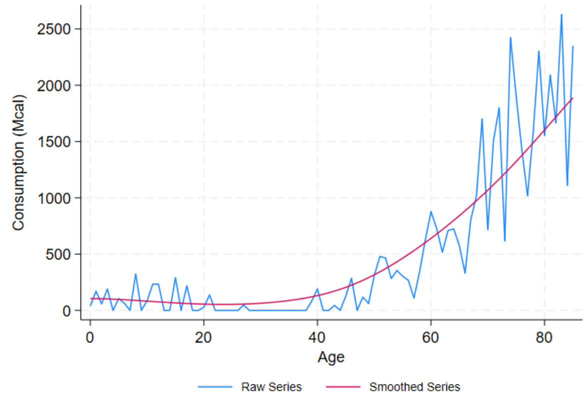
(b) Smoothed Series by Household Type

Figure 5: Age-specific City Gas Consumption

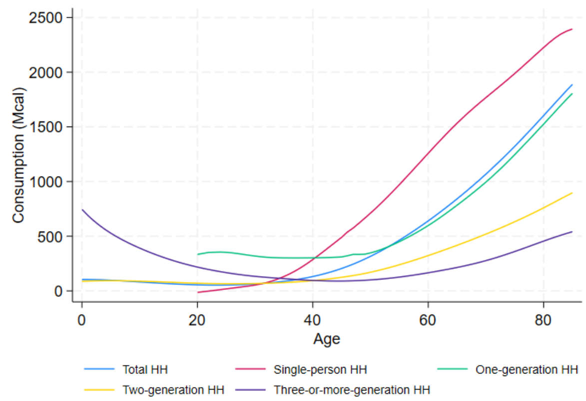
3.4. Age Profile of Petroleum-based Fuel Consumption

Petroleum-based fuels – including kerosene, LPG, and propane – serve primarily as substitute energy sources for heating and hot water use in the residential sector. As shown in Figure 6-a, consumption remains very low before the age of 40. However, it rises sharply from the 40s through the 50s and continues to increase steadily, even among individuals aged 70 and above. This upward trend can be interpreted as follows. During the 40s and 50s, higher consumption likely reflects household formation and expansion, accompanied by larger dwelling spaces. Among older adults (aged 70 and above), the continued increase in consumption is likely driven by minimum heating and hot water requirements, as well as residence in areas not connected to city gas networks. These results indicate that certain population groups remain excluded from the coverage of city gas and district heating systems, and that reliance on kerosene boilers and LPG remains relatively high in detached, low-rise, and older housing structures.

When petroleum-based fuel consumption is analyzed by household type, the steepest increase in per capita consumption with age is observed among single-person households (see Figure 6-b). This finding may be due to the fact that single-person households cannot share basic heating needs and are more likely to reside in smaller, older, or detached dwellings located outside city gas or district heating service areas, resulting in less efficient heating energy use relative to housing size. One-generation households also display an upward consumption pattern sharply among older age groups, whereas two-generation and three-or-more-generation households exhibit more moderate increases. This difference can be attributed to the shared use of heating and hot water systems, as well as to higher rates of city gas or district heating connectivity among multi-generational households. Consequently, in older age groups, the consumption gap widens progressively from single-person to multi-generational households, reflecting structural differences in housing type, energy accessibility, and efficiency of shared energy use.



(a) Raw and Smoothed Series



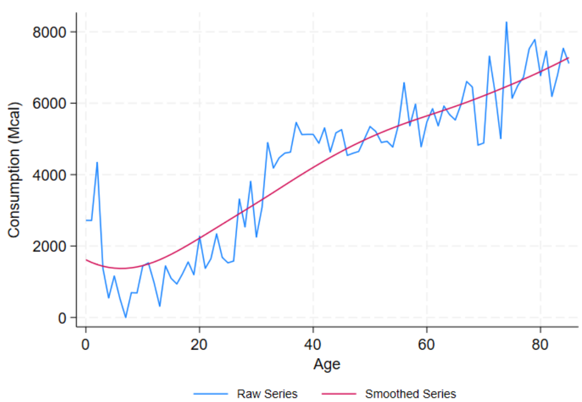
(b) Smoothed Series by Household Type

Figure 6: Age-specific Petroleum-based Fuel Consumption

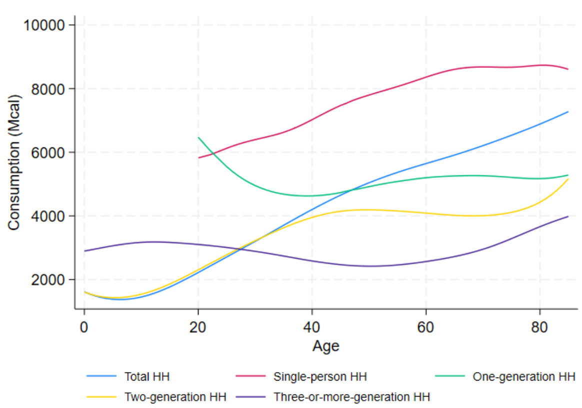
3.5. Age Profile of Total Energy Consumption

Figure 7 presents the age profile of per capita total energy consumption, calculated by summing all energy sources reported in the Household Energy Panel Survey (HEPS), including total electricity (general + off-peak), city gas, district heating, and petroleum-based fuels. The age profile of total energy consumption indicates that energy consumption starts at a relatively low level among individuals in their early 20s, rises sharply from the 30s through 50s, and continues to increase, albeit at a slower rate, beyond the 60s (see Figure 7-a). This pattern clearly illustrates the typical life-cycle trajectory of household energy consumption, showing low energy use during the early independence stage, a sharp increase during the household formation and expansion stage – driven by larger dwelling size, greater adoption of appliances and heating systems, and childrearing – and a gradual increase in energy consumption throughout middle and later adulthood.

When total energy consumption is disaggregated by household type, the results consistently demonstrate the presence of economies of scale (Figure 7-b). Per capita energy consumption is highest in single-person households, followed by one-generation households, two-generation households, and three-or-more-generation households, in that order. This hierarchy is observed consistently across all age groups. Moreover, the variation in individual total energy use by age becomes less pronounced as the number of household generations increases. In single-person households, the absence of shared base loads, combined with continued needs for indoor comfort, safety, and thermal stability in old age, leads to persistently higher and steadily increasing energy use throughout the life course. In contrast, individuals in two-generation and three-or-more-generation households benefit from shared fixed loads such as heating, hot water, cooking, and lighting, resulting in lower and more stable per capita energy consumption profiles.



(a) Raw and Smoothed Series



(b) Smoothed Series by Household Type

Figure 7: Age-specific Total Energy Consumption

4. Summary and Policy Implications

This study applied the National Transfer Accounts (NTA) methodology to reallocate household-level energy consumption to the individual level and to construct per capita age profiles of energy use by energy source. This approach overcomes the limitations of conventional analyses, which are based solely on the household head's age, allowing for a more precise examination of heterogeneous consumption patterns across life stages and household types.

The empirical findings reveal that total household energy consumption tends to increase gradually with age and remains at a stable increasing level even among older adults, reflecting sustained basic needs for comfort and safety rather than a decline in demand for energy. In particular, electricity consumption rises rapidly from the late 20s to the late 30s. It continues to grow at a pace through middle and later adulthood, confirming a strong dependence on electricity among older households. Off-peak electricity use, although no longer available to new customers since 2010, continues to rise among older and rural households due to residual subscriptions and the persistence of storage-type heating systems.

District heating consumption showed only slight variation across age groups, possibly reflecting differences in housing type and construction period among the surveyed households. City gas consumption exhibited an inverted U-shaped pattern, increasing steadily until around age 50 and then declining moderately thereafter – consistent with reduced activity levels, but the persistence of minimum heating and hot water needs among older adults. Petroleum-based fuels (including kerosene, LPG, and propane) remain important energy sources for elderly households residing in older or detached homes not connected to city gas networks, particularly among single-person households. Across household types, clear economies of scale were observed, with per capita energy consumption decreasing as the number of household generations increased.

These empirical findings yield several important policy implications. First, demand forecasting systems should be refined to account more explicitly for population aging. Future energy demand models need to incorporate not only total population size but also the evolving age structure, as aggregate models often fail to capture behavioral shifts associated with demographic transitions. Integrating age-specific energy consumption profiles can substantially enhance the accuracy of long-term demand projections. Second, energy welfare policies targeting older adults should be strengthened. Because heating, lighting, and hot water are essential for safety and well-being, older adults have limited flexibility to reduce consumption. Single-person elderly households, in particular, face higher energy costs and lower efficiency. Tailored measures – such as discounted tariffs, financial assistance for efficient heating systems, and personalized energy management services – should therefore be prioritized. Third, demand management strategies must be differentiated by energy source. Electricity use among the elderly continues to rise, whereas consumption of city gas, district heating, and petroleum-based fuels displays distinct age-related patterns. Policy measures should reflect these differences by incorporating age-sensitive approaches into fuel-switching initiatives, tariff reform, and energy-efficiency incentive programs. Fourth, household composition should be explicitly integrated into energy policy design. The observed economies of scale indicate that household structure has a significant impact on energy efficiency. As the prevalence of single-person households increases, policy frameworks must anticipate changes in housing composition and provide differentiated support mechanisms for smaller households. Finally, the age-profile estimation framework employed in this study can serve as a valuable tool for policy targeting and statistical improvement. The age-specific energy consumption profiles developed here can enhance the precision of national energy statistics and enable more fine-grained policy interventions. By identifying distinct consumption patterns across demographic groups, policymakers can design customized strategies that better reflect the diverse energy needs of different age cohorts.

In conclusion, population aging represents not merely a demographic transition but a structural force reshaping household energy demand. By quantifying the direct and heterogeneous impacts of population aging on energy use, this study provides an empirical foundation for developing evidence-based strategies to forecast energy demand, enhance welfare, improve efficiency, and decarbonize an aging society.

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