

## Heating practices in slovenian households: Socio-spatial and structural drivers of energy choices

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### ABSTRACT

The European Union aims to reduce its dependence on fossil fuels by increasing renewable energy use, including sustainable wood biomass. Achieving these goals requires an understanding of heating practices at both national and household levels. This study explores heating patterns in Slovenian households, focusing on wood-based fuels and the influence of socio-demographic, spatial, and structural factors on heating choices and energy consumption.

Survey results indicate that firewood is the primary heating source in Slovenia, reflecting the high proportion of forest owners. When heating energy sources are grouped by category, wood fuels dominate among households with multiple heating systems, accounting for 36% of those households. Among single-system households, fossil fuels lead (31%), followed by electricity (30%). Firewood is the most common wood fuel, followed by pellets, chips, briquettes, and residues. Rural households rely heavily on wood fuels, whereas urban households prefer fossil fuels or electricity. Overall, the median wood-fuel consumption is 66.2 GJ per household per heating season.

Heating patterns are strongly linked to building characteristics. Individual systems prevail in single- and two-family houses, while collective systems are typical of multi-apartment buildings. Forest owners, mainly living in rural single-family homes, source firewood from their own forests and show little willingness to change their practices.

These findings underscore the need to integrate socio-spatial and structural factors into renewable energy policy. Promoting efficient biomass use, replacing outdated appliances, developing markets for small-diameter wood, and expanding modern district heating systems based on sustainably sourced wood biomass could accelerate Slovenia's progress towards climate neutrality and support EU renewable energy and air quality objectives.

### 1. Introduction

The European Union's (EU) Renewable Energy Directive (RED III), as part of the Fit for 55 package, establishes a binding target to increase the proportion of renewable energy in the EU's total energy consumption to 42.5 % by 2030 (EU, 2023/2413). Although cascading use and prioritizing material applications are generally preferred, the energy use of woody biomass will continue to play an important role in meeting these ambitious targets and supporting the transition from fossil fuels to renewable energy sources. In addition, woody biomass can provide dispatchable energy, helping to balance the intermittency of renewables such as wind and solar (Thees et al., 2020). The inclusion of greenhouse gas emissions and removals from land use, land use change, and forestry

(LULUCF) in the EU 2030 climate and energy framework (EU, 2018/841) further emphasizes the role of forests in climate mitigation. The LULUCF Regulation obliges Member States to ensure that emissions do not exceed removals over the 2021–2030 period, covering all relevant land categories. This binding framework highlights the importance of sustainable forest management and the careful use of forest biomass for energy.

Despite its potential, the sustainable supply of biomass remains a key challenge. Unsustainable harvesting of wood for energy can lead to deforestation, soil degradation, reduced availability of industrial raw materials, and diminished carbon sink capacity (Balat and Bozbas, 2006). In countries with a high share of forest cover and strong reliance on wood fuels, such as Slovenia, these risks are closely linked to national

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forest management practices, harvesting limits, and competing demands for wood from the energy and industrial sectors. Regional market conditions, policy frameworks, and local infrastructure therefore play a decisive role in determining how much of the theoretical biomass potential can be sustainably mobilised for heating purposes.

A study by the European Commission on forest biomass for energy (Camia et al., 2021) revealed that the overall use of woody biomass in the EU increased by approximately 20 % over the past two decades, with a growing proportion used for energy purposes. Data indicate that households remain the dominant users of biomass for energy in the EU, while heat plants and combined heat and power installations primarily rely on industrial residues and processed fuels. Wood-based bioenergy relies largely on secondary woody biomass, such as industry by-products and post-consumer wood, which accounts for 49 % of reported use, while primary biomass, including stemwood, tree tops, and branches, represents at least 37 % of the EU's energy wood input. The remaining 14 % is uncategorized but likely consists mainly of primary sources. However, the study also identified substantial inconsistencies in reported data, with the use of woody biomass for energy and material purposes exceeding reported supply by over 20 %, highlighting the need for improved data quality and availability.

In Slovenia, approximately 30 % of forest wood assortments are currently used for energy, mainly for heating, while the remainder is processed in the wood industry (Krajnc and Piškur, 2006; Ščap, 2022). Wood fuels are particularly important in rural areas, where forest accessibility and traditional practices facilitate their use. A survey by the Slovenian Forestry Institute (Sever et al., 2017) found that over 55 % of rural households rely on wood fuels for heating, with 56 % obtaining wood from their own forests, indicating a high degree of self-sufficiency. Firewood use is more prevalent among lower-income households (below EUR 500/month, 59 %) compared to higher-income households (above EUR 2500/month, 18 %), highlighting the socio-economic dimensions of wood fuel use.

National-level data on wood fuel production and consumption in Slovenia remain fragmented due to household self-sufficiency and decentralized supply chains. Households consume approximately 1 million tonnes of wood fuels annually (SURS, 2023), corresponding to roughly 1.3–1.4 million m<sup>3</sup> of roundwood equivalent. Production from forests is estimated at about 1 million m<sup>3</sup> per year (Ščap, 2022). The estimated theoretical market potential for lower-quality hardwood in 2021 was 2.372 million m<sup>3</sup>, however, only 31 % of this potential was utilized. The remaining share reflects limited demand for deciduous lower-quality wood, insufficient domestic processing capacity, and economic constraints related to harvesting and transport, especially in privately owned forests (Ščap and Triplat, 2023). This underutilization indicates that part of the wood currently used for energy could instead serve higher-value applications in wood products, enabling more efficient use of existing processing infrastructure.

Given the strategic importance of woody biomass in Slovenia's energy landscape and the EU's broader climate targets, understanding household-level heating practices and preferences is essential. This focus on individual households represents a bottom-up approach to assessing current heating behaviours and potential for change. Only by accurately assessing current conditions can improvements be identified, guidelines formulated, and progress made towards reduced dependence on fossil fuels. The results of this study will serve as a basis for recommendations aligned with EU energy and climate objectives.

The objective of this study is to analyse household heating practices in Slovenia, focusing on the role of wood fuels and the potential for transition to other renewable sources. Specifically, the study addresses the following research questions:

- What are the primary and secondary energy sources used for household heating in Slovenia?
- Are there socio-demographic differences between households using wood fuels and those using other heating sources? Do households

with non-wood heating systems intend to switch to wood or other renewable energy sources?

- Are there differences in total energy consumption for heating based on settlement type or building characteristics?

## 2. Methods

In February 2023, a nationwide survey was conducted to investigate household heating practices in Slovenia. The survey targeted a representative sample of households stratified by region, settlement type, and respondent age to ensure broad coverage of demographic and geographic variability. Soft quotas were applied by respondent age to maintain representativeness.

The survey consisted of two parts:

1. Recruitment questionnaire – completed by all selected household representatives. It included eight questions on demographics (age and gender), type and location of residence, primary and secondary heating sources, and potential plans to transition to wood fuels if these were not currently in use.
2. Main questionnaire – administered only to households using wood fuels for heating. It comprised 17 core questions on heating practices, including type and number of heating devices, year of installation, and quantitative consumption of various wood energy sources (firewood, wood pellets, wood chips, briquettes, and wood residues). An additional set of five questions was directed to forest-owning households regarding firewood production and sales.

The gross sample included 4276 households. Data were collected using both Computer-Assisted Telephone Interviewing (CATI; 2149 households, 50.3 %) and Computer-Assisted Web Interviewing (CAWI; 2127 households, 49.7 %). The net sample, consisting of households that use wood fuels and agreed to participate in the main questionnaire, comprised 2000 households. The survey included 945 forest owners or co-owners.

According to ISO 16559:2022 (ISO, 2022), the woody materials considered in this study are woody solid biofuels (hereafter referred to as wood fuels), including wood chips, firewood, briquettes, pellets, and wood residues.

Respondents reported wood-fuel consumption in various units, including kilograms (kg), fresh metric tonnes (t), bulk cubic metres (bcm), stacked cubic metres (stcm), and solid cubic metres (m<sup>3</sup>). For wood pellets and wood briquettes, a net calorific value of 17.82 GJ t<sup>-1</sup> was assumed, for wood chips, a net calorific value of 14.87 GJ t<sup>-1</sup>, and a net calorific value of 14.71 GJ t<sup>-1</sup> was assumed for firewood (Krajnc et al., 2009). All reported mass and volume quantities were converted to oven-dry tonnes for analytical consistency using standardized conversion factors (Table 1). Oven-dry tonnes were then converted to energy units (GJ).

For analytical purposes, heating energy sources were grouped into broader categories (Table 2).

Households were classified according to the number of heating systems used. Single-system households use only one heating source, while multi-system households use two or more heating sources in parallel. In households with multiple heating systems, the primary heating source

**Table 1**

Conversion factors between measurement units and thermal energy equivalents for wood fuels (Krajnc et al., 2009, 2014).

Wood energy source	tonne (t)	bcm	stcm	m <sup>3</sup>
Wood chips (P30)	0.18	1.00		
Firewood	0.50		1.00	
Wood residues	0.37		1.00	
Wood residues	0.50			1.00
Wood residues	0.18	1.00		

**Table 2**  
Categories of heating energy sources.

No.	Group of heating energy sources	Heating energy source
1	Wood fuel	Firewood, wood pellets, wood chips, wood briquettes, wood residues
2	Electricity	Electric radiators, electric furnaces, infrared heating (IR) panels, heat pumps
3	Fossil fuels	Gas pipeline, fuel oil, coal (various types), LPG (gas storage)
4	Hot water system	District heating system
5	Solar energy	Photovoltaics, solar panels

refers to the system used most frequently or for the largest share of space heating, while secondary heating sources are used occasionally or as a supplement. To examine differences according to building type and settlement size, original categories were recoded into shorter codes (Table 3).

Statistical analyses were performed using the R programming environment (R Core Team, 2025). Differences in means were assessed using parametric or non-parametric tests depending on data distribution. Differences in categorical variables were tested using Pearson’s  $\chi^2$  test, while Levene’s test was used to assess homogeneity of variances. For multiple-group comparisons, the Kruskal–Wallis test was applied, and for two-group comparisons, Welch’s *t*-test was used. Statistical significance was set at  $\alpha = 0.05$ . Respondents with missing data were excluded from each analysis.

### 3. Results

#### 3.1. Prevalence of heating sources in slovenian households

The results show that firewood is the most commonly used heating source in Slovenian households. Among single-system households (relying on only one heating source), firewood accounts for 22 %, followed by electricity (18 %), natural gas (15 %), heating oil (13 %), district heating systems (13 %), and heat pumps (12 %). In multiple-system households, firewood remains the dominant primary heating source (28 %), followed by natural gas (15 %), heat pump (15 %), and heating oil (13 %), and district heating systems (10 %). As a secondary heating source in multiple-system households, electricity is the most prevalent (30 %), followed by wood fuels (19 %) and fosile fuels (10 %). Percentages do not sum to 100 % because only the most common heating categories are reported in the text; complete distributions of heating sources are provided in the Supplementary materials.

When heating systems are grouped by energy source (Fig. 1), wood fuels are the most widespread heating option in multi-system households, accounting for 36 % of households. Among single-system households, fossil fuels prevail (31 %), closely followed by electricity (30 %).

**Table 3**  
Categorization codes for building types and settlement sizes.

Description	Short description (code)
Total	TO
Buildings of a different type (mainly office buildings, schools, fire stations, bachelor residences, emergency shelters, etc.)	K1
Two-family house	K2
Single-family house	K3
Multi-apartment building with 3 to 9 dwellings	K4
Multi-apartment building with 10 or more dwellings	K5
In a city of >10,000 inhabitants	K6
In a settlement with fewer than 3000 inhabitants	K7
In a settlement with >3000 inhabitants and fewer than 10,000 inhabitants	K8

#### 3.2. Heating source preferences in urban and rural areas

Settlement size has a statistically significant effect on heating practices (Table 4). In urban areas with >10,000 inhabitants, non-wood heating sources predominate, representing 88 % of all primary heating sources. The proportion of households using wood fuels increases steadily with decreasing settlement size, reaching 48 % in settlements with fewer than 3000 inhabitants. No statistically significant differences were observed by gender or age of household representatives in the use of wood versus non-wood heating sources.

At the regional level, wood fuels are used more frequently than non-wood fuels (in over 50 % of households) in only three Slovenian regions: Primorsko-notranjska, Jugovzhodna, and Goriška (Fig. 2). The lowest proportion of households using wood fuels as the primary source is found in Central Slovenia (21 %), followed by the Obalno-kraška, Podravska, and Gorenjska regions, where the proportion is below 30 %.

#### 3.3. Household willingness to switch to wood-based fuels

Overall, 16 % of respondents reported a willingness to change their heating system, and 47 % of these respondents would switch to other renewable energy sources. Among respondents willing to change, 53 % currently use firewood, followed by 16 % who currently use heating oil. Among respondents currently using non-wood fuels (primarily fossil fuels), 7 % reported that they were considering switching to a wood-based heating source. Of these, the majority (60 %) expressed a preference for firewood, followed by wood pellets (Table 5).

#### 3.4. Building type, settlement size, and energy consumption

The median firewood consumption per household among all respondents was 4.00 tonnes per year, with lower median values reported for wood pellets (3.00 t yr<sup>-1</sup>), wood briquettes (0.72 t yr<sup>-1</sup>), wood chips (1.08 t yr<sup>-1</sup>), and wood residues (0.74 t yr<sup>-1</sup>). Table 6 and 7 presents estimated wood energy consumption (in tonnes) and the total energy consumption (in GJ) by building type and settlement size. The majority of responses were from households in single-family houses or settlements with fewer than 3000 inhabitants, which together represent the largest user group of wood fuels. Because the analysis focuses exclusively on wood-based heating, total energy consumption refers to energy derived from wood fuels only.

Building type has a statistically significant impact on total annual energy consumption for heating (Table 7). The highest consumption occurs in multi-apartment buildings with ten or more dwellings, where the median annual consumption of wood residues is 10.5 tonnes. Significant differences ( $p < 0.05$ ) in consumption were also observed for households using firewood and wood pellets across building types.

Most households (90 %) use an individual heating system, particularly in single-family and two-family houses. In contrast, in multi-apartment buildings with more than ten dwellings, 45 % have an individual heating system, whereas 55 % rely on a shared system. Households living in two-family houses reported the largest heated area (median 150.00 m<sup>2</sup>, Q1= 100.00 m<sup>2</sup>; Q3 = 200.00 m<sup>2</sup>). Respondents from urban settlements with between 3000 and 10,000 inhabitants reported relatively large heated areas (median 130.00 m<sup>2</sup>; Q1 = 90.00 m<sup>2</sup>; Q3 = 200.00 m<sup>2</sup>). Approximately 66 % of respondents heat their homes with a central heating system, and 29 % use a wood-burning stove. Across all types of wood biomass heating, the typical pattern is one heating unit per household, with an average appliance age of about 12 years.

#### 3.5. Forest owners

Welch’s *t*-test confirmed significant differences between respondents who own forest land and those who do not in terms of firewood consumption, total energy consumption for heating, and heated living area.

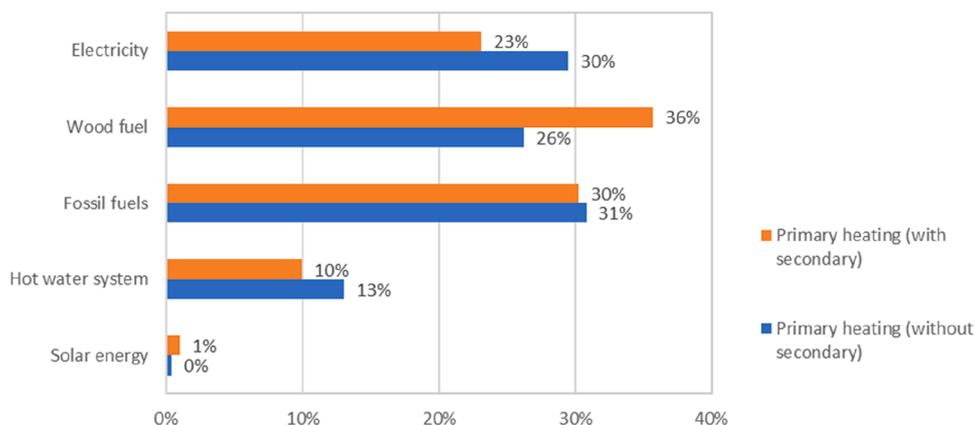


Fig. 1. Comparison of the frequency of use of different energy-source groups in households with only a primary heating source versus households with both primary and secondary heating sources.

**Table 4**  
Socio-demographic and settlement-size comparison of heating source preferences.

	Total, N = 4,276 <sup>1</sup>	Users of non-wood heating sources, N = 2,276 <sup>1</sup>	Users of wood heating sources, N = 2,000 <sup>1</sup>	p-value <sup>2</sup>	q-value <sup>3</sup>
Settlement size				<0.001**** <sup>4</sup>	<0.001***
In a city of >10,000 inhabitants	1476 (35 %)	1165 (51 %)	311 (16 %)		
In a settlement with fewer than 3000 inhabitants	2124 (50 %)	768 (34 %)	1356 (68 %)		
In a settlement with >3000 inhabitants and fewer than 10,000 inhabitants	676 (15 %)	343 (15 %)	333 (17 %)		
Age	47.70 (16.11) <sup>6</sup>	48.11 (16.11) <sup>6</sup>	47.22 (16.09) <sup>6</sup>	0.076 <sup>5</sup>	0.082
Gender				0.7 <sup>4</sup>	0.7
Male	1944 (45 %)	1041 (46 %)	903 (45 %)		
Female	2332 (55 %)	1235 (54 %)	1097 (55 %)		

<sup>1</sup> n/N ( %).

<sup>2</sup> \*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001.

<sup>3</sup> False discovery rate correction for multiple testing.

<sup>4</sup> Pearson's chi-squared test.

<sup>5</sup> Wilcoxon rank-sum test.

<sup>6</sup> Mean (SD).

A substantial proportion of forest owners (65 %) live in single-family houses, predominantly in small settlements with fewer than 3000 inhabitants (74 %). Their primary heating source is firewood, used by 71 % of forest owners. The vast majority of households use individual heating systems, including both forest owners (92 %) and non-forest owners (89 %), most commonly a central heating boiler (Table 8). Regarding fuel sourcing, 80 % of forest owners obtain firewood independently, either from their own forests or from forest land owned by

relatives, primarily for household use rather than for sale. Broadleaf species account for 76 % of the harvested wood. The majority of forest owners (85 %) reported no intention to change their current heating source in the future. Forest owners reported a higher annual consumption of both firewood (median 5.00 tonnes) and wood chips (median 1.89) than non-forest owners (median 2.50 tonnes of firewood and 0.35 tonnes of wood chips), reflecting differences in access to own wood resources. Although median wood-chip consumption is substantially higher among forest owners, this difference is not statistically significant, reflecting the small number of households using wood chips and the high variability in reported consumption.

#### 4. Discussion

One of the main objectives of the European Union's climate and energy policy is to reduce dependence on fossil fuels, a goal that directly influences household heating choices across Member States. Slovenia already largely aligns with the EU's de-fossilization objective in the heating sector, as the results of this study reveal a strong reliance on wood fuels for household heating. Firewood is the most frequently used energy source, similar to other South-East European countries, where primary forest biomass plays a central role in bioenergy supply (Rauč et al., 2015). This dependence on wood-based fuels is particularly pronounced in rural areas, where many households source firewood directly from their own forests, reflecting a high degree of self-sufficiency and a strong cultural tradition of local resource utilization. In contrast, the use of fossil fuels is more common among urban households and among those without forest ownership, which have limited access to forest resources. Similar spatial patterns have been reported in neighbouring Croatia (Filipović, 2025), where wood fuels are predominantly used in rural areas, whereas heating with wood has largely disappeared from apartment buildings in larger cities. However, wood remains important for single-family homes in both countries, either as the primary or a supplementary heating source. Germany's long-term energy strategy provides an interesting comparative perspective: biomass is expected to remain an important component of the heating sector by 2050, supporting renewable energy expansion and CO<sub>2</sub>-emission reduction goals (Syrbe et al., 2022). However, the sustainability of such use depends on the adoption of the cascade principle, i.e., the sequential use of harvested wood for material applications first, with only residual or end-of-life wood products used for energy. This principle enhances resource efficiency and contributes to a circular bioeconomy. Any increase in the use of wood fuels for heating should not compromise the supply of industrial roundwood required by the wood-processing industry. While Slovenia follows the EU objective of reducing fossil fuel dependence, implementing the cascade principle remains a significant challenge. Despite substantial potential for producing higher-value

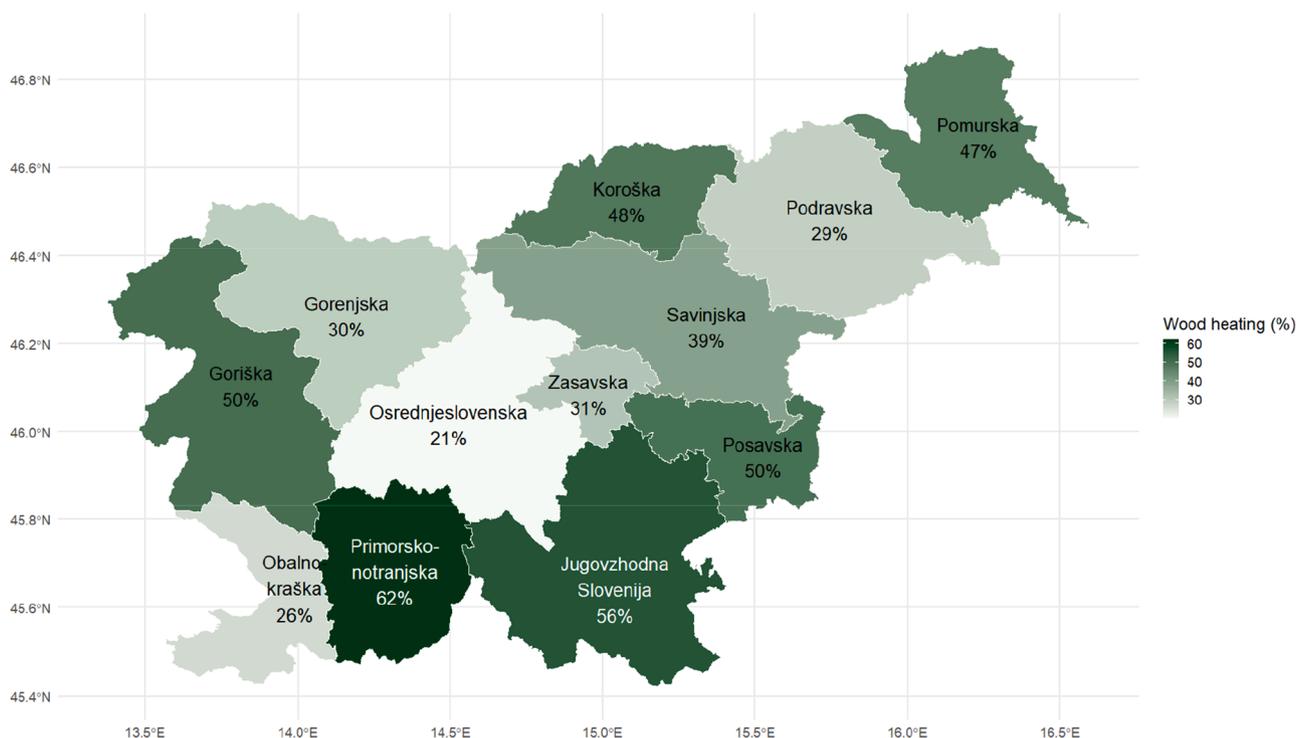


Fig. 2. Proportion of wood heating by region in Slovenia.

Table 5

Users of non-wood heating systems considering a transition to wood-based heating (percentages do not sum to 100 % because respondents were allowed to select multiple responses).

	Total, N = 167 <sup>1</sup>	Electricity (electric radiators, electric furnaces, IR panels, heat pumps), N = 52 <sup>1</sup>	Fossil fuels (pipeline, fuel oil, coal, LPG), N = 88 <sup>1</sup>	Solar energy, N = 4 <sup>1</sup>	Hot water system, N = 23 <sup>1</sup>	p-value <sup>2</sup>	q-value <sup>3</sup>
Wood pellets	68 (41 %)	24 (46 %)	33 (38 %)	0 (0 %)	11 (48 %)	0.3 <sup>4</sup>	0.7
Wood briquettes	21 (13 %)	4 (7.7 %)	12 (14 %)	1 (25 %)	4 (17 %)	0.4 <sup>4</sup>	0.7
Wood chips	17 (10 %)	5 (9.6 %)	9 (10 %)	0 (0 %)	3 (13 %)	>0.9 <sup>4</sup>	>0.9
Firewood	100 (60 %)	33 (63 %)	52 (59 %)	3 (75 %)	12 (52 %)	0.8 <sup>4</sup>	>0.9

<sup>1</sup> n/N ( % of respondents indicating option).

<sup>2</sup> \*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001.

<sup>3</sup> False discovery rate correction for multiple testing.

<sup>4</sup> Fisher's exact test.

wood products, Slovenia does not fully exploit this opportunity, primarily because a well-developed market for small-diameter wood is lacking (Triplat et al., 2023). Consequently, small-diameter wood is burned directly for firewood rather than being used first in higher value-added material pathways, undermining resource efficiency and the broader goals of the EU bioeconomy strategy.

Small private forest owners, who constitute the majority of forest owners in Slovenia, typically harvest wood primarily for their own household needs rather than for market sale. This pattern is clearly reflected in the results, which show significantly higher median firewood and wood chips consumptions, as well as total wood-based energy consumption, among forest-owning households compared with non-owners (Table 8). Median total wood-based energy consumption among forest owners exceeds 70 GJ per household, whereas non-owners consume substantially less. These differences are not indicative of lower energy efficiency, but rather of lower marginal fuel costs and greater availability of own wood resources.

At the same time, the wide dispersion observed in wood-fuel consumption reflects heterogeneous heating practices, with some households using wood as a primary heating source and others only supplementing other energy source. Heating choices among forest

owners are therefore shaped mainly by economic considerations and long-standing traditions. Because firewood harvested for own use has little or no perceived market value, forest owners tend to report higher total heating-energy consumption and show weaker incentives to invest in energy-saving measures, including building insulation, more efficient energy use, or the adoption of modern high-efficiency heating systems. As a result, they are generally less willing to modify existing heating technologies. This reluctance highlights the need for targeted policy measures and financial incentives to encourage the uptake of modern low-emission solutions while maintaining the benefits of locally available renewable resources.

Urban areas, due to their higher population density and greater distance from forest resources, generally exhibit lower reliance on wood-based fuels. This pattern is confirmed by the results, which show lower median wood-based energy consumption in larger settlements compared with smaller and more rural areas (Table 6). In urban contexts, where individual wood heating is less prevalent and air-quality concerns are more pronounced, district heating systems based on wood chips offer a promising solution, combining renewable energy use with efficient emission control. In Slovenia, successful examples include the district heating networks in the cities of Kočevje and Celje, where

**Table 6**  
Median estimated wood-fuel consumption (GJ) by fuel type and median total wood-based energy consumption (GJ) settlement size.

Characteristic	K6 N = 311 <sup>1</sup>	K7 N = 1,356 <sup>1</sup>	K8 N = 333 <sup>1</sup>	p-value <sup>2</sup>	q-value <sup>3</sup>
Firewood	29.42 (14.71, 73.55)	58.84 (22.07, 110.33)	58.84 (14.71, 110.33)	<0.001*** <sup>4</sup>	<0.001***
Wood pellets	44.55 (8.91, 71.28)	53.46 (26.73, 71.28)	44.55 (17.82, 71.28)	0.5 <sup>4</sup>	0.5
Wood briquettes	10.42 (5.35, 35.64)	15.33 (3.56, 35.64)	35.64 (4.46, 53.46)	0.7 <sup>4</sup>	0.7
Wood chips	5.20 (1.49, 23.79)	20.52 (5.95, 80.30)	20.07 (1.49, 74.35)	0.047* <sup>4</sup>	0.059
Wood residues	2.30 (0.30, 16.51)	10.86 (2.23, 40.15)	15.69 (7.44, 74.35)	0.025* <sup>4</sup>	0.036*
Total wood-based energy consumption (GJ)	32.69 (14.71, 73.55)	71.28 (29.42, 110.33)	58.84 (23.06, 110.33)	<0.001*** <sup>4</sup>	<0.001***

<sup>1</sup> Median (Q1, Q3).

<sup>2</sup> \**p* < 0.05; \*\**p* < 0.01; \*\*\**p* < 0.001.

<sup>3</sup> False discovery rate correction for multiple testing.

<sup>4</sup> Kruskal–Wallis rank sum test; Total wood-based energy consumption represents the sum of all reported wood fuels and does not include other household energy sources.

centralized systems enable continuous and reliable heat supply while maintaining low particulate emissions, an essential consideration for urban air quality. The expansion of such systems is supported through national financial incentives and subsidies that promote investment in renewable energy and energy efficiency in residential buildings across Slovenia.

A relatively high share of respondents willing to change their heating system currently rely on firewood. This does not necessarily indicate lower satisfaction with wood heating, as satisfaction was not directly assessed in the survey. Rather, willingness to change may reflect the practical burdens associated with wood-based heating systems, such as fuel handling, storage requirements, time demands, and exposure to price and supply variability. In addition, users of traditional biomass systems may perceive a greater potential benefit from switching to more automated renewable technologies, such as heat pumps or district heating, particularly in the context of energy transition policies. These results suggest that households currently using firewood may represent a key target group for policies aimed at promoting cleaner and more

automated renewable heating technologies. Nevertheless, the survey results show that the majority of respondents using non-wood heating sources would not choose to replace their current heating system with a wood-based one. This finding indicates limited willingness to shift to wood-based heating, even where district heating or other modern wood-fuel technologies are available. Consequently, future increases in wood fuel use are likely to depend more on technological improvements and efficiency gains among existing users than on large-scale conversions from other energy sources.

The study also found no statistically significant influence of gender or age on heating practices, suggesting that heating choices are shaped primarily by structural and contextual factors, such as housing type, local energy infrastructure, and resource availability, rather than individual demographic characteristics. This pattern indicates stable cultural adaptation in energy use, where heating habits persist across generations and reflect long-term adjustment to local socio-economic and environmental conditions.

Moreover, the relationship between building type and total annual energy consumption underscores the importance of structural characteristics in household energy behaviour. Households living in two-family houses, particularly those using wood chips, tend to exhibit higher total consumption levels due to larger living spaces, higher space-heating demand and the operation of shared heating systems. The wide variation in reported dwelling sizes reflects substantial structural heterogeneity in the housing stock, including differences in building age, dwelling type, number of household members, renovation status, and the partial heating of living space. In both rural and urban areas, larger and often older detached houses are common, with only parts of the building heated regularly, which further contributes to dispersion in reported floor-area values and associated energy consumption. Conversely, multi-apartment buildings are more likely to employ collective heating systems, consistent with greater urbanization and centralized infrastructure. The predominance of individual heating systems (90 %) among single- and two-family houses illustrates the highly decentralized nature of the Slovenian heating sector.

Traditional heating technologies remain prevalent: approximately 66 % of households use central heating boilers, and 29 % rely on wood-burning stoves. The average appliance age of around twelve years suggests ongoing replacement cycles rather than rapid modernization. Heating systems typically represent long-term investments with lifetimes of several decades, which contributes to strong path dependency and explains why many households are reluctant to replace functioning systems prematurely. In addition, high upfront investment costs, uncertainty regarding future energy prices and support schemes, as well as technical or spatial constraints, may further reduce willingness to switch. In the case of wood-based heating, relatively low operating costs

**Table 7**  
Median estimated wood-fuel consumption (GJ) by fuel type and median total wood-based energy consumption (GJ) by building type and settlement size.

Characteristic	N	TO N = 2,000 <sup>1</sup>	K1 N = 8 <sup>1</sup>	K2 N = 527 <sup>1</sup>	K3 N = 1,288 <sup>1</sup>	K4 N = 133 <sup>1</sup>	K5 N = 44 <sup>1</sup>	p-value <sup>2</sup>	q-value <sup>3</sup>
Firewood	1693	58.84 (22.07, 110.33)	47.81 (22.07, 73.55)	73.55 (22.07, 110.33)	58.84 (22.07, 110.33)	29.42 (7.36, 73.55)	14.71 (7.36, 36.78)	<0.001*** <sup>4</sup>	<0.001***
Wood pellets	315	53.46 (17.82, 71.28)	17.82 (8.91, 427.68)	53.46 (35.64, 71.28)	53.46 (32.08, 71.28)	21.38 (14.26, 44.55)	21.38 (5.35, 71.28)	0.032* <sup>4</sup>	0.046*
Wood briquettes	91	12.83 (3.56, 35.64)	0.89 (0.89, 0.89)	26.73 (10.69, 35.64)	8.91 (2.67, 35.64)	8.64 (2.87, 26.73)	18.71 (1.78, 35.64)	0.2 <sup>4</sup>	0.2
Wood chips	65	16.06 (2.97, 53.53)	1.49 (1.49, 1.49)	29.44 (14.87, 160.60)	15.46 (2.97, 49.81)	10.63 (2.48, 38.81)	1.49 (0.01, 14.87)	0.052 <sup>4</sup>	0.065
Wood residues	113	11.00 (1.49, 38.51)	44.61 (44.61, 44.61)	14.87 (2.68, 74.35)	9.37 (1.49, 33.01)	2.30 (0.74, 7.44)	156.14 (14.87, 297.40)	0.10 <sup>4</sup>	0.11
Total wood-based energy consumption (GJ)	2000	58.84 (22.07, 110.33)	47.81 (22.56, 110.33)	73.55 (29.42, 110.33)	58.84 (22.07, 110.33)	26.73 (8.83, 71.28)	14.87 (7.36, 58.16)	<0.001*** <sup>4</sup>	<0.001***

<sup>1</sup> Median (Q1, Q3).

<sup>2</sup> \**p* < 0.05; \*\**p* < 0.01; \*\*\**p* < 0.001.

<sup>3</sup> False discovery rate correction for multiple testing.

<sup>4</sup> Kruskal–Wallis rank sum test; Total wood-based energy consumption represents the sum of all reported wood fuels and does not include other household energy sources.

**Table 8**  
Wood-fuel consumption and selected household characteristics by forest-ownership status (tonnes).

	N	All, $N = 2,000^1$	Yes, $N = 945^1$	No, $N = 1,055^1$	Beta (95 % CI) <sup>2,3</sup>	p-value <sup>2</sup>	q-value <sup>4</sup>
Firewood	1693	4.00 (1.50, 7.50)	5.00 (2.00, 7.50)	2.50 (1.00, 5.00)	1.8 (1.3, 2.3)***	<0.001	<0.001
(No answer)		307	82	225			
Wood pellets	315	3.00 (1.00, 4.00)	3.00 (1.00, 4.00)	3.00 (1.20, 4.00)	-0.18 (-1.4, 0.99)	0.8	0.9
(No answer)		1685	853	832			
Wood briquettes	91	0.72 (0.20, 2.00)	0.70 (0.15, 2.00)	0.86 (0.20, 2.00)	-0.03 (-2.0, 1.9)	>0.9	>0.9
(No answer)		1909	926	983			
Wood chips	65	1.08 (0.20, 3.60)	1.89 (0.90, 5.20)	0.35 (0.10, 1.62)	7.8 (-1.1, 17)	0.085	0.14
(No answer)		1965	913	1022			
Wood residues	113	0.74 (0.10, 2.59)	0.74 (0.10, 3.70)	0.73 (0.10, 2.00)	0.15 (-1.4, 1.7)	0.9	>0.9
(No answer)		1887	890	997			
Number of household members	2000	4.00 (2.00, 4.00)	4.00 (3.00, 5.00)	3.00 (2.00, 4.00)	0.55 (0.41, 0.69)***	<0.001	<0.001
Type of heating system	2000				0.09		
Individual heating system		1801 (90 %)	865 (92 %)	936 (89 %)			
Common heating system		199 (10.0 %)	80 (8.5 %)	119 (11 %)			
Household size	2000	120.00 (84.00, 200.00)	140.00 (100.00, 200.00)	120.00 (80.00, 170.00)	27 (18, 37)***	<0.001	<0.001

<sup>1</sup> Median (Q1, Q3); n/N (%).

<sup>2</sup> Welch's two-sample *t*-test; standardized mean difference.

<sup>3</sup> \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

<sup>4</sup> False discovery rate correction for multiple testing; Abbreviation CI = confidence interval.

and local fuel availability can also contribute to a high level of acceptance, even when systems are associated with higher labour requirements. Together, these factors suggest that the observed willingness to change is shaped more by structural and economic considerations than by simple dissatisfaction with existing heating systems. From a policy perspective, this indicates the need for targeted measures, such as incentives for upgrading to high-efficiency, low-emission biomass technologies in rural and suburban single-family homes, alongside the expansion of clean district heating networks in urban areas.

In 2024, Slovenia adopted a new Energy Act (EZ-2), which introduces targeted restrictions on heating technologies in areas with persistent air quality problems. The act prohibits the design and installation of heating systems using solid or liquid fuels in new buildings located within densely populated settlements. Importantly, the legislation does not represent a blanket ban on wood-based heating. Slovenia continues to promote district heating systems based on wood biomass, as well as the use of biomass in individual household heating systems outside densely populated areas, recognizing wood as a strategically important domestic and renewable energy source that contributes to national energy security and security of energy supply. This approach reflects the country's long-term commitment to reducing air-pollution hotspots while maintaining sustainable utilization of forest resources.

Residential heating with solid biomass remains a major contributor to Slovenia's air pollution, especially during the heating season. National evidence indicates that small-scale domestic wood combustion is among the leading sources of primary PM<sub>2.5</sub> emissions due to incomplete combustion (OP NOZ, 2024). To address these impacts, Slovenia adopted the Operational Programme for Air Pollution Control (OP NOZ) in May 2024 as its national air-pollution control programme towards 2030. OP NOZ prioritizes measures to reduce emissions from small combustion installations, including accelerated replacement of outdated biomass boilers, tighter fuel-quality and performance standards, and the expansion of renewable district heating in densely populated areas. These measures align with broader EU climate and energy frameworks, most notably the European Green Deal, the Fit for 55 package, and the Energy Performance of Buildings Directive (EPBD), which require structural changes in the heating sector, including modernization of appliances, improvements in building insulation, and a stronger role for renewable-based district heating systems. At the same time, ensuring good air quality in both rural and urban areas requires high-quality wood fuels and modern combustion technologies. Supporting smaller-scale district heating systems or shared heating facilities in

densely populated settlements can significantly reduce emissions by replacing numerous individual stoves. Slovenia already operates several medium-sized bioenergy and cogeneration plants, such as the Ljubljana District Heating Plant, which uses wood biomass as part of its fuel mix. Recent policy instruments, such as the Regulation on the Allocation of Financial Incentives for Promoting Energy from Renewable Sources and High-Efficiency Cogeneration and for Energy-Efficient District Heating and Cooling (Official Gazette of the Republic of Slovenia, No. 32/24), define the framework for state support for investments in renewable-based district heating, biomass-fuelled heating and cogeneration systems, and other high-efficiency heating and cooling infrastructure. Complementary measures offered by the Eco Fund, which provides non-repayable financial incentives to households for improving energy efficiency and promoting renewable energy use in buildings, further support this transition. In addition, successive Slovenian public calls have supported the construction and restructuring of district heating and cooling systems based on renewable energy sources (including wood-biomass solutions), providing non-repayable grants from the Cohesion Fund and the Recovery and Resilience Facility that can cover up to around 45 % of eligible investment costs. However, beyond energy-focused measures, it is equally important to strengthen the implementation of the cascade principle in Slovenia. This requires accelerating the development of markets for small-diameter wood and other lower-quality assortments, which are currently underutilized for material applications. Establishing such markets would enable higher-value uses before energy recovery, improving resource efficiency and aligning with EU bioeconomy objectives.

In the context of the European Green Deal, the Fit for 55 package, and the Energy Performance of Buildings Directive, Slovenia's heating sector represents both an opportunity and a challenge. Achieving climate neutrality will require integrated measures, including upgrading heating technologies, improving building insulation, and supporting renewable-based district heating, complemented by financial incentives and awareness campaigns. Importantly, policy interventions must account for settlement-specific characteristics and household-level behavioural patterns to ensure a socially acceptable and effective transition. Strengthening the link between forest policy, energy policy, and bioeconomy strategies will be crucial for balancing renewable energy expansion, air quality improvement, and sustainable forest-resource management.

Altogether, these findings emphasize the crucial role of sustainably managed forest biomass and modern heating technologies in Slovenia's path towards renewable energy independence, improved air quality, and alignment with European climate goals. Given the limited

willingness to switch from non-wood to wood-based heating, policy measures should prioritize modernizing existing biomass systems and promoting alternative renewable solutions, such as heat pumps or district heating, rather than expecting significant uptake of wood heating among current non-users. Furthermore, policy measures should be adapted to the specific characteristics of different settlement sizes rather than applying uniform solutions. Our survey results reveal notable differences in heating practices and preferences across settlement types; therefore, recognizing these variations is essential for designing effective interventions. The integration of household-level behavioural patterns with structural energy policies will be essential for achieving a balanced, low-emission, and socially acceptable heating transition.

## 5. Conclusions

This study demonstrated that wood fuels remain a cornerstone of household heating in Slovenia, particularly in rural areas and among forest-owning households, where access to local resources, long-standing traditions, and cost considerations strongly shape heating choices. At the same time, urban households show lower reliance on wood fuels, reflecting differences in settlement structure, infrastructure availability, and air-quality constraints.

The results indicate that future increases in biomass use are unlikely to stem from large-scale switching among current non-wood users. Instead, progress towards climate and air-quality goals will depend primarily on improving the efficiency and emissions performance of existing biomass-based heating systems and expanding renewable-based district heating in densely populated areas. These findings highlight the importance of targeted, context-sensitive policy approaches rather than uniform measures across regions and settlement types.

More broadly, the study underscores the need to better integrate energy policy, forest policy, and bioeconomy strategies. Strengthening the implementation of the cascade principle and developing markets for lower-quality wood assortments are essential to ensure that continued use of wood fuels for heating supports both climate objectives and sustainable forest-resource management. Aligning household behaviour, technological innovation, and policy design will be critical for achieving a low-emission, socially acceptable heating transition in Slovenia and comparable forest-rich countries.

## CRedit authorship contribution statement

**Nina Škrk Dolar:** Writing – review & editing, Writing – original draft, Validation, Investigation, Formal analysis, Data curation, Conceptualization. **Katarina Flajšman:** Formal analysis, Data curation. **Nike Krajnc:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition. **Špela Ščap:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Matevž Triplat:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

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

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## Supplementary materials

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## Data availability

These data are not publicly available due to anonymity requirements. Data will be made available on request.

## References

- Balat, M., Bozbas, K., 2006. Wood as an energy source: potential trends, usage of Wood, and energy politics. *Energy Sources, Part A: Recovery, Utiliz., Environ. Effects* 28 (9), 837–844. <https://doi.org/10.1080/00908310600718791>.
- Camia, A., Giuntoli, J., Jonsson, R., Robert, N., Cazzaniga, N.E., Jasinevičius, G., Avitabile, V., Grassi, G., Barredo, J.I., Mubareka, S., 2021. The use of woody biomass for energy purposes in the EU, EUR 30548 EN. European Union. <https://doi.org/10.2760/831621>.
- EU. (2018/841). Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from Land Use, Land Use Change and forestry in the 2030 Climate and Energy Framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013. *Official Journal of the European Union*, L 156, 25 p.
- EU, 2023. Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. *Official J. European Union*. <https://data.europa.eu/eli/dir/2023/2413/oj>.
- Filipović, M., 2025. Mnogi se još griju na drva. N1 Info Portal. <https://n1info.hr/vijesti/mnogi-se-jos-griju-na-drva-evo-kakve-su-cijene-i-iskustva-kuc-u-grijemo-na-drva-a-dogrijavamo-na-plin/#dmid=0fc287ce-4fef-4fdf-90fe-ed60019d813d>.
- ISO. (2022). 16559:2022. Solid biofuels — Vocabulary; Int. Organiz. Standard. <https://www.iso.org/standard/75261.html>.
- Krajnc, N., & Piškur, M. (2006). Tokovi okroglega lesa in lesnih ostankov v Slovenije. *Zbornik gozdarstva in lesarstva*(80(Krajnc, 2006 #1564)), 31–51.
- Krajnc, N., Piškur, M., Klun, J., Premrl, T., Piškur, B., Robek, R., Mihelič, M., Sinjur, I., 2009. Lesna goriva: drva in lesni sekanci: proizvodnja, standardi kakovosti in trgovanje. *gozdarski inštitut slovenije*. Založba Silva Slovenica.
- Krajnc, N., Piškur, M., Prislán, P., & Triplat, M. (2014). *Kakovostna lesna goriva za vsakogar - Koristne informacije za vse, ki se ogrevajo z lesom* (N. Krajnc, Ed.). OPNOZ, 2024. Operativni program nadzora nad onesnaževanjem zraka (OP NOZ) - Revizija OP NOZ iz 2019. Vlada Republike Slovenije, Gregorčičeva 20-25, SI 1001 Ljubljana. Retrieved from. <https://www.gov.si/assets/ministrstva/MOPE/Okolje/Zrak/zrak-emisije/OPNOZ.pdf>.
- R Core Team, 2025. R: a language and environment for statistical computing. r foundation for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Rauch, P., Wolfsmayr, U.J., Borz, S.A., Triplat, M., Krajnc, N., Kolck, M., Oberwimmer, R., Ketikidis, C., Vasiljević, A., Stauder, M., Mühlberg, C., Derczeni, R., Oravec, M., Krissakova, I., Handlos, M., 2015. SWOT analysis and strategy development for forest fuel supply chains in South East Europe. *For. Policy. Econ.* 61, 87–94. <https://doi.org/10.1016/j.forpol.2015.09.003>.
- Ščap, Š., 2022. Tokovi okroglega lesa. In: Triplat, M. (Ed.), *Kazalniki gospodarjenja z gozdovi v sloveniji*. Gozdarski inštitut Slovenije, pp. 48–59. <https://doi.org/10.20315/sfs.183>.
- Ščap, Š., & Triplat, M. (2023). Raba lesa, tržne količine in projekcije potencialov okroglega lesa listavcev v Sloveniji. *Les/Wood*, 72(1). <https://doi.org/10.26614/les-wood.2023.v72n01a02>.
- Sever, K., Krajnc, N., & Piškur, M. (2017). Poraba lesa za ogrevanje v gospodinjstvih v kurilni sezoni 2016/2017. *Strokovna ekspertiza v okviru nalog javne gozdarске službe GIS aktivnosti 5/3.2*.
- SURS. 2023. *Končna poraba energije po vrsti energetskega vira (naravne enote), gospodinjstva, Slovenija, letno (Final energy consumption by type of energy source (natural units), households, Slovenia, annually)*. SiStat. <https://pxweb.stat.si/SiStat/Data/pxweb/sl/Data/-/1815404S.px/>.
- Syrbe, R.U., Han, T.T., Grunewald, K., Xiao, S., Wende, W., 2022. Residential heating using woody biomass in germany—supply, demand, and spatial implications. *Land. (Basel)* 11 (11). <https://doi.org/10.3390/land11111937>.
- Thees, O., Erni, M., Lemm, R., Stadelmann, G., Zenner, E.K., 2020. Future potentials of sustainable wood fuel from forests in Switzerland. *Biomass Bioener.* 141. <https://doi.org/10.1016/j.biombio.2020.105647>.
- Triplat, M., Helenius, S., Laina, R., Krajnc, N., Kronholm, T., Ženko, Z., Hujala, T., 2023. Private forest owner willingness to mobilise wood from dense, small-diameter tree stands. *Forest Policy Econom.* 148. <https://doi.org/10.1016/j.forpol.2022.102901>.