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Unveiling rural energy pattern determinants: insights from forest-dwelling rural households in the Zagros Mountains, Iran

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Introduction: This study examines the determinants of energy sources among rural households in the forested regions of the Zagros Mountains in Iran.

Methods: The research focuses on 157 forest villages, categorized into three groups based on their access to different fuel sources: wood, kerosene and liquefied petroleum gas (LPG), and natural gas (NG). A survey was conducted among 346 rural households using a multi-stage stratified random sampling approach and a questionnaire.

Results: The findings reveal that firewood plays a significant role in household energy patterns, particularly in remote areas. Income is identified as a crucial determinant of energy structure, but non-income socio-economic factors also strongly influence energy patterns. Moreover, commercial energy sources exhibit higher energy efficiency, resulting in reduced annual energy consumption compared to the use of firewood as the primary fuel.

Discussion: The study emphasizes the urgent need to address the reliance on low-efficiency energy sources to mitigate deforestation risks. In countries like Iran, where forest resources are limited, transitioning from firewood to higher efficiency fuels becomes imperative for forest conservation and sustainability. The implications of this research underscore the importance of considering both economic and social dimensions in energy planning and interventions, promoting accessible and affordable alternatives to traditional biomass fuels, and designing targeted policies to encourage the adoption of cleaner and more efficient energy sources in rural areas.

KEYWORDS

rural household, energy pattern, firewood, non-commercial fuels, forest dwellers

1 Introduction

In developing countries, the energy consumption of rural households plays a significant role in the overall energy consumption of the country (Zou and Luo, 2019). Rural residents rely on various energy sources, which can be categorized as and non-commercial. Non-commercial sources include firewood, crop residues, dung-cake, and agricultural waste, while commercial sources include liquid petroleum gas (LPG), gasoline, kerosene, and electricity (Li et al., 2019; Yawale et al., 2021). In developing countries, non-commercial fuels, particularly biomass such as fuelwood and charcoal, make up a significant portion of household energy consumption (Karekezi and Kithyoma, 2002; Miah et al., 2010; Zou and Luo, 2019). In fact, it is estimated that biomass is the primary source of energy for 2.8 billion people worldwide (Shen et al., 2022). For example, in India, 77% of rural households depend

on biomass for their energy needs (Yawale et al., 2021), while in Nepal and Bangladesh, the figures are even higher at 92% and 76.2%, respectively (Pokharel, 2007; Miah et al., 2010). However, the heavy dependence on traditional biomass energy sources, especially fuelwood, in rural areas can have adverse environmental effects, including deforestation, greenhouse gases emissions, and pollution, which contribute to global warming and environmental concerns on a global scale (Oyedepo, 2012). At the local level, these energy sources can negatively impact agriculture and forest productivity, leading to soil erosion, land desertification, indoor air pollution, health risks, and hindered education for children and women (Li et al., 2009; Pira et al., 2013; Muller and Yan, 2018; Zi et al., 2021).

Rural households use energy from different sources, resulting in different energy consumption patterns. These patterns can be visualized as a "ladder-like" progression, representing a gradient of quality, convenience, and cost. Solid fuels like firewood and charcoal are situated at the bottom of the ladder, followed by liquid fuels such as gas and oil in the middle, and electricity at the top (Leach, 1992). The movement from the bottom to the top of the ladder is influenced by several factors including household income (Rahut et al., 2016), household characteristics (Song et al., 2018; Pye et al., 2020), fuel price and availability, housing attributes, cultural and socio-economic factors, and government policies (Mensah and Adu, 2015; Zhang et al., 2016; Ravindra et al., 2019). Each of these factors can influence the share of biomass, particularly fuelwood, in household energy consumption. Policy interventions and initiatives have been implemented in various countries to reduce the reliance on traditional biomass energy sources. For example, in Ghana, the promotion of LPG and the establishment of the West African gas pipeline led to a decrease in fuelwood consumption from 69% in 1990 to 58% in 2005 (Twumasi et al., 2020). Similarly, in China, access to alternative energy sources such as LPG and electricity resulted in a decline in biomass contribution to household energy consumption from 73.7% in 1998 to 37% in 2016. However, some studies have shown that in areas with access to LPG, people still prefer to use fuelwood, which can be attributed to factors such as economics, tradition, culture, and personal preference for fuelwood-cooked foods (Lee et al., 2015; Coelho et al., 2018; Li et al., 2019). Conversely, some rural communities perceive biomass energy as inconvenient and have gradually replaced it with commercial sources (Li et al., 2020). Research indicates that wealthier rural households tend to reduce their use of non-commercial energy sources and increase their consumption of commercial energy sources (Démurger and Fournier, 2011; Zou and Luo, 2019). Villages with higher incomes also tend to consume more commercial energy (Zhang et al., 2022). An increase in total annual household income is associated with a greater consumption of clean energy sources (Twumasi et al., 2020). Additionally, households with larger family sizes and older household heads tend to prefer non-clean fuels like fuelwood due to their lower cost and accessibility (Rahut et al., 2016; Adusah-Poku and Takeuchi, 2019; Twumasi et al., 2020; Wassie et al., 2021).

The existing literature on rural household energy patterns in developing countries has predominantly focused on general factors influencing energy consumption, such as income, fuel costs, and household characteristics. However, there is a notable research gap regarding the specific determinants of energy sources among forest-dwelling rural households in the Zagros Mountains region of Iran. This study aims to address this gap by examining the energy patterns and their determinants in this unique context. By investigating the factors influencing energy choices and consumption among forest dwellers, this research contributes to a better understanding of the dynamics of energy use in remote rural areas. Compared to previous publications in this field, this research offers several novel contributions. Firstly, it focuses on forest-dwelling rural households, a specific subset of the rural population that has received limited attention in previous studies. By examining the energy patterns of these households, the research sheds light on the unique challenges and opportunities they face in terms of energy access and consumption. Secondly, by considering these additional factors, such as cultural and socio-economic influences, the research provides a more comprehensive understanding of the complexities underlying energy choices in forest-dwelling rural households. Furthermore, the study highlights the potential benefits of transitioning to higher efficiency fuels in terms of reduced environmental impact and forest conservation by comparison between commercial energy sources and the prevalent use of firewood. By examining the energy efficiency and associated annual energy consumption.

1.1 Review on rural energy patterns in Iran

Iran, situated in the Middle East, is categorized as a low forest cover country (LFCC) with only 7.3% or 14.2 million hectares of land covered by forests. Among these forests, the Zagros oak forests are particularly significant, covering approximately 6 million hectares and accounting for about 45% of Iran's total forest area. These forests, classified as semiarid and commonly referred to as dry forests, play a crucial role in the country's water production, contributing to almost 40% of the total water supply (Sagheb Talebi et al., 2014). The Zagros forests are home to approximately 10% of Iran's population, and many residents depend on these forests for their livelihoods (Salehi et al., 2010). Over the years, the forests have been utilized for various purposes, including livestock breeding, grazing, the collection of non-timber forest products (NTFPs), and agriculture (Soltani et al., 2011; Henareh Khalyani et al., 2013; Khosravi et al., 2017). However, the Zagros forests have suffered from degradation, and their management falls under the responsibility of the government's natural resources and watershed organization (Khalyani et al., 2014). Research has shown that households living in the Zagros forests adopt different livelihood strategies. The relative income derived from forest products varies depending on the household's income level and the geographical location of the forests (Soltani et al., 2011; Khosravi et al., 2014). One prevalent degrading factor in the area is the use and trade of fuelwood as an energy source. The consumption of fuelwood varies across different parts of the Zagros forests due to various factors such as climate, developmental stage, and socio-economic conditions. For example, in the southern Zagros region, 72% of rural households gather firewood for energy, averaging 5.4 cubic meters per household annually (Salehi et al., 2010). In central Zagros, this quantity increases to 10.5 cubic meters among nomadic communities and 24.18 cubic meters in rural areas (Bazgir et al., 2022). As educational levels and alternative sources of income outside of the forest increase, households in the Zagros forests become less reliant on forest resources (Salehi et al., 2010). This trend can lead to a decrease in firewood consumption. However, the Zagros forests have faced challenges in

recent years, including oak decline phenomena[1] and severe droughts (Goodarzi et al., 2019; Ghanbari Motlagh and Kiadaliri, 2021). Both literature and government organizations suggest that the dependency of local communities on these forests for their needs is a primary factor contributing to forest degradation. This pressure also renders the forests more susceptible to secondary factors such as droughts and oak decline. To address these issues, the government has implemented several measures to reduce the dependency of local communities on the Zagros forests. These measures include providing rural communities with alternative fuels as a means to decrease firewood consumption.

The strategy of providing alternative fuel to forest dwellers in Iran primarily relies on significant reserves of kerosene and natural gas (NG). As one of the world's major oil producers, Iran has historically been heavily dependent on oil as an energy source and a catalyst for economic growth. Since the first discovery of oil in 1908 at Masjid Solaiman, the Iranian economy, like many others globally, has increasingly relied on crude oil consumption and export revenue for industrial development (Solaymani, 2021). However, over time, the dependency on oil has gradually decreased in Iran, as well as in other countries, due to the utilization of other energy sources such as natural gas and renewable energies. The share of oil in total energy demand has decreased from 91% in 1980 to 43% in 2018, primarily due to the increased use of natural gas (Ministry of Energy, 2020). The Energy Model Reform of Iran, outlined in Chapter 10 and Articles 61 and 62, emphasizes the use and investment in renewable and nuclear energy. According to this law, the Ministry of Energy is mandated to support the expansion of renewable energy sources, including wind, solar, geothermal, small-scale hydropower plants, marine energy, and various forms of biomass (including agricultural and forest waste, municipal waste, industrial waste, livestock waste, biogas, and biomass). For several decades, the government has implemented measures to provide rural areas with kerosene and liquefied petroleum gas (LPG) (Shaditalab and Naidar, 2009). In recent years, the policy of replacing kerosene with natural gas has been pursued to improve household energy patterns. The percentage of rural households with access to natural gas increased to 42% in 2017 (Ashouri et al., 2019). Furthermore, according to the latest statistics published by the Ministry of Energy, 100% of rural households in Iran had access to electricity by the end of 2014 (Ministry of Energy, 2020).

However, traditional fuels are still prevalent in rural areas of Iran, primarily due to the vast territory of the country, the presence of remote and inaccessible regions, and the lack of development in these areas. A significant portion of rural energy consumption is derived from the use of firewood obtained from forest areas. While several studies have examined the amount of fuelwood consumption and its contribution to rural income, there is a limited understanding of the factors influencing rural household energy patterns in the Zagros forests (Soltani et al., 2011; Sagheb Talebi et al., 2014; Khosravi et al., 2017). Although providing rural households with affordable alternative energy sources is crucial in developing countries (Song et al., 2018), there are various determinants that can influence the energy usage patterns of rural households. Therefore, this study aims to examine the factors that affect rural energy patterns. The findings of this research can contribute to a comprehensive understanding of these factors and can be utilized by managers in extension and education programs to promote the reduction of firewood consumption. Given that the energy patterns of rural households involve a variety of energy sources to meet their requirements, it is essential to explain the determinants of rural household energy consumption from a policy perspective. The results of this study can assist policymakers and energy planners in considering these determinant factors when designing energy policies and interventions for rural areas.

2 Methodology

2.1 Study area

This research was undertaken in the forest villages of Khorramabad County in Lorestan province (Figure 1). Forest villages refer to rural areas which are in or close to forests and are depend on forests for their needs. According to the results of the recent general population and housing census, 144,958 households were living in this county, of which 33,251 households (about 23%) lived in rural areas. Khorramabad with an area of 5,002 square kilometers is the largest county in Lorestan province and in terms of forest area, it ranks second in the province with 32% of the forest area of the province.

2.2 Classification of villages

The study focused on an area encompassing 157 forest villages with a total of 3,343 households in Khorramabad County. To identify these forest villages, information was gathered from various sources including the National Oil Company, the Departments of Gas and Natural Resources of the province, as well as through interviews with local informants and group discussions. Through this process, the primary fuel sources used by the villagers were determined. Since a significant portion of household fuel is utilized for home heating (Bazgir et al., 2015), the villages were categorized based on their access to fuel sources for this purpose. Consequently, the forest villages were divided into three categories. The first category comprises villages that lack access to alternative energy sources, with wood being their primary source of energy. This group consists of remote villages where obtaining alternative fuel is challenging. In these villages, there is no local distributor for liquefied petroleum gas (LPG), and the distribution of kerosene is also hindered due to factors such as a lack of agreement with the distribution agent. Additionally, the condition of the road network poses a limiting factor for accessing alternative fuels, particularly during the winter months when weather and road conditions worsen. While some households in this category occasionally use LPG cylinders, these cylinders are obtained from nearby villages. The second category includes villages with access to kerosene and LPG. In these villages, local distributors supply rural residents with LPG cylinders and kerosene (Figure 2). The third category consists of villages with access to natural gas (NG). In this group, NG serves as the main energy source, although households also utilize firewood, LPG, and kerosene alongside NG.

1 The term "decline" describes a condition in which a number of damaging agents interact with one another to weaken trees and bring about their deterioration, sometimes resulting in premature death (Goodarzi et al., 2019).

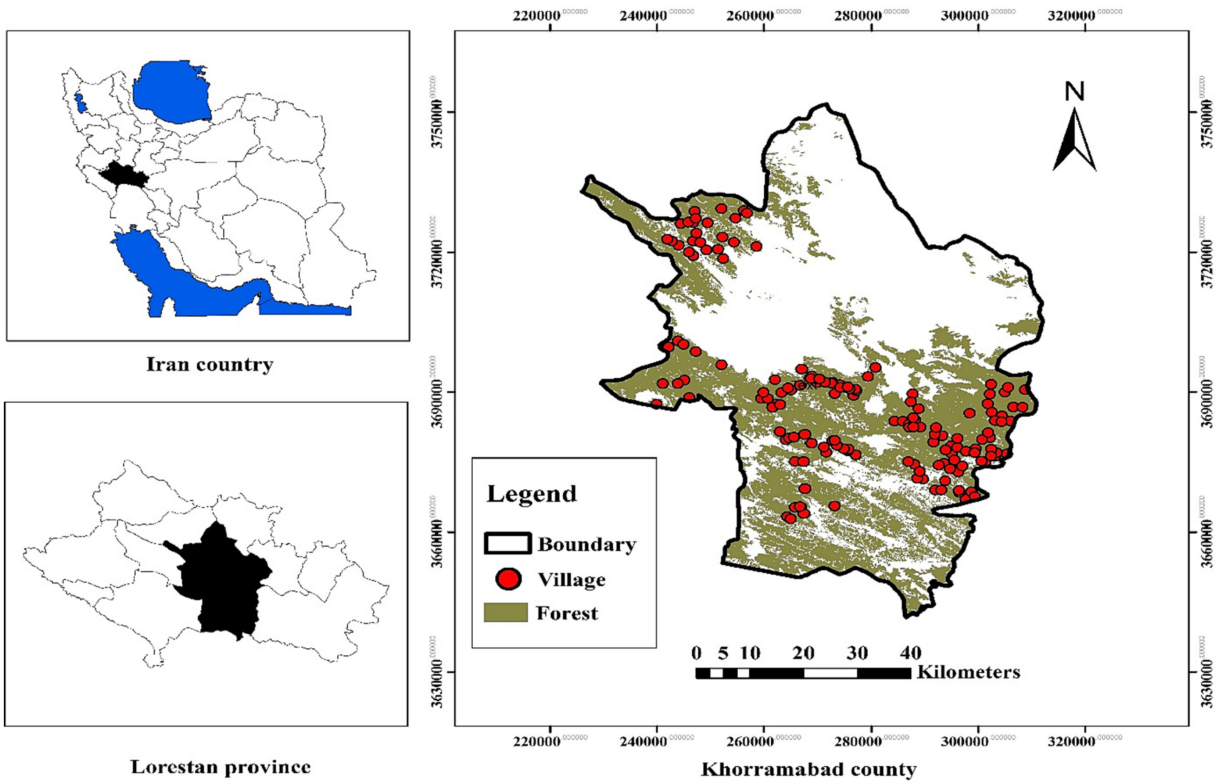

FIGURE 1
Map of selected villages in Khorramabad County and location of Khorramabad within Iran.

FIGURE 2
Local distributers of Kerosene (right) and LPG (left).

2.3 Sampling method

The total sample size was determined to be 346 households based on the Krejcie and Morgan table (1970), which provides guidelines for sample size determination. A multi-stage stratified random sampling method was employed to select households in each category for the survey. At the first stage of sampling, the villages were classified based on their dominant fuel source, as mentioned in 2.2. section. In the second stage of the sampling process, the total number of observations determined by the Krejcie and Morgan table were divided by assigning a proportionate number of observations to each category based on population size. In this stage 32, 217, and 97 observations were assigned to first, second, and third categories (Table 1), respectively. This ensured that each category was adequately represented in the sample. Then, we selected some representative villages for each category. Subsequently, in selected villages of each category, the households were randomly sampled.

2.4 Data gathering

A structured household-level questionnaire was designed to collect data for the study. The questionnaire comprised two parts:

TABLE 1 Number of villages, households, and selected households in three groups.

Fuel category	Number of villages	Number of households	Number of sampled households per category
First	19	297	32
Second	114	2,103	217
Third	24	943	97
Total	157	3,343	346

the first part focused on gathering basic information, including gender, age, family income, and family population. The second part aimed to collect specific household fuel-related data, such as the types of fuel used, the consumption levels of different fuel types, and other relevant information. In May 2021, a pre-test survey was conducted to validate the sample and refine the wording of the questions to ensure clarity and user-friendliness of the questionnaire. Data collection took place from April 2021 to August 2022. The final version of the research questionnaire was administered through home visits, with the assistance of local informants. Face-to-face interviews were conducted with the head of the household or other key members. The presence of a local informant during the interviews was intended to foster trust among survey respondents and enhance data accuracy.

To determine the consumption levels of various types of fuel, the following methods were employed: For households in villages with access to natural gas (NG), the amount of NG consumption was obtained by extracting data from the Iran Gas Company's website, using the gas subscription number of each household, for the study period. To calculate the consumption of liquefied petroleum gas (LPG) and kerosene, specific consumption units for each fuel type were determined and utilized for measurement. The consumption unit for LPG was an 11 kg cylinder, while for kerosene, it consisted of 220 L barrels and 2 L tanks. Household electricity consumption data were obtained from the electricity distribution company of the province, using the subscription numbers of households. In order to quantify the volume of firewood consumed by villagers, local units of firewood consumption (such as armpit, donkey load, or tractor load) were utilized. Once these units were identified, the dry weight of each consumed unit was measured (Figure 3).

The total energy consumption for households was calculated using the standard coal equivalent energy conversion index (Table 2). The density of kerosene is equal to 0.8 g/cm^3 and by using this coefficient, the amount of kerosene consumed in liters is converted to kilograms. The equation for total energy consumption of each household can be summarized as follows (Equation 1):

$$T_e = \sum_{i=1}^{n} \left[1.7L(x) + 0.6F(x) + 1.46\,K(x) + 0.12\,E(x) + 1.27\,N(x)\right] \quad (1)$$

T_e = total energy consumption of each household, $L(x)$ = LPG consumption (kg), $F(x)$ = firewood consumption (kg), $K(x)$ = kerosene consumption (kg), $E(x)$ = electricity consumption (kw/h), $N(x)$ = NG consumption (m^3).

2.5 Data analysis

The collected data was subjected to both descriptive and inferential statistical analyses. The descriptive statistics focused on examining the socio-economic and demographic factors that were hypothesized to influence the choice of energy sources. This analysis specifically explored characteristics of household heads, such as age, education level, household size, monthly income, and the number of male individuals over 15 years old, as it was observed during the pre-survey analysis that males in this age group were involved in firewood collection as an energy source, although women have played a role in this field in the past. Additionally, characteristics of housing, such as the size of the heated area in the house, were investigated. This analysis aimed to provide insights into whether rural households in the study area followed the energy ladder theory, which posits a progression towards cleaner and more efficient energy sources over time. For the variables examined within the majority group, measures such as mean and range were determined. Furthermore, the association between the characteristics of rural households and their primary fuel sources was analyzed using Pearson's statistic. This analysis aimed to assess the strength and direction of the relationship between the identified household characteristics and the main fuel sources used by households.

3 Results

3.1 Characteristics of heads of households and houses

The descriptive results of the research related to the characteristics of heads of households (survey respondents) are shown in Table 3. Data also show that 100% of the respondents of first category are male. This quantity for second and third categories are 94.5% and 74.2%, respectively.

3.2 Energy consumption structure

The findings of the study regarding the annual fuel consumption structure revealed that firewood is the dominant energy source in the first category of villages. On average, each household in this category consumed 17,852.6 kg of firewood annually, while the consumption of kerosene was recorded as 0 L, and the consumption of LPG was 284.6 kg (Table 4). In the second category of villages, the average annual fuel consumption per household was 7,524 kg of firewood, 1094.8 L of kerosene, and 283.6 kg of LPG. For the third category, which includes villages with access to natural gas (NG), the average annual fuel consumption per household was 909 kg of firewood, 23.5 L of kerosene, 44 kg of LPG, and 1,341 m^3 of NG.

These findings provide valuable insights into the energy consumption patterns in different categories of villages, highlighting the significant reliance on firewood in the first category, and the varying levels of consumption across different fuel sources in the second and third categories.

In line with the research methodology, the total energy consumption of households was computed by utilizing the conversion index of standard coal equivalent. The outcomes are clearly depicted

FIGURE 3
A donkey load of firewood (left) and measure the weight of the firewood (right).

TABLE 2 Index of conversion of energy consumption to the equivalent of standard coal.

Source of energy	Unit	Standard coal (kg)	Reference
LPG	kg	1.7	Cai and Jiang (2010)
Fuelwood	kg	0.6	Cai and Jiang (2010) and Peng et al. (2010)
Kerosene	kg	1.46	Peng et al. (2010)
Electricity	kw/h	0.12	Cai and Jiang (2010)
NG	m^3	1.27	Hu et al. (2016)

in Table 5. The average annual energy consumption per household was determined to be 11,420 kg, 6,832.4 kg, and 2,588.1 kg of standard coal for the first, second, and third categories, respectively. Within the first and second fuel categories, firewood emerged as the predominant energy source, constituting 93.8% and 66.1% of the total energy consumption, respectively.

3.3 Correlation analysis

In this research section, we examined the relationship between annual energy consumption (measured in kg of standard coal) and various factors related to the heads of households, including their age, education level, household size, economic characteristics such as the number of family workers and income, housing characteristics such as heated area, and fuel characteristics such as the number of heaters. We conducted a correlation analysis (see Table 6) to analyze these associations.

The results of the analysis showed that energy consumption in all categories was significantly and positively correlated with household size, income, heated area, and number of heaters. The number of male workers over 15 years old was also found to be positively correlated with energy consumption in the first and second categories, but not in the third category. The findings in the first and second categories revealed a significant negative correlation between energy consumption and the education of the head of the household. This suggests that households with higher levels of education exhibit lower energy consumption. In the third category, no significant relationship was found between the education levels of household heads and energy consumption.

The results of investigating the relationship between the number of between the number of heating devices used and annual energy consumption in the first and second category have shown that there is a positive and significant relationship between the number of firewood heaters and annual energy consumption, and also in the second category a negative and significant relationship between the number of kerosene heaters and annual energy consumption. Also in the third category, there is a positive and significant relationship between annual energy consumption and the number of gas heaters.

3.4 Mean comparison of household's energy consumption

In this section, we conducted a comparison of average energy consumption among households with different energy portfolios within each category. The results of these comparisons, presented in Tables 7, 8, indicate significant differences in energy consumption based on the use of various energy sources such as electric heaters, LPG water heaters, and firewood for heating milk and dairy product processing.

Among households in the first and second categories, those utilizing electric heaters and LPG water heaters exhibited significantly lower annual energy consumption. Conversely, the use of firewood for dairy product processing and heating milk resulted in a substantial increase in annual energy consumption. Furthermore, the results from Tables 7–9 reveal that the utilization of firewood for bakery purposes significantly increased the average annual energy consumption for households in the second and third fuel categories.

TABLE 3 Descriptive statistics of household head and house characteristics.

Fuel category	Variable	Age	Education (year)	Family size	Monthly household income (million tomans)	Male workforce over 15 years	The amount of heated area of the house (m^2)	Age of house (year)
First	Mean	49.6	5	4.3	3.7	0.8	33	28.7
	Range	24–78	0–11	2–7	1.2–15.8	0–3	14–110	5–50
	Majority group	≥40 and 41–50	0	3–6	1–2	0	16–30	1–15
Second	Mean	49.5	3.3	3.8	2.7	0.5	32.7	29.7
	Range	22–87	0–15	1–8	2–4	0–3	8–110	2–60
	Majority group	>60	0	3–6	0.5–10.5	0	16–30	1–15
Third	Mean	62.1	3.1	3.5	1.6	0.5	35.9	23.8
	Range	28–90	0–15	1–8	0.7–3.5	0–3	10–90	3–60
	Majority group	>60	0	1–3	1–2	0	46–60	1–15

TABLE 4 Average annual energy consumption among rural households.

Energy source				
Fuel category	Firewood (kg)	Kerosene (L)	Natura has (m^3)	LPG (kg)
First	17852.6	0	0	284.6
Second	7,524	1094.8	0	283.6
Third	909	23.5	1,341	44

The findings presented in Tables 8, 9 indicate that the use of kerosene Cheragh,[2] as a heating aid did not have a significant impact on the annual energy consumption of households in the second and third categories. In the first category, the use of solar water heaters has the potential to decrease firewood consumption (Table 7). Another aspect of energy consumption we analyzed was milk and dairy product processing. In the first and second categories, the use of firewood for these purposes led to a significant increase in energy consumption (as shown in Tables 7, 8). Conversely, households in the third category utilized natural gas (NG) for milk and dairy product processing, resulting in an insignificant reduction in total energy consumption (as shown in Table 9).

4 Discussion

4.1 Several factors affect the structure of energy consumption

This heavy reliance on firewood in the first and second categories can be primarily attributed to the lack or high cost of alternative energy sources. In the first category, the use of alternative fuels is more expensive due to the absence of fuel distributors and the associated transportation costs. Similarly, in the second category, although LPG is available, its usage remains limited due to high purchase prices and transportation expenses. Consequently, firewood continues to be the primary source of energy for heating purposes in this category. As heating represents the main energy consumer in the area (Bazgir et al., 2015), LPG has not been able to significantly reduce firewood consumption. According to the studies, several factors influence households' choice of energy sources, including cost, availability, convenience, and cleanliness (Kowsari and Zerriffi, 2011; Li et al., 2016). The respondents in our study indicated that energy cost is the primary factor influencing their fuel selection. The decrease in firewood consumption underscores the importance of providing affordable alternative energy sources as a means to reduce reliance on firewood.

While the use of natural gas (NG) in the third category significantly reduces firewood consumption, it still accounts for 21% of the total energy consumption. This can be attributed to the preference for wood-cooked foods, such as traditional bread (Saji) and grilled dishes (Kabab), among the residents. A similar preference has been observed in studies conducted in Indonesia during special occasions (Lee et al., 2015). Factors such as the unreliability of modern energy sources, the convenience of traditional fuel use, and cooking habits contribute to the persistent use of firewood, even in households supplied with LPG (Wassie et al., 2021).

Barriers to replacing firewood with alternative fuels include affordability issues, such as high initial and refilling costs, lack of availability, delays in application approval, and waiting times for refills (Ali and Khan, 2022). Respondents also indicated a decline in access to alternative energy sources during the COVID-19 outbreak. This situation is more prevalent in the first category due to its remote location and limited access to alternative fuels.

4.2 Socio-economic factors affect energy consumption

The results of investigating the effect of socio-economic factors on energy consumption showed that energy consumption in all categories was significantly and positively correlated with household size, income, heated area, and number of heaters. This finding is consistent

2 Cheragh is a device, smaller than a kerosene heater which is used for heating and cooking.

TABLE 5 Average annual energy consumption among rural household (kg of standard coal).

Fuel category						
Fuel source	First		Second		Third	
	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage
Firewood	10711.6	93.8	4514.3	66.1	545.6	21
Kerosene	0	0	1598.4	23.4	34.3	1.3
NG	0	0	0	0	1703.2	65.9
LPG	483.8	4.2	482.1	7.1	74.8	2.9
Electricity	225.4	2	237.6	3.5	230.2	9.2
Total	11,420	100	6832.4	100	2588.1	100

TABLE 6 Pearson's test of association between annual fuel consumption with characteristics of households head and house.

First random variable	Second variable	First		Second		Third	
		p-value	Coff.	*p*-value	Coff.	*p*-value	Coff.
Annual consumption of dominant fuel	Age	0.584**	0.001	0.087^{ns}	0.202	-0.153^{ns}	0.135
	Number of years of education	−0.625**	0.000	−0.254**	0.000	0.047	0.648
	Income	0.599**	0.000	0.141*	0.038	0.274**	0.007
	Family size	0.798*	0.000	0.554**	0.000	0.588**	0.000
	Workforce number	0.779**	0.000	0.395**	0.000	0.032	0.632
	Heated area	0.856**	0.000	0.234**	0.000	0.443**	0.000
	Number of firewood heater	0.925**	0.000	0.653**	0.000	—	—
	Number of kerosene heater	—	—	−0.167*	0.014	—	—
	Number of NG heater	—	—	—	—	0.217*	0.032

**Significant at 0.01 level. *Significant at 0.05 level. —Indicates that this usage does not exist in this group.

with previous studies conducted by Atieno (2012), Baiyegunhi and Hassan (2014), Kandel et al. (2016) and Zou and Luo (2019). It can be argued that households with larger family sizes require more living space, which in turn necessitates more heaters. Additionally, these households tend to consume more energy for cooking and heating water, resulting in higher energy consumption overall. Energy consumption also is correlated to number of male workers over 15 years in first and second categories. As the results showed, in the first and second groups, firewood is the primary energy source, and it is collected by the male workforce over 15 years old. Therefore, an increase in the number of workers can lead to more firewood collection and subsequently higher household energy consumption. This positive correlation between the number of male workers over 15 years old and annual energy consumption has also been observed in previous studies by Atieno (2012) and Zou and Luo (2019). It should be noted that probably in the past and perhaps in very remote and nomadic areas, the role of women in collecting firewood was greater than today. Other studies have also mentioned the role of women in gathering firewood in other parts of the world (Batliwala and Reddy, 2003; Njenga et al., 2021). However, in the present study, due to reasons such as the lack of firewood around the villages, the change in lifestyle and the use of machines (such as tractors, vans, motorcycles, etc), and also, collecting firewood during shepherding by men and carrying them by donkeys, it is mostly done by men. Furthermore, an increase in the heated area of the house was found to be associated with a higher number of heating devices and, consequently, increased energy consumption.

One of the most important factors that has an important effect on energy consumption is household income. The results of the current research also showed that income has a positive effect on energy consumption in all categories. In the first and second categories, this association suggests that the annual consumption of firewood also increases with income, in line with findings from various studies conducted by Chun-sheng et al. (2012) and Kowsari and Zerriffi (2011). However, it is important to note that these results differ from the energy ladder model and many studies conducted in other countries, where the use of primary fuels decreases as household income rises, and there is an increase in the use of fossil fuels and alternative energy sources (Shaditalab and Naidar, 2009; Miah et al., 2010; Lee et al., 2015). According to the combined energy model, energy consumption and the shift in energy sources are influenced by various factors beyond income, including access to alternative fuels, fuel prices, household preferences and cultural practices, traditional cooking methods, trust in fuel supply, and housing characteristics (Lenzen et al., 2006; Pachauri and Jiang, 2008; Atieno, 2012). In our research, local residents mentioned higher prices and transportation costs of alternative fuels, a preference for fire-cooked foods and bread, the time-consuming nature of accessing alternative fuels, and the unreliable supply of kerosene and liquid gas as the main barriers to adopting these energy sources.

Another factor investigated was the education of the head of the household, which can have different effects on the lives of villagers. The results in the first and second categories showed significant negative relationship between energy consumption and education of

TABLE 7 Comparison of average annual energy consumption based on different energy usage in the first category.

Grouping variable	Groups	Number	Mean	S.D.	*t*-value	Sig.
Electronic water heater	Y	6	8079.3	962.5	4.772**	0.000
	N	26	12206.9	3928.9		
Using firewood for heating water	Y	22	13428.7	2801.8	1.637	0.129
	N	10	10525.8	5278.9		
Using LPG for heating water	Y	6	16,432	4814.9	−3.027*	0.025
	N	26	10279.3	2631.5		
Using firewood for milk heating	Y	6	11970.3	726	4.593**	0.000
	N	18	7940.5	3503.9		
Using firewood for dairy products processing	Y	4	7491.6	260.8	2.370*	0.027
	N	20	11657.1	3451.8		

Y (yes), the group that has this use; N (no), the group that does not have this use. **Significant at 0.01 level. *Significant at 0.05 level.

TABLE 8 Comparison of average annual energy consumption based on different energy usage in the second category.

Grouping variable	Groups	Number	Mean	S.D.	*t*-value	Sig.
Using kerosene Cheragh	Y	120	6,611	2437.8	−0.631	0.529
	N	97	6,391	2683.7		
Electronic water heater	Y	42	5142.7	2346.3	4.057**	0.000
	N	169	6872.4	2502.8		
Using firewood to bakery	Y	199	6820.8	2419.3	−12.774**	0.000
	N	17	3145.5	952.5		
Using firewood for heating water	Y	99	8025.9	2,375	−9.541**	0.000
	N	118	5243.4	1920.7		
Using solar water heater	Y	10	5159.4	1532.9	1.728	0.085
	N	207	6578.2	2570.2		
Using hot water tank in summer	Y	39	6294.6	2716.3	0.590	0.556
	N	178	6560.7	2513.9		
Using firewood for milk heating	Y	78	8160.8	2352.2	−6.427**	0.000
	N	83	6007.8	1851.4		
Using firewood for dairy products processing	Y	119	7580.6	2287.6	−4.940**	0.000
	N	24	5138.5	1752.5		

Y (yes), the group that has this use; N (no), the group that does not have this use. **Significant at 0.01 level. *Significant at 0.05 level.

the head of the household. Rahut et al. (2016) noted that education can influence household energy consumption in two distinct ways: firstly, education enhances income, resulting in increased knowledge and influencing cultural and consumer preferences. While research indicates that families with higher education tend to prefer energy sources with higher efficiency, leading to a decrease in overall energy consumption (Kowsari and Zerriffi, 2011), the reasons for this association in our study may differ. Studies conducted in the region suggest that higher education promotes environmentally conscious behaviors (Tatari et al., 2019; Latifinia et al., 2022). It can be argued that households with higher education levels possess a greater awareness of the importance of forest conservation and exhibit a willingness to engage in environmental behaviors, thereby reducing their reliance on firewood and overall energy consumption. On the other hand, the lack of relationship between education level and energy consumption can be attributed to the age of the household heads and their attitudes towards environmental issues. This category comprises older heads with lower levels of education. According to studies in the region (Tatari et al., 2019; Latifinia et al., 2022), older individuals with lower education levels are less inclined to engage in environmental behaviors. As lower energy consumption is considered an environmental behavior, individuals with lower education levels may not be motivated to reduce their energy consumption due to environmental concerns.

The positive and significant association between the number of firewood heaters and annual energy consumption in the first and second categories, as well as the negative and significant relationship between the number of kerosene heaters and annual energy consumption in the second category, further support the idea that the use of more efficient fuels, such as kerosene, leads to a reduction in annual energy consumption. In the third category, there is a positive and significant relationship between annual energy consumption and the number of gas heaters. This can be explained by the fact that households requiring more heating space will need a greater number

TABLE 9 Comparison of average annual energy consumption based on different energy usages in the third category.

Grouping variable	Groups	Number	Mean	S.D.	*t*-value	Sig.
Using kerosene Cheragh	Y	14	2338.6	865.3	0.727	0.469
	N	83	2630.6	1456.4		
Electronic water heater	Y	4	2291.9	597.6	0.435	0.665
	N	93	2601.3	1411.4		
Using firewood to bakery	Y	28	3905.7	1701.8	−5.544**	0.000
	N	69	2054	749.6		
Using NG for heating water	Y	85	2020	1418.7	−1.527	0.130
	N	12	2668.8	1009.3		
Using hot water tank in summer	Y	56	2411.4	1317.3	1.479	0.143
	N	41	2830.4	1458.6		
Using NG for milk heating	Y	18	2370.8	2096.6	−1.990	0.060
	N	5	3498.6	620.6		
Using NG for dairy products processing	Y	10	2746.1	970	1.134	0.273
	N	13	3568.2	2367.1		

Y (yes), the group that has this use; N (no), the group that does not have this use. **Significant at 0.01 level. *Significant at 0.05 level.

of heating devices, resulting in the usage of more gas heaters and consequently an increase in annual household energy consumption.

4.3 Factors that increase and decrease energy consumption

The results showed that in the first and second categories, the use of electric heaters and LPG water heaters has reduced the household's annual energy consumption, while the use of firewood for dairy product processing has led to an increase in annual energy consumption. These differences can be attributed to the lower efficiency of firewood as an energy source. The adoption of electric heaters for home heating led to a reduction in firewood consumption, consequently lowering the overall energy consumption. It is worth noting that the prevalence of electronic heating systems is limited due to the high cost of electricity, except in cases of unauthorized electricity consumption. On the other hand, the use of LPG for heating milk and dairy product processing contributed to a decrease in firewood consumption and annual energy consumption. This finding aligns with previous research indicating the positive impact of LPG usage on reducing firewood consumption for dairy processing (Joon et al., 2009).

From the findings, the use of firewood for baking bread significantly increased the average annual energy consumption for households in the second and third categories. Previous studies by Joon et al. (2009), Bazgir et al. (2015) and Eshaghi Milasi and Mahmoudi (2019) have highlighted the role of using LPG instead of firewood for bakery activities in reducing firewood consumption. Specifically, Eshaghi Milasi and Mahmoudi (2019) argued that the adoption of LPG, with its higher efficiency, leads to a reduction in annual energy consumption. It is important to note that 1 kg of firewood is equivalent to 0.6 kg of standard coal, while 1 kg of LPG produces energy equivalent to approximately 3 kg of firewood (Cai and Jiang, 2010). This evidence underscores the significance of providing rural households with alternative fuels that can mitigate forest destruction and minimize the detrimental environmental consequences associated with firewood consumption (McKendry, 2002).

We found that the use of kerosene Cheragh did not have a significant impact on the annual energy consumption of households of the second and third categories. This limited effect can be attributed to the low usage of this device among the households. Similarly, the adoption of solar water heaters, which was only observed among a small number of villagers in the second category, resulted in an insignificant reduction in energy consumption. However, it is important to note that promoting these alternative energy sources as substitutes for firewood can play a crucial role in overall energy consumption reduction. In the first category, as stated, the use of solar water heaters has the potential to decrease firewood consumption. A similar approach, known as the "hot water tank," is a local method for utilizing solar energy to heat water (Shaditalab and Naidar, 2009). This method involves using a metal tank to heat water using solar radiation. Although this system did not result in a significant reduction in energy consumption, it highlights the potential of solar energy in the study area. However, it is important to note that the limited impact of this approach may be due to its restricted usability, which is only possible during hot days of the year and among a limited number of households.

The results related to the processing of dairy products in the first and second categories showed that the use of firewood leads to an increase in energy consumption. In the third floor, the use of natural gas (NG) leads to a reduction in energy consumption. This finding implies that the adoption of NG should be considered as a strategy to reduce overall energy consumption. Providing households in the first and second categories with access to NG can effectively replace the use of firewood for these purposes.

5 Conclusion

This study examines the energy consumption patterns and determinants of rural households in the Zagros forest region of

western Iran. It aims to contribute to the existing body of knowledge by focusing on the differences among various types of rural areas based on their primary energy sources. The data for this study were collected through questionnaires administered to households in three different categories. The findings reveal significant variations in annual energy consumption among households. Notably, firewood constitutes a significant portion of the household energy mix, particularly in remote areas. The analysis demonstrates that household energy consumption patterns are complex and multifaceted, indicating that income alone does not solely determine energy consumption patterns. The results confirm that higher household income levels, larger workforce sizes (above 15 years old), greater heating areas in houses, and an increased number of firewood heaters are associated with higher annual energy consumption. Conversely, higher education levels are associated with lower energy consumption levels. The study findings indicate that limited access to roads and energy infrastructure, high costs of alternative fuels, and cultural preferences for traditional cooking methods are factors that contribute to the predominant use of firewood. Overall, the study highlights that while income plays a significant role in shaping household energy structures, rural energy consumption patterns are also influenced by non-income factors and socio-economic characteristics. Therefore, the successful transition to more efficient, clean, and modern fuels in rural areas of developing countries depends not only on household income but also on factors such as access to alternative fuels, the presence of adequate road networks, fuel transportation costs, and socio-cultural considerations. The analysis clearly demonstrates that commercial energy sources, such as liquefied petroleum gas (LPG) and natural gas (NG), offer higher energy efficiency and contribute to a reduction in annual energy consumption among households. In contrast, firewood, the primary energy source in two of the categories, exhibits low energy efficiency. The continued use of this inefficient energy source contributes to deforestation, greenhouse gas emissions, environmental pollution, global warming, and associated health issues at the household level. This poses a significant challenge, particularly in countries with limited forest resources like Iran. The utilization of Zagros forests as a source of firewood further exacerbates the degradation of these fragile ecosystems. The study emphasizes the imperative of replacing firewood with sustainable and cleaner energy sources or higher efficiency fuels, such as solar systems, NG, and LPG. Such a transition is not merely a choice but a necessary step towards improving household energy patterns. Promoting the use of LPG, NG, and solar systems can effectively reduce fuel consumption and contribute to sustainable development and climate change mitigation efforts.

The findings of our survey underscore the fact that rural households in the study area tend to choose fuels based on factors such as accessibility, affordability, and cultural acceptability. Therefore, any policy interventions aimed at promoting alternative energy sources must encompass a range of measures. These measures should include ensuring a secure supply of alternative fuels, making them economically feasible for households, and implementing educational programs to raise awareness about the health and environmental benefits associated with adopting new energy sources or technologies. Investing in education in these rural areas is particularly crucial, as households with higher levels of education are more likely to prefer modern and clean energy sources. Additionally, individuals with higher education are more inclined to consider environmental concerns when making energy choices. Given that household economic conditions play a significant role in shaping energy patterns, it is essential for the government to prioritize improving the economic conditions in the study area and reducing poverty. These efforts will enhance the capacity for an energy transition from firewood to alternative energy sources. Considering the climatic conditions of the study area, characterized by a substantial number of sunny days, solar energy systems emerge as a promising energy source. This indicates the potential for harnessing solar power in the region.

5.1 Empirical and policy implications

The findings of this study provide empirical insights into the determinants of energy patterns among rural households in the forested regions of the Zagros Mountains in Iran. The research highlights the prominent role of firewood as a primary energy source, particularly in remote areas. Income is identified as a crucial determinant of energy structure, but non-income socio-economic factors also strongly influence energy patterns. Additionally, the study reveals that commercial energy sources exhibit higher energy efficiency, resulting in reduced annual energy consumption compared to the use of firewood. These empirical implications emphasize the urgent need to address the reliance on low-efficiency energy sources in rural areas to mitigate deforestation risks and promote sustainable energy practices.

The policy implications derived from this research underscore the importance of considering both economic and social dimensions in energy planning and interventions for rural areas. Policies should focus on promoting accessible and affordable alternatives to traditional biomass fuels, such as kerosene, liquefied petroleum gas (LPG), and natural gas (NG). Initiatives should be designed to encourage the adoption of cleaner and more efficient energy sources, particularly among rural households with higher incomes. Furthermore, targeted policies should be implemented to address the specific needs and challenges of remote areas, where firewood remains the predominant energy source. By promoting the transition from firewood to higher efficiency fuels, governments can contribute to forest conservation efforts and mitigate environmental concerns. These policy implications highlight the importance of integrating energy planning with sustainable development goals and ensuring access to clean and efficient energy sources for rural communities.

Conducting studies like ours comes with limitations and challenges. The most significant limitation or challenge in our research was gaining the trust of rural residents to participate. Due to the prohibition of firewood production and the use of forest wood as fuel in Iran, rural residents were very cautious in this regard, making it difficult to gain their trust for participation in such research. Additionally, obtaining accurate information about household fuel consumption required a significant amount of time. In fact, the authors had to spend a considerable amount of time in the villages to measure the amount of fuel, particularly firewood.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants or their legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

AB: Data curation, Methodology, Writing – review & editing. RM: Conceptualization, Project administration, Validation, Writing – original draft, Writing – review & editing. MR: Writing – review & editing, Formal analysis, Methodology, Software.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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