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An Evaluation of People's Acceptability of Rural Household Energy: A Study of Kaski District, Nepal

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ABSTRACT

Rural energy infrastructure development is essential for promoting holistic and sustainable advancement in emerging nations. This effort seeks to address poverty, improve quality of life, protect the environment, and strengthen resilience against external disruptions. The involvement of governments, development organizations, the private sector, and local communities is essential to ensuring the widespread availability of modern energy services for rural people. The effective implementation of rural energy initiatives hinges on the pivotal issue of popular acceptance. We utilized Multi-Criteria Decision Making (MCDM) techniques to determine the public's view of the suitability of various resources (Firewood, LPG, Kerosene, Electricity, and Biogas) for household cooking in local communities. This assessment was based on eight distinct criteria. The criteria have been derived from prior research and a preliminary survey conducted in the rural Kaski area of Nepal. Moreover, the fuzzy Analytic Hierarchy Process (AHP) will be employed to determine individuals' preferences for various energy sources. Based on the input from customers and impartial experts, the study determined that the most sustainable sources of energy in the rural Kaski area of Nepal are electricity and biogas, notwithstanding their limited usage. According to the study, firewood is the optimal choice for cooking in rural areas attributable to its exceptional effectiveness concerning food preparation, availability, and friendliness. Although the LPG is widely acknowledged as a most dependable energy source, it is not favored by users due to concerns of safety, friendly, and cost. Rural users regard electric cooking as unreliable, with safety concerns and food quality testing, but people generally embrace it as a healthy and ecologically friendly option. The utilization of biogas is influenced by factors such as cost, reliability, and sensory perception of food.

Keywords: Fuzzy AHP, Household Energy, MCDM, People's Acceptability, Rural Consumption
JEL Classifications: D81, P18, Q43, D10

1. INTRODUCTION

The utilization of energy consumption has exhibited substantial variation due to the heterogeneous geographical landscape, socioeconomic conditions, and the accessibility of energy resources (Mbaka, 2022). The lifestyles of individuals are intricately linked to the present accessibility and availability of several energy sources. The existing energy consumption and structure in rural regions have a substantial influence on the enhancement of the quality of life of individuals (Li et al., 2016). The utilization of energy behavior of individuals residing in rural regions has transformed, particularly in the shift from traditional biofuels to contemporary energy sources (Han et al., 2018). Ensuring secure and environmentally friendly energy provision to the population is a crucial measure for promoting sustainable economic growth. Individuals residing in rural regions predominantly encounter challenges related to energy poverty, specifically in terms of obtaining consistent and affordable access to energy (Piwowar, 2021). Similarly, underdeveloped nations grapple with the issue of reliable electricity access due to geographical factors such as mountainous terrain, sparse and dispersed populations, and low energy consumption rates, which render energy provision more costly compared to urban areas (Torero, 2015). The key to resolving issues in rural areas is ensuring access to clean, affordable, and dependable electricity. The creation of a sustainable energy supply is closely linked to the improvement of socioeconomic, educational, health, food security, gender equality, and ecological circumstances in rural areas. Nepal is a geographically varied country with a substantial rural population, and as per the Economic Survey of 2023, 95% of the inhabitants have electricity accessibility. Nepal, as a low-income nation, encounters substantial fiscal constraints in addressing the escalating need for contemporary energy and electricity provisions in rural regions. Consequently, rural residents depend on traditional energy sources to suit their household requirements. Likewise, individuals have encountered numerous challenges about their means of living, well-being, and concerns related to long-term viability. This study aims to evaluate the factors that influence decision-making and the level of acceptability of different home energy sources for cooking, as well as to discover sustainable energy sources in the rural parts of the Kaski district in Nepal. The study's findings are anticipated to offer useful insights that would facilitate informed decision-making to advance sustainable energy utilization in rural regions of Nepal.

2. STUDY AREA AND METHODOLOGY

Situated in the center area of Nepal, the Kaski district assumes the role of the administrative epicenter within the broader framework of the Gandaki province (Figure 1). The latest Nepal NPHC, Report for the year 2021 reveals a population count of 599,504 for the district. The topography of this region spans altitudes ranging from 450 meters to the zenith at 8091 meters, featuring one major urban center and four rural communities. Kaski stands distinguished for its intricate interplay of geographical and cultural facets, positioning it as a noteworthy locale within the national landscape. From a geographic standpoint, Kaski is positioned in the upper tropical to trans-Himalayan realms. Culturally, the district encapsulates an astounding mosaic of diversity, hosting approximately 84 castes, 44 languages, and eleven distinct religious affiliations. The city of Pokhara, holding dual roles as the administrative nucleus of the Gandaki province and the primary hub of Kaski, assumes paramount significance within this intricate tapestry. Of particular note is the demographic composition, wherein the rural populace constitutes a mere 11% of the total, a markedly lower figure in comparison to the urban demographic. Furthermore, this percentage has demonstrated a consistent decline since the preceding nationwide Census conducted in 2011 in Nepal.

The research endeavor transpired within the rural domains of Kaski district, Nepal. Table 1 provides an overview of the district's four separate rural municipalities, each comprising multiple villages and a specific number of homes chosen for sampling. The selection of these locales as the focal points of investigation was purposeful.

The initial phase of the study involved a meticulous exploration of antecedent scholarly articles to discern the principal determinants influencing individuals' decisions vis-à-vis the acceptability of energy sources. Furthermore, the investigation encapsulated a cohort of 204 primary earners within households, recognized for wielding considerable influence in shaping decisions related to energy consumption. A stringent inclusion criterion was imposed, necessitating that respondents assume the role of breadwinners within their respective households. A survey instrument, structured on the nine-point Saaty scale, was administered to the denizens, thereby soliciting their preferences across delineated categories. The finalization of the multi-criteria decision-making model for person prioritization was achieved through the implementation of the fuzzy Analytic Hierarchy Process (AHP) methodology. Concurrently, five autonomous specialists were convened to complete and submit the administered questionnaire. This panel not only served to ascertain the perceived significance of each criterion underpinning rural sustainability but also contributed to the validation process. The overarching goal of current work is to discern the most sustainable energy sources, with due consideration accorded to the comprehensive impact of each energy resource and its alignment with established standards of acceptability

3. REVIEW OF LITERATURE

Due to the political austerity in developing countries, the availability of local energy has been reduced and the progress in developing rural infrastructure has been very slow. As a result, people in rural areas are experiencing sustainability problems. It is crucial to recognize the significance of these issues in rural areas (Naumann and Rudolph, 2020). An enhanced execution of rural energy policy entails establishing a rural energy management system that considers the diverse viewpoints of rural inhabitants. This will lead to positive transformations in rural areas and enhance the overall sustainability of rural communities (Shaaban and Petinrin, 2014). Collaboration with the community is essential for attaining sustained results in energy development, and it is essential to cultivate a strong relationship with the community (Bothwell et al., 2021). Recognizing the difference in energy security between urban and rural locations is essential for maintaining a reliable and sustainable provision of clean energy in rural regions. Rural communities are particularly susceptible to energy insecurity due to the limited availability of crucial supplies (Sinha et al., 2009). In impoverished rural regions of developing countries, solid biomass, such as firewood, and animal dung, has traditionally been the primary fuel source. This is mainly owing to insufficient availability of renewable energy sources and economic

Table 1: Rural areas status of Kaski district

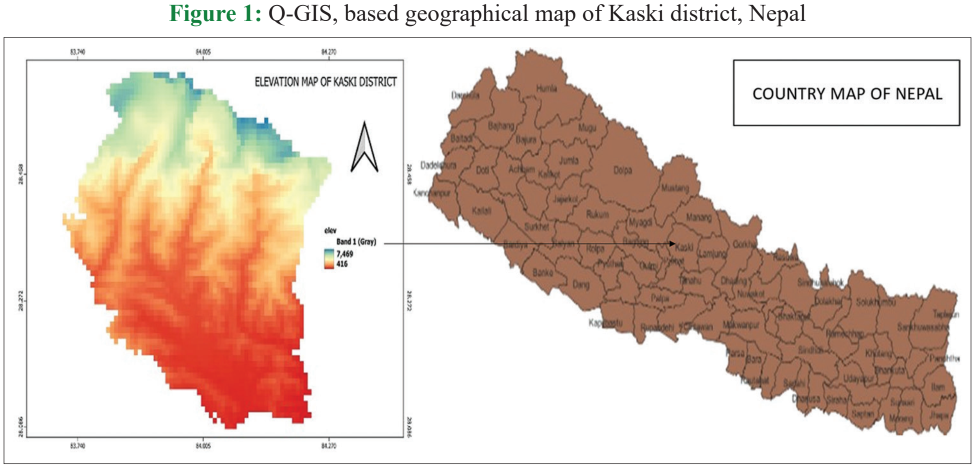
S. N	Name of rural local bodies	Center	No. of the ward village units	Total areas (Sq/Km)	Sample household
1	Madi	Yamjakot	7	563	50
2	Machhapuchhre	Lahachock	9	544.58	48
3	Rupa municipality	Rupakot	7	94.81	56
4	Annapurna	Lumle	11	350.37	50

limitations. The energy consumption pattern in rural areas is shaped by multiple factors, including geographical location, household income, behavioral habits, and socio-economic status. The presence of this diversity has a substantial impact on the welfare of individuals and the ability to maintain long-term viability (Behera et al., 2015). The introduction of renewable energy-based local energy assessments has greatly improved the overall sustainability of communities in economic, social, and environmental aspects. This has been accomplished by generating a significant amount of secure employment opportunities for villagers, transforming agricultural land into renewable energy facilities through the leasing procedure, fostering micro-enterprises and tourism ventures in rural regions, and mitigating environmental damage. These endeavors are the aims of sustainable development goals (Prado and Domingo, 2021). The energy culture framework in the developing country illustrated the socio-technical nature of energy by examining the material changes in energy circumstances. However, it did not ensure equal empowerment of all stakeholders in society. Specifically, there has been a lack of consistent efforts to empower women. As a result, the benefits of new renewable energy and its associated technology have been limited to certain influential groups within society. Therefore, the government and policy-making authorities must intensify their endeavors toward the promotion of sustainable renewable energy, under SDG7 (Oliver et al., 2019). Women are responsible for managing the food and household energy sources and cooking systems. The energy and time expended by humans for various cooking methods, including conventional open-fire cookstoves, charcoal, briquettes, and upgraded cookstoves have been in practice in the rural areas of Nepal, and compared with them the traditional cooking system demands less time and human metabolic energy in context Nepal (Das et al., 2019). The prolonged energy crisis in Nepal has significantly hindered the country's overall economic progress. The country faces energy challenges such as the use of inefficient equipment, high costs of hydropower, inadequate energy supply chain, and infrastructure, losses in transmission lines, energy theft, unstable pricing schemes, and a weak energy market. The escalating energy crisis exacerbates the geopolitical and geographical challenges in the country (Poudyal et al., 2019). The people's acceptability of energy sources and technology is influenced by multiple factors. Huijts et al. (2012) present a comprehensive framework for decision-making levels regarding energy sources and technology by mindset, norms of society, believed behavioral control, and individual values. Furthermore, they determined that the acceptance attitude is affected by other factors, such as the perceived costs, risk level, rewards, positive and negative emotions linked to technology, trust, procedural justice, and distributive fairness. The influence on individual norms depends on factors such as perceived costs, risks, benefits, the efficacy of results, and awareness, which are also vital factors in people's acceptance of various energy sources and technologies. The findings suggest by De Groot et al. (2022) that the way individuals perceive the advantages of something is a key factor in understanding how they evaluate its acceptability. However, the importance of risk perceptions becomes more pronounced when persons have insufficient knowledge of energy technology. In the opinion of Emmerich et al. (2020), the acceptability of energy technology is determined by several factors, including trust in corporate and municipal government, environmental self-identity, perceived concerns, and overall approval. Furthermore, the prioritization of broad acceptance is significantly higher than that of other factors. The study conducted by Li et al. (2022) reveals that psychological factors have a substantial influence on the association between energy attribute features and adoption intention. More precisely, the phenomenon of herd mentality plays a crucial role in shaping farmers' inclination toward adopting clean energy. Command-and-control policy measures partially reduce the moderating influence, but monetary incentives and policy tools that incorporate publicity and guidance significantly moderate the association between psychological characteristics and the intention to adopt. Another article by Wang (2022) concluded that the efficacy of energy policy implementation depends heavily on the public's acceptance of a sustainable energy transition and examined the impact of various factors, such as knowledge about climate change, self-identity related to the environment, willingness to embrace change in one's life, energy-saving behaviors, personal norms, perceived control over one's surroundings, and concerns about steady energy supply, on the public's acceptance of a sustainable energy transition.

4. RURAL ENERGY CONSUMPTIONS STATUS IN NEPAL

Traditional biomass energy sources such as firewood, agricultural waste, and dung cake are widely used energy sources in Nepal.

Figure 1: Q-GIS, based geographical map of Kaski district, Nepal



According to the National Population and Housing Census (NPHC) of 2021, the majority of the population, specifically 51%, relies on firewood for cooking. LPG is used by 44.2% of the population, while electricity is used by just 0.49%. A small percentage of the population, 2.87%, utilizes animal dung as a cooking fuel, while 1.7% use biogas. Kerosene is used by a very small fraction, only 0.05%, and the remaining 0.10% use various types of energy for cooking. Figure 2 depicts a comparison between rural and urban locations regarding the energy sources utilized for cooking. The data reveals that firewood is used for cooking in 70% of rural areas, whereas it is used in 39% of urban districts. In urban regions, the utilization of LPG stands at 56.67%, while in rural areas, it is only 19% for identical reasons. The prevalence of animal manure in rural areas is 4.4%, which is twice as high as in urban areas. The other sources of energy for cooking in both regions are negligible.

Figure 3 illustrates a contrast between the energy sources utilized for lighting in rural and urban regions of the country. The electricity penetration percentage in urban areas is 96%, whereas rural areas have a penetration rate of 85%. Solar energy usage in rural areas is 13%, whereas in urban areas it is only 3.5%. Alternative sources of energy for comparable purposes are negligible in both domains.

The use of renewable energy sources is still in its nascent phase in the nation. The renewable energy sector accounts for a mere 7.5% of the whole energy mix, as stated in the country's economic survey report, 2023. Although the country has a large population, they have historically had low electricity consumption per person, with only 351 kilowatt hours. However, there are still many unresolved challenges related to achieving SDG 7 by 2030 (Pokharel and Rijal, 2021). Nepal, as a nation abundant in mountains, has a substantial capacity for harnessing its native renewable resources. Based on a study conducted by Gulagi et al. (2021), Nepal has the financial capacity to shift to a completely renewable energy-dependent economy by 2050. The inadequate utilization of renewable energy in the country has led to adverse health consequences and environmental issues, such as indoor pollution, health hazards, and sustainability difficulties. Likewise, imported petroleum products are the main commodities imported into the country. Every year, the Nepalese government sets aside a significant amount of funds to import petroleum items from neighboring countries. While it increased the country's trade imbalance, it also intensified its level of energy dependency. Hence, it is crucial to ascertain alternate energy sources that are readily available within the country. The country has experienced a gradual increase in the rate of migration from rural to urban areas, primarily due to insufficient access to employment opportunities, basic services, and other factors related to sustaining a livelihood (KC, 2020). Continuous availability of power is a crucial element in the everyday lives of people living in rural areas. Due to the inconsistent availability of energy in rural sections of the district, there is a notable amount of movement among young individuals towards urban centers. To tackle this problem, it is imperative to augment employment prospects and build small-scale industries at the village level. However, attaining this objective relies on guaranteeing a steady and reliable energy provision. The dynamic trends in energy use by individuals are essential for devising a forthcoming energy plan that fosters sustainable growth, particularly in developing nations. Regrettably, the pertinent government officials do not properly acknowledge the importance of this issue. The research seeks to ascertain the predominant perspective of energy acceptability among rural residents in the Kaski regions of Nepal. This is a crucial component for planners and decision-makers in their efforts to enhance the rural energy situation and foster greater community acceptance.

Figure 2: Comparisons of rural and urban status of energy sources for cooking (NPHC, 2021)

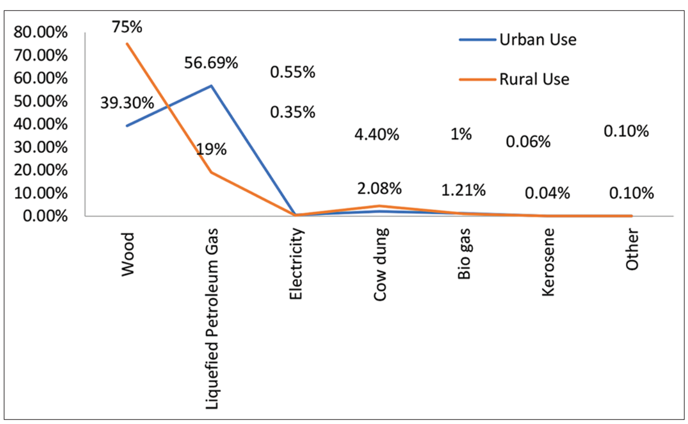
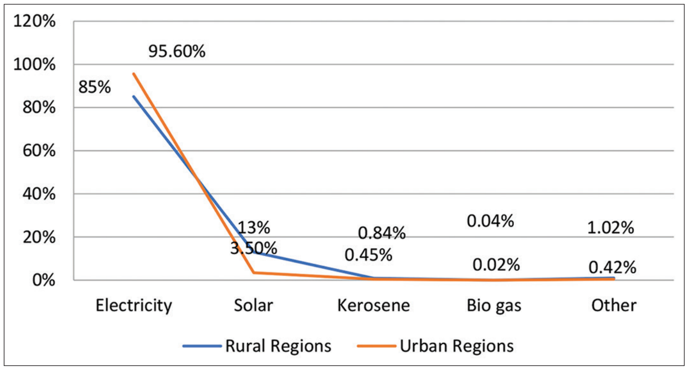


Figure 3: Comparison of rural and urban status of energy sources of lighting (NPHC, 2021)



5. MULTI-CRITERIA DECISION MAKING (MCDM) AND FUZZY AHP TECHNIQUE

Every decision can be determined according to the particular procedure. Decision-making is a cognitive process that involves overcoming obstacles and striving to select a favorable outcome by evaluating multiple alternatives. Moreover, it might be influenced by implicit or explicit assumptions, which are influenced by various aspects including physiological, biochemical, cultural, and social characteristics (Taherdoost and Madanchian, 2023). Various mathematical techniques, economic principles, and computer technology have been employed to address intricate problems in modern times. Among these, Multiple Criteria Decision Making (MCDM) stands out as a precise method for decision-making, often regarded as a groundbreaking development in this field. Benjamin Franklin conducted one of the initial scientific studies on MCDM when he presented his findings on the moral algebra concept. Since the 1950s, numerous empirical and theoretical scientists have dedicated their efforts to studying (MCDM) methods. The objective of their research has been to assess the mathematical modeling capabilities of these methods. The ultimate goal is to develop an MCDM framework that can effectively organize decision-making problems and derive preferences from alternative options. There are various methods to compute the Multiple Criteria Decision Making (MCDM). The methodology employed in the study is as follows.

$DA=\{DA_i \mid i=1,2, 3……., n\}$

Whereas, DA expresses the distinct or finite set of alternatives and n is its number.

$C=\{Ci \mid i=1,2,3………, n\}$

Where C is a set of criteria for the evaluation of DA and n is its number.

$W=\{W_j \mid j=1,2,3…., n\}$

Here, W represents a collection of standardized weights that are assigned to each criterion according to their significance. Various researchers have employed different methodologies based on Multiple Criteria Decision Making (MCDM) to generate optimal solutions for various challenges. The Fuzzy Analytic Hierarchy Process (AHP) is a commonly employed technique under MCDM for fuzzifying the AHP process. It has been discovered that the combination of two approaches results in a superior option compared to using only one strategy. The fuzzy technique is an extended form of AHP. While the Analytical Hierarchy Process (AHP) is a robust method for determining the best answer, conflicts may arise while evaluating the relationship between criteria and possibilities. These conflicts can lead to discrepancies in the evaluation and ranking criteria, resulting in changes in the rankings (Meshram, 2019). Therefore, we opted for the fuzzy Analytic Hierarchy Process (AHP) as a solution to address the acceptability decision by the rural people several phases have been completed in the process of calculating the fuzzy Analytic Hierarchy Process (AHP). These steps have been amplified in Figure 4.

Fuzzy logic employs a membership function to determine the degree to which a component corresponds to a fuzzy collection or subset. The numerical values assigned to each component of the discourse universe range from zero to one, indicating the level of membership or truthfulness.

5.1. Criteria for Energy Sources' Acceptability

Table 2 outlines the criteria utilized in the study to assess the public's acceptance and decision-making regarding energy sources and determine the most sustainable sources of energy. To facilitate further calculation, each criterion is encoded using acronyms.

5.2. Development of Hierarchal Structure

The establishment of a hierarchical structure within the Fuzzy Analytical Hierarchy Process (FAHP) is a pivotal stage, serving to systematically organize the intricacies of the decision problem at hand. This hierarchical delineation delineates the discrete strata encompassing criteria and alternatives necessitating nuanced consideration in the decision-making continuum. Figure 6 provides an exhaustive exposition of this hierarchical architecture. At the zenith of this hierarchical arrangement, the paramount objective is the prioritization of the acceptability of energy sources. This prioritization is meticulously informed by an exhaustive inquiry, comprising an extensive literature review and a methodical pilot study conducted within the study region. The culmination of these investigative efforts is the identification of paramount criteria that wield substantive influence over the decision-making process. Concurrently, at the nadir of the hierarchy, scrutiny is concentrated on the meticulous examination of the diverse spectrum of available energy sources specifically germane to culinary applications within the predefined study areas. The introduction of fuzzy logic augments this hierarchical paradigm, deploying a discerningly structured membership function. This function, in turn, ascertains the extent to which a given component aligns with a designated fuzzy collection or subset. The numerical values accorded to

Figure 4: Fuzzy output calculation process

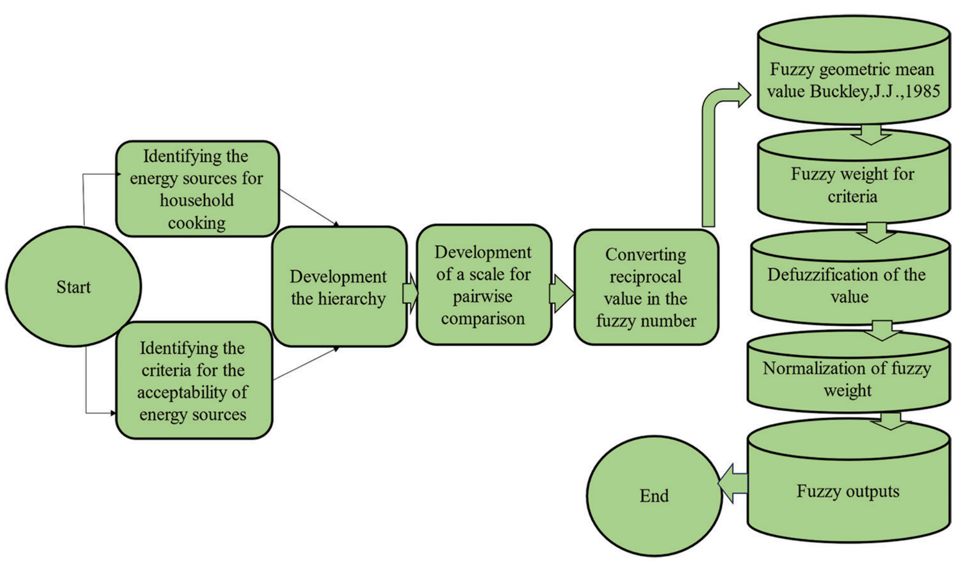


Table 2: Criteria for energy sources' acceptability

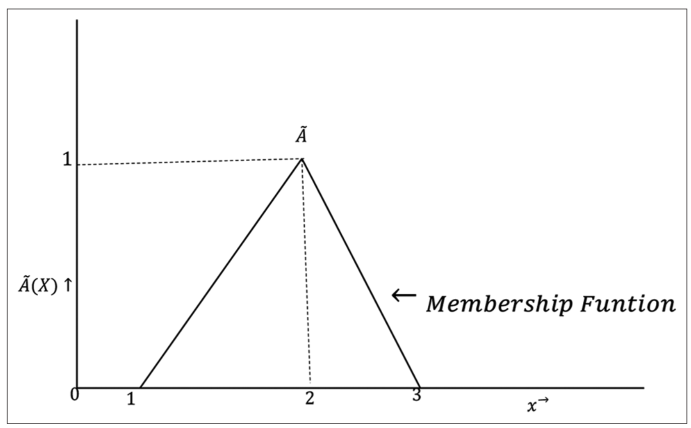
Acronym	Criteria	Explanation of criteria	References
CH	Cheap	The user's subjective evaluation of the cost-effectiveness of different energy sources.	(Neves and Leal, 2010; Aldy et al., 2012; Halder et al., 2012; Hujits et al., 2012; Wolsink, 2012; Perlaviciute and Steg 2014; Sharifi and Yamagata, 2016)
FR	Friendly	Effortlessly manage energy and its associated technology without requiring any technical expertise or prior experience in conversion.	(Aklin et al., 2018, Thomas et al., 2019; Siksnelyte-Butkiene, 2020)
RL	Reliability	The energy sources must exhibit the essential characteristics of trustworthiness, consistency, and dependability to meet the user's expectations for consumption.	(Hujita et al., 2012; Wolsink 2012; Siksnelyte-Butkiene, 2020).
AC	Accessibility	The energy sources should be readily available to a wide demographic and individuals, particularly those residing in rural regions, have the resources necessary to acquire and employ energy for their everyday tasks.	(Wolsink, 2012; Sharifi and Yamagata, 2016; Wang, 2022)
HE	Healthy	The user's assessment of their level of total physical and mental well-being resulting from the usage of energy sources.	(Neves and Leal, 2010; Geremew et al., 2014; Slovic et al., 2014; Twumasi et al., 2021; De et al., 2024).
EF	Environment Friendly	The user's level of awareness regarding the total societal well-being resulting from the utilization of energy resources.	(Neves and Leal, 2010; Geremew 2014; Perlaviciute and Steg, 2014; De et al., 2024)
SF	Safety	Safety refers to the condition of being shielded from danger, destruction, or injury. It includes many actions, precautions, and procedures implemented to prevent accidents, minimize hazards, and ensure the well-being of individuals when utilizing energy sources.	(Hujita et al., 2012, Perlaviciute and Steg, 2014; Slovic et al., 2014; Thomas et al., 2019)
FT	Food Testy	"Tasty food" is a term used to describe food that is prepared utilizing various energy sources and is savory, pleasurable, and pleasing to the senses, especially the sense of taste. It conveys a positive assessment of its flavor, texture, scent, and overall deliciousness.	(Ahn et al., 2011; De Dieu Iyakaremye et al., 2019; Bottinelli and Valva 2017; Montanari and Brombert, 2015), Pilot Study (2023)

each constituent of the discourse universe span the continuum from zero to one, serving as quantitative proxies denoting the magnitude of membership or veracity intrinsic to each component. This numerical assignment is encapsulated by Equation (1) which embodies the mathematical underpinning of the fuzzy logic membership function, thereby systematizing the quantification of membership degrees for each pertinent component.

$$\hat{A}(X) = \begin{cases} 0, & x \le l \\ \dfrac{x-l}{m-l}, & l < x \le m \\ 1, & x = m \\ \dfrac{u-x}{u-m}, & m < x \le u \\ 0, & x \ge u \end{cases} \tag{1}$$

The equation (1) represents a matrix of membership functions, where $\tilde{A}(x)$ generates fuzzy subsets A within a universe of discourse X (Figure 5). Each component x in the set X is transformed into a non-negative integer between zero and one using the function $\tilde{A}(x)$. A triangle membership function is a commonly used type of membership function in fuzzy logic. The definition of this is determined by three parameters: The place where the left point begins, the highest point, and the point where the right point ends. The triangular membership function exhibits a triangular shape, where the membership value begins at 0 and rises linearly to 1 at the highest point, then decreases linearly to 0 at the rightmost point. Similarly, the variables l, u, and m correspond to the values of the lower, middle, and upper scales in equation (1).

Figure 5: Tringular membership function (Murshid et al, 2011)



5.3. Development Scale of Pair Comparison

To obtain information from the villagers regarding energy decisions the Saaty scale has been employed which consists of 1 being Equally Important and 9 being Absolutely Important. The Saaty scale is a quantitative scale consisting of absolute values that quantify the level of importance or preference between different aspects. It is commonly displayed as a matrix of values in Table 3 where each member is compared to every other element. The scale is comprised of integers, where each integer corresponds to a specific level of preference or priority. The Triangular fuzzy numbers (TFNs) were employed to augment the respondents to address the potential uncertainties in subjective evaluations.

Figure 6: Hierarchical structure of goals, criteria, and energy sources

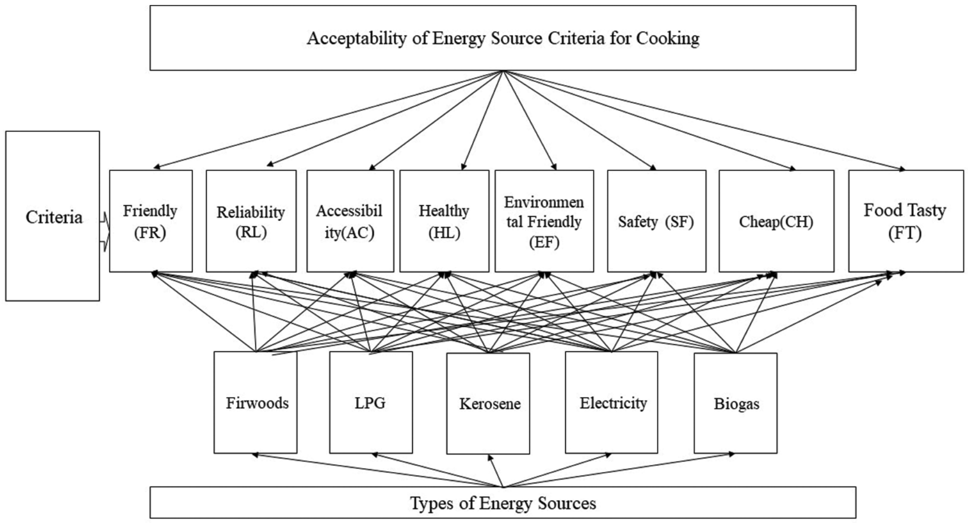


Table 3: Fuzzy linguistic comparison scale

Linguistic term	AHP scale	TFNs scale (*l*, *m*, *u*)	Reciprocal TFNs value
Equally important	1	1, 1,1	1,1,1
Weakly important	3	2,3,4	¼, 1/3, 1/2
Fairly important	5	4,5,6	1/6, 1/5, 1/4
Strongly important	7	6,7,8	1/8, 1/7, 1/6
Absolutely important	9	9,9,9	1/9,1/9/, 1/9
The middle value between two adjacent scales	2	1,2,3	1/3,1/2, 1
	4	3,4,5	1/5, ¼, 1/3
	6	5,6,7	1/7, 1/6, 1/5
	8	7,8,9	1/9, 1/8,1/7

5.4. Converting the Reciprocal Value into the Fuzzy Number

The fuzzy number can be converted into its reciprocal value using equation (2), where u represents the upper value, m represents the intermediate value, and l represents the lower value.

$$\hat{A}^{-1} = (l, m, u) - 1 = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right) \quad (2)$$

5.5. Determining the Value of Fuzzy Geometric Mean

The value is determined by the fuzzy geometric mean, as described by Buckley (1985), using equation (3).

$$\hat{A} \otimes \hat{A} = (l_1 * m_1 * u_1) \otimes (l_2 * m_2 * u_2) = (l_1 * l_2, m_1 * m_2, u_1 * u_2) \quad (3)$$

5.6. Determine the Fuzzy Weights

$$\widetilde{wj} = \widetilde{rj} \otimes (\hat{r}1 \oplus \hat{r}2 \oplus \ldots\ldots\ldots\ldots \widetilde{rn}.)^{-1.} \quad (4)$$

5.7. Defuzzification Process

$$\text{Centre of Area (COA)} \;\; w_i = \left(\frac{l + m + u}{3}\right) \quad (5)$$

5.8. Fuzzy Process Normalization

$$Nwi = wi / \sum_1^n wi \quad (6)$$

Table 4: Pairwise comparison matrix of firewood sources

Criteria	FR	RL	AC	HL	EF	SF	CH	FT
FR	1	2	1/6	5	4	4	4	1/8
RL	1/2	1	1/3	5	5	2	5	1/8
AC	6	3	1	5	7	3	5	1/8
HL	1/5	1/5	1/5	1	1	1/3	2	1/8
EF	1/4	1/5	1/7	1	1	1/6	1/4	1/8
SF	1/4	1/2	1/3	3	6	1	5	1/8
CH	1/4	1/5	1/5	1/2	4	1/5	1	1/8
FT	8	8	8	8	8	8	8	1

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

6. INTERPRETATIONS OF RESULT

Tables 4-13 depict the degree of approval among rural inhabitants about different energy sources. The preferences of rural customers for energy sources have been determined by following equations I to IV. Additionally, the sustainability criteria have been evaluated in Tables 14 and 15 based on the perspectives of 5 unbiased experts. Table 5 demonstrates that individuals have a preference for firewood, while the food test (FT) is of the highest importance to the user. Similarly, the criteria of accessibility (AC), reliability (RL), and friendliness (FR) closely follow in terms of user priorities. The user considers environmentally friendly (EF) and healthful (HL) to be of low importance. Furthermore, the cost of firewood as an energy source appears to be high despite its availability in rural areas. Table 7 demonstrates that users

Table 5: Defuzzification and normalization matrix of firewood sources

Criteria	Fuzzy Geo-mean value $(\tilde{A} \otimes \tilde{A})$			fuzzy weight $(\tilde{W_j})$			Defuzzification (COV)	Normalized (N)	Rank
FR	1.18767	0.88599	1.4402875	0.0814141	0.071523582	0.124276214	0.092404627	0.0912151	4th
RL	1.41421	1.2291	1.61503	0.0969433	0.099221926	0.139353993	0.11183973	0.1104	3rd
AC	1.8874	2.1268	2.2888	0.1293802	0.171690824	0.197490708	0.166187234	0.1640479	2nd
HL	0.326329	0.400856	0.32748	0.0223697	0.032360023	0.028256841	0.027662176	0.0273061	7th
EF	0.245575	0.279461	0.32748	0.016834	0.022560132	0.028256841	0.022550332	0.02226	8th
SF	0.722284	0.909636	1.090508	0.0495121	0.073432459	0.094095245	0.072346617	0.0714153	5th
CH	0.317352	0.386697	0.49696	0.0217543	0.031217005	0.042880541	0.031950614	0.0315393	6th
FT	5.48859	6.168843	6.8385	0.3762396	0.497994048	0.590064754	0.488099483	0.4818162	1st
*Fuzzy reciprocal values							1.013040814	Σ N=1	
	0.086285699		0.080727301		0.217959135				

Table 6: Pairwise comparison matrix of LPG

Criteria	FR	RL	AC	HL	EF	SF	CH	FT
FR	1	1/5	2	1/5	1/2	1/4	1/2	1/2
RL	5	1	6	1/2	4	7	5	2
AC	1/2	1/6	1	1/3	1/2	5	4	1/3
HL	5	2	3	1	1	4	3	4
EF	2	1/4	2	1	1	5	5	2
SF	4	1/7	1/5	1/4	1/5	1	2	1/3
CH	2	1/5	1/4	1/3	1/5	1/2	1	3
FT	2	1/2	3	1/4	1/2	3	1/3	1

Table 7: Defuzzification and normalization matrix of LPG

Criteria	Fuzzy Geo-mean value $(\tilde{A} \otimes \tilde{A})$			fuzzy weight $(\tilde{W_j})$			Defuzzification (COV)	Normalized (N)	Ranked
FR	0.3460752	0.472870805	0.7071068	0.0263715	0.046929711	0.094167097	0.0558228	0.050444804	7th
RL	2.1634913	2.837305901	3.6313886	0.1648618	0.281586315	0.483600683	0.3100163	0.280149245	1st
AC	0.5747316	0.742714719	1.0519895	0.0437955	0.07371017	0.140095953	0.0858672	0.077594761	5th
HL	1.8612097	2.481963049	3.035055	0.1418274	0.246320577	0.404185514	0.2641112	0.238666653	2nd
EF	1.156495	1.630689409	2.0597671	0.0881269	0.161836558	0.274304106	0.1747559	0.157919854	3rd
SF	0.3886757	0.498435351	0.6338093	0.0296178	0.049466846	0.084405895	0.0544968	0.0492466	8th
CH	0.3970184	0.527556413	0.7071068	0.0302535	0.052356944	0.094167097	0.0589258	0.053248918	6th
FT	0.6213674	0.884614204	1.2968396	0.0473493	0.087792879	0.172703218	0.1026151	0.092729165	4th
*Fuzzy reciprocal values							1.1066111	1	
		0.076201724		0.099244256		0.133172386			

Table 8: Pairwise comparison matrix of kerosene technology

Criteria	FR	RL	AC	HL	EF	SF	CH	FT
FR	1	1	2	2	2	2	1	1/2
RL	1	1	2	2	2	2	2	1/2
AC	1/2	1/2	1	3	3	2	2	2
HL	1/2	1/2	1/3	1	1	1/2	1/2	1/2
EF	1/2	1/2	1/3	1	1	1/2	1/2	1/2
SF	1/2	1/2	1/3	2	2	1	3	1/2
CH	1	1/2	1/2	2	2	1/3	1	1/2
FT	2	2	1/2	2	2	2	2	1

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

observe LPG resources as the most reliable (RL) compared to other criteria. Additionally, people also consider it to be healthy (HL) and environmentally friendly (EF). However, safety (SF) and friendliness (FR) criteria are given the least value in the users' opinion. The utilization of kerosene in rural regions appears to be minimal. The locals utilize it as a source of fuel for cooking and lighting in places without electricity. According to Table 9, the order of preference is as follows: Food Test (FT) > AC (Accessibility) > RL (Reliability) > Friendly (FR) > Safety (SF) > Cheap (CH) > EF (Environmentally Friendly) and Healthy (HL). Table 11 illustrates that individuals perceive electricity for cooking as being more environmentally friendly (EF), healthier (HL), and accessible (AC) in comparison. While it appears to be less dependable in terms of reliability (RL), safety (SF), and performance in food testing (FT). The rural community in the Kaski district has embraced biogas as a source of energy, as indicated in Table 13, due to its environmental friendliness (EF), health advantages (HL), and safety (SF). Although it is often

Table 9: Defuzzification and normalization matrix of kerosene technology

Criteria	Fuzzy Geo-mean value $(\tilde{A} \otimes \tilde{A})$			fuzzy weight $(\tilde{W_j})$			Defuzzification (COV)	Normalization	Rank
FR	0.871686	1.29684	1.732051	0.06912764	0.15194	0.313245	0.178104177	0.143670678	4th
RL	0.871686	1.414214	1.987013	0.06912764	0.165691	0.359356	0.198058264	0.159766971	3rd
AC	0.903602	1.435189	2.135185	0.07165872	0.168149	0.386153	0.208653506	0.168313799	2nd
HL	0.423196	0.565218	0.917004	0.0335609	0.066222	0.165842	0.088541642	0.071423579	7th
EF	0.423196	0.565218	0.917004	0.0335609	0.066222	0.165842	0.088541642	0.071423579	7th
SF	0.607366	0.917004	1.435189	0.04816623	0.107438	0.259557	0.138386967	0.111632134	5th
CH	0.556957	0.799339	1.206845	0.04416863	0.093652	0.218261	0.118693679	0.095746218	6th
FT	0.871686	1.542211	2.279507	0.06912764	0.180688	0.412254	0.220689762	0.178023043	1st
*Fuzzy reciprocal value							1.239669642	1	
	0.07930341		0.117161427		0.180852272				

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

Table 10: Pairwise comparison matrix of electricity

Criteria	FR	RL	AC	HL	EF	SF	CH	FT
FR	1	3	1/7	1/7	1/9	3	3	3
RL	1/3	1	1/6	1/9	1/9	1/2	1/4	1/2
AC	7	6	1	1/3	1/9	4	1/3	3
HL	7	9	3	1	1	8	8	8
EF	9	9	9	1	1	8	8	8
SF	1/3	2	1/4	1/8	1/8	1	1/2	1/2
CH	1/3	4	3	1/8	1/8	2	1	5
FT	1/3	2	1/3	1/8	1/8	2	1/5	1

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

Table 11: Defuzzification and normalization matrix of electricity

Criteria	Fuzzy Geo-mean value $(\tilde{A} \otimes \tilde{A})$			Fuzzy weight $(\tilde{W_j})$			Defuzzification (COV)	Normalized	Rank
FR	0.638943	0.809107	0.970984	0.04253819	0.060819	0.082936526	0.062097775	0.060313045	5th
RL	0.236534	0.284456	0.377398	0.01574744	0.021382	0.032235409	0.023121577	0.022457048	8th
AC	1.028286	1.256733	1.53679	0.068459	0.094466	0.131264839	0.09806316	0.095244762	3rd
HL	3.724687	4.199683	4.626632	0.24797421	0.31568	0.395183654	0.319612647	0.310426774	2nd
EF	4.728819	4.97164	5.196152	0.3148252	0.373706	0.443829181	0.377453551	0.366605293	1st
SF	0.301669	0.39967	0.563763	0.02008386	0.030042	0.048153816	0.032759959	0.031818417	7th
CH	0.722284	0.942942	1.176615	0.04808671	0.070879	0.10050057	0.073155324	0.071052793	4th
FT	0.326329	0.439373	0.572125	0.02172562	0.033027	0.048868024	0.043327118	0.042081869	6th
*Fuzzy reciprocal value							1.02959111	1	
	0.06657586	0.075167602		0.085414966					

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

Table 12: Pairwise comparison matrix of biogas

Criteria	FR	RL	AC	HL	EF	SF	CH	FT
FR	1	4	4	1/5	1/8	1/7	4	3
RL	1/4	1	1/2	1/6	1/9	1/4	2	2
AC	1/4	2	1	1/5	1/7	1/3	2	2
HL	5	6	5	1	1	8	8	7
EF	8	9	7	1	1	8	8	8
SF	7	4	3	1/8	1/8	1	4	4
CH	1/4	1/2	1/2	1/8	1/8	1/4	1	1/4
FT	1/3	1/2	1/2	1/7	1/8	1/4	4	1

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

perceived as costly and carries a cultural prejudice against its palatability. Moreover, the material is considered unreliable for culinary purposes in the rural setup.

Table 14 exhibit the triangular fuzzy numbers representing several sustainability factors. Table 15 displays a comparative ranking of sustainability attributes, with Healthy (HL) being ranked as the highest priority, followed by environmental friendliness (EF), Cheap (CH), Accessible (AC), reliability (RL), safety (SF), friendliness (FR), and Food test (FT) in sequential order.

6.1. Overall Weight of Sources

The weights of the different criteria have been determined using equation 7, where $\sum c_j$ represents the sum of the weights

Table 13: Defuzzification and normalization matrix of biogas

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Criteria	Fuzzy Geo-mean value $(A^{\sim} \otimes A^{\sim})$			Fuzzy weight $(W_j^{\sim})$			Defuzzification (COV)	Normalized	Rank
FR	0.771105413	0.953933059	1.146060621	0.051627501	0.073405398	0.102347247	0.075793	0.0737397	4th
RL	0.347295994	0.468343537	0.621367359	0.023252365	0.036039157	0.055490292	0.038261	0.0372239	6th
AC	0.423853814	0.60950895	0.811194802	0.028378109	0.046901873	0.07244255	0.049241	0.0479066	5th
HL	3.519084253	4.012556486	4.483549236	0.235611787	0.308767267	0.400396725	0.314925	0.3063921	2nd
EF	4.356104002	4.747473642	5.120210511	0.291652423	0.365319334	0.457252817	0.371408	0.3613445	1st
SF	1.189207115	1.46311146	1.733736087	0.07962049	0.112586808	0.154828734	0.115679	0.1125443	3rd
CH	0.239908319	0.297301779	0.407197422	0.016062482	0.022877449	0.036364163	0.025101	0.0244212	8th
FT	0.351208107	0.443178661	0.61262707	0.023514291	0.034102713	0.054709753	0.037442	0.0364277	7th
*Fuzzy reciprocal value							1.027851	1	
	0.066952585	0.076950261	0.089303519						

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

Table 14: Fuzzy triangular value (TFN) of overall sustainability criteria

Criteria	FR	RL	AC	HL	EF	SF	CH	FT
FR	1,1,1	5,6,7	1/4,1/3,1/2	1/9,1/8,1/7	1/9,1/8,1/7	1/6,1/5,1/4	1/5,1/4,1/3	2,3,4
RL	1/7,1/6,1/5	1,1,1	1,1,1	1/8,1/71/7	1/8,1/7,1/6	2,3,4	6,7,8	6,7,8
AC	2,3,4	1,1,1	1,1,1	1/8,1/7,1/6	1/8,1/7,1/6	2,3,4	2,3,4	5,6,7
HL	7,8,9	6,7,8	6,7,8	1,1,1	1,1,1	3,4,5	3,4,5	3,4,5
EF	7,8,9	6,7,8	6,7,8	1,1,1	1,1,1	5,6,7	1/5,1/4,1/3	6,7,8
SF	4,5,6	1/4,1/3,1/2	1/4,1/3,1/2	1/5,1/4,1/3	1/7,1/6,1/5	1,1,1	1/5,1/4,1/3	5,6,7
CH	3,4,5	1/8,1/7,1/6	1/4,1/3,1/2	1/5,1/4,1/3	3,4,5	3,4,5	1,1,1	6,7,8
FT	1/4,1/3,1/2	1/8,1/7,1/6	1/7,1/6,1/5	1/5,1/4,1/3	1/8,1/7,1/6	1/7,1/6,1/5	1/8,1/7,1/6	1,1,1

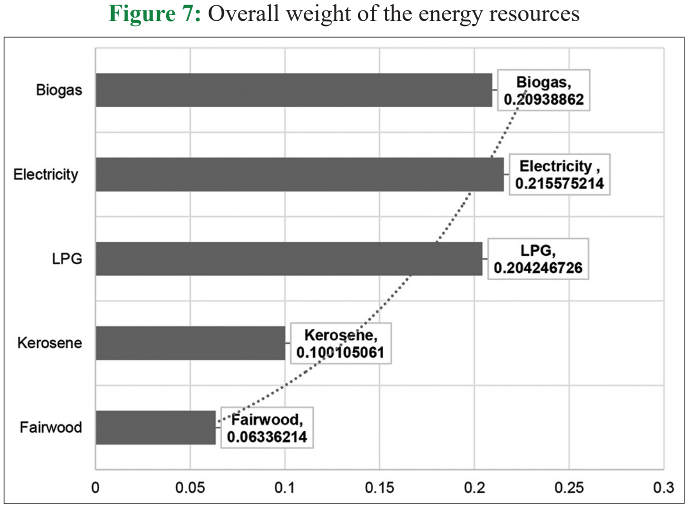
FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

Table 15: Defuzzification and normalization overall criteria matrix

Criteria	Fuzzy Geo-mean value $(A^{\sim} \otimes A^{\sim})$			Fuzzy weight $(W_j^{\sim})$			Defuzzification (COV)	Normalization (N)	Rank
FR	0.423196	0.511526	0.626749	0.03412114	0.046154	0.066624148	0.048966439	0.047742535	7th
RL	0.795714	0.917004	1.045011	0.0641562	0.08274	0.111085855	0.085993871	0.083844475	5th
AC	0.942942	1.161221	1.370478	0.07602682	0.104775	0.145683299	0.108828304	0.106108167	4th
HL	3.013669	3.547589	3.547589	0.24298381	0.320092	0.377112634	0.313396247	0.305562984	1st
EF	2.497146	2.83015	3.191069	0.20133801	0.255359	0.339214169	0.26530377	0.258672566	2nd
SF	0.53918	0.657016	0.833676	0.04347262	0.059281	0.088620649	0.063791531	0.062197077	6th
CH	1.001554	1.23275	1.515173	0.08075254	0.111229	0.161064569	0.117681931	0.1147405	3rd
FT	0.193838	0.225763	0.273012	0.01562859	0.02037	0.02902149	0.021673418	0.021131696	8th
*Fuzzy reciprocal value							1.025635511	1	
	0.080627241		0.090228132		0.106301117				

FR: Friendliness, AC: Accessibility, RL: Reliability, FR: Friendly, SF: Safety, CH: Cheap, EF: Environmentally friendly, FT: Food test

Figure 7: Overall weight of the energy resources



assigned to the different resources, and r_j represents the weight of each criterion for sustainability. The Figure 7 displays the comprehensive ranking, indicating that electricity is the most sustainable resource for household purposes, accounting for 21.55% of the total, followed by biogas at 20.9%. Likewise, LPG, kerosene, and firewood had acceptance rates of 20.4%, 10%, and 6.3% correspondingly, based on the perspective of the people and expert opinions of sustainable energy sources in rural areas of Kaski, Nepal.

$$w_j = \sum c_j \otimes r_j \quad (7)$$

7. CONCLUDING OPINIONS

The study unveiled the degree of acceptance and viability of available energy sources in the rural sections of the Kaski district in Nepal. Household activities in the research area heavily depend on traditional biomass, specifically firewood, as their primary energy source. The use of firewood by rural households is contingent upon various factors, such as its taste, availability, and dependability.

However, individuals are cognizant of the detrimental impacts of firewood on human health and ecological welfare. The second dominant resource is LPG, which is experiencing a growing trend in rural areas (NPHC, 2021). The study demonstrates that LPG is a reliable source in their regions according to user perceptions. Nevertheless, LPG is considered the least prioritized option when it comes to safety, affordability, and user impression of cooking methods. Furthermore, it is a substantial imported product in the nation and a contributing factor to the trade deficit of the country (MFN, 2023) and has not been taken as a sustainable source. According to Figure 7, electricity and biogas sources appear to be more sustainable based on the acceptable perception of the general public and the judgments of experts. Currently, both resources have had a limited contribution to the overall energy composition in the country. The primary cause for this is the user's sense of the acceptability of the impact on those resources. The public's acceptance of electricity for domestic cooking has been affected by dependable provision, assurance of safety, user-friendly cooking appliances, high tariff rates, and unpleasing test experiences with prepared meals in rural areas. Promoting the use of electricity for domestic purposes is crucial for a country like Nepal, considering its substantial reliance on traditional biomass and imported LPG. This situation necessitates the exploration of alternatives, such as adopting an electric cooking system. Ensuring a dependable and consistent provision of energy has been a crucial necessity in this particular circumstance. Additionally, it is crucial to implement techniques to efficiently manage electricity consumption during times of increased demand, enhance the pricing mechanism, and strengthen the electricity infrastructure. The government and other pertinent authorities should augment the subsidies allocated for the implementation of energy technology at the village level. A comprehensive statewide awareness campaign should be initiated to promote the advantages of employing electric cooking equipment among the population. Biogas is a feasible and accessible energy source in rural regions. Table 13 evaluates the acceptability standards of biogas based on public opinions. It is generally seen as beneficial for health and the environment. However, the high cost, unpleasant food test, and dependability issues are significant obstacles to its widespread acceptance in rural areas. To promote the use of biogas in rural areas, the relevant authorities must take proactive measures. This includes offering subsidies to farmers for the installation of biogas systems and conducting awareness programs to address cultural biases that may hinder the acceptance of biogas as a viable energy source. Reliability is a significant concern when it comes to implementing biogas in rural regions. It is crucial to take appropriate measures to enhance the consistency, trustworthiness, and reliability of its performance. In addition, Nepal acknowledges the substantial availability of firewood resources in rural regions. It is important to prioritize the implementation of new cooking technology in rural areas to reduce the emission of smoke caused by the laborious practice of burning firewood for cooking, which is a major source of energy in these regions.

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