Research article

Biogas adoption in Nepal: empirical evidence from a nationwide survey

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A R T I C L E   I N F O

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A B S T R A C T

Using nationally representative survey data, we identify and examine the determinants of biogas technology adoption in Nepal. Because of its dependence on biomass energy, the Government of Nepal has been promoting alternative sources of energy, particularly for rural households. Biogas has been identified and promoted as a viable alternative renewable energy source alongside many others. In addition to providing low-cost sustainable energy, biogas offers a wide range of additional benefits. Because of the many benefits of adopting biogas, the Government of Nepal has made expanding biogas technology a priority. Despite the policy priority and several benefits, the drivers and barriers to household-level biogas technology adoption have not been investigated at the national level. We use newly collected survey data to investigate the determinants and barriers to biogas adoption. We use probit models to quantify the marginal effect of these determinants on biogas adoption. Our analysis shows that income, land holdings and the number of livestock are key socioeconomic determinants of biogas adoption in Nepal. Our result suggests that households in the country’s hilly region are less likely to adopt biogas indicating the difficulty of installing and operating biogas in mountain and hilly regions. The findings also indicate that lack of access to a bank and the number of biogas service providers are among the main obstacles to biogas adoption in Nepal. Our findings provide information that can make valuable contributions to the energy policy of developing countries for the sustainable development of alternative energies.

1. Introduction

Access to energy is essential to economic development and contributes to development through improvements in living standards and productivity. However, more than 2.6 billion people lack access to clean cooking facilities and still rely on traditional sources such as firewood, crop residues, and livestock manure for cooking (IEA, 2022). In Nepal, about 10 percent of the population lack access to electricity, and about 69 percent of the total energy demand is met by biomass energy. Despite the huge renewable energy potential, only 3.2 percent of the total energy consumption in Nepal is covered by renewable energy (AEPIC, 2021). Extending the national grid, especially in remote rural areas, is difficult and costly due to difficult terrain and high costs. The need to develop renewable energy technology is made even more necessary by the problems associated with environmental challenges. Given these challenges and its reliance on biomass energy, the Government of Nepal has adopted a policy to encourage alternative energy sources. Biogas technology has been identified and promoted as a viable alternative renewable source of energy along with several others such as solar and wind energy. Biogas technology generates methane-rich gas through the anaerobic fragmentation of biodegradable organic materials. Domestic biogas technology converts animal manure, crop residues and other biodegradable organic waste into combustible methane gas. Methane-rich combustible gas is used mostly for cooking and lighting. Bio-slurry, the residue, is used as a fertilizer for improving agricultural productivity.

Research suggests that biogas technology offers a wide variety of benefits. In addition to providing low-cost sustainable energy, biogas technology also improves rural livelihoods by saving time for firewood collection and cooking. Reduction in emissions improves the health of the family members. The technology also provides organic fertilizers that can contribute to agricultural productivity improvements. Biogas technology has the potential to help reduce Greenhouse Gas (GHG) emissions reduction. It reduces the use of fuel wood and consequently deforestation (Katuwal and Bohara, 2009; Meeks et al., 2019; Somanathan et al., 2015). Because of its multiple benefits, the Government of Nepal has been supporting the advancement and adoption of biogas technology for over four decades.

In Nepal, biogas technology is promoted as a key alternative energy technology. In spite of the multiple benefits and favorable conditions for high growth potential, the share of biogas technology is relatively small.

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The Alternative Energy Promotion Center (AEPC) progress report indicates that the biogas installation success rate is low due to a lack of demand (AEPC, 2021). Analysis of the factors that determine biogas demand is important for developing and improving biogas technology. A few studies are available that explore other aspects of biogas technology such as the current state, future challenges and benefits of biogas adoption (Gautam et al., 2009; Katuwal and Bohara, 2009). However, there are no studies evaluating the drivers of the adoption of alternative energy technologies such as biogas in Nepal. Despite the policy priority, the drivers and obstacles to the adoption of household-level biogas have not been investigated at the national level. In this study, we use newly collected nationally representative household survey data to identify and investigate the determinants and barriers to biogas adoption in Nepal. We use probit models to quantify the marginal effects of these determinants on biogas technology adoption.

Our analysis shows that income and size of landholdings are key socioeconomic determinants for the adoption of biogas in Nepal. Our results indicate that households in the country's hilly region are less likely to use biogas technology indicating the difficulty of installing and operating biogas in mountain and hilly regions. The findings also suggest that the number of biogas service providers and lack of access to the bank are key impediments to the adoption of biogas in Nepal. Our results provide insights that can make valuable contributions to Nepal's energy policy for the sustainable development of alternative energies. Additionally, this study's findings may be useful to other developing economies that are promoting biogas technology to provide clean energy with additional health benefits and potential for climate change mitigation.

The rest of the paper is organized as follows. We discuss the background and relevant literature in the next section. The methodology is discussed in the third section, followed by the results. We conclude with a few policy recommendations in section 5.

2. Background and relevant literature

Although biogas technology was introduced on an experimental basis in 1955, a rapid expansion of biogas technology began in 1977 (Bajgain and Shakya, 2005). Since then, the Government of Nepal has partnered with multiple agencies and donors to continuously promote biogas technology as one of the key renewable energy technologies. The number of biogas installations has continued to increase in response to policy priorities (Figure 1). So far, more than 400,000 household level biogas plants have been installed in Nepal (AEPC, 2021). However, about 10% of the biogas digesters are not functional because of technical problems (Lohani et al., 2021).

Biogas technology produces a colorless methane-rich gas that burns with a clean blue flame such as liquefied petroleum gas. The fixed-dome model with an underground digester is one of the most widely used digester systems in Nepal. Primarily, livestock dung with other agricultural residues are used to produce methane through anaerobic digestion which is then used for cooking and lighting. The feedstock is prepared by mixing manure with water. A large number of biogas systems are also attached to toilets to capture human excreta (Bajgain and Shakya, 2005). In Nepal, small biogas systems ranging in size from 4 m³ to 10 m³ have been promoted for households (Bajgain and Shakya, 2005). Given the potential for 1.9 million biogas plants, the number of biogas digesters installed to date indicates that much remains to be done to realize the full potential (Bajgain and Shakya, 2005). One of the main factors behind the successful expansion of biogas technology is the government subsidy. Subsidies are provided by the government for the installation of biogas digesters in Nepal (Bajgain and Shakya, 2005). Nonetheless, multiple AEPC reports indicate that the agency has not been able to meet its installation target due to a lack of demand (AEPC, 2021).

Biogas technology offers numerous benefits at the household, national and global scales (Bajgain and Shakya, 2005). There are a few studies that assess the current status and benefits associated with the adoption of biogas technology (Gautam et al., 2009; Katuwal and Bohara, 2009), the potential for climate change mitigation and sustainable development in Nepal (Meeks et al., 2019; Somanathan et al., 2015), a potential link to Sustainable Development Goal of ensuring access to affordable, reliable, sustainable and modern energy for all (SDG 7) (Lohani et al., 2021), and willingness to pay for biogas plants in Nepal (Thapa et al., 2021). Using biogas user survey data, Katuwal and Bohara (2009) explored the benefits of adopting biogas technology in Nepal. The authors found that the biogas technology, in addition to providing clean cooking and lighting energy source, offers additional benefits in terms of improved health, increased farm productivity, and reduced time for

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**Figure 1.** Number of biogas plant installations in each fiscal year.
firewood collection and cooking. The authors also noted that biogas technology contributes to mitigating global warming and climate change impacts by reducing greenhouse gas emissions (Katuwal and Bohara, 2009). Similarly, Gautam et al. (2009) discussed the current state and also explored the multiple benefits offered by biogas technology in Nepal. The author concluded that in addition to the health benefits, biogas technology has a positive impact on saving time and reducing the use of chemical fertilizers.

Somanathan et al. (2015) used national survey data to investigate the reduction in fuelwood collection, and found that the adoption of biogas reduces firewood collection from 2400 kg to 1100 kg per year per household. The authors concluded that the reduction in fuelwood collection is large enough for biogas technology adoption costs to be heavily subsidized through carbon credits. Similarly, Meeks et al. (2019) analyzed the reduction in firewood use and confirmed the prior findings that biogas use reduces fuelwood collection by 800 kg–2000 kg per year per household. In addition, the authors noted that biogas technology saves 23–47% of firewood collection time and that the adoption of biogas can make a moderate contribution to sustainable development. Lohani et al. (2021) assessed the role biogas technology can play to achieve the Sustainable Development Goal of improving the share of the population using modern cooking solutions and concluded that biogas can help in achieving those goals with appropriate plans and policies. In their willingness to pay study, Thapa et al. (2021) concluded that households in Nepal are willing to pay about US$ 362 for a biogas plant. The authors also noted that the willingness to pay is less than the full market price but higher than the household's share of the market price i.e. more than the difference between the current price and government subsidies.

Although there is a lack of studies that examine the factors determining biogas adoption in Nepal, several studies have explored the factors influencing biogas adoption in sub-Saharan Africa and other Asian countries. These studies suggest that demographic characteristics such as household head's age and gender, and family size are some of the key determinants of biogas adoption. Income, farmland size, and the number of livestock animals owned by households are identified as main socio-economic factors. Previous studies also suggest that institutional factors such as access to market, access to the bank, and access to credit are some of the key institutional factors in determining whether or not households in developing economies adopt biogas technology. In one of the early studies to investigate the factor affecting biogas technology adoption in Kenya, Mwirigi et al. (2009) found that a farmer's socio-economic characteristics significantly influence the decision to adopt the biogas technology, and the majority of the adopters are of medium socio-economic status. In another similar study in sub-Saharan Africa, Walekhwa et al. (2009) found that income, number of livestock animals, number of family members, and cost of traditional fuel are positively associated with family-sized biogas adoption in Uganda. The age of the head of household, the remoteness of the residency, and the household farmland area were found to be negatively associated. Mengistu et al. (2016) and Kelebe et al. (2017) analyzed the factors influencing the adoption of biogas in Ethiopia. Education level, household size, number of livestock animals, distance to firewood source, access to credit were found to be positively associated with the biogas adoption. A more recent study from South Africa found education level, age, number of cattle, income, number of people in the family, availability, and distance to firewood source to be positively associated with the decision to adopt biogas (Uchanamure et al., 2019).

Previous studies in Asian countries have also highlighted the socio-economic characteristics of households as key determinants of biogas technology. For example, Kabir et al. (2013) reported that educational attainment, income, number of livestock and female-headed households are positively associated with the adoption of biogas technology in Bangladesh. Qu et al. (2013) analyzed what factors are important in determining whether or not households install a biogas plant using survey data from four different provinces in China. According to the authors, the household head's age, household size, income and the individual discount factor are crucial for the household's decision to install a biogas plant. Similar to the current study, Das et al. (2017) investigated the factors that influence the household's decision to adopt biogas in India using a nationally representative household level survey. The authors found that wealthy families are more likely to use biogas than poor and marginalized families. In Pakistan, wealth, education and access to credit were found to play a significant and positive role in the adoption of biogas (Yasmin and Grundmann, 2019).

Studies in Nepal show that biogas technology has several benefits, but challenges remain. Yet, much less attention is paid to the demand side of biogas technology in Nepal. The majority of the global studies on biogas adoption are based on purposeful sampling and purposive sampling may limit the study's ability to generalize. Also, as noted by Walekhwa et al. (2009), it is challenging to generalize on the factors influencing biogas adoption due to differences in ecological and economic settings. To our knowledge, studies on the determinants of the adoption of biogas technology at the national level in Nepal are virtually non-existent. In this study, we attempt to fill this gap by examining the key determinants affecting biogas technology adoption in Nepal using a nationally representative sample.

3. Data and methodology

3.1. Survey and data

This study uses data from multiple sources. The main data come from a nationally representative multistage Household Risk and Vulnerability Survey 2018 (HRVS) covering 6,000 households in 50 districts in Nepal (Walker and Jacoby, 2019). The survey was conducted by the World Bank with financing from the UK Department for International Development (DFID). The survey was approved by the Ethical Review Board, Nepal Health Research Council (NHRC). Informed consent was obtained from the participants before conducting the interviews. We also combine data from official AEPC records and documents. The sampling framework of the HRVS survey comprises all households from non-metropolitan areas of Nepal. Four hundred Primary Sampling Units (PSUs) were selected for the survey. PSUs are wards of the municipalities and the number of PSUs is based on population distribution in each district. Fifteen households were interviewed from each PSU. A multistage questionnaire was completed for each household interviewed (Walker et al., 2019). Among several other topics, the survey also asks about the main cooking fuel households use for cooking. We use the response to the survey question, which asks if the household uses biogas as the primary fuel source for cooking, as a dependent variable in this analysis. The questionnaire used for this study can be found in the supplementary materials.

The HRVS data set contains households that may not be a potential candidate for biogas technology adoption. Nepal is divided into three distinct ecological belts: Mountains, Hills and Terai. The Terai is lowland and is characterized by high temperatures and a humid climate. The Hill area is of moderate altitude and mild climate. Temperature plays a significant role in the production and efficiency of biogas technology. The Mountain region is too cold for biogas technology, and it is difficult and costly to operate biogas in the Mountain region (Meeks et al., 2019). The HRVS surveyed households from Terai, Hill, and Mountain ecologic regions. We excluded households from the Mountain region and used data only for the households in the Hills and the Terai region, which account for 90% of the HRVS sample, for this analysis. The widespread cattle ownership is a good indicator of the potential adoption of biogas technology. Households that do not have cattle are not potential candidates for biogas installation. Households without livestock were removed from the dataset for analysis purposes.

A summary of descriptive statistics of the variables used in the analysis is presented in Table 1. About 77% of household heads are male and household heads are, on average, 51 years old. The average family size is about 4. In terms of caste and ethnicity, 14% of the households are Brahmin.
The average education level of the head of the household is about 9 years (equivalent to completing lower secondary school). About 11 percent of household heads have completed high school or a higher level of education. The average household income is NPR 253,500 (US$ 2317) per year. Agriculture and livestock farming are the main occupation of the majority of the households. The average landholding size is 0.53 ha. Among the landholders, 24% are small holders (0.16 ha–0.33 ha), 45% are medium holders (0.33 ha–1 ha) and 12% are large holders (more than 1 ha). On average, households own 4 cow equivalent livestock. The average traveling time to the nearest bank is 1.52 h. About 36 percentage households are from the Terai ecological region and 52 percent of the households are from rural areas. There are, on average, 2 biogas service providers in each district that are prequalified by AEPC to provide biogas-related services to households.

3.2. Theoretical framework and empirical model

The basic theoretical framework for this study originates from the Random Utility Model (RUM) which aims to model the choices of individuals among a discrete set of alternatives. The total utility of an alternative depends on the utility from the characteristics that an individual observes and the utility that an individual does not observe (Das et al., 2017; Kelebe et al., 2017). The household chooses the one with the highest utility.

The utility of alternative \( j \) is:

\[
U_i = \beta_j X_i + \epsilon_i \tag{1}
\]

Where \( X_i \) is the vector of observed characteristics of alternative \( j \) and the individual \( i \), \( \beta_i \) is the vector of the parameter associated with the alternative \( j \) and \( \epsilon_i \) is the random error terms that account for the unobserved attributes of the alternatives and individual.

A utility-maximizing household \( i \) will choose choice \( j \) if:

\[
U_i > U_k \forall j \neq k \tag{2}
\]

Changing the utility of alternatives \( j \) and \( k \), as defined in Eq. (1), the probability of choosing alternative \( j \) in Eq. (2) can be calculated as:

\[
Pr(y = 1) = Pr(U_i > U_k) \tag{3}
\]

Under the assumption that the random terms are normally distributed, \( Pr(y = 1) \) in Eqs. (3) and (4) can be estimated using the probit model.

A dichotomous variable for adopting biogas, the dependent variable, is 1 if the household adopts biogas, zero otherwise. Since our dependent variable is dichotomous, probit models were used to examine the effect of potential determinants on the adoption of biogas technology. A number of factors affect the decision of a household to adopt biogas. In this study, the selection of variables that are likely to influence biogas adoption is based on existing global research, supplemented by the local context. As indicated by global research, demographic and socioeconomic factors are some of the key determinants of biogas adoption (Das et al., 2017; Kabir et al., 2013; Kelebe et al., 2017; Mengistu et al., 2016; Mwirigi et al., 2009; Qu et al., 2013; Uahunumure et al., 2019). In addition, literature also suggests that infrastructure and institutions significantly influence the decision on whether or not to adopt biogas (Das et al., 2017; Yasmin and Grundmann, 2019). In accordance with existing literature, the age and gender of the head of household and family size were used to capture the influence of demographic characteristics. Young household heads are more likely to embrace new technology but may be constrained by resources. Thus, the age of the head of household could be positively or negatively associated with the installation and use of biogas technology. Biogas digester requires manual labor on a daily basis to operate. If the household believes additional members can provide extra resources to operate biogas plant, family size may positively impact the adoption of biogas technology. On the contrary, having a large family may also mean the need for more resources which may impact biogas adoption negatively. Therefore, the family size may positively or negatively influence biogas adoption based on the perception and availability of other resources. We use the number of family members (hhsize) to empirically

### Table 1. Descriptive statistics and definition of the variables used in the analysis.

| Variables       | Definition                                      | Mean | SD  | Max  | Min  |
|-----------------|-------------------------------------------------|------|-----|------|------|
| hhsize          | Number of family members                        | 3.80 | 1.60| 16   | 1    |
| age             | Age of the household head                       | 51.16| 13.78| 95   | 15   |
| male            | Household head is male (~1 if yes, else 0)      | 0.77 | 0.42| 1    | 0    |
| brahmin         | Belongs to Brahmín caste (~1 if yes, else 0)    | 0.14 | 0.35| 1    | 0    |
| kshetri         | Belongs to Kshetri caste (~1 if yes, else 0)    | 0.21 | 0.40| 1    | 0    |
| highschool      | Household head has completed high school degree or higher level (~1 if yes, else 0) | 0.11 | 0.32| 1    | 0    |
| income          | Household annual income (ten thousands Nepalese rupee) | 25.35| 31.52| 570.86| 0    |
| smalllandholder | Household is small land holder (~1 if 0.16ha < land size ≤0.33, hectares, else 0) | 0.24 | 0.42| 1    | 0    |
| medlandholder   | Household is medium land holder (~1 if 0.33ha < land size ≤1 ha, else 0) | 0.45 | 0.50| 1    | 0    |
| largelandholder | Household is large land holder (~1 if land size >1 ha, else 0) | 0.12 | 0.33| 1    | 0    |
| livestock       | Number of livestock (cow equivalent)¹            | 3.69 | 2.73| 40   | 0.02 |
| bankaccess      | Distance to the nearest bank (in hours)         | 1.52 | 2.01| 45   | 0    |
| terai           | Household is in Terai ecological belt (~1 if yes, else 0)¹ | 0.36 | 0.48| 1    | 0    |
| rural           | Household is in rural area (~1 if yes, else 0)²  | 0.52 | 0.50| 1    | 0    |
| biogaservices   | Number of biogas service providers in the district | 1.95 | 1.91| 6    | 0    |
| savinggroup     | Household member is member of a saving group (~1 if yes, else 0)³ | 0.62 | 0.49| 1    | 0    |

¹ Brahmins and Kshetris are traditionally privileged caste groups amongst over a hundred caste groups in Nepal.  
² Households are divided into four categories based on the size of the farm land they own; marginal landholder (farm land size ≤0.16 ha), smallholder (0.16ha < farm land size ≤0.33 ha), medium landholder (0.33ha < farm land size ≤1 ha) and large landholder (farm size >1 ha).  
³ ‘livestock’ is cow equivalent number of livestock. The cow equivalent livestock index is created by combining the number of cows, buffaloes, horses, pigs, goats and poultry based on the potential production of biogas from the corresponding animal manure.  
⁴ Terai and Hill are two ecological belts: the Hill region is the base category.  
⁵ Rural and urban are two areas: the rural area is the base category.
examine this effect. Biogas is mostly used for cooking and cooking is primarily done by female members of the household. From this perspective, it could be expected that female heads of families would have a positive impact on the adoption of biogas technology. At the same time, the primary decision-makers in typical Nepalese households are men, suggesting that women may have less influence in deciding whether to adopt biogas technology. A categorical variable (male) is used to empirically investigate the effect of gender on biogas adoption. Similar studies in other Asian countries have revealed that inherited social status such as caste and ethnicity could be a potential deterrent to biogas adoption (Das et al., 2017). Over a hundred different castes in Nepal are divided into three major caste groups; the higher caste (Brahmin and Kshetris), Janajatis (e.g. Magar, Tharu, Tamang etc.) and Dalits (e.g. Kaami, Damai Saarki etc.). We use caste and ethnicity (brahmin and kshetri) to capture the effect of social status on biogas adoption.

Previous studies suggest that the educational attainment of the head of household positively affects biogas gas adoption. It is argued that higher education level is associated with more information and more knowledge indicating that the individual can have a better understanding and thus affect biogas adoption positively (Mengistu et al., 2016; Walekhwa et al., 2009). We use the education levels of the household head (highschool) to capture the effect of education level on biogas adoption.

While biogas is a relatively simple technology, there is a significant cost associated with biogas digester installations. Thus, income and wealth can have a significant impact on adopting biogas technology. At the same time, relatively rich households may have access to better technologies and have already switched to better energy technologies such as liquid petroleum gas or electricity. In general, research suggests that income has a positive impact on the adoption of biogas. We use the annual household income from the survey to study the impact of income on biogas adoption.

Farmland provides feedstock to operate biogas digester. The size of the landholdings is also an indicator of the socio-economic status in Nepal. Households with medium landholdings are more likely to install biogas digesters than the small land holders. On the other hand, households with relatively large farmland may have already switched and used other modern fuel sources for cooking. Therefore, having relatively large farmlands may not necessarily impact the adoption of biogas technology.

We use the size of farmland owned by a household to capture this influence. Following Kumar et al. (2020) and Koirala et al. (2022) we create four categorical dummy variables (marginallandholder, smalllandholder, medlandholder and largelandholder) based on household’s landholdings to capture the effect of landholding on biogas adoption. Marginal size landowner is used as a base category. Livestock farming is one of the main activities in Nepal. Livestock manure is one of the key ingredients of biogas feedstock and is required to operate the digester to produce methane that can be used for cooking and lighting. In addition to cattle dung, goat, sheep, horse and pig manure, human excreta, poultry droppings and kitchen residue are also used as major feeding materials. Based on this premise, the number of livestock possessed could increase the probability of adopting biogas. Lohani et al. (2021) estimate the biogas production potential from livestock and poultry manure in Nepal. For example, biogas production for cattle is 0.44 m$^3$ per day per cattle and biogas production for buffalo is 0.64 m$^3$ per day per buffalo. Since different animals have different levels of potential biogas production capacity, following Lohani et al. (2021), we combine the number of cows, buffaloes, goats and poultry to create a cow equivalent livestock index based on potential biogas production. The cow equivalent livestock index (livestock) is used to examine the impact of livestock on the adoption of biogas in Nepal.

We extend the probit model by further including additional institutional and infrastructural variables. Although biogas technology is subsidized in Nepal, the installation of digesters requires a significant upfront investment. Additionally, reports also show that majority of the household level biogas are financed through credit (Bajgain and Shakya, 2005). Market access and access to credit are needed to finance the plant. Given this premise, we expect that access to the market and bank would increase access to credit thereby increasing the likelihood of adopting biogas technology. To analyze this effect of access to credit, we use the time needed to travel from the household to the nearest bank (bank-access) as a proxy for access to a bank. Large variations in elevation over a fairly short distance have provided Nepal with three different ecological regions; Terai, Hill, and Mountain (WECS, 2010). These ecological regions differ in climate, terrain, and infrastructure. To control for the effect of different ecological belts on biogas adoption, we create a categorical variable (terai) and used it in our probit models. The biogas industry is highly institutionalized in Nepal (Lohani et al., 2021). AEPC is the executive body and biogas digesters are installed by companies that are prequalified by AEPC. There are about a hundred and seventeen private sector biogas service providers that are prequalified for the installation of biogas plants throughout the country (Lohani et al., 2021).

These prequalified companies are allowed to provide installation and other related services to households in Nepal. Thus, access to these biogas companies is required and crucial for biogas digester installation. We use the number of companies (biogaservices) in each district to control the effect of having access to the biogas service provider.

At an administrative level, Nepal is divided into provinces, districts and municipalities. Municipalities are classified as rural and urban municipalities. Urban municipalities and classified as Municipality, Sub-metropolitan areas, and Metropolitan areas. This classification is based on population, infrastructure and access to services. Rural and urban municipalities differ with respect to infrastructure, opportunities and utilities. Since the adoption of biogas technology is affected by infrastructure and other services, we create a categorical variable for rural municipalities (rural) to control for the impact of the household being in a rural area. Community participation or social networking might also impact the adoption of household-level biogas (He et al., 2022). We use saving group membership (savinggroup) as a proxy for networking to capture the effect of networking on biogas adoption.

4. Results

We estimate multiple probit models. We first estimate the probit model by including demographic variables and then progressively include socio-economic (model 2), and institutional and infrastructural variables in model 3. Probit model regression results are presented in Table 2. The coefficients in the probit model do not provide a direct quantitative interpretation of the impact of the explanatory variables on the dependent variable. We calculate the marginal effect using our most extended model to investigate the quantitative effect of determinants on biogas adoption. Table 3 presents the marginal effects from our final model (model 3).

As it can be seen from our regression results, several factors affect the adoption of biogas technology indicating that a good number of reasons motivate households to embrace biogas technology. The coefficient of the age of the household head is not significant indicating household head’s age has no effect on the adoption of biogas technology. Similarly, the coefficient of household size is not statistically significant in any of the models. Results from previous studies indicate that the impact of gender on biogas adoption has been mixed. For example, Mwirigi et al. (2009) and Mengistu et al. (2016) conclude that male-led families are more likely to install biogas in Kenya and Ethiopia respectively. On the contrary, Kelebe et al. (2017) and Kabir et al. (2013) find that households with male household head are less inclined to adopt biogas in Ethiopia and Bangladesh respectively. Our results suggest that households with a male household head are more likely to adopt biogas technology and that the results are consistent across the three models. We find that male-headed households are 1.4 percentage points more likely to adopt biogas, indicating limited decision-making by their female counterparts.

In terms of social institutions, our results indicate that Brahmins are more likely to adopt biogas than the other caste and ethnicity in Nepal.
### Table 2. Probit model results for biogas adoption.

| Biogas adoption | Model 1 | Model 2 | Model 3 |
|-----------------|---------|---------|---------|
| hhsize          | 0.0109  | -0.0095 | -0.0289 |
| age             | 0.0026  | 0.0020  | 0.0032  |
| male            | 0.3510** (0.1236) | 0.2744** (0.1267) | 0.2727** (0.1389) |
| brahmin         | 0.4933*** (0.0989) | 0.4064*** (0.1047) | 0.2587** (0.1149) |
| kshetri         | -0.1158 (0.1192) | -0.1442 (0.1227) | -0.1681 (0.1355) |
| highschool      | 0.1251 (0.1235) | 0.1113 (0.1319) |          |
| income          | 0.0084*** (0.0024) | 0.0065*** (0.0021) |          |
| income_squared  | -0.00002* (0.00001) | -0.00001 (0.00001) |          |
| smalllandholder | 0.2373 (0.1539) | 0.2781* (0.1684) |          |
| medlandholder   | 0.2940** (0.1409) | 0.3054** (0.1542) |          |
| largelandholder | 0.3296* (0.1688) | 0.3315* (0.1836) |          |
| livestock       | 0.0075 (0.0157) | 0.0065*** (0.0165) |          |
| bankaccess      | -0.2862*** (0.0792) |          |          |
| terai           | 0.2352** (0.1148) |          |          |
| rural           | -0.2288** (0.0967) |          |          |
| biogaservices   | 0.0091*** (0.0248) |          |          |
| savinggroup     | 0.4019*** (0.1124) |          |          |
| Constant        | -2.4156*** (0.2020) | -2.7068*** (0.2345) | -3.0871*** (0.2951) |
| Observations    | 3734   | 3734    | 3734    |
| Log Likelihood. | -506.13 | -491.13 | -437.29 |
| Akaike Inf. Crit. | 1024.26 | 1008.26 | 910.58  |
| McFadden PseudoR² | 0.4019*** (0.0248) |          |          |
| N               | 3734   |          |          |

Notes: Standard errors in parentheses. ***p < .01; **p < .05; *p < .1.

### Table 3. Probit model marginal effects results (Model 3).

| Biogas adoption | Model 1 | Model 2 | Model 3 |
|-----------------|---------|---------|---------|
| hhsize          | -0.0018 (0.0015) |          |          |
| age             | 0.0002 (0.0002) |          |          |
| male            | 0.0144** (0.0064) |          |          |
| brahmin         | 0.0177** (0.0090) |          |          |
| kshetri         | -0.0094 (0.0069) |          |          |
| highschool      | 0.0072 (0.0091) |          |          |
| income          | 0.0004*** (0.0001) |          |          |
| income_squared  | -0.000001* (0.000000) |          |          |
| smalllandholder | 0.0192 (0.0129) |          |          |
| medlandholder   | 0.0190* (0.0097) |          |          |
| largelandholder | 0.0242 (0.0153) |          |          |
| livestock       | 0.0034*** (0.0009) |          |          |
| bankaccess      | -0.0173*** (0.0054) |          |          |
| terai           | 0.0142* (0.0077) |          |          |
| rural           | -0.0132** (0.0058) |          |          |
| biogaservices   | 0.0055*** (0.0015) |          |          |
| savinggroup     | 0.0216*** (0.0058) |          |          |
| N               | 3734   |          |          |

Notes: Standard errors in parentheses. ***p < .01; **p < .05; *p < .1.
are about two percentage points more likely to install and use biogas than those with no saving group memberships. This result is in line with He et al. (2022) findings in which the authors find that social networks can foster renewable technologies adoption through relevant information diffusion.

5. Conclusions

The main purpose of this article was to examine the key factors affecting the adoption of biogas technology in developing countries. We use probit models to identify and investigate important factors affecting biogas using nationally representative survey data from Nepal. Our results show that gender and caste are some of the key demographic characteristics that affect biogas adoption. We find that income, land ownership and the number of livestock are key socioeconomic determinants of biogas adoption. Furthermore, our findings also suggest that institutional factors such as access to banks and the number of biogas service providers are also important in determining the adoption of renewable technologies.

Despite policy priorities to increase the participation of the marginalized castes group such as Janajatis and Dalits in the adoption of biogas technology, the Brahmins remain important caste groups who adopt biogas in Nepal. Our result suggests that there is much to be done to increase the share of modern cooking fuel for underprivileged and marginalized groups such as Janajatis and Dalits. Women are primarily responsible for fuelwood collection and cooking in rural households in Nepal and thus are exposed to indoor air pollution. Heavy dependence on traditional fuel affects women disproportionately and the adoption of biogas technology has a significant impact on women's health and wellbeing. Since women are the primary energy consumers and beneficiaries, women's participation in the decision-making process is crucial. However, our results indicate that the head of household being a woman is negatively associated with the adoption of biogas.

Despite the provision of subsidies, the poor and marginalized households with marginal landholdings are still behind medium landholding households in adopting clean fuel for cooking. Although biogas installation is subsidized, households are required to invest more than fifty percent of the total installation costs. There is still a significant upfront cost and a significant cash contribution is required to install the biogas digester. Biogas technology provides fuels for cooking and lighting; however, it does not generate income directly. The marginalized and poor households may be reluctant to install biogas plant because of the fear that they might not be able to pay back the loan they need to borrow to install biogas. This indicates that poor and marginalized households may not be able to take advantage of the subsidies because of a lack of cash to cover the upfront cost. Additionally, households may be unaware of other benefits such as health benefits, saved time and the potential use of bio-slurry to improve agricultural productivity. They may not be aware of the subsidies for biogas installation. Increasing outreach and raising awareness through educational and promotional activities about these benefits may help increase the demand for biogas for marginalized and poor households.

Our result is consistent with results from previous studies from sub-Saharan and Asian countries in that market and banking access are critical for biogas adoption. Our findings also suggest that families living in rural areas are less likely to adopt biogas than their urban counterparts. Despite strategic priorities, households that need it most are not adopting biogas technology i.e. rural areas. Access to the bank and the bank's willingness to provide loans could be additional constraints to switching to biogas. Poor households in rural areas may not be able to raise enough funds to cover installation costs. Access to credit facilities such as banks and microfinance is crucial for these households. Access to a biogas service provider appears to be another limiting factor. The expansion of the currently existing banking and microfinance network will provide an additional boost to the demand for biogas. Policymakers and planners are seeking to expand the adoption of renewable energy technology such as biogas technology in developing economies. Investigation of the factors that are important for biogas adoption provides crucial information which is useful for increasing the adoption of renewable energy technologies in rural areas of developing economies. These findings are useful in assisting agencies in Nepal and elsewhere in their efforts to expand biogas technology to increase access to renewable energy technologies.

While this study expands the existing analysis of biogas technology adoption in Nepal using a nationally representative survey, the study has some limitations. We are not able to investigate some key determinants that are expected to impact biogas adoption. For example, distance to the nearest forest or time needed to collect firewood, availability of different types and sources of water were not available in the survey and we are not able to evaluate these important determinants. In addition to the key drivers identified and examined in this analysis, the price and availability of alternative cooking fuels also play a significant role in the adoption of biogas technology. Unfortunately, we were not able to include and examine the impact price of these substitute fuels in our current analysis because of the unavailability of related information in the survey data. This might be addressed in future research. Also, more research is needed to understand the fuel transitions from traditional biomass to modern fuel in developing countries.

Declarations

Author contribution statement

Hari Katuwal: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors do not have permission to share data.

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The authors declare no conflict of interest.

Additional information

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