Performance Evaluation and Adaption of Biogas Plant Users among Rural Households of Pakistan

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Biogas technology has become vital in addressing the concerns of energy scarcities. The study examines the performance of biogas plants in Rawalpindi Division, Pakistan and identifies the factors that supposedly affect the adoption decision of biogas users. The key stakeholders in this study are rural households who are using the biogas technology. Data was collected from all active biogas plant users from rural households through a detailed questionnaire. Performance evaluation was done through a DEA non-parametric technique. A Logit model was employed to identify the factors affecting adoption of biogas plants. Number of animals and number of meals cooked have significantly increased the adoption of biogas technology, however, the stinging odor from the dung used has minimized the adoption of biogas technology. Most feasible performance was found for biogas plant of size 10 m3 as it satisfies the maximum cooking and related needs of a normal family. However, we found that biogas technology is more suitable for small families as compared to large families. There is a dire need to establish national level programs for the development of biogas technology and to create awareness among rural people to adopt this technology.

Key words: *Biogas plants; Adoption; rural development; performance of biogas plants; Sustainability factors*

1. INTRODUCTION:

Without any doubt energy has become a vital component for economic growth and socio-economic development for any country.(Kumar et al, 2017).It affects living standards of people in terms of environmental, political, and social dimensions with provision of water, agriculture efficiency and other general issues. Resultantly, delivery of inexpensive, effective and reliable energy facilities with minimum negative effects is very important(Amigun et al, 2008). On one hand industrial development demands massive amounts of energy, and on the other hand household activities of humans are depleting nonrenewable sources of energy and are threatening the environment. (Kumar et al., 2017) In developing countries, the most common source of energy is fossil fuel and the rate of daily consumption of fossil fuels is growing rapidly which leads to disturbances in the ecological system (Karekezi, 2002). According to the International Energy Agency, approximately 1.3 billion people across the globe don't have access to electricity and more than 2.6 billion people still depend on wood, biomass or charcoal for their daily consumption for cooking and heating (Meryem et al, 2013).

Biogas is a convenient and effective replacement of traditional sources of energy which is derived from anaerobic digestion of biological substances such as animal manure, cow and buffalos' dung, kitchen residue, poultry and agriculture waste, and forest residue (Mirza et al, 2009). Biogas is a nonhazardous and renewable energy source that has no harmful effects on the environment and has substantial importance for sustainable growth. Households that use biogas technology contribute 48% less emissions than households without biogas systems (Cheng et al, 1997). From a Health perspective, anaerobic digestion treats livestock waste onsite thus reducing the incidents of pollution of watercourses due to nutrients from animal and human wastes (Mirza et al., 2009). Biogas has gained immense significance after rising requirements for renewable energy sources.

Pakistan an agriculture country with widespread livestock, has a lot of potential for renewable energy, which if used properly can fulfill the energy requirements of all its population. Almost over 1 million tons of animal waste, 225000 tons of crop scum and 50000 tons of food and solid waste are produced on a daily basis. Due to such massive tons of livestock manure, the potential production of biogas is 8.8e17.2 billion m^3 of gas annually which can generate energy from approximately 55 to 106 TWh (Abbas et al, 2017). In addition, the annual electricity generation from biomass is predicted to be 5700 Gwh which is 6.6 percent of Pakistans existing power production. Pakistan is a country with a huge population of 197 million people, but electricity production is nearly 234 kilo watt per hour per capita. This is very low when compared to other developing countries and does not fulfill the country's energy needs.

The introduction of biogas technology in Pakistan can be traced to 1959 when the idea was first considered and subsequently executed in the 1990s which continues till today. Over a long span of time just 6000 plants were installed, while another initiative was undertaken by Pakistan Dairy Development Company to fix biogas plants, with an aim to deliver a sustainable source of energy at low cost among rual housholds (Smith et al., 2013). In Pakistan, biogas energy is used in areas where people don't have easy access to narural gas. In rural areas of Pakistan most of the individuals are engaged in agricultural activities and therefore do not have opportunity for higher income (Abbas et al., 2017).

Pakistan spends approximately 20 percent of foreign reserve on imports of fossil fuels (Shafiee et al, 2009). Traditional means of energy such as oil, natural gas and coal play a valuable role in fulfilling the energy demands locally but their constant use has exhausted the reserves rapidly and is also affecting our environment negatively (Arthur et al, 2011). Due to continuous increases in oil prices and other health consequences, it is important to switch towards more sustainables sources of energy. The current scenario of energy deficit and the environmental consequences resulting from the generation of energy from nonrenewable sources, considering the significance of energy and its substitute sources has become necessary (Cheng et al, 1997).

This study provides comprehensive understanding of the situation and determines social, economic, and health factors which are associated with performance and sustainability of Biogas plants. An analysis such as this has not been done before in Pakistan. It will help owners and companies that have installed biogas plants to integrate factors related to adoption of biogas plants. The advantages and positive impacts of biogas technology are well documented in previous literature. Several gaps related to biogas technology in developing countries have been identified. In the case of Pakistan, it is imperative to find out the potential impact of biogas technology at the household level. The specific objective of the study is to find out the rate of adoption of biogas plants among the rural households of Rawalpindi division, with an aim to consider to what extent biogas plants are benefiting and promoting the renewable sources of energy among the rural community. The study will also discover the effiency of different boigas plant sizes to identify which plant size is providing better performance. On the basis of the results derived from the study, recommendations are made to improve the future adoption of biogas plants to increase the potential of the country.

This study is comprised of the following sections; introduction, research methodology, results along with discussion, conclusions and policy implications.

1.1. THEORETICAL FRAMEWORK

The basis of this research is energy choice theory. Mostly domestic fuel choice theory is based on an energy ladder model or fuel switching (Amigun et al, 2011). Environmental, health, demographic and socio-economic characteristics in energy choice theory are

incorporated in energy choice theory. Domestic energy choice is used which has a linear-three-stage switching method. The stage one of this process significantly depends on conventional biomass fuels. In the second stage, conventional fuels are referred to as the 'Transition phase', while the final stage demands the usage of new energy fuels like LPG, natural gas, and electricity. Many countries tried but failed to provide clean and healthy energy to the masses from conventional sources, resultantly renewable energy has been considered to fulfill the demands of the people. The modern form of energy choice theory proposes that a vector of variables i.e. income, technological, institutional, and environmental characteristics are significant in manipulating a households energy choice (Garfí et al, 2012).

2.   MATERIALS AND METHODS:-

The primary objective of the study is to evaluate the performance of biogas plants and to analyze different factors which effect the adoption of biogas plants. Presently a low number of biogas plants are employed, but the degree of adoption is rising with the increasing issue of energy scarcity. The current study was confined to the Rwalpindi division including the entirety of four Tehsils. Respondents are local household families of different villages of the Rawalpindi division who are users of biogas technology.

For data collection, a questionnaire was designed with open-ended as well as close-ended questions. The questions were split into four aspects including health, environmental, social and economic indicators (Kabir et al, 2013). These indicators determine the adoptability and performance of biogas plants. The study was conducted in rural areas of Rawalpindi division which is purely based on agricultural activities with low income households (Abbas et al., 2017). In the study area a number of plants were installed by the public private partnerships. We purposively interviewed and collected data from rural households who were using biogas technology. Information about the number of biogas plants was obtained from government and private organisations i.e. PECRT, NRSP, and RSPN. We collected data from all operational biogas plants in rural areas of the Rawalpindi division of Pakistan. The data was collected through interviews and self-observation methods with regard to the families using biogas plants.

2.1. LOGIT MODEL

Logit regression analysis along with the Maximum Likelihood Method was used to check the effect on different indicators of the adoption of biogas plants. The dependent variable of our study is dichotomous which is why we used logit analysis. The logistic regression model is desirable for the situation where a researcher identifies the presence and absence of a particular event (Bonney, 1987). This model reflects the effect of the explanatory variable on the dependent variable in the form of likelihoods or odds. The predicted value of dependent variable in binary logistic regression is coded in the form of "0" or "1". In logit model "0" reflects the absence of any characteristic whereas "1" shows the presence of a certain

characteristic (Gujarati, 1978). As the assumption of the regression model asks for values of the explanatory variable to be normally distributed which cannot be achieved (Bircan, 2004). Therefore, maximum likelihood model is used to examine the constraint as an alternative to the least square method.

In order to check the acceptability rate of biogas plant in Rawalpindi, a multivariate logistic regression model has been applied.

The general form of logistic regression model is

$$\text{Logit (P)} = \log\left(\frac{P}{1-P}\right) \tag{1}$$

$$\text{Let } Pi = Pr\left(\frac{Y=1}{X=xi}\right), \text{ then the model can be written as} \tag{2}$$

$$Pr\left(y=\frac{1}{x}\right) = \frac{\exp^{x'b}}{1+e^{x'b}}; = \log\left(\frac{Pi}{1-Pi}\right) = \text{Logit(Pi)} = \beta 0 + \beta 1\, xi \tag{3}$$

Formula for logit model

Where Pi is the probability of deciding to adopt adaptation strategies (dependent variables), Xi's are the independent variables, β0 is the intercept and β1 is the regression coefficient.

We can write the model in terms of odds as.

$$\frac{Pi}{(1-Pi)} = \exp(\beta 0 + \beta 1\, xi) \tag{4}$$

Formula for odd ratios

Logit Equation of the study:

In this model coefficients are used to estimate the probability or odd ratios of each dependent variable;

$P(Y) = \beta_\circ + \beta_1 DIS + \beta_2\, DF + \beta_3\, FM + \beta_4 BRN + \beta_5 STN + \beta_6 AG + \beta_7 INC + \beta_8 MEAL + \beta_9 ANM + \beta_{10} PB + e$

Where;
P = Probability that biogas technology is adopted.

P = 1 shows that biogas technology is being adopted.

P = 0 shows that biogas technology is not being adopted.

$\beta_\circ$= Constant Term

DF = Deforestation

BRN = Burns from cooking

STN = Stinging odor

AG = Age

MEAL= Number of meals

ANM = Number of animals

PB = Public safety

DIS = Distance from city

FM = Family size

Table 1   Expected Signs from logit Analysis:

	variable names	units	Excepted signs
Dependent variable	adoption of biogas plant	categorical	
Independent variable	deforestation	less wood cutting	+
	meals	number of meals cooked	+
	livestock	number of animals	+
	safety	children and public safety	+
	burns	burns from cooking	+
	stinging odour	stinging odour due to leakage	+
	distance from city	in kilometres	-
	age	years	+/-
	family size	number of people in family	-

2.2. DATA ENVELOPMENT ANALYSIS: -

Data envelopment analysis (DEA) is calculated to estimate performance of biogas plants installed in rural areas of Rawalpindi Division. DEA was presented by Cooper, Charnes and Rhodes in 1978 by assuming constant returns to scale that undertakes multiple inputs and outputs. DEA is a non-parametric measurement method (Minh et al,2008).

Data envelopment analysis is used to calculate technical efficiency of decision-making units in a complicated system by evaluating relative change in outputs and inputs (Charnes et al, 1978). The measurement of technical efficiency of decision-making units has become significant in estimating performance (Barros, 2005). This approach has been effectively functional in several sectors of the economy such as health, education, energy, public administration, and social support (LI et al, 2009).

DEA is a relatively competent approach that allocates weights to the inputs and outputs of the DMUs being measured. The actual value of inputs and outputs is then multiplied by estimated weights to discover the technical efficiency score. In each case, efficiency is measured in terms of a proportional change in inputs or outputs.

In all variant forms of the DEA models, the DMU(s) with the best essential efficiency in transforming inputs Xi, X2,...,x,, into outputs Yi, Y2,...,Ym is recognised, and other DMUs are classified according to DMUs which are most efficient. For DMU 0, CRS input orientated model of DEA is used here which is measured as follows:

$$\max h_0 = \frac{\sum_r u_r . y_{rj_0}}{\sum_i v_i . x_{ij_0}}$$

$$\text{subject to} \quad \frac{\sum_r u_r . y_{rj}}{\sum_i v_i . x_{ij}} \leq 1 \quad \text{for each unit } j$$

$$u_r . v_i \geq 0$$

Formula for DAE performance measurement

The ur and w are the weights applied to input xij and output yn, and these are selected for enhancement of efficiency score (h0) to maximum of DMUo. The limit for the efficiency score is that it must not be more than 1.0 for any of the DMU. DMU(s) that are present on the frontier show level of efficiency of 1.0 and those which are present inside are operating at lower than maximum level of efficiency that is less than 1.

Following indicators are used for the current study:

Indicators:

Inputs
- ✓ Amount of water
- ✓ Cost
- ✓ Dung
- ✓ Outputs
- ✓ Fertilisers produced
- ✓ Number of meals

3. RESULTS AND DISCUSSION:

3.1. RELIABILITY ANALYSIS:

Reliability is the measure of results when the sample is repeated again and similar results are obtained which shows the consistency of a measure. It is obtained by measuring the values taken by the different variables. Cronbach's Alpha is used for the measurement of reliability and a value greater than 0.7 is a good measure of Reliability (George et al, 2003).

Table 2 shows that the Cronback's Alpha of independent variable Environmental benefits has a value greater the 0.7 which tells us that this variable is reliable. Similary the values of other independent variables social, health and economic benefits and sustainabilty are 0.757, 0.750, .755, 0.740 and .781 respectively which are considerably above the 0.7 value which depicts that the variables are reliable.

Table 2   Reliability Analysis of Variables

Variables	Cronbach's alpha	Items	variable type
Environmental benefits	0.757	8	independent
Social benefits	0.750	8	independent
Economic benefits	0.755	7	independent
Health benefits	0.740	6	independent
Sustainability	0.781	10	independent

Author's own calculation

The multivariate logistic regression model was employed to find the effect of the socio-economic, environmental and health characteristics of sample households on the adoption decisions of biogas plant users. In Table 4 deforestation, income, number of meals, animals held by households, public safety, stinging odor, reduction in burns, distance from city and family size demonstrated significant effects on adopting biogas technology, while age was found insignificant. Cox and Snell R^2 Nagelkerke R^2 shows the relevance to the logistic regression model. The value of Cox and Snell R^2 is .572 and Nagelkerke R^2 is .849 which confirms the authenticity of the results.

The results obtained are explained below:

Ln P(1-P) = 23.20 - 1.45 DF +1.337 NM + 1.487 NA-2.967 PS-2.557 LK - 3.578 RB +.145 DC -.491FS-0.001AG+ €i

Table 4   Variables in Logit equation

variable names	Beta	Significance	valid	odd ratios
Deforestation	-1.45	.023**	Significant	.239
Number of meals	1.337	.018**	Significant	3.808
Number of animals	1.487	.028**	Significant	4.425
Public safety	-2.967	.001 *	Significant	.051
Stinging odor	-2.557	.004*	Significant	.078
Reduction in Burns	3.578	.002*	Significant	.028
Distance from city	.145	.017**	Significant	1.156
Family size	-.491	.006*	Significant	.612
Age	-.001	.982	Not significant	0.999

Notes: * denote: Sig<.01*, sig<.05**, sig<.10***

Deforestation:

In rural areas of Pakistan, firewood is the most important source of energy. The main two sources of firewood are natural as well as artificial plantation. Availability of a large number of trees could provide for the household's energy and thus there is lesser probability of taking up biogas technology. However the immense effects of deforestation are widespread. In our study, deforestation indicates reduction in cutting of trees but the slope coefficient for deforestation has a negative sign and is highly significant in indicating that the odds of adoption of biogas plant is higher by .239 for cutting one additional tree. A quick increase in deforestation suggests reduced dependency on firewood and more reliance on other sources of energy.

Number of meals:

The first and foremost concern of biogas plants is to provide clean and healthy energy for cooking food in an efficient and affordable manner to rural community. In this study, if the number of meals from biogas increase with 1-time meals then the odds of adoption of biogas plant are higher by the factor of 3.808. Results imply that there is a positive and significant association among number of meals and adoption of biogas plant.

Number of animals:

The livestock kept by household is a decisive factor in adopting biogas technology as it provides animal dung which is used for primary input in biogas plants in Pakistan. The size of an animal herd kept by a household is an important requirement for biogas plant. In this study an increase in the number of animals kept by a household by one animal will increase the probability of adopting biogas digester plant by 4.425. Findings infer that households with a higher number of animals are more likely to adopt biogas plant as it indicates the accessibility of feedstock that is a key input in running biogas plant. Similar results are described by (Abbas et al., 2017)**,** (Kabir et al., 2013)**,** (Gujarati, 1978) in Pakistan, Bangladesh and Uganda respectively.

Public safety:

Biogas is a rapidly growing source of energy in developed as well as developing countries. On one hand it provides cost effective, efficient and sustainable energy but at the same time it causes serious accidents that occur due to leakage from biogas chambers, accidental discharge of H_2S, existence of hazardous products in raw material etc. In this study, we find that the odds of adoption of a biogas plant are higher by the factor of .051 if public safety from a biogas plant decreases by 1 unit.

Stinging odour:

Odour emissions from operating biogas plants have become a great concern due to the suffering and public health issues they cause. During the production process of biogas, different organic and inorganic contaminated compounds are discharged. These toxic compounds may create a serious odour nuisance in urban or rural areas, thus carrying a valid threat to public health and security of the ecological system. More specifically, ammonia NH_3 emmisions cause respiratory diseases, as well as eye, throat and skin allergies. However, in this study, we find that the odds of adoption of a biogas plant are higher by .024 if stinging odor decreases by 1 unit. Thus, a biogas plant has positive effects on the wellbeing of its users.

Reduction in Burns:

In most of the rural areas of Pakistan, firewood has been replaced with gas stoves after installation of biogas plants. This technology brought convenience to rural women and saved them from the hard job of collecting firewood and encountering burning accidents. The results of this study imply an insignificant but negative relationship (-3.578 coefficient; .028 odd ratio) among reduction in burns while cooking. This result implies that biogas

technology is safer and reduces the probability of burning accidents which occur due to utilization of oil and kerosene stoves because of a lesser ratio.

Distance from city:

The distance from home to fuel sources has positive or negative effects in taking up biogas technology. As distance increases by 1 km, the odd ratios of adopting biogas technology falls by factor of 1.156. among fuel sources and distance. Although rural households face fuel deficiency, this has not affected their choice and decision to adopt biogas plants. The decision is due to the initial higher cost of biogas plants, so people move towards other efficient and easily accessible sources such as LPG cylinders. LPG is an economic fuel which cooks food faster and more conveniently than any other fuel such as firewood and kerosene due to its high calorific worth. This factor leads to low probability of adopting biogas plants.

Family size:

Family size may cause either positive or negative results. Large households provide more workers that may be employed for biogas plant's functional operations and maintenance activities. However, in this study, we find that family size has a negative but significant impact on the decision to adopt biogas technology. As household size increases by 1 person, the odd ratios of adopting biogas technology falls by factor of 0.612. These results are consistent with and verify the results of **6**. This is due to the fact that the small size of a biogas digester is inadequate in bearing the burden of a large rural family size so they switch to alternative means of energy. Another reason is that rural families have low income opportunities, and people don't have sufficient financial resources to invest in biogas technology.

Age:

Age of household is predicted to have either a positive or negative impact on decision of using biogas technology. Our findings show that the age of the household head and adoption of biogas technology has an insignificant and negative relationship. This negative association indicates that households with an older head have not had good experiences with biogas technology. However older households have wealth accumulation and are more financially stable, but still they are reluctant to switch to new technology and save themselves from risks. These result are in line with the findings of Uganda, Faso and Burkina (Walekhwa et al, 2009) who stated that there is negative association among the age of a household head and adoption of biogas technology which means older rural communities still follow traditional sources of energy and are not ready to move to new technology.

3.2. MEASURING BIOGAS PLANT EFFICIENCY

Cow dung and water are used as variable inputs in production of biogas plants while other constant or fixed variables have not been considered for this study due to linear programming methodology that considers only variable inputs for computation.

Input measure for DEA:

Farmers used cow dung as a key input in biogas digester. Table 5 shows the mean of dung used daily. It demonstrated different averages of usage of biogas plants according to size. Secondly, the most imperative input is water as it is used by villagers for making manure for the production of biogas on a daily basis. Table 5 shows daily use of water as well as the average of water used in different sized plants. The last input used for the DEA method is cost. Cost covers installation and maintenance charges on an annual basis. The table shows the average cost of different plant sizes installed by villagers.

Table 5   Descriptive analysis of inputs

Plant size	4m3	5m3	6m3	8m3	10m3	Overall mean
Dung in kilo gram	18	20	24	37	57	21
Water in liters	27	32	34	44	70	33
Cost in rupees	28881	29955	29375	31400	36667	29569

Author's own calculation

The main objective of biogas technology is to produce biogas at its optimum level for preparation of meals. Two types of outcomes were obtained by using animal residue and water such as biogas and slurry which are byproducts of the entire production process of biogas.

Output measure for DEA

It is hard to measure the actual capacity of biogas produced because in rural areas people do not have any indicator or equipment to measure the volume of biogas produced. So, we measured biogas in terms of the number of meals cooked on a daily basis, as the key purpose of biogas production is cooking food in a sustainable and affordable way. An additional output is slurry and it is the by-product of biogas technology. Slurry is a bio-fertilizer with highly enriched nutrients. People use this slurry as fertilizer for their crops. Table 6 shows the average number of meals produced and the average slurry produced according to plant size.

Table 6   Descriptive analysis of outputs

Plant size	4m3	5m3	6m3	8m3	10m3	Overall mean
Number of meals daily cooked	2	2	3	2	3	2
Slurry in kilograms	13	16	18	32	50	17

Author's own calculation

3.3. DESCRIPTIVE ANALYSIS

Table 6 shows an overall descriptive analysis of the results of data envelopment analysis. According to this graph, mean efficiency of biogas plant with plant size of 4m3 is 0.764271. Likewise, the mean efficiency of biogas plants with plant sizes of 5m3, 6m3, 8m3 and 10m3 is 0.71, 0.78, 0.85 and 0.96 respectively. This data concludes that a plants size of 10m3 provides the best performance.

Fig. 1. Descriptive Analysis of Efficiency

3.4. RESULTS OF DATA ENVELOPMENT ANALYSIS:

The following graph represents efficiency with respect to decision making units which in our case are the number of biogas plants. At X- axis, there is efficiency and at Y-axis there is DMUs. According to the results, a different efficiencies scale has been found from several decision-making units. A total of fourteen plants have been evaluated for the most efficient plant with 100 percent performance whereas the rest of the plants are not operating efficiently as their technical efficiency rate is below 1.00. DMU. Eighteen plants from figure 2 show least efficient performance which is 038. Biogas plants with a plant size of 10m^3 has the best performance efficiency which is 0.96. So, it is most sustainable for adoption by household villagers and can fulfil cooking needs of household families.
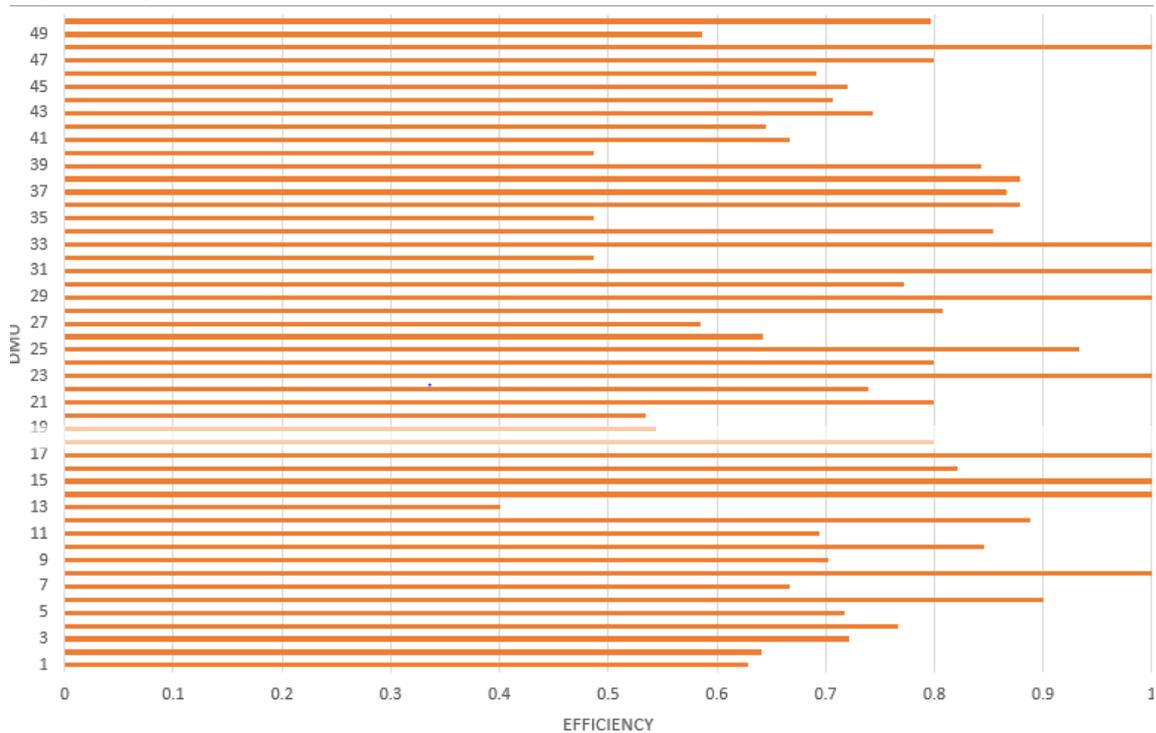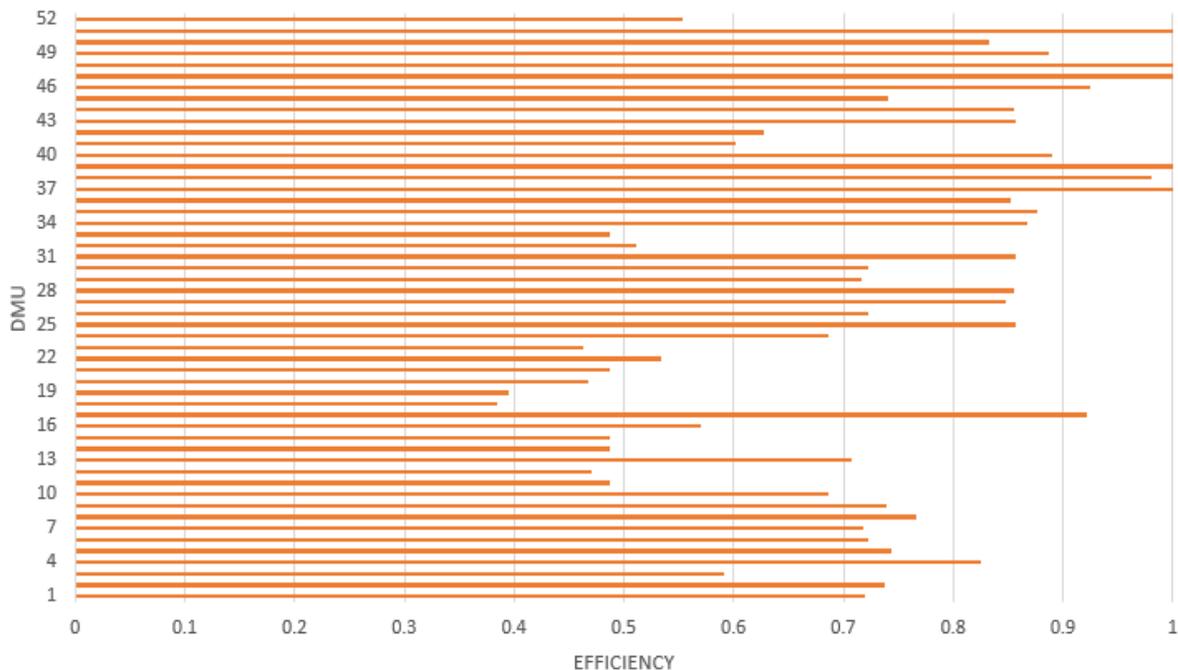
Fig. 2.Graph of efficiency

Fig. 3. Graph of Efficiency

The below mentioned graph indicates efficiency on its y-axis and DMUs on its x-axis. These figures show efficiency of all the biogas plants with respect to size of the plant. Different plant sizes gave diverse results; Figure 3 illustrates 23 biogas plants that were observed with size of $4m^3$ out of which 4 plants gave 100 percent performance while most of them were performing below 80 percent with overall efficiency of 76 percent.

The largest cluster of biogas plant holders comprised of 65 biogas plants holders of $5m^3$ size. These plant holders were using biogas plants in order to fulfill domestic needs of cooking. From figure 4, a total of 5 plants were estimated as super-efficient with 100 percent technical efficiency. The remaining plants showed strong variation in terms of technical efficiency, however their inclusive efficiency was very insignificant which was up to 71 percent. This allows us to conclude that plants that were of size $5m^3$ did not satisfy family needs and were costly.

Fig. 4. Efficiency of plant size $4m^3$
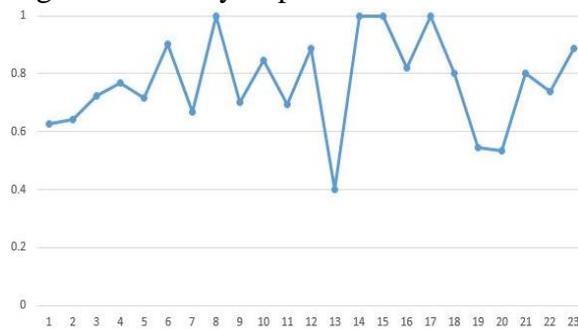
Fig. 5. Efficiency of plant size $5m^3$
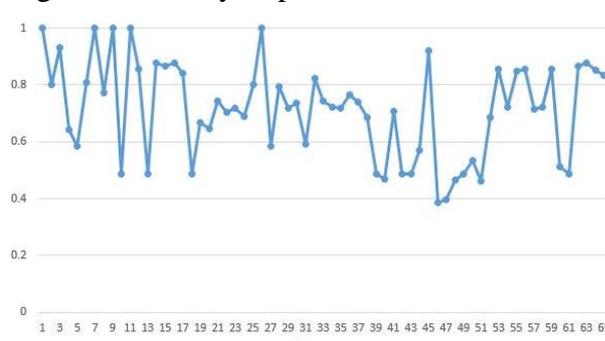
Statistics were taken from 8 biogas plant owners of $6m^3$ size and results showed that 3 biogas plants were functioning most competently as their rate of efficiency was 100 percent. The average efficiency of $6m^3$ biogas plants was up to 78 percent. Just 3 biogas plants of size $10m^3$ and $8m^3$ were a part of this study. Mostly rural people used the $10m^3$ biogas plant because it was more than enough to fulfill the domestic requirement of a large family size. Mean efficiency of biogas plant with plant size of 8m3 and 10m3 was 85 and 96 percent respectively which allows us to conclude that plant size of 10m3 delivered the best performance.
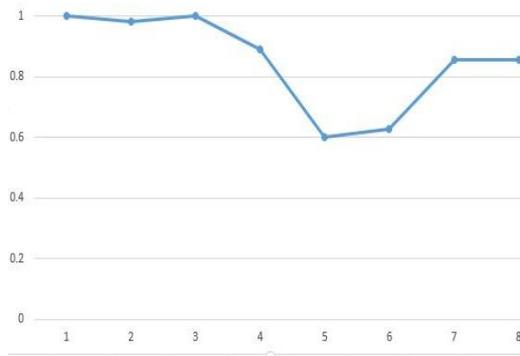
Fig.6. Efficiency of plant size 6m^3
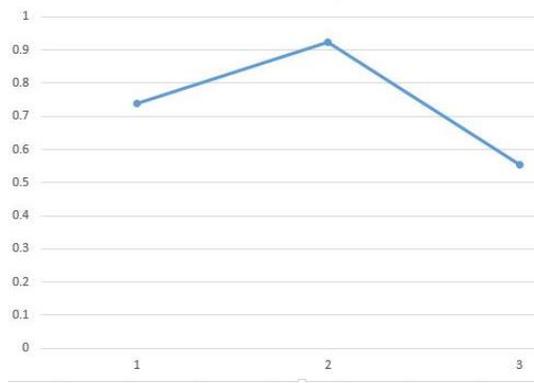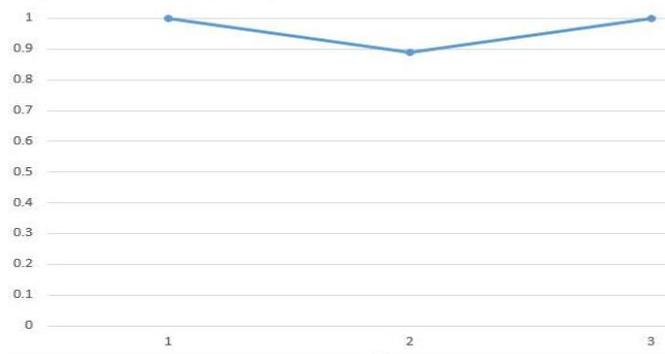
Fig.7. Efficiency of plant size 8m^3

Fig.8. Efficiency of plant size 10m^3

4. CONCLUSION:

The study identified factors affecting adoption of biogas technology in the rural area of Rawalpindi division. Biogas offers a sustainable and cost-effective source of energy along with several environmental benefits. Socio-economic factors play an imperative role in adopting biogas plants. On one hand, the number of animals, number of meals and distance from the city are positively influencing households to adopt biogas technology. The number of animals people have plays a significant role in adopting biogas technology as the more

animals people have, the higher the chances of adopting biogas plants due to abundance of animal manure. Reduction in burns is another key factor towards adoption decision of biogas users, as due to this technology, firewood has been replaced with gas stoves which are safer, and provide an efficient source of energy. Moreover, this technology has provided a convenient way of life particularly for rural women and saved a lot of time that was being consumed in collecting firewood for preparing meals. Women get more benefits from this technology as compared to men.

The study also analysed the technical efficiency of different sizes of biogas plants by using a data envelopment analysis approach. Biogas plants are of many different sizes starting from $4m^3$ to $10m^3$ and are being operated in different villages at household levels. A biogas plant size of 10m3 size was found to be the most economical biogas plant with the highest benefits. It is obvious from the result that overall, the average performance efficiency of biogas plant is 82 percent. Thus, there is still room for improvement to increase efficiency by 18 percent 100 percent efficient level can be attained. Even with the huge potential and several advantages of renewable energy, the role of biogas technology still lags behind ambitious claims made because of initially higher investment, lack of research in bioenergy field, inefficient practices of government organisations and poor economic arrangements.

5. POLICY IMPLICATIONS:

Based on the findings of this study, there is a need for the promotion of renewable sources of energy country-wide particularly in the study area, and for campaigns to be formulated. There is a need to highlight the achievements and success stories of biogas technology in the provinces and at a national level. This can be done through sharing experiences and information. It is important to be truthful and properly guide new adopters to the core requirements that are mandatory to operate biogas plants successfully. Forests are of vast economic and environmental importance, but due to increasing deforestation Pakistan is facing severe environmental and climatic challenges. Forests are easily accessed by local residents whereby trees are chopped down for firewood. The time has come to impose restrictions on firewood collection, especially within government forests that should not be so easily accessible. There are governmental bodies that are supposed to preserve forests by implementing environmental law as an instrument. When environmental legislation is properly imposed, it will prevent the destruction of forests and wildlife. Increasing operational and maintenance services such as procedural and technical support are needed. After adopting biogas plants it is observed that authorities do not provide assistance and technical support required to keep the plant operational and maintained.

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AUTHORS CONTRIBUTION:

All the authors have contributed equally in writing this Research Manuscript
DATA AVAILABILITY STATEMENT:

The dataset generated for this study is available on request to the corresponding author.

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