International Journal of Engineering Works
ISSN-p: 2521-2419
ISSN-e: 2409-2770
Vol. 6, Issue 09, PP. 314-323, September 2019
https://www.ijew.io/
https://doi.org/10.34259/ijew.19.609314323

Analysis of Biogas Technology Adoption at Household Level and its Impact on Sustainable Livelihoods

Muhammad Haseeb[1], Saddam Ali[2], Saim Saher[3]
[1,2,3] United States Pakistan Center for Advanced Studies in Energy UET Peshawar, Pakistan
Received: 06 September, Revised: 15 September, Accepted: 17 September

***Abstract*—**The incessant depletion of world energy resources and the global environmental deterioration are a good indicator of banishing the conventional energy extraction technologies in favor of renewable and sustainable options. Pakistan being an agrarian society is home to one of the largest proportion of population dependent on agricultural products and livestock to make ends meet. Fortuitously this also provides an abundant resource for biomass which can be utilized for generating biogas energy. In the era of renewable energy boom, the resource has poignantly not been fully utilized. Whatever portion of the biogas energy has been tapped is not proliferating across the country owing to the lack of knowledge about the impacts of this precious resource. This research endeavor attempted to investigate the impact the biogas technology is imposing on the households that have adopted it. A total of 162 households composed of both adopters and non adopters of the technology were surveyed in the Dera Ismail Khan District of Pakistan in addition to the meetings and discussions with the relevant stakeholders. Resultantly the factors vastly impacting the adoption of the biogas technology were uncovered. Accordingly the apprehensions and misconceptions of the households not employing the technology despite possessing the resources necessary also came to surface. It was found out that the technology had profound impacts on the environment, education, and the health of the adopting families. However the age, education level, and gender of the target population did not bear any correlation with the decision to adopt the technology itself. The major barrier to the adoption of the technology in the target area was the high upfront costs of the technology, and low awareness about the technology's installation, and maintenance.

***Keywords*—** Biogas, Social impact, Livelihoods, rural development, Environment

I. INTRODUCTION

Global fossil fuel deposits are depleting at an alarming pace and slated to run out somewhere in the late third quarter of the ongoing century. Contrarily the energy demand, and consequently the fossil fuel prices, is increasing the world over. The most plausible way the staggering demand could be satiated is to augment the conventional energy resources with the alternative sources. This will have the added benefit of tackling the soaring pollution and the resultant global warming. Besides following Kyoto protocol there is a growing consensus among the world leader that the energy demands be met mostly by alternative resources and the dependence on the conventional resources should be mitigated. The energy demand in the developing countries of Asia and Africa is slated to surpass the energy demand in the developed countries for the first time in 2020 [1].

Renewable energy has witnessed the most remarkable proliferation into the energy arena in the last decade, leading to an increased competitiveness with the fossil fuels in terms of marketability and annual deployment. According to International Energy Agency (IEA) Renewable Energy Report for the year 2017 renewable energy makes the lion's share of new energy projects with 167 GW of new additions compared to 57 GW from coal and 29 GW from gas. The same report posits a forecasted renewable deplo0yment of another 920 GW by 2022, as shown in the figure 1, which is an upward adjustment in the previous year's forecast, enabling renewables to make up 30% of total energy resources around the world. All this points to a bright future for the renewable energy [2].

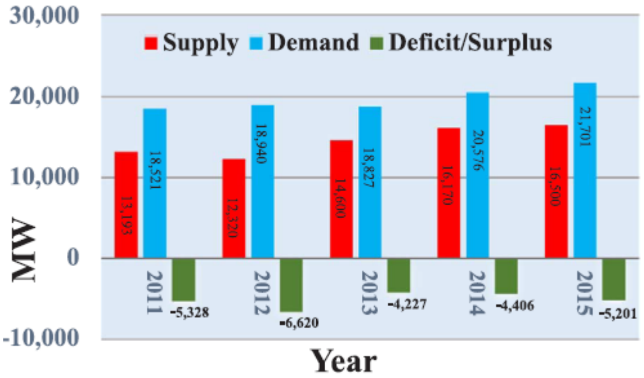

Figure.1 Electricity shortage in Pakistan [5]

Unfortunately the renewable energy potential has not been tapped mostly due to the high capex and technology. Pakistan is an agrarian country with more than 60% of the country's population dependent on agricultural income directly or indirectly [16].

This provides an opportunity in the form of abundance of biomass in the form of crop residue, forest residue, and more importantly the animal waste. Capitalizing on this opportunity and extracting a portion of the available resources could provide clean energy for rural community as well as industries where organic waste is generated. Even the sugar mills in the country produce biomass sufficient for a potential energy generation of 3000 MW. Only 4 sugar industries are currently generating 145.1 MW electricity from the bagasse, that is a byproduct of sugar cane [18, 19]. In addition to these operational projects another 9 projects are in various developmental stages and are estimated to produce a total of 297 MW electricity upon completion [18, 19] as shown in the table 1.

TABLE 1 SUGAR MILLS IN VARIOUS STAGES OF BIOGASS PLANT DEVELOPMENT [18,19]

Sr. no.	Company	Capacity(MW)
1	RYK Energy	36
2	Alliance Sugar Mills Ltd.	19
3	Layyah Sugar Mills Ltd.	41
4	Safina Sugar Mills	20
5	Chanar Energy Ltd	22
6	Etihad Power Generation Ltd.	67
7	Shahtaj Sugar Mills Ltd.	32
8	Almoiz Industries Ltd.	45
9	Hamza Sugar Mill Ltd.	15
	Total	297

Social value of energy is defined as the cumulative sum of the benefits derived by person or society from energy including the obvious economic gains, the concomitant development and prosperity minus any adverse impacts the energy generation may carry in the form of health impacts, environmental impact or any other negative outcome [24]. The challenge of energy poverty has thus far been tackled by access to basic level of energy provision [25-27].

Certain drawbacks are part and parcel of this approach including its inability to convert the energy access in to durable value for the communities leading to poverty alleviation [28,29]. Here social value consideration in the designing and implementation of energy projects is of key importance. In economically destitute societies energy resources are usually scarce, and thus the electrification projects relatively non-economical [30].

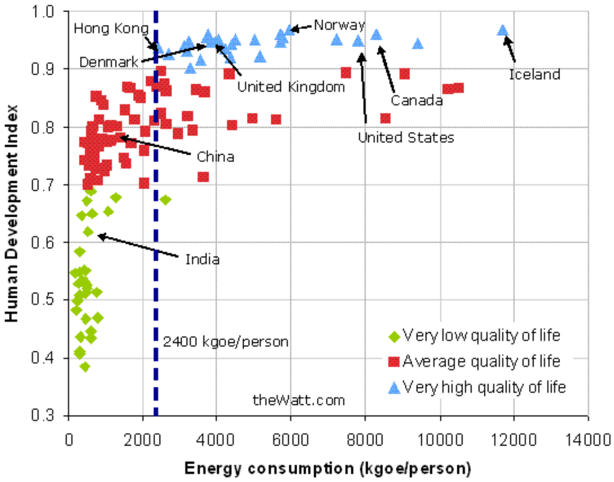

Figure 2 HDI-Energy correlation [23]

Usually the concept of social value is incorporated into the project by the measure of HDI index as function of energy consumption per capita as witnessed in the figure 4 as well [33]. However it is also evident from the figure that some countries achieve a much higher HDI for similar levels of energy consumption per capita. For instance Denmark while having similar levels of HDI as Canada consumes less than half the energy per capita. Same is the scenario for China and Costa Rica. Thus the ratio of energy consumption per capita to the HDI could point to the ability of the country to derive social value from the energy as shown in the table 2.

This discussion is at the heart of the second objective of this thesis; to gauge the social value produced by the biogas plants installed in Khyber Pakhtunkhwa province of Pakistan. The social value here is measured in terms of the satisfaction of the adopters and the health, education, and other benefits they derive from the energy produced by the biogas plants installed at domestic level

Studies related to adoption and socioeconomic impacts of biogas have been done but there are very few studies that analyze adoption and socioeconomic impact collectively. This study uses integrated approach to identify barriers to adoption and the various benefits in terms of socioeconomic impacts that can be enjoyed with the adoption of biogas technology. This study will be based on the detailed survey of biogas plants . The study aims to assess the role of biogas technology in saving wood, mitigating green-house gases emissions, improving livelihoods and impacting the households socially and economically. The current study will also investigate the various social and economic factors effecting the adoption of biogas plants. For this purpose both adopters and non-adopters of biogas will be interviewed and the adoption will be analyzed. Impact of biogas on the livelihoods of the households will be assessed by using DFID (1999) framework on sustainable livelihoods [34]. Carbon emission reduction will be calculated from fuel consumption reduction with biogas use, and will be presented in CO2 equivalent.

TABLE 2 RATIO OF ENERGY CONSUMPTION TO THE HDI_ INDICATOR OF SOCIAL VALUE [24]

Country	Human development index (HDI)	Percapita electricity consumption (kWh	Ratio
India	0.58	700	1
Denmark	0.9	6100	0.17
Canada	0.9	16500	0.06
China	0.71	3300	0.25
Costa Rica	0.76	1800	0.48

There are two types of Biogas plants currently prevalent in the market.

1. Floating Gas Holder Biogas Plant [44]
2. Fixed Dome Biogas Plant [45]
3. Expansion Chamber with Fixed Dome Biogas Plant [46]

A. Biogas Resources of Pakistan

Paksitan is regarded as an agrarian society with close to 60% of its population directly or indirectly dependent on agriculture or livestock for their subsistence [5]. The crop residue and cattle waste are an ideal resource for biogas generation. In addition poultry farms are also a useful biomass resource capable of being used in biogas generation. The poultry population in the country is 319 million generating revenue of 750 billion annual revenue [47]. Resultantly billions of kilograms of biomass is produced in the country which can be used as biomass.

Sugar cane is an important cash crop in Pakistan. Paksitan is the world's 5th largest producer of sugarcane with its annual sugar cane production averaging 50 million tons, resulting in by product of 10 million tons of bagasse [48]. The 84 odd sugar mills in the country have an estimated potential of 3 GW of electricity generation from biogas resource. Unfortunately the current tapped potential is only 700 MW [48].

Similarly livestock sector of Pakistan is well equipped for biogas electricity generation. The 159 million cattle population in the country has the ability to produce manure for electricity generation as well as environmental impacts are extraordinary [49].Even half the available potential, if tapped, would produce 8.1 million m3 per day biogas [50].

Biogas technology has been prevalent in Pakistan for quite a while dating back to 1959 when the first use of this technology was made in construction of a farm manure plant in Sindh for biogas generation, used mostly in cooking [51]. Government of Pakistan, in 1974, made its first major step in the mainstreaming of the biogas technology through a project of 4137 biogas units; first stage with government funding, second stage with shared funding, and last stage with technical assistance only. Albeit the project was ambitious hardly any further progress was made. Another resurgence of the program occurred in 1990 when 1700 new plants were installed all over the country [52]. Similarly, in 2000 Biogas Support Programme (BSP) helped set up 1200 new digestors, amounting to 27% of domestic biogas capacity.

II. METHODOLOGY

The study was carried out in the Dera Ismail Khan District of Khyber Pakhtunkhwa province of Pakistan. The district shown in the figure 3.1 is the most populated district in the southern half of the province. Located on the west bank of River Indus, it is located at a distance of approximately 300 km from the provincial capital. The population of Dera Ismail Khan according to the 2017 census is 1,627,132, and ranks 37th in population across country. The climate of Dera Ismail Khan is hot desert like with extreme hot weather in summers and mildly cold in winters.

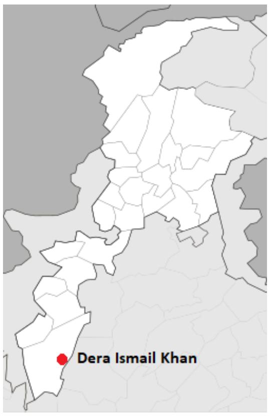

Figure 3. Geographic location of Dera Ismail Khan

The geographical spread of Dera Ismail Khan is 9,334 km2. The main crop of Dera Ismail khan is Wheat and sugar cane. It is home to three sugar mills. The educational situation is extremely bleak with only 47% literacy among the male and 21% literacy rate among the female population.

1) 3.2 Methods and Approach

a) Data collection

Primary data for DI Khan District was collected through questionnaires and sureveys conducted on ground. Secondary data was collected through internet research and consultation with relevant stakeholders such as Pakhtunkhwa Energy Development Organisation (PEDO), Provincial Energy Ministry, Municipal Corporation of DI Khan, and local elected bodies of each village visited. The surveys were targeting data relating to:

1. Socio economic spectrum of the respondents
2. Age of the respondents
3. Education level of the respondents
4. Questions relating to the satisfaction level of the households
5. Reasons for adopting biogas technology
6. Reasons for not adopting biogas technology
7. Financial details of the biogas installation and the cost benefits

b) Sampling procedures

Purposive Stratified Sampling Protocol (PSSP) was incorporated in the selection of the households for sampling of data and the sampling size and various dimensions in itself. Adopters and non adopters were selected from various villages and union councils of DI Khan District. The sample of household was geographically spread as much as possible to capture the whole strata of economic, social and educational variations. A total of 100 households were surveyed for the purpose of this research from 10 villages of DI Khan split among adopters and non adopters in 70 ratio 30.

c) Data Analysis

Following the collection and sorting of primary and secondary data in MS Excel, Statistical Package for Social Science (SPSS) and Statistical Analysis Systems (SAS) software were used for getting insights in to the raw data.

SPSS and SAS software have provision for performing various tests on social sector data for instance t-tests, chi-square test for determining significance of the data to end outcome, while logistic regression tests have the capacity to establish correlation among various variables in the data. Here we determined the impact of biogas technology on different socio economic variables and also the impact of socioeconomic and educational factors on the adoption of technology. A major question of the research: impact of biogas technology on livelihoods, was determined using DFID (1999) framework for sustainable livelihoods.

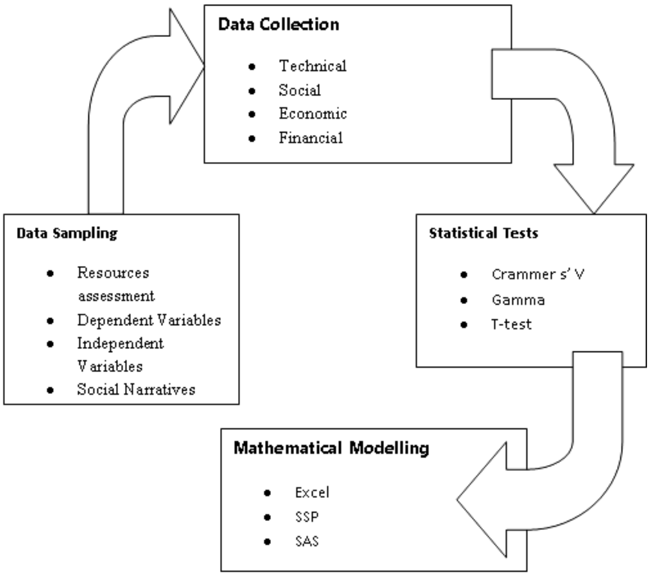

Figure 4 Concept of the research subject

d) Other analysis

In addition to the direct impact of the biogas technology on livelihoods and socioeconomic impacts, additional analyses were carried out as a part of the research. These analyses included:

1. Fuel and wood savings resulting from the use of biogas technology
2. Motivation of adopters for adopting the technology and barriers to non adopters in adopting the technology
3. Comparison of fuel usage and the concomitant savings for adopters of biogas technology
4. Time and workload reduction in fire wood collection
5. Impact of the technology on improving health of the adopters against the non adopters

A schematic of the research methodology from the data sampling techniques to the end impact assessment of the technology through SPSS, SAS software is given in the schematic below.

III. RESULTS AND DISCUSSIONS

This chapter deals with the various correlations and statistical analysis of the adopter and non adopters of the biogas technology. The analyses presented in the form of the tables and figures in the following sections are based in the first sections on establishing the significance of the various parameters to the end output i.e. the decision to adopt or not to adopt the biogas technology, while in the later sections the impact is quantified in form of the savings for adopters or environmental impact or the health benefits of the technology.

1) Socioeconomic demographic characteristics of the subjects

The research was based on 100 household surveys conducted in the district of DI Khan, among which 70 had biogas plants installed on their farms or households, while 30 did not have the technology. In the coming sections of this chapters the factors that the respondent perciece to be a deciding factor in their installing or not installing the technology is also delineated. A household, for the purpose of this study, was said to be adopter of the technology if the biogas plant installed on their premises was operational at the time of the survey or was operational for a considerable amount of time, say more than 6 months, to give them a better idea of the perks and benefits of the technology.

2) Size of the household

Here the role of size of the family is vetted in the adoption of biogas technology. It observed that size of the family for a major chunk of the respondents, 61.9% for adopters and 66.7% for non adopters, ranged from 2-5 persons. A few households, however, had members greater than ten. Chi-square test suggests that the very little significance is imparted to size of family in the determination of them being adopters or non adopters of the technology, $\chi2$ was 0.811with df=2, and P=0.667 as shown in the table 3.

TABLE 3 SIZE OF THE HOUSEHOLD

Household size	Adopters Stats	Non-Adopters Stats	Total Dist.	Chi square $\chi2$	P value

	N	%	N	%	0.811 (ns)	0.667
2 to 5	60	61.9	42	63.8		
6 to 9	33	34	19	32.5		
10 to 13	4	4.1	2	3.8		

The average family size for the 162 households was 5.3 and 4.9 for the biogas adopters and non adopters respectively. The T-test did not point to any significance for family size as influencer in the adoption of the technology as well, as shown in the table 4.

TABLE 4 IMPACT OF VARIOUS DEMOGRAPHICHS OF THE HOUSEHOLDS ON ADOPTION

Variable	Adopters stats			Non adopters stats		
	Mean	Std. Dev.	Std. Mean Error	Mean	Std. Dev.	Std. Mean Error
Family size	5.30	1.98	0.14	4.98	1.75	0.16
Farm Size	2.24	1.88	0.15	1.78	1.65	0.16
Age of Household Head (Yrs)	53.4	10.7	0.79	47.1	11.5	1.04
Children below 5 years	1.60	1.37	0.20	1.43	0.68	0.11
Number of People Living in the Household	1.60	1.37	0.20	1.43	0.68	0.11
Number of Cattle	9.20	7.40	0.52	5.19	4.34	0.42

3) Impact of farm size on adoption of biogas technology

The results for the chi square test for the adopters and non adopters of biogas technology among the 162 respondents are given in the table 3 below. The results show that the land size on average among the adopters is 2.24 while among the non adopters it is 1.78 acres. The land size in majority of the cases was between 0.1 and 1 acre as shown in table 5, in 78.2% among non adopters and 68.3 % among adopters. Farm size was found to be a significant influencing factor in the decision to adopt biogas technology as the chi squared value of 2.08 suggests. This could be because a larger land could mean greater wealth and resultantly no impact on other expenditures from diverting funds to installation of the plant. Also it could be because of the greater number of cattle or livestock on large farm and hence more feed for the plant.

4) Impact of Age, Education, and Gender of respondents on satisfaction

In the majority of the cases a single person in the household was responsible for the financial decision making in the family as is required when deciding to install a biogas plant. This head of household was usually the respondent in our survey. The gender of the household in most cases was male owing to the culture of DI Khan district. Gender of the head of household was not found in any considerable conformation with the adoption of the technology; a fact also supported by literature [90].

Furthermore the middle age group of 41 to 60 years was most recurrent when the respondents were asked about their ages. The age of the respondent, or age in general, was significant in the adoption of the technology as shown in the table 6 with Chi square value of 18.41 and P value of 0.001.

Surprisingly the education level of the adopters and non-adopters of the biogas technology did not indicate any statistically significant correlation with the decision to adopt the technology as shown in the table 3with a Chi square value of 2.12 and P value of 0.331.

TABLE 5 IMPACT OF FARM SIZE ON ADOPTION OF BIOGAS TECHNOLOGY

Farm parameters	Adopters Details		Non-Adopters Details		Total distribution		Chi Square	P value
	N	%	N	%	N	%		
Farm Size in Acre								
0.1-1.0	56	68.3	43	78.2	99	68.3	2.08 (s)	0.038
2.1-3	12	14	7	12.7	19	14		
3.1-4.0	9	11	2	4.5	11	11		
4.1-12	5	6.7	3	4.5	8	6.7		
Construction material in the households								
Mud and stone	19	0	35	62.2	22	1	63.36	<=0.001
Wood	0	19.6	3	2.7	58	35.1		
Cement, bricks	78	80.4	20	35.1	98	63.9		
Roof Type in the households								
Cement	59	47	59	93	105	80.8	18.87 (s)	P<= .001
Steel Sheets	5	7	5	7	32	19.2		

TABLE 6 IMPACT OF AGE, EDUCATION, AND GENDER OF RESPONDENTS ON SATISFACTION

Demographics	Adopters		Non-adopters		Total		Chi Square	P Value
	Number	Percent	Number	Percent	Number	Percent		
Age Demographics								
21-40	12	13.3	20	32	32	20.8	18.41 (s)	≤0.001
41-60	57	63	35	57.4	92	60.7		
61-80	21	23.8	6	10.7	27	18.5		
Gender Demographics								
Male	78	87.7	53	83.5	132	85.9	1.11 (ns)	0.292
Female	11	12.3	11	16.5	22	14.1		

Education Demographics								
Primary	24	29.1	17	33	41	30.6	2.12 (ns)	0.331
Secondary	33	40	24	44.3	57	41.7		
Tertiary	26	30.9	12	22.6	38	27.7		

5) Livestock type and abundance: Impact on biogas adoption

Since the country as a whole and DI Khan specifically is an agricultural country, the elevated levels of cattle and livestock ownership is not surprising. The variety and abundance of the livestock is shown in the table 7. Interestingly the non-adopters also owned livestock in significant numbers, hence the availability of animal waste or biomass, or lack thereof, could not be deemed a significant factor in the adoption of the technology.

TABLE 7 LIVESTOCK TYPE AND ABUNDANCE

Type of Livestock	Adopters				Non-adopters			
	N	Mean	Std Deviation	Std. Error of Mean	N	Mean	Std Deviation	Std. Error of Mean
Cattle	98	4.11	7.44	0.29	55	2.6	2.11	0.21
Poultry	47	69.4	190.4	19.54	35	18.3	38.5	4.68
Sheep	15	2.25	1.94	0.384	9	3.74	4.93	1.33

6) Why do the adopters prefer biogas technology

When asked about the reasons why they preferred biogas technology to the conventional technologies, the respondents gave a variety of reasons. In most cases the biogas technology being clean energy technology and its fuel cost saving potential is considered the most convincing reason for the technology adoption among other reasons as shown in the table 8.

7) Information access about biogas technology

The first step in the adoption of the biogas technology, or any technology for that matter, is knowledge about its existence and its installation procedures along with the benefits it offers. Our survey of the adopters and non adopters of the biogas technology suggests that they came to know about the technology from varying sources. The majority of cases of awareness of the technology was brought about by word of mouth with 75% in adopters and 54% in non adopters. The government and NGOs have a lot of work to improve their share in the awareness creation about this useful technology with their 18 % influence rate through aggressive campaigns as shown in the table 9.

TABLE 8 WHY DO THE ADOPTERS PREFER BIOGAS TECHNOLOGY

Motivation	Responses		
	N	%	Rank
Cooking time	77	77	1
Fuel savings	76	77	2
Economical	73	73	3
Environmentally beneficial	63	62.5	4
Smoke eradication	61	61	5
Health	36	36	6
Affordable cost	27	27.5	7

Subsidy from govt.	26	15.5	8
Social benefits/ status symbol	17	16.5	9
Avenue of use for farm wastes	11	11	10
Durability	9	9.5	11
Neighbors inspired	7	7.5	12
Service provider motivated	4	3.5	13
High cost of other fuels	2	1.5	14
Other motivators	3	1.5	15

TABLE 9 SOURCES OF INFORMATION ABOUT BIOGAS TECHNOLOGY

Source of information	**Adopters**		**Non Adopters**		
	N	**%**	**Non Adopters**	**%**	**rank**
Word of Mouth	79	75	43	54	1
Government or NGO	18	18	14	17.4	2
TV or Radio	14	14	13	16.8	3
Exhibitions and Promotional events	9	9	7	9.7	4
Relatives	4	3.5	-	-	5
Shops	0	0	1	0.6	6

The abovementioned analyses have given us a first of its kind insight into the hurdles and supporting factors in the progression of biogas plant installations in the Khyber Pakhtunkhwa Province of Pakistan.

The recommendations based on these findings in the next chapter will be extremely helpful in making biogas plants common in the rural areas of the province. Furthermore the lessons learnt will be instrumental in devising the strategies and policies in future by the energy department and NGOs to best tackle the issue.

CONFLICT OF INTEREST

The author declares no conflict of interest.

CONCUSLION

Biogas provides energy in the adopting households essential to the life of the adopters. Primarily installed as a cheap cooking resource, the technology is a groundbreaking addition to the rural electrification cause. Despite all the benefits of the technology the adoption rate is extremely low for which this research was successful in investigating the root causes.

At first a variety of independent variables for instance size of the farm, Education level of the households in general and the decision makers in particular, type and abundance of cattle owned by the households, and the age and gender of the decision makers in the households was compared with the adoption to investigate the existence of any correlation, however these factors were all found to have low significance in the adoption of the technology.

In addition the surveys uncovered the most important reasons the adopters of the technology gave for their installation of the technology. The major awareness factor about the technology for adopters was through the word of mouth. On the contrary the chief hampering agent in the adoption of the technology among the non adopting families was found to be the high upfront installation costs of the technology.

Furthermore the health benefits of the biogas technology adoption were beyond the initial expectation accrued mainly from the reduction of hazardous wood smoke that the family members are subjected to during conventional cooking techniques of directly burning the wood under the food. This indirectly leads to ease of work for the female population of the adopting household, giving them extra time for doing progressive skill acquisition practices and enhanced child care.

The technology was found to give a more efficient mechanism for burning biomass than the conventional techniques. The costs thus saved on conventional fuel procurement by the economically disadvantaged population of DI Khan are very desirable for the social and economic upliftment of the area. The technology could be emulated in other regions of the province and country to extend these social and livelihood enhancement.

The environmental benefits of the technology are another desirable factor which could be used to advocate the technology to funding and governmental agencies. On average a single biogas plant installed in the DI Khan District was found to be mitigating approximately 2.2 tones of CO2 from being released in to the atmosphere on account of the conventional fuel avoided, and efficient burning of the fuel.

The type of the digester being used by the locals did not seem to influence the adoption rate of the technology. This could be because of the small impact the type of digester has on the performance of the plant.

REFERENCES

[1] J. C. L. Liu Yang, Haiyan Yan, “Thermal comfort and building energy consumption implications- A review,” Appl. Energy, vol. 115, pp. 164–173, 2014.

[2] World Energy Outlook 2017. OECD, 2017.

[3] H. Zhao and F. Magoulès, “A review on the prediction of building energy consumption,” Renew. Sustain. Energy Rev., vol. 16, no. 6, pp. 3586–3592, Aug. 2012.

[4] I. Economic Adviser’s Wing, Finance Division, Government of Pakistan, “Economic Adviser’s Wing, Wing Finance Division, Government of Pakistan, Islamabad www.finance.gov.pk,” 2018.

[5] M. ud D. Q. Ahmed Sohail, “Energy-Efficient Buildings in Pakistan,” A Sci. J. COMSATS – Sci. Vis. Vol.16 Vol. 17, vol. 16, no. December, pp. 27–38, 2011.

[6] A. Masood, “SAARC Energy Centre,” 2010.

[7] K. Ahmad, A. F. Rafique, and S. Badshah, “Energy Efficient Residential Buildings in Pakistan,” Energy Environ., vol. 25, no. 5, pp. 991–1002, 2014.

[8] ASHRAE, Handbook Heating, Ventilating, and Air-Conditioning system and equipement. Atlanta: The American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 2012.

[9] B. A. Holm, L. Blodgett, D. Jennejohn, and K. Gawell, “Geothermal Energy : International Market Update Geothermal Energy Association,” no. May, 2010.

[10] U. Younas et al., “Pakistan geothermal renewable energy potential for electric power generation: A survey,” Renew. Sustain. Energy Rev., vol. 63, pp. 398–413, 2016.

[11] H. Zaisheng, “Geothermal Heat Pumps in China – Present Status and Future Development,” pp. 31–33, 2008.

[12] G. Florides and S. Kalogirou, “Ground heat exchangers-A review of systems, models and applications,” Renewable Energy. 2007.

[13] L. Ozgener, “A review on the experimental and analytical analysis of earth to air heat exchanger (EAHE) systems in Turkey,” Renew. Sustain. Energy Rev., vol. 15, no. 9, pp. 4483–4490, 2011.

[14] E. Mands, M. Sauer, E. Grundmann, B. Sanner, and U. Gbr, “Shallow geothermal energy use in industry in Germany,” Eur. Geotherm. Congr. 2016, vol. 2010, no. 2013, pp. 19–24, 2016.

[15] A. Chel and G.N.Tiwari, “Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate,” Energy Build., vol. 41, no. 1, pp. 56–66, Jan. 2009.

[16] R. Kumar, S. C. Kaushik, and S. N. Garg, “Heating and cooling potential of an earth-to-air heat exchanger using artificial neural network,” Renew. Energy, vol. 31, no. 8, pp. 1139–1155, 2006.

[17] G. Mihalakakou, “On estimating soil surface temperature profiles,” Energy Build., vol. 34, pp. 251–259, 2002.

[18] K. Labs, “Ground cooling, in: J. Cook (Ed.), Passive Cooling.” MIT Press, Cambridge, 1992.

[19] G. Florides and S. Kalogirou, “Ground heat exchangers-A review of systems, models and applications,” Renew. Energy, vol. 32, no. 15, pp. 2461–2478, 2007.

[20] B. B. Popiel, C., J. Wojtkowiak, “Measurements of temperature distribution in ground,” Exp. Therm. Fluid Sci., vol. 25, pp. 301–309, 2001.

[21] A. O. Ogunlela, “Modelling Soil Temperature Variations,” J. Agric. Resour. Dev., pp. 100–109, 2003.

[22] H. Ben Jmaa Derbel and O. Kanoun, “Investigation of the ground thermal potential in tunisia focused towards heating and cooling applications,” Appl. Therm. Eng., vol. 30, no. 10, pp. 1091–1100, 2010.

[23] F. Al-Ajmi, D. L. Loveday, and V. I. Hanby, “The cooling potential of earth-air heat exchangers for domestic buildings in a desert climate,” Build. Environ., vol. 41, no. 3, pp. 235–244, 2006.

[24] R. J. Sharan, G., “Soil temperature regime at Ahmedabad,” J. Agric. Eng., vol. 39, no. 1, 2002.

[25] A. G. Kanaris, A. A. Mouza, and S. V. Paras, “Flow and Heat Transfer Prediction in a Corrugated Plate Heat Exchanger using a CFD Code,” Chem. Eng. Technol., vol. 29, no. 8, pp. 923–930, 2006.

[26] V. P. Kabashnikov, L. N. Danilevskii, V. P. Nekrasov, and I. P. Vityaz, “Analytical and numerical investigation of the characteristics of a soil heat exchanger for ventilation systems,” Int. J. Heat Mass Transf., vol. 45, no. 11, pp. 2407–2418, 2002.

[27] M. Santamouris, G. Mihalakakou, A. Argiriou, and D. N. Asimakopoulos, “ON THE PERFORMANCE OF BUILDINGS COUPLED EARTH TO AIR HEAT EXCHANGERS WITH If a balance temperature , Tb is used where :,” Sol. Energy, vol. 54, no. 6, pp. 375–380, 1995.

[28] G. Mihalakakou, M. Santamouris, J. O. Lewis, and D. N. Asimakopoulos, “On the application of the energy balance equation to predict ground temperature profiles,” Sol. Energy, vol. 60, no. 3–4, pp. 181–190, 1997.

[29] O. Ozgener, L. Ozgener, and J. W. Tester, “A practical approach to predict soil temperature variations for geothermal (ground) heat exchangers applications,” Int. J. Heat Mass Transf., vol. 62, no. 1, pp. 473–480, 2013.

[30] H. Su, X. Liu, L. Ji, and J. Mu, “A numerical model of a deeply buried air – earth – tunnel heat exchanger,” Energy Build., vol. 48, pp. 233–239, 2012.

[31] A. Sehli, A. Hasni, and M. Tamali, “The potential of earth-air heat exchangers for low energy cooling of buildings in South Algeria,” Energy Procedia, vol. 18, pp. 496–506, 2012.

[32] M. De Paepe and A. Janssens, “Thermo-hydraulic design of earth-air heat exchangers,” Energy Build., vol. 35, no. 4, pp. 389–397, 2003.

[33] J. Pfafferott, “Evaluation of earth-to-air heat exchangers with a standardised method to calculate energy efficiency,” Energy Build., vol. 35, no. 10, pp. 971–983, 2003.

[34] A. De Jesus Freire, J. L. Coelho Alexandre, V. Bruno Silva, N. Dinis Couto, and A. Rouboa, “Compact buried pipes system analysis for indoor air conditioning,” Appl. Therm. Eng., vol. 51, no. 1–2, pp. 1124–1134, 2013.

[35] K. H. Lee and R. K. Strand, “The cooling and heating potential of an earth tube system in buildings,” Energy Build., vol. 40, no. 4, pp. 486–494, 2008.

[36] P. Hollmuller, “Analytical characterisation of amplitude-dampening and phase-shifting in air/soil heat-exchangers,” Int. J. Heat Mass Transf., vol. 46, no. 22, pp. 4303–4317, 2003.

[37] M. Cucumo, S. Cucumo, L. Montoro, and A. Vulcano, “A one-dimensional transient analytical model for earth-to-air heat exchangers, taking into account condensation phenomena and thermal perturbation from the upper free surface as well as around the buried pipes,” Int. J. Heat Mass Transf., vol. 51, no. 3–4, pp. 506–516, 2008.

[38] V. Badescu, “Simple and accurate model for the ground heat exchanger of a passive house,” Renew. Energy, vol. 32, no. 5, pp. 845–855, 2007.

[39] X. Li, J. Zhao, and Q. Zhou, “Inner heat source model with heat and moisture transfer in soil around the underground heat exchanger,” Appl. Therm. Engiineering, vol. 25, no. 10, pp. 1565–1577, 2005.

[40] J. Zhao, H. Wang, X. Li, and C. Dai, “Experimental investigation and theoretical model of heat transfer of saturated soil around coaxial ground

coupled heat exchanger," Appl. Therm. Engiineering, vol. 28, no. 2–3, pp. 116–125, 2008.

[41] T. S. Bisoniya, A. Kumar, and P. Baredar, "Study on Calculation Models of Earth-Air Heat Exchanger Systems," J. Energy, vol. 2014, pp. 1–15, 2014.

[42] V. Bansal, R. Misra, G. Das Agrawal, and J. Mathur, "Performance analysis of earth – pipe – air heat exchanger for winter heating," Energy Build., vol. 41, no. 11,05, pp. 1151–1154, 2009.

[43] K. W. A.Flaga-Maryanczyka, J. Schnotale, J. Radon, "Experimental measurements and CFD simulation of a ground source heat exchanger operating at a cold climate for a passive house ventilation system.pdf," Energy Build., vol. 68, pp. 562–570, 2014.

[44] L. Ramírez-Dávila, J. Xamán, J. Arce, G. Álvarez, and I. Hernández-Pérez, "Numerical study of earth-to-air heat exchanger for three different climates," Energy Build., vol. 76, pp. 238–248, Jun. 2014.

[45] R. Kumar, A. R. Sinha, B. K. Singh, and U. Modhukalya, "A design optimization tool of earth-to-air heat exchanger using a genetic algorithm," Renew. Energy, vol. 33, no. 10, pp. 2282–2288, Oct. 2008.

[46] F. Ascione, L. Bellia, and F. Minichiello, "Earth-to-air heat exchangers for Italian climates," Renew. Energy, vol. 36, no. 8, pp. 2177–2188, 2011.

[47] A. N. Z. Sanusi, L. Shao, and N. Ibrahim, "Passive ground cooling system for low energy buildings in Malaysia (hot and humid climates)," Renew. Energy, vol. 49, pp. 193–196, Jan. 2013.

[48] N. Aziah, M. Ariffin, A. Nur, Z. Sanusi, and A. M. Noor, "Materials for the Earth Air Pipe Exchanger (EAPHE) system as a passive ground cooling for hot-umid climate," 2nd Int. Conf. Emerg. Trends Sci. Res. 2014, no. November, 2014.

[49] S. Jakhar, R. Misra, M. S. Soni, and N. Gakkhar, "Parametric simulation and experimental analysis of earth air heat exchanger with solar air heating duct," Eng. Sci. Technol. an Int. J., vol. 19, no. 2, pp. 1059–1066, 2016.

[50] M. K. Ghosal, G. N. Tiwari, D. K. Das, and K. P. Pandey, "Modeling and comparative thermal performance of ground air collector and earth air heat exchanger for heating of greenhouse," Energy Build., vol. 37, no. 6, pp. 613–621, Jun. 2005.

[51] A. H. Poshtiri and N. Gilani, "Feasibility study on using solar chimney and earth-to-air heat exchanger for natural heating of buildings," World Renew. Congr., pp. 1773–1780, 2011.

[52] S. F. Ahmed, M. M. K. Khan, M. G. Rasul, M. T. O. Amanullah, and N. M. S. Hassan, "Comparison of earth pipe cooling performance between two different piping systems," Energy Procedia, vol. 61, pp. 1897–1901, 2014.

[53] M. S. Kristen, "Final report laboratory research for the determination of the thermal properties of soils," 1949.

[54] K. H. Lee and R. K. Strand, "The cooling and heating potential of an earth tube system in buildings," Energy Build., vol. 40, no. 4, pp. 486–494, 2008.

[55] F. Ascione, L. Bellia, and F. Minichiello, "Earth-to-air heat exchangers for Italian climates," Renew. Energy, vol. 36, no. 8, pp. 2177–2188, 2011.

[56] A. P. H. Maerefat, "Passive cooling of buildings by using integrated earth to air heat exchanger and solar chimney," Renew. Energy, vol. 35, no. 10, pp. 2316–2324, 2010.

[57] Incropera, Introduction to Heat transfer. 1996.

[58] "Engineering Toolbox," 2009. [Online]. Available: https://www.engineeringtoolbox.com/prandtl-number-d_1068.html 9.

Muhammad Haseeb is a postgraduate researcher at United States Pakistan Center for Advanced Studies in Energy at University of Engineering and Technology Peshawar, Pakistan. He is studying Materials for Energy Storage and Conversion at MS level after doing his undergraduate degree in Mechanical Engineering. His research interest include finding ways to maximize the social and economic benefits of the distributed energy systems with an end goal of poverty alleviation through sociotechnical models. This paper is a part of his Masters degree research studies.