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Efficiency Of Biogas Generation For Household Consumption Using Different Raw Materials And Biogas Plant Models: A Micro Perspective

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Many fuels are utilized in households for cooking. These fuels are categorized as solid and clean eco-friendly sources. Biogas generation is an example of waste-to-energy conversion. Biogas is generated through the conversion of organic waste such as kitchen waste, animal waste, and agricultural residue (rubber wash) generated in households/ small farms through the bio-methanation process. Different types of biogas plants are installed and adopted in households. There are 2 types that are widely adopted and installed, (i) Fixed dome and (ii) Floating drum. The study area was the Kanyakumari District of Tamil Nadu. The biogas beneficiaries list was collected from authentic sources such as District Rural Development Agencies, NGOs, and Turn-key agents (People/Organisations who help users adopt biogas at home). The census method was adopted to identify and interview 270 biogas users in the district with the help of a detailed questionnaire. Biogas is an excellent choice of fuel for cooking purposes. Results from the study are that, of three different raw materials-based biogas plants, agriculture residue (rubber wash) is more efficient in which quantity of gas generated is higher. Likewise, fixed dome type of biogas plant generates more gas in quantity. The study with a micro perspective recommends more rubber wash-based fixed dome-type biogas plants to be installed and adopted in higher numbers in the study area.

Keywords: Biogas, Waste to Energy Conversion (WTE), Raw Materials, Type of biogas plants, Households

Introduction

India is one of the fastest developing nations globally aiming at a $5 trillion economy by 2025-26. There is an increasing need for energy in all households for varied purposes such as cooking, lighting, heating, etc. Indian households have been utilizing various sources of energy for cooking. These sources could be broadly classified as conventional solid and clean eco-friendly fuels. Firewood, Charcoal/ Coal, Cow dung cakes, etc come under the category of conventional solid fuels whereas Biogas, Solar, Liquid Petroleum Gas, and Piped Natural Gas fall under the clean, eco-friendly source of fuel. Due to the utilization of conventional solid fuel, there are lots of environmental concerns arising such as forest cover destruction, indoor air pollution, etc. For example, due to indoor air pollution in India, it is estimated that one in seven people will face death prematurely (Source: Khondoker Abdul Mottaleb and Dil Bahadur Rahut -2019).

From the report India Residential Survey 2020, it is evident that LPG cylinders will be delivered only to 54% of the rural households in their doorsteps. So, it is significant to make clean energy fuel accessible to all sections of the people cost-effectively. Biogas is a viable and alternative source where the raw material used is organic, bio-degradable and it is available locally at free or low cost. The utilization of biogas for cooking can be beneficial in many ways both in urban and rural households. Biogas has been used as a fuel source for around five decades in the nation. The rural population has been on a decrease and the urban population on the increase according to the census 2011 and later surveys. As of November 2021, in India, the energy generated by conventional sources, especially fossil fuel is 59.9 % of total energy generation. Non-conventional sources contribute to 38.4 % of energy generation. Energy generation through nuclear is 1.7%. Among the non-conventional sources of energy, the share of bioenergy is only 2.6 %. There are also other non-conventional sources such as solar, wind, hydro, etc. (Source: Central Electricity Authority).

Review of Literature

Several articles reviewed diverse aspects of the biogas plants adopted and utilized at household levels. One such article delves into the potential of conversion of dairy waste into biogas for fulfilling the needs of rural energy in India. Livestock waste is a significant source of greenhouse gas emissions if not utilized properly. It is one of the top-ranking commodities in India, based on Food and Agriculture Report (FAO). Livestock waste can be utilised as fuel sources, enriched organic manure and this waste can be used as raw material for household biogas plants. Two significant types of household biogas plants are (i) Fixed Dome and (iii) Floating Drums. The efficiency of these models and their advantages are discussed below. The quantity of gas generated is higher and losses are lower in the fixed dome model of the biogas plant. The cost of the floating drum model is higher than the fixed dome per unit volume. Some constraints are faced by biogas, for example, in rural regions, economic conditions are a constraint, in urban areas, awareness and adoption of biogas are relatively less due to lack of space, raw material availability, etc. The present policy in place is NNBOMP (New National Biogas and Organic Manure Programme) which has been implemented to facilitate biogas production with sizes ranging from 1-25 m^3. It can be used by both small- and large-scale farms in the country.

Another article illustrates that in rural India, biogas can be a viable option as a cooking fuel. Three popular models were taken into consideration for this paper. Comparative analysis was done for three types which are KVIC (Khadi and Village Industry Commission), Janta, and Deenabandhu. Family-size biogas plant was studied in this article. The factors that determined which model is comparatively better are installation cost, raw-material cost, cost of operation every year, income received from the plant, etc. The size of the biogas model was 1-6 m^3. Factors like installation cost, and cost of the operations were higher for the KVIC model, then Janta and followed by Deenabandhu. Raw material cost (of cow dung), maintenance cost, and cost of depreciation are fixed percent as a part of the installation cost payback period is higher for the KVIC model, then for the Janta model, and then for the Deenabandhu model. As the capacity of the biogas plant increases, the payback period comes down. The paper concludes that taking most of the significant factors into consideration, the Deenabandhu model is a viable option.

Materials and Methods

In India, there are many models of household biogas plants in utilization such as KVIC, Janta, Deenabandhu, etc., and these biogas plants use different raw materials. Predominantly in utilization are two types of biogas plants of varied models. They are

(a) Fixed Dome Biogas Plant

(b) Floating Drum Biogas Plant

The different types of raw materials used for the biogas plants are waste from different livestock such as cow, buffalo, goat, poultry, etc., and different types of agricultural residue such as jute bagasse, neem leaves, paddy waste, rubber wash, night soil, etc. Gas generated through these raw materials varies according to quantity, efficiency, etc. The quantity of gas generated is also dependent on various factors such as temperature, season, capacity of the plant, etc.

Study area

Kanyakumari district was selected as the study area and it is the southernmost district of Tamil Nadu state and nation. It has an agro-climatic zone where mountains from western ghats, plains, and coastal areas coexist. The complete list of biogas users/ beneficiaries was collected from authentic sources including the District Rural Development Agency, Resource Organisations such as Vivekananda Kendra, biogas experts, and turn-key agents. The biogas users' details were from the years of 2014-2022. This list was used to identify 270 active biogas users in the district. Census method has been adopted to carry out the study according to the biogas beneficiaries from the list collected from different sources. Primary data including different socio-economic, institutional, and environmental aspects of the biogas users was collected by personal visits by the researcher to each of the households. The study was carried out in the months of May-June 2022.

The users have installed both fixed dome and floating drum biogas plants in their homes based on a lot of factors such as space and area of the house, number of family members, installation cost, available subsidy, etc. The number of fixed dome biogas plants is 116 and floating dome biogas plants is 154. The cost involved in installing fixed dome biogas plants is higher than that of the floating drum biogas plants. The size of floating drum biogas plants is 1 m^3 whereas fixed dome biogas plants' size ranges from 2-8 m^3. The payback period also varies according to the installation cost. Most of the biogas users having floating dome models were part of the Tamil Nadu Government Programme known as PTSLP (Post-Tsunami Sustainable Livelihoods Programme) and these plants were of cost ₹20000 and were subsidized as part of the program at ₹10000 per unit and the rest ₹10000 was paid by users as micro-loans through civil society organizations such as Panchayat Level Federation, SHG's etc. The fixed dome-based biogas plants have a standard subsidy of ₹12500 in the state of Tamil Nadu. The subsidy could increase or decrease in amount according to geographical regions.

Kitchen waste-based biogas plant is floating drum type. Likewise, Rubber wash and Animal waste-based biogas plant is fixed dome model. Floating drum is a portable type of biogas plant that can be shifted if any user wants to shift the home. Whereas the fixed drum type can't be shifted and can be built according to the user's requirement. The investment in kitchen waste-based biogas plants is less expensive at ₹ 13040 where the animal waste-based biogas plant is ₹49876 and for rubber wash-based biogas plants it is ₹56823 from the respondents. The number of years both types of biogas plants operate is largely based on the user's utilization and maintenance of the plant. However, the fixed dome model is more viable with around 15-20 years of functionality with less maintenance cost. Whereas the floating dome model is viable for around 10 years of functionality; as the years pass by technological advancements could take place, requiring refurbishments.
Kitchen waste-based biogas plants help in converting the organic waste generated in households and also provide fuel for cooking. It reduces the dependency on the utilization of other sources of fuel such as firewood, coal, LPG, etc. Firewood, Coal, etc. are solid and unclean fuels. LPG is clean but it could be expensive. Animal waste-based biogas plants help in converting waste by the livestock, where rearing has been practiced in the country for many decades as a primary/secondary occupation. Animal waste disposal is a main concern when it comes to livestock rearing. Biogas plants using this as a raw material offer Waste to Energy conversion offering contemporary solutions for animal waste disposal and gas is generated as a source of fuel. Bio slurry is a byproduct of biogas generation which is enriched organic manure. It can be used for a home garden or can be value added as vermicompost, then can be sold in a small business venture set up by households. Rubber wash is a raw material found unique to the study area. There are around 20000 hectares of land which is used for rubber cultivation. Only rubber farmers who have rubber sheet-making machines can install biogas plants. There is an extra investment required to install a rubber sheet-making machine in their households. People from the neighbourhoods come to convert rubber latex to rubber sheets and pay a small amount for the service. There are around 33000 small landholders who are cultivating rubber. Rubber latex is converted into a rubber sheet by using formic/ acetic acid. This acid water if not treated properly will cause environmental degradation. Rubber sheet-making machines are found in houses with stable income because it requires additional investment and maintenance costs. Rubber wash-based biogas plant is a solution to solve the problem of environmental degradation. Usually, there are complaints about untreated acid water creating various environmental problems such as affecting the soil, water, mosquito breeding, etc. So, the local government offers assistance and guidance to build and utilize fixed dome models according to user needs and space availability.

Results and Discussions

Biogas generated varies according to raw materials, and plant model installed and utilized by the biogas users. To test and statistically prove that the quantity of biogas generated varies due to different raw materials-based plants and types of biogas plants adopted, a few statistical tests have been applied.

To understand if there is a variation in the quantity of gas generated through three different raw materials, ANOVA and Duncan's test is applied as the latter compares means within the groups. Using biogas as a source of fuel for cooking in the household is beneficial for the household as well for environmental management because it reduces dependency on other solid fuels such as firewood, coal, etc. The utilization of solid fuels causes indoor air pollution, so substituting it with biogas is an excellent choice. Second, due to increased population, there is a higher proportion of waste generated by households which becomes a serious concern as the waste reaches the landfill along with non-biodegradable waste which in turn leads to greenhouse gas emission, land pollution, etc. So, converting waste into energy where this organic waste is a raw material for producing biogas as a cooking fuel is exemplary. Using different raw materials and understanding which raw material is producing a higher quantity of gas is what the study is looking into. It is also imperative to understand that kitchen waste and animal waste generated by households are available all year long and their availability for conversion into gas is certain. However agricultural residue (rubber wash) is a raw material available only for 8-9 months of the year during winter and summer. In the rainy season, the availability of rubber latex is less. Therefore, results from ANOVA and Duncan test are given below to understand which raw material has higher efficiency in terms of the quantity of gas generated

TABLE 1: ANOVA

Gas generated in a day	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	19.974	2	9.987	193.404	.000
Within Groups	13.788	267	.052		
Total	33.762	269			

The Table above shows that there are differences in the quantity of gas generated in a day depending upon the different sources of raw materials. The amount of gas generated in a day with kitchen waste as raw material is 0.5646 kgs. With animal waste as a raw material, gas generated in a day is 0.6525 kgs. When rubber wash is used as a raw material for biogas plants, the gas generated in a day is the highest that is 1.2475 kgs. This shows that gas generated with rubber wash as raw material is greater when compared with the other two raw materials. This has been analyzed with the help of the Duncan test a result of which is given below

Duncan Test

The table below shows the amount of gas generated per day depending upon the raw material used by respondents. The highest amount of gas generated is by rubber wash as raw material. So, there is variation in gas generated in a day depending upon the type of raw material;

TABLE 2: DUNCAN TEST

Gas Generated in A Day				
source of raw material	N	Subset for alpha = 0.05		
		1	2	3
Kitchen Waste	161	.5646		
Animal waste	52		.6525	
Rubber wash	57			1.2475
Sig.		1.000	1.000	1.000
Means for groups in homogeneous subsets are displayed.				
a. Uses Harmonic Mean Sample Size = 69.790.				
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.				

As stated earlier, two types of biogas plants are installed and utilized for biogas generation. One is a fixed dome and the other one is floating drum. Fixed dome biogas plant is built in various sizes starting from 2 m^3 – 6 m^3. It is constructed with the help of specially trained masons. Turn key agents are the point of contact between beneficiaries and masons. Biogas-trained officers in local administration offices usually build a communication channel between the beneficiary and turn key agents. The Fixed dome type has a higher investment cost, and subsidy is standard from the Central Government according to the size of the plant. The floating drum is a portable type and it can be taken along with the biogas users in case of a change of house etc. The floating drum installed in the biogas user's household is of size 1 m^3 - 2 m^3.

Adopting which type of biogas plant depends upon various factors such as the income of the household, space availability, requirements of the households, investment cost, accessibility of the raw material, etc. Independent Sample T-test is applied here to find if there is a variation in the quantity generated due to the type of plant in usage.

TABLE 3: INDEPENDENT SAMPLE T-TEST

Group Statistics

Independent Samples Test

gas generated in a day		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
	Equal variances assumed	112.278	0.000	10.64	268	0.000	0.389	0.036	.31724	.46131
	Equal variances not assumed			9.67	149.0	0.000	0.389	0.040	.30975	.46879

Independent Sample T Test is used to understand whether the gas generated in a day is influenced by the type of biogas plant installed at home. Portable model is installed at homes with the viewpoint it can be taken along in case of any relocation due to various reasons such as work, family situations, etc. Other reasons to install portable models are the quantity of raw material available is limited in capacity, cost constraints, limited space availability, and the like. The fixed model is installed due to various reasons including the following: occupation of the household head, quantity of raw material available, space available for construction of the biogas plant. The results show the average gas generated in a day in a fixed dome biogas plant is .9477 Kgs and for gas generated in a day by the portable type is 0. 5584 kgs.

There is variation between gas generated in a day depending upon the type of biogas plant. There is variation in gas generation due to the size of the biogas plant (it is higher in fixed biogas plants than portable). For fixed dome biogas plants, the raw material is rubber wash (agricultural residue) and animal waste; kitchen waste is the raw material used for the floating drum model in the study area.

Conclusion

Biogas generation is an efficient method of converting waste (raw material) into energy (biogas and bio-slurry). However, this study pertains to biogas generation by using available raw materials (which can be collected from households, neighbourhoods, and farms) and the appropriate type of biogas plants. These models are usually recommended by the Government or Turn key agents depending on the requirements of biogas users based on affordability, raw material accessibility, space availability in the household, etc. Rubber wash is a raw material that is unique to the study area if not used for biogas generation, then environmental degradation (soil and water pollution) will be a result. So, there is a lot of scope for outreach and scaling up of rubber wash-based fixed dome biogas plants in these regions which constructively convert potential pollutants of soil and water. The study concludes that biogas is a feasible and viable choice of fuel for households with three kinds of raw materials and two available types when successfully deployed in biogas generation with varying degrees of efficiency.

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