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Research Article

COMPARATIVE ENERGY ANALYSIS, LIFE CYCLE ASSESSMENT AND FINANCIAL STUDY OF INSTITUTIONAL AND FAMILY SIZE KVIC BIOGAS PLANT MODELS

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abstract: Due to pressure of meeting energy demands of large population, India is shifting its focus from use of fossil fuels towards renewable-energy applications. being world's second largest biogas programme operator, India is looking at biogas as a mission to fulfil rural energy demands. although family size biogas plants are achieving its peak; institutional biogas plants are not very popular throughout the country. the government is trying to persuade large-scale goshalas (cattle farms) to install institutional biogas plants. there is a vast potential for installation of biogas plant as large counts of animals are present under one roof. furthermore, this will have large effect as compared to smaller family-size units. the initial assessment has examined that institutional biogas plant requires heavy infrastructure with net energy investments along with financial ones. by using multi appraisal methodology, the biogas generation and utilization pathway were observed for various end utilizations. multiple appraisal methodologies involved determination and prediction of net embodied energy use, environment impact analysis using life cycle assessment methodology and financial investment assessments. family size biogas plant has more environmental impacts per m^3 biogas production as compared to institutional biogas plant. the embodied energy suggests that energy investment required for producing biogas in family size biogas plant is more with more energy payback period and energy required for producing energy. an institutional scale biogas plant contrary to family size biogas plant can process large amount of waste at one utility.

keywords: *ICA, Biogas plant, Family size biogas plant, Institutional biogas plant*

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Introduction

Biogas is one the most successful renewable energy technology throughout India. Ministry of New and Renewable Energy (MNRE), New Delhi, Govt. of India is practising technology of production of biogas from animal manure for last 6 decades through various dissemination schemes. The oldest and far most successful biogas plant design was Gram-lakshmi III, Khadi and Village Industries Commission (KVIC), Mumbai adopted it and promoted as KVIC Floating drum type biogas plant. The KVIC biogas plant has two chambers one for digestion of manure i.e. digester and other for collection of biogas i.e. gasholder. [1]– [3]. Basic programme for biogas dissemination, world's largest biogas programme has mainly focused on family sized biogas plant models mainly KVIC (1-10 m^3) and Deenbandhu (1-6 m^3). [3], [4] Despite efforts made for popularising community scale biogas plant across country, they were unsuccessful across villages. But rather, institutional biogas plants were more successful and limited in numbers. Ministry of New and Renewable Energy has been promoting both family size and institutional scale biogas plants providing proper subsidies and technical guidance. Currently, biogas with off-gird and grid connected systems has given preference to produce electricity at hub and supply to grid.[5], [6]. Embodied energy defines the energy needed for production and creation of any goods and services. Product incorporate embodied energy within itself. To produce energy needs energy; and it may represent how cheaper or expensive the production or resources are? Now a day energy analysis has vast importance as like financial investment analysis. Any system can be feasible with energy and finance but needs environmentally susceptible too. Life Cycle Assessment (LCA) technique assess environmental feasibility and is a tool to find out various positive and negative aspects on environment of system within whole life cycle. LCA provides an acceptable instrument for environmental decision support. The International Organisation for Standardisation (ISO), a world-wide federation of national standards bodies, has standardised this within the series ISO 14040 on LCA. [7], [8]. In Rajasthan currently, more than 2000 small and large Institutional Cattle farms are functioning throughout districts and villages comprising of millions of cattle. The institutions are also facing problems with processing of sizeable quantity of manure available daily.

These farms store dung manure on open ground, which in addition contributes to GHG emissions and other gases. Because of Lack of research on LCA in India, this research frames a study with the broad mindset for covering institutional and family size biogas plant and its applications with energy, environment and financial points. The energy based economic analysis and environmental impact study can set benchmark for spread of biogas technology across institutions with various biogas applications. So, we took on a study to compare institutional and family sized biogas plants in all sorts of features such as embodied energy, life cycle environmental impacts and economics of biogas production and use.

Materials and methods

Experimental site

The study area for analysis and research work falls at Department of Renewable Energy Engineering, College of Technology and Engineering (DREE), Udaipur. We selected institutional scale biogas plant from Nathdwara nearby Udaipur and family size biogas plant from biogas experimental yard at DREE, Udaipur for study.

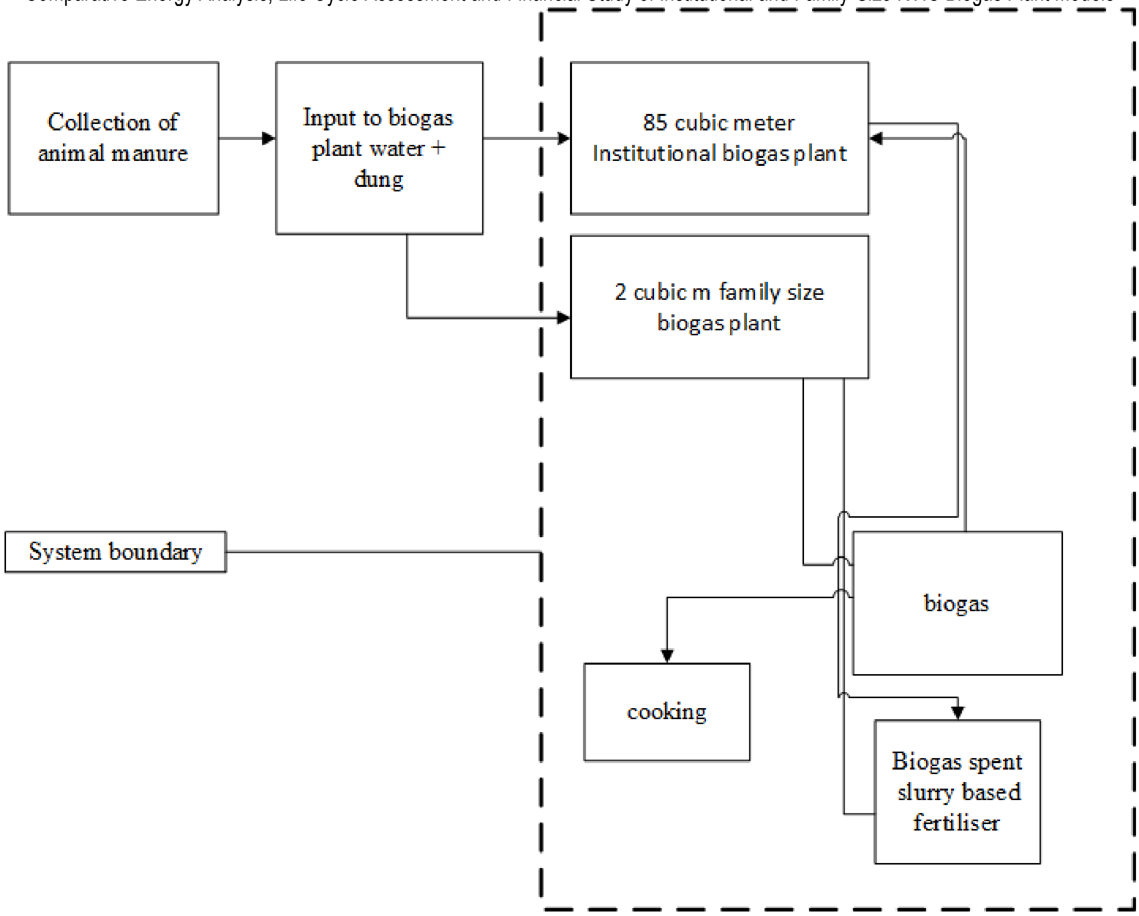

Fig-1 System boundary of biogas plant

Data acquisition

Field studies, reviews, reports and literatures available provided data needed for this study. Design data was available in standard IS 9478: 1989 for family size KVIC biogas plant while private firm setting up biogas plants in Udaipur region provided data for Institutional KVIC biogas plant. Experiments conducted time to time and visits to institutional biogas plant provided data of biogas production and use.

Biogas plants at experimental site

Institutional biogas plant site at Nathdwara has well settled biogas plant setup composing of 3 units 85 m^3 of KVIC floating drum type biogas plant models. While family size biogas plant at DREE Udaipur was of 2 m^3 production ability.

Embodied energy analysis of biogas plant

As life cycle analysis of any system start with identification of energy source and progress through suitable steps of energy change-over and transport up to the final product providing energy service. The basic need for embodied energy analysis is biogas plant construction materials. Energy needed to produce the material in its present form is its embodied energy. Further, embodied energy and energy output provides energy payback period. Energy requirements for biogas plant account for all direct and indirect energy inputs into process of biogas production and utilisation. Calculation of energy analysis of biogas production is more complex. It needs operational and embodied energy to produce energy than more simple other renewable energy. Biogas production need energy inputs like feed stock collection including wastage or losses, transport including losses and fossil fuels used during supplementary processes. Due to variable types of biogas plants and parameters in biogas production units, energy inputs shows notable amount of variations. Primary energy *i.e.* MJ of energy needed to produce output energy decides viability of any process. This term referred as the Energy requirement for Energy (ERE). The data for various embodied energy coefficients was collected from Kumar & Tiwari (2009), Jain & Salgude (2015) and Venkatarama Reddy & Jagadish (2003). Following relations provides calculation of embodied energy:

Embodied energy $=\sum m_i e_i$

Where, mi = mass of materials used in construction of biogas plant in kg

ei = energy density of the material in MJ/kg.

Energy output can be calculated as

Energy output = CV of biogas x biogas plant capacity x 365 x biogas plant efficiency.

Energy payback period can be calculated as,

EPP = Embodied energy/Energy output

Life cycle Assessment of biogas plants

Goal and Scope of LCA study

The goal of this assessment was to examine and identify the life cycle environmental impacts of energy production and use from family size and institutional scale biogas plants. The objective was to identify the most important positive and negative impacts on environment. By determining the environmental load of biogas production from Institutional biogas plant and family size biogas plant, it was possible to identify which scale process has beneficial or detrimental effects on the environment. This was assessed using a number of environmental impact categories, including damage to human health, damage to ecosystems and the depletion of global resources. The assessment examined the production, delivery and the use of the biogas (cradle to grave). The by-product *i.e.* biogas spent slurry is used as a source of natural fertiliser, was also examined as a displacement of chemical fertilisers. Throughout the assessment, the production of the plant was accounted for and linked to the biogas and natural fertiliser outputs.

Functional Unit

The functional unit of the analysis was a 1m^3 of biogas produced. As the methane-quality was known, this was easily converted to an equivalent cubic metre of methane. The process of biogas generation is a multi-output process. As a result, the second output (digested slurry based fertiliser) had a functional unit of mass (kilogram).

The production of 1 cubic m biogas is assumed equivalent to 10 kg fertiliser. The life cycle for biogas plant was assumed as 20 years.

System boundaries of the study

The system boundary of the assessment is as shown in [Fig-1]. The analysis system boundary commenced at point of collection of feedstock *i.e.* manure from the cattle housing. Truncated system boundary stands for biogas use for cooking application only. The boundaries did not consider the transport and spreading of the digestate *i.e.* bio-fertiliser. Emissions associated with the biogas plant construction were considered in terms of material use (mass) and some key manufacturing processes. The fertiliser was considered up to production and substitution of artificial fertiliser. The effects of using the digestate as an artificial fertiliser were considered outside the scope of the study, as biogas for energy use was the primary focus. The study focused primarily on the biogas energy. The system boundary was the same as for the energy analysis, including the digestate as a potential artificial fertiliser replacement.

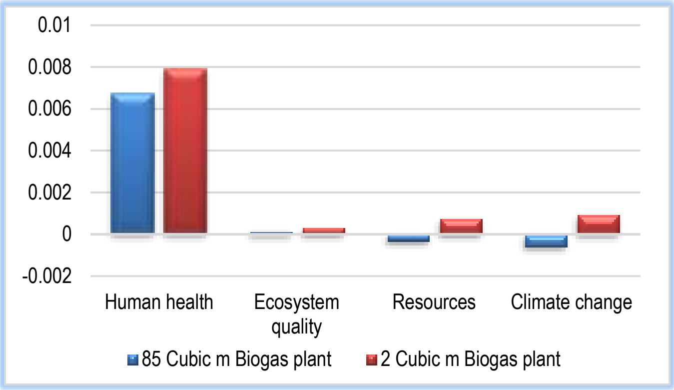

Fig-2 Results indicating characterised results for biogas production, plant construction and bio-fertiliser production

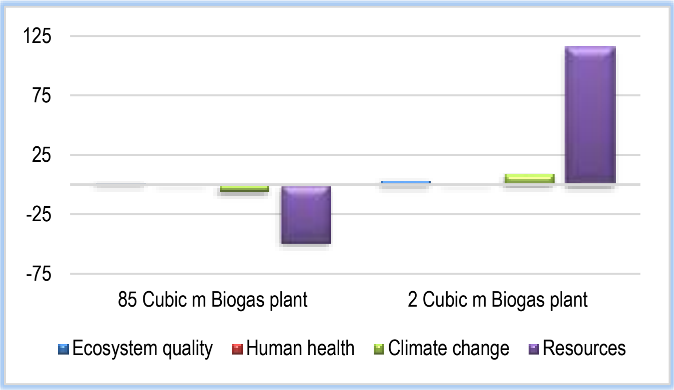

Fig-3 Damage assessment results of LCA for biogas production, plant construction and bio-fertiliser production

Life Cycle assessment analysis

The procedure for LCA was followed as per IS 14040:2006 [7] and IS 14044:2006 [12]. Life cycle assessment analysis of biogas plant for both family size and institutional scale biogas plants was attempted using SimaPro 8.3.3 software using Impact 2002+ methodology based on Eco-Invent database 3.1. Based on LCI values, we considered 14 impact results. The results were characterised into four categories like Human Health, Ecosystem Quality, and Climate change and resource depletion.

Financial analysis of system

The financial evaluation of institutional and family size KVIC biogas plant was carried out in terms of net present worth, payback period, cost benefit ratio and internal rate of return.

Net present worth

The net preset worth can be computed by subtracting the total discounted present worth of the cost stream from that of the benefit stream.

$$\sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where,

C_t = Cost in each year

B_t = Benefit in each year

t = 1, 2, 3................n (years)

i = Discount rate, %

Benefit cost ratio

This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream.

Mathematically benefit-cost ratio can be expressed as:

$$\text{Benefit cost ratio} = \frac{\sum_{t=1}^{t=n} B_t}{\sum_{t=1}^{t=n} C_t}$$

Internal rate of return (IRR)

Another way of using the internal cash flow for measuring the worth of a project is to find the discount rate that makes the net present worth to the incremental cash flow equal to zero. This discount rate is called the internal rate of returns.

$$\sum_{t=1}^{t=n} \frac{(B_t - C_t)}{(1+i)^t} = 0$$

Payback period

The payback period is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment.

Payback period = (Total investment)/(Net profit)

Results and Discussion

Embodied energy analysis of institutional and family size biogas plants

Institutional biogas plant is multi-input and output system contains, biogas plant unit, water scrubbing unit, vermin-composting unit and supplementary civil arrangements while family size biogas plant system is simple. Embodied energy analysis results shows that there is significant investment of initial energy for construction and operation of systems in institutional biogas plant. The following subsections express and discuss in brief about embodied energy every subunit available at Institutional biogas plant site, Nathdwara and family size 2 m^3 unit available at Udaipur.

Embodied energy for construction and operation of biogas plant units

The institutional biogas system comprises of KVIC model of biogas plant with metallic gas holders. The life of biogas plant's masonry structure was assumed as 20 years and 10 years for gas holder. This means that during whole life cycle of single biogas plant two gas holder units would be required. The embodied energy coefficients and their values are mentioned in [Table-1] while [Table-2] illustrates embodied energy used for construction for biogas plants. The embodied energy required for construction of whole institutional biogas plant unit was found to be 586.6 GJ. The operational energy used for biogas plant functioning was found to be 131.4 GJ. The total amount of embodied energy invested in construction and operation of institutional biogas plant unit is 718 GJ. The major amount of biogas plant operational energy was due to use of mechanical power for slurry mixing, handling and motorised water supply to inlet. But in case of family size biogas plant embodied energy required for construction was around 40.16 GJ. The operational energy was observed to be only for feeding and emptying of biogas plant and is quantified to 9.782 GJ. The total was found to be 49.94 GJ. This amount was reflecting to be 7 % of institutional biogas plant; while production capacity was 2.35 % of institutional biogas plant. Considering the fact that biogas was used for cooking purpose, institutional biogas plant was considered with having community size biogas stove while family size biogas plant having small biogas stove. This embodied energy of cookstove and piping towards total embodied energy was negligible as compared to embodied energy of plant construction; so, was neglected for calculation.

Table-1 *Embodied energy coefficients*

SN	Item	Embodied Energy MJ/kg	Unit	Reference
1	Mild Steel Stand	34.2	kg	Kumar and Tiwari (2009)
2	Mild Steel Clamp	34.2	kg	
3	Mild Steel Frame	34.2	kg	
4	Mild Steel	34.2	kg	
5	Rubber Gasket	11.83	kg	
6	GI Pipe	44.1	kg	
7	Copper Wire	110.19	kg	
8	Paint	90.2	litre	
9	Nuts/Screws/Flanges	31.06	kg	
10	Aluminium Sheet	170	kg	
11	Copper Sheet	132.7	kg	
12	Glasswool	139	per m3	
13	Cement	5.85	kg	Reddy and Jagadish (2003)
14	Lime	5.63	kg	
15	Lp Portland Cement	2.33	kg	
16	Steel	42	kg	
17	Aluminium Sheet	236.8	kg	
18	Glass Toughened	66	per m2	Kumar and Tiwari (2009)
19	Clay Brick	5.75	per brick	Reddy and Jagadish (2003)
20	Sand	0.02	kg	Jain and Salgude (2015)

Table-2 *Embodied energy used for biogas plant construction*

Part of biogas plant	Embodied energy required for 85 cubic m biogas plant	Embodied energy required for 2 cubic m biogas plant
Biogas plant digester	271.5 GJ	22.86 GJ
Metallic gasholder	315.1 GJ	32.58 GJ
Total	586.6 GJ	55.44 GJ

Table-3 *Characterised results of LCA for institutional and family size biogas plants*

Impact category	Unit	85 Cubic m Biogas plant	2 Cubic m Biogas plant
Aquatic ecotoxicity	kg TEG water	9.1143457	370.03615
Terrestrial ecotoxicity	kg TEG soil	4.6767228	197.97826
Terrestrial acid/nutri	kg SO_2 eq	2.5621441	2.7742143
Ionizing radiation	Bq C-14 eq	1.5750629	56.409319
Aquatic acidification	kg SO_2 eq	0.51311553	0.57047177
Respiratory inorganics	kg PM2.5 eq	0.068157948	0.078076062
Mineral extraction	MJ surplus	0.022862958	0.95677289
Carcinogens	kg C_2H_3Cl eq	0.004564279	0.28021508
Land occupation	m2org.arable	0.003639332	0.14977781
Non-carcinogens	kg C_2H_3Cl eq	0.002798337	0.18879224
Aquatic eutrophication	kg PO_4 P-lim	4.59E-05	0.001870655
Ozone layer depletion	kg CFC-11 eq	1.78E-08	7.19E-07
Respiratory organics	kg C_2H_4 eq	-0.000268382	0.00544372
Global warming	kg CO_2 eq	-5.8073204	9.545953
Non-renewable energy	MJ primary	-49.032444	114.94104

Table-4 *Financial analysis results*

Parameter	Unit	Institutional	Family size
KVIC biogas plant construction (A)	Rs.	10,00,000	65000
Operational cost (B)	Rs.	1,00,000	5000
Maintenance cost (C)	Rs.	100000	5000
Total (A+B+C) D	Rs.	1200000	75000
Fertilizer production (Rs. 6/kg) (E)	Rs.	1861500	43800
Annual substitution of LPG (Rs. 45 per kg) (F)	Rs.	644823.6	14224.05
Total benefits (E+F)	Rs.	2506323.6	58024.05
Payback period for LPG substitution	Years	1.860974071	5.27276
Payback period for fertiliser production	Years	0.644641418	1.712329
B:C ratio		2.088603	0.773654
NPV	Rs.	2,94,627.00	-2894
IRR		231%	67%

According to [13], the total amount of N_2, P_2O_5 and K_2O available from 1000 kg dry biogas manure is 17, 15 and 10 kg respectively. This refers to total amount of 62,05,000 kg of dry manure from institutional biogas plant equivalent to 105485 kg N_2, 93075 kg P_2O_5 and 62050 kg K_2O. While family size biogas plant will provide 1,46,000 kg of dry manure equivalent to 2482 kg N_2, 2190 kg P_2O_5 and 1460 kg K_2O. The energy equivalents for N, P and K are 66.14 MJ/kg, 12.4 MJ/kg and 11.5 MJ/kg respectively [14]. Considering chemical fertiliser replaced by equivalent amount of NPK from biogas spent slurry it was observed that institutional biogas provides replacement of 8844.405 GJ within whole life cycle while family size biogas plant provided replacement of 208.105 GJ.

Energy payback period and Energy required for producing energy

The total embodied energy of whole institutional biogas plant unit was found to be 718 GJ. Considering whole life cycle biogas production of 9928 GJ and 8844.405 GJ for fertiliser replacement for 20 years; the energy payback period of 1 year 6 months or 528 days (approx.) was observed for biogas production for institutional biogas plant. Fertiliser replacement gave energy payback period of 1 year 8 months or 592 days (approx). In case of family size biogas plant total embodied energy invested was 49.94 GJ and fertiliser replacement provided total whole life cycle income of 208.15 GJ and biogas production of 233.6 GJ. Means, energy payback period for family size biogas plants was 4 years 4 months or around 1561 days (approx.) for biogas production while for fertiliser replacement was 4 years and 10 months or 1751 days (approx). This explains how cheaper the process of biogas manure production process is as the amount of energy invested directly reflects into money. In family size biogas plant the energy required for producing 1MJ of biogas energy was 0.279 MJ/MJ. This denotes that to produce 1m^3 of biogas requires 5.58 MJ of energy for whole life cycle. But, in case of institutional biogas plant energy required for producing 1MJ of biogas energy was 0.0723 MJ/MJ. And this reflected that to produce 1m^3 of biogas requires 1.446 MJ of energy for whole life cycle.

Life cycle assessment analysis of institutional and family size biogas plants

The life cycle assessment analysis of institutional 85 m^3 and family size 2 m^3 biogas plant was carried out with the methodology expressed in above. The construction, production and fertiliser replacement of the plant was then compared to the functional unit (1 cubic metre of biogas). This enabled the impacts of the plant manufacture to be evenly distributed across the entire biogas output of the plant. Therefore, the emissions of the plant manufacture contributed to 0.000001611 (1.6 x 10^{-6}) times of plant per m^3 of biogas output for 85 m^3 plant while contributed to 0.000068493 (6.8 x 10^{-5}) times of plant per m^3 of biogas output. [Fig-2] depicts graphical representation of results indicating characterised results for biogas production, plant construction and bio-fertiliser production (*i.e.* chemical fertiliser replacement). [Table-3] provides detailed Characterised results for impacts made by adoption of institutional and family size biogas plants as per 1m^3 functional unit. Characterised results shows that process for production of biogas and utilisation for cooking along with replacement of chemical fertiliser by biogas spent slurry based bio-fertiliser has positive impacts on environment in two categories for institutional 85 cubic m biogas plant *viz*. depletion of resources and climate change due to production of bio-fertiliser. Also, in all impact categories impact per m^3 biogas produced was lower for institutional biogas plant as compare to family size biogas. These results also depicts that chemical fertiliser replacement using bio-fertiliser from family size biogas plant is does not overcome the climate change and resource depletion impacts due to its own construction impacts. This means it will be more feasible to popularise institutional biogas plants as a natural fertiliser producing units. But, despite family size biogas plants are smaller in capacity and inability to overcome impacts they shall be promoted as they are in distributed in manner and are located at the point of fertiliser use *i.e*. nearby farms of farmers. But, as system boundary was terminated at the point of biogas production and spent slurry collection; it is very early to predict bio-fertiliser's application emissions impacts as impacts of application of digested slurry *i.e*. bio-fertiliser were outside the point of study. The damage assessment results of LCA are presented in [Fig-3]. These results shows that institutional 85 m^3 biogas plant has damage impact on ecosystem quality about 2.70 PDF*m^2*yr per m^3 compared to 4.633 PDF*m^2*yr per m^3 of family size biogas. This denotes that potentially disappeared fraction of species is around 1.71 times more for family size biogas. Similarly, human health, climate change and resources results were 4.77E-05 and 5.60E-05 DALY per m^3, -5.8073204 and 9.545953 kgCO_2eq per m^3 and -49.009581 and 115.89781 MJ per m^3 respectively for institutional and family size plant. These results were approximately 1.17 to 2.3 times more for 2 m^3 biogas plants.

Financial analysis of institutional biogas plant

[Table-4] provides detail results of economic analysis of institutional and family size KVIC biogas plants. The results showed that payback period for institutional scale biogas plant was lower with higher benefit cost ratio as compare to family size biogas plant. NPV was found positive for institutional biogas plant with IRR of 231% while negative NPV was observed for family size biogas plant with IRR of 67%. The payback periods for LPG substitution for 85 and 2m^3 plants were 1.8 and 5.7 years, respectively.

Conclusion

It can be concluded that family size biogas plant has more environmental impacts per m^3 biogas production as compared to institutional biogas plant. The embodied energy suggests that energy investment required for producing biogas in family size biogas plant is more with more energy payback period and energy required for producing energy. An institutional scale biogas plant contrary to family size biogas plant can process large amount of waste at one utility. So this research insists bio-energy entrepreneurs and cow farms across India to adopt institutional biogas plant more enthusiastically. The energy-environment-financial analysis concludes that institutional biogas plants requires huge financial and energy investments but are found to be more suitable to environment.

Application of research: Study of determining an impact of climate change on environment due to construction of renewable energy device for both small scale and large scale application.

Research Category: Renewable Energy

Abbreviations:

BP = Biogas Plant
CO = Carbon monoxide, CO_2 = Carbon dioxide
EIA = Environment Impact Analysis
et al. = Et alii (and others)
GHG = Greenhouse gas
GI = Galvanized Iron
GWh = Giga Watt Hour
GWP = Global Warming Potential
kg = Kilo gram, kJ = Kilo Joule
KVIC = Khadi and Village Industries Commission
kWh = Kilo Watt Hour
LCA = Life Cycle Analysis
LCI = Life Cycle Inventory
LCIA = Life Cycle Impact Analysis
MJ = Mega Joule
MNRE= Ministry of New and Renewable Energy
MS = Mild steel
MWh = Mega Watt Hour
NPV = Net Present Value
NPW = Net Present Worth

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University: M.P. University of Agriculture and Technology, Udaipur, 313001
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Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Biogas plant from Nathdwara nearby Udaipur

Cultivar / Variety / Breed name: Nil

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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