Eco. Env. & Cons. 26 (February Suppl. Issue) : 2020; pp. (S143-S150)

ISSN 0971–765X

Embodied energy analysis, life cycle energy assessment and financial study of institutional KVIC biogas plant model

Sudhir Narayan Kharpude and Deepak Sharma

College of Agricultural Engineering and Post Harvest Technology, Ranipool, Gangtok 737 135, Sikkim

(Received 7 October, 2019; accepted 13 November, 2019)

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 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, life cycle energy utilization and financial investment assessments. The total embodied energy of whole institutional biogas plant unit of three 85 m^3 KVIC plants and biogas up gradation setup was found to be 3269.77 GJ with the energy payback period of 2 year 3 months or 818 days. Economic analysis concluded that institutional biogas plant is economically viable and should be adopted. The payback period of institutional biogas plant unit for LPG substitution was found as 5.61 years and for both fertilizer and LPG substitution was 2.09 years. Positive IRR and NPV values indicate beneficial investment in biogas plant. Multi-appraisal technique to observe energetic and economic analysis concluded that institutional biogas plant is viable option and is adaptable in current state-of-art.

Key words : *Biogas plant, Mbodied energy, Kvic biogas, Institutional biogas*

Introduction

Bio-energy in India

In India, main resources used for producing bio-energy are agrarian residues, forest residues, and molasses of sugarcane, bio-diesel and biogas. Agricultural residues and forest residues produce 99% of present bio-energy. India's estimated bio-energy production is about 1842 TWh/ year and has 25% share of total energy consumption of India. Close to 70% of rural population depend on biomass to meet their daily energy needs (Devi, 2016).

India offers a conducive environment for hastening the use and popularization of Bio-energy Technologies (BET's). India has vast experience in marching bio-energy packages. The Ministry of New and Renewable Energy (MNRE) recognizes this potential. MNRE, state governments, central and state regulatory commissions have developed several policy instruments (tariff support) and monetary incentives (capital subsidy, the interest subsidies) to support bio-energy development (Ministry of New and Renewable Energy, 2016). Despite this, empirical evidence shows the rate of spread of BETs is low because of institutional, technical, informational, market and economic barriers. The main bioenergy technologies used across India are biogas, biomass gasification, biomass combustion and improved cook stoves.

Biogas Technology

Biogas production is an untainted low carbon technology for efficient management and conversion of fermentable animate wastes into clean cheap and versatile fuel and bio or living manure. It has the potential for leveraging sustainable livelihood development as well as tackling local and global land, air and water pollution. Biogas obtained from anaerobic digestion of cattle dung, and other loose-leafy organic biomass wastes are used as an energy source for cooking, heating, space cooling or refrigeration, electricity generation and gaseous fuel for vehicular application. Based on cattle dung alone from about 304 million cattle, there exists an estimated potential of about 18,240 million cubic meter of biogas generation each year (Vijay *et al.*, 2015).

India is carrying out one of the World's largest programme in renewable energy. India ranks second in biogas use (Ministry of New and Renewable Energy, 2016). Biogas can be generated and supplied around the clock in contrast to solar and wind, which are intermittent in nature. Biogas plants provide the three-in-one solutions of gaseous fuel generation, organic manure production and wet biomass waste disposal and management.

Mindset Behind Research

In Rajasthan, more than 2000 small and large Institutional Cattle farms are functioning throughout districts and villages comprising of millions of cattle. India is mainly known across the world for family-sized biogas plants, and technology is disseminated widely. However, in case of institutional scale biogas and farm based biogas; India has a lot of scope for improvement and establishment. The amount of dung produced in institutional plants is substantial in quantity at one place compared with scattered potential seen in family size biogas plants. The institutions are also facing problems with processing of sizeable quantity of manure available daily. The energy based economic analysis is needed as an indicator for spread and dissemination of biogas technology across institutions along with various biogas applications.

Materials and Methodology

Experimental site

The analysis and research work was conducted at Department of Renewable Energy Engineering, College of Technology and Engineering, Udaipur. The study area falls at 24^0 38'N latitude, $73^0$43'N longitude and at altitude of 582.5 m above sea level. The field data collection and on-site evaluation was performed at the Institutional biogas plant site at Adesh Gopalan Samiti's Goshala, Nathdwara. The field area is situated at $24^0$93′ N latitude, $73^0$82′ E longitude and at altitude of 585 m above the sea level.Experimental site is equipped with a well-established biogas plant setup comprising of 3 units of KVIC floating drum type biogas plant models. The capacity of biogas plant was 85 m^3 each. The biogas plant experimental site is illustrated and photographically presented in Figure 1. The biogas scrubbing unit comprise of a scrubber, a water supply system, a gas supply system, a low capacity compressor, a pressure vessel, pipe fittings and various accessories. Figure 2 shows pictorial view of biogas upgrading unit with water scrubbing and compressor unit.

Fig. 1. View of institutional biogas plant experimental site at Nathdwara

Data collected

Data for this study was collected mainly from field sites, review, reports and literature available cited at particular data points in this chapter. Data for biogas plant construction and material required were collected from standard designs from KVIC Mumbai. The biogas production and utilization data was obtained from institutional biogas plants

Fig. 2. View of Biogas upgrading unit with water scrubbing column and compressor unit at experimental site

site at Nathdwara. Biogas scrubbing and supplementary utilization for vehicular activity were obtained from log book. The electricity and water consumption data were obtained from electricity and water meters available at site.

Embodied energy analysis of biogas plant

Embodied energy and Lifecycle energy analysis of any system start with identification of energy source and progress through appropriate steps of energy conversion and transportation up to the final product providing energy service. The basic requirement for embodied energy analysis is material used for construction of biogas plants. The embodied energy is the amount of energy required to produce the material in its present form. For calculation of energy payback period, it is required to evaluate embodied energy and energy output. Energy requirements for institutional biogas plant account for all direct and indirect energy inputs into process of biogas production and utilization. The energy analysis of biogas production is more complicated for calculation. It requires operational and embodied energy to produce energy than more simple other renewable energy systems. Biogas production need energy inputs like feed stock collection including wastage or losses, transportation 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 considerable amount of variations. The viability of any system is decided by primary energy i.e. MJ of energy required to produce output energy. This term is also referred as the Energy requirement for Energy (ERE). The data for various embodied energy coefficients was collected from Kumar and Tiwari (2009) and Jain (2015) and is tabulated in Table 1. Embodied energy can be calculated by the following relation:-

Embodied energy =$\Sigma m_i e_i$

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

e_i = 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

Energy Input and Output analysis of fresh cow dung, digestate and digested slurry

Energy input and output analysis of digestate and digested slurry describe amount of energy to be produced i.e. biogas and fertiliser. The energy input output of digestate and digested slurry in the form of NPK content was determined and fresh slurry, digestate and vermi-compost NPK's were compared. The methodology used for determination of N, P and K content is based on Kjeldhal method, Olsen method and flame photometry, respectively. The mass balance for biogas plant operation was depicted based on references mainly Vivekanandan and Kamraj (2011) and Pathak *et al.* (1985). The emissions from biogas production phase were calculated by using reference values mentioned in Borjesson and Berglund (2006); Stucki *et al*. (2011); Afrane and Ntiamoah (2011) and Mittal (1996).

Economic analysis of system

The economics evaluation of institutional 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 present worth can be computed by subtracting the total discounted presentworth 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 thepresent 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 projectis to find the discount rate that makes the net present worth to the incremental cash flowequal 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 untilthe net value of the incremental production stream reaches the total amount of the capitalinvestment.

$$\textit{Payback period} = \frac{Totalinvestment}{Netprofit}$$

Results and Discussion

Energy Input and Output analysis of fresh cow dung, digestate and digested slurry:

Fresh slurry amount of 6.375 tonne was entering daily into institutional biogas plant. As per data obtained from logbook and visits it was observed that average biogas production of institutional biogas plant was 186.4 m^3 per day. This value provided overall life cycle biogas production of 13, 60,720 m^3.

With reference to Seadi(2008) the density of biogas and its heating, i.e. calorific value was calculated as below based on biogas composition mentioned in Table 2.

Density (in kg/m^3) @ STP for CH_4: 0.717; CO_2: 1.977; N_2: 1.2506; O_2: 1.429 & H_2S: 1.434 (*Source:* Seadi, *2008*)

Table 1. Embodied energy coefficients

Sr. No.	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	L	
9	Nuts/Screws/Flanges	31.06	kg	
10	Aluminium Sheet	170	kg	
11	Copper Sheet	132.7	kg	
12	Glass wool	139	per m^3	
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 m^2	Kumar and Tiwari (2009)
19	Clay Brick	5.75	per brick	Reddy and Jagadish (2003)
20	Sand	0.02	kg	Jain (2015)

Table 2. Composition of Biogas

Gas	Percentage (%)
Methane CH_4	58.5
Carbon-di-oxide, CO_2	36
N_2	5
O_2	0.32
H_2S	0.18

Biogas density = 0.717*0.585 + 1.977*0.36 + 1.2506*0.05 + 1.429*0.0032 + 1.434*0.0018 = 1.20 kg/m^3

Biogas heat value = 9.94*0.585 (CH_4 heat value = 9.94 kWh/m^3)

= 5.8149 kWh/m^3 = 20.879 MJ/m^3 or 17.399 MJ/kg

The physic-chemical properties of fresh cow dung, digested slurry and vermi-compost were observed by using methodology mentioned in chapter III. The parameters considered for laboratory scale study were TS, VS, TKN, P and K. The results of laboratory analysis are illustrated in Table 3 provided below.

The results significantly prove that there is a loss of N content during vermi-composting due to evolvement of N_2O through composting pits. The potassium content was observed higher, this may have occurred due to soil used or due to species of earthworms used. But these results showed that conversion of fresh cow dung to bio-digested slurry is a good fertiliser production option and should be adopted.

The total dung entering daily to biogas plant was 6.375 Tonne and 46.537 Kilo Tonne per 20 year life span. Throughout the life cycle of biogas plant the amount of fertilizer to be produced by investing 25 kg fresh dung is around 10 kg dry amount. According to Nijaguna (2006), 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 18615 Tonne of dry manure from biogas plant equivalent to 316.455 Tonne N_2, 279.225 Tonne P_2O_5 and 186.150 Tonne K_2O at experimental site.

Embodied energy for construction and operation of biogas plant units

The institutional biogas system comprises of three 85 m^3 capacity KVIC models 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 (Mittal 1996). This means that during whole life cycle of single biogas plant two gas holder units would be required. So, total of six gasholders would be utilised through whole life cycle. Table 4 illustrates embodied energy used for construction of biogas plant. Table 5A to 5E provides detailed calculation of embodied energy.

The embodied energy required for construction of whole institutional biogas plant unit was found to be 1759.8 GJ. If a single metallic gas holder is required for whole 20 years life cycle, the embodied energy of biogas plant unit significantly decreases to 1287 GJ. The operational energy used for biogas plant functioning was found to be 433.32 GJ. The total amount of embodied energy invested in construction and operation of biogas plant unit is 2193.12 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.

Table 3. Physico-chemical properties of fresh cow dung, digested slurry and vermi-compost

Parameter	Fresh cow dung	Digested slurry	Vermi-compost
TS%	15.6- 17.1	11.8-13.1	—
VS%	76-81	48-53	—
TKN% TS	1.29	1.52	1.36
P% TS	0.7	0.85	0.92
K% TS	0.8	1.07	1.49

Table 4. Embodied energy used for biogas plant construction

Part of biogas plant	Embodied energy required for single unit	Total embodied energy for whole system (3 units)
Biogas plant digester	271.5 GJ	814.5 GJ
Metallic gasholder	157.55 GJ	945.3 GJ
Total	429.05 GJ	**1759.8 GJ**

Table 5a. Embodied energy required for digester of Biogas plant:

Material	Units	Required for 85 Cubic m plant	Embodied Energy Coefficients	Total Energy MJ
Bricks	nos	29800	5.75	171350
Cement	kg	10750	5.85	62887.5
Stone ballast	kg	39312	0.083	3262.896
brick ballast	kg	6800	3.294	22399.2
Sand	kg	52000	0.1	5200
150 mm dia PVC pipe	feet	80	80	6400
Energy Required for single digester				814498.8
Energy Required for Three digester				271499. 596

Table 5B. Embodied energy required for metal work of Biogas plant:

Material	Units	Required for 85 Cubic m plant	Embodied Energy Coefficients	Total Energy MJ
MS Angle	60*60*6 per m 8.14 kg /m weight	2035	34.2	69597
MS Sheet	3.15 mm thick 8*4	2211.25	34.2	75624.75
Bolts	16 mm thick	7.748	34.2	264.9816
Flange Plate	1200 mm *1200 mm *6 mm thick	268	34.2	9165.6
Ms Pipe	150 mm pipe	35.51	34.2	1214.442
Ms Pipe CGF	125 mm 4 mm thick	47.42	34.2	1621.764
Brass Valve	2	0.28	62	17.36
Embodied energy required for single metal work				**157505.9**
During life cycle metal work is required 6 times for whole institutional biogas unit, so total metal work embodied energy is				**945035.4 MJ**

Table 5C. Embodied energy required for Vermi-compost Unit:

Material	units	Amount	Embodied Energy Coefficients	Total
Bricks	Nos.	86000	5.75	494500
Cement	kg	26730	5.85	156370.5
Stone ballast	kg	38000	0.083	3154
brick ballast	kg	4500	3.294	14823
Sand	kg	18100	0.1	1810
Total embodied energy invested for vermi-composting unit				670657.5 MJ 670.65 J

Table 5D. Embodied Energy investment for Water Scrubbing Unit:

Material	units	Amount	Embodied Energy Coefficients	Total
MS Metallic scrubbing column	kg	200	34.2	6840
Scrubbing column angle frame	kg	100	34.2	3420
Bricks	Nos.	9000	5.75	51750
Cement	Kg	2750	5.85	16087.5
Stone ballast	Kg	5500	0.083	456.5
brick ballast	kg	4000	3.294	13176
Sand	Kg	4000	0.1	400
Embodied energy investment for Water Scrubbing Unit				92130MJ 92.130GJ

Table 5E. Operational Energy

Unit	Energy required	For whole life cycle energy required	Total
Biogas Plant	Electricity = 15 units daily	394.2 GJ	433.32 GJ
Biogas plant	Human = 4 labours	39.12 GJ	
Vermicomposting unit	Electricity =5 units daily	105 GJ	128 GJ
Vermicomposting unit	Human =	23 GJ	
Biogas Scrubbing unit	Electricity =5 units daily	131.4 GJ	186 GJ
Biogas Scrubbing unit	Human	54.6 GJ	
Total	**747.32 GJ**		

Table 6. Economic analysis of Institutional Biogas plant

Costs	Amount (Rs.)
KVIC biogas plant construction	30,00,000/-
Scrubbing unit & compression	25,00,000/-
Generator set	2,50,000/-
Sub Total Cost (A):-	57,50,000/-
Operational cost (B)	2,50,000/-
Maintenance cost (C)	1725000/-
Total (A+B+C) D	77,25,000/-
Annual Benefits	Amount (Rs.)
Fertilizer production (Rs. 2.5/kg)	23,26,875/-
Annual substitution of LPG (Rs. 45 per kg)	13,76,989/-
Total benefits (E)	37,03,864/-
Payback period for LPG substitution and fertiliser production	2.09 years
Payback period for LPG substitution	5.61 years
NPV for 5% Discount rate	Rs. 12,29,871
IRR	47.94%

Biogas scrubbing unit is used for purification and compression of biogas to cylinders and used as vehicular fuel. The amount of embodied energy invested in scrubbing unit construction and operation is around 92 GJ and 186 GJ respectively. This comprises that total embodied energy for biogas scrubbing unit is 278 GJ.Considering the fact that being a secondary function assembly, vermi-composting unit still required highest amount of embodied energy due to its civil construction and metallic roof and it contributed to around 670.65 GJ. The operational expenses of unit were 128 GJ. This comprises that total embodied energy for vermi-composting unit is 798.65 GJ.

The total embodied energy of whole institutional biogas plant unit was found to be 3269.77 GJ. Considering whole life cycle biogas production of28575.12 GJ for 20 years, i.e. 1428.75 GJ per year, the energy payback period of 2 year 3 months or 818 days was observed. Based on manure output through biogas plant energy payback period for replacing equivalent chemical fertiliser of 4087 GJ energy was 292 days, i.e. 10 months. The energy required for producing 1MJ of biogas energy was 0.11MJ/MJ. This denotes that 1m^3 of biogas production requires 2.31 MJ of energy.

Economic analysis of Institutional biogas plant system

The economic analysis of Institutional biogas plant has been described in following section. Table 6 provides variable used in economic analysis. The payback period of institutional biogas plant unit for LPG substitution was found as 5.61 years, i.e. 5 years and 222 days and both fertilizer and LPG are 2.09 years, i.e. 2 years and 33 days. It is also revealed that production of fertilizer from biogas plant has higher values than the produced gas. The payback, period for fertilizer production is around 3.32 years, i.e. 3 years and 117 days.

Conclusion

The total amount of 18615 Tonne of dry manure can be produced from biogas plant during 20 years life and was equivalent to 316.4 Tonne N_2, 279.2 Tonne

P_2O_5 and 186.15Tonne K_2O. The total embodied energy of whole institutional biogas plant unit of three 85 m^3 KVIC plants and biogas up gradation setup was found to be 3269.77 GJ with the energy payback period of 2 year 3 months or 818 days. The energy required for producing 1MJ of biogas energy was 0.11MJ/MJ. This denotes that to produce 1m^3 of biogas equivalent to 20 MJ requires 2.31 MJ of energy.This explains how cheaper the process of biogas manure production process is as the amount of energy invested directly reflects into money. Economic analysis concluded that institutional biogas plant is economically viable and should be adopted. The payback period of institutional biogas plant unit for LPG substitution was found as 5.61 years and both fertilizer and LPG are 2.09 years. Positive IRR and NPV values indicate beneficial investment in biogas plant. Multi-appraisal technique to observe energyand economic analysis concluded that institutional biogas plant is viable option and is adaptable in current state-of-art.

Acknowledgment

The authors are thankful to SimaPro for providing faculty license, and to Head, Department of Renewable Energy Engineering for providing necessary facilities to carry out research work. Authors are also thankful to Adesh Gopalan Samiti's Goshala, Nathdwara for permitting and helping analysis at their plant site.

References

Afrane, George and Augustine Ntiamoah, 2011. Comparative Life Cycle Assessment of Charcoal, Biogas, and Liquefied Petroleum Gas as Cooking Fuels in Ghana. *Journal of Industrial Ecology.* 15(4) : 539–549. http://dx.doi.org/10.1111/j.1530-9290.2011.00350.x.

Börjesson, Pål and Maria Berglund, 2006. Environmental Systems Analysis of biogas Systems—Part I: Fuel-Cycle Emissions. *Biomass and Bioenergy*. 30(5): 469–485. http://www.sciencedirect.com/science/article/pii/S0961953405001984.

Devi, Seema. 2016. Energy Security in India Geography.*GJRA - Global journal for research analysis.* 5 (7): 273–276.

Jain, Jayeshkumar S. 2015. Comparison of Carbon Emission & Embodied Energy between Brickwork & Waffle Wall Method for Industrial Building. *International Journal of Innovative And Emerging Research In Engineering* 2(6): 1–4.

Kumar, Shiv, and Tiwari, G N. 2009. Life Cycle Cost Analysis of Single Slope Hybrid (PV / T) Active Solar Still/*Applied Energy* 86. (10): 1995–2004. http://dx.doi.org/10.1016/j.apenergy.2009.03.005.

Ministry of New and Renewable Energy, Government of India, 2016. Bio-Energy. http://www.mnre.gov.in/schemes/r-d/thrust-areas-2/bioenergy/ (May 25, 2016).

Mittal, K M. 1996. *Biogas Systems: Principles and Applications*. New age international limited publishers. https://books.google.co.in/books?id=38HrAAAACAAJ.

Nijaguna, B. T. 2006. *Biogas Technology*. New Age International Limited publishers.https://books.google.co.in/books/about/Biogas_Technology.html?id=QfLDbf3qbcEC

Pathak, B. S., A. K. Jain, and D. S. Dev. 1985. Biogasification of Cattle Dung and Cattle Dung-Rice Straw Mixture at Different Solid Concentrations. *Agricultural Wastes* 13(4): 251–259.

Seadi, T.A. 2008. *Biogas Handbook.* http://www.lemvigbiogas.com.

Stucki, M., Jungbluth, N. and Leuenberger, M. 2011. Life cycle assessment of biogas production from different substrates. *Final report. Bern: Federal Department of Environment, Transport, Energy and Communications, Federal Office of Energy.*

Venkatarama Reddy, B. V., and K. S. Jagadish. 2003.Embodied Energy of Common and Alternative Building Materials and Technologies.*Energy and buildings* 35(2): 129–137.

Vijay, Virendra Kumar, Rimika Kapoor, Abhinav Trivedi, and Vandit Vijay. 2015. Biogas as Clean Fuel for Cooking and Transportation Needs in India. In: *Ad vances in Bioprocess technology*, ed. Pogaku Ravindra. Cham: Springer International Publishing, 257–275. http://dx.doi.org/10.1007/978-3-319-17915-5_14.

Vivekanandan, S. and Kamraj, G. 2011. Investigation on Cow Dung as Co-Substrate with Pretreated Sodium Hydroxide on Rice Chaff for Efficient Biogas Production . *International Journal of Science and Advanced Technology* 1(4): 76–80.