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ENERGY ANALYSIS AND CARBON CREDIT EARNED BY BIOGAS SYSTEM

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ABSTRACT

An attempt has been made to estimate embodied energy from the building materials used in construction of various type of biogas plants, energy payback time and potential carbon dioxide (CO_2) mitigation using renewable energy and different biomass for domestic cooking in India. Using the data available in literature survey and the simple frameworks presented in this paper results of some typical calculations are presented and discussed. The payback periods have also been computed by considering the equivalent savings in alternate fuels, viz. firewood, coal, kerosene, liquid petroleum gas (LPG) and electricity. The payback periods have been calculated by considering the compound annual interest rate, maintenance cost and inflation in fuel prices and maintenance cost per year. If this type of project is installed only in 20% of the Indian rural areas, then the carbon credit earned by the biogas system becomes Rs. 8900 crores annually.

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1. INTRODUCTION

The availability and consumption of energy is an index of prosperity of a country. We need more energy, due to population growth, industrialization, more agriculture production, and rising living standards. The energy consumption per person in India is very low and is about 610 kWh/year whereas for China it is 1400, Germany 6900 and USA 13000 with world average of 2400 kWh/year. The human development index (HDI) in India is also very low (below 0.6). The HDI (relating education, health and prosperity) is a composite index and is directly proportional to the energy consumption per year per capita [1].

The present electric installed capacity in India is about 144980 MW and the energy demand growth is around 8 to 9% per year which shows that we will be needing around 1,00,000 MW additional capacity by 2012 [2].

In India, about 70% of the population lives in villages while 70% of conventional power is used by urban consumers and nearly 80% of rural population depends on agriculture and allied activities for its livelihood. About 50% of the rural people live below poverty line and a vast number of these rural poor belong to schedule caste, scheduled tribe, backward classes, landless labourers, small and marginal farmers and rural artisans who cannot pay electricity charges.

Since a large majority (around 80%) of the rural population do not have enough purchasing power, they survive on non-commercial energy sources like firewood, cow dung cakes and agricultural wastes which constitute 65, 15 and 20% shares, respectively.

Biogas is a clean, less polluting, smoke and soot free fuel. It is produced from cattle dung and human waste mixed with water and decomposed in the absence of air in digester of biogas plant by anaerobic fermentation. The maximum gas is produced at 35 ^{o} C- 40^o C. it contains 55-70% methane, which is inflammable and the rest is carbon dioxide. It burns with blue flames in specially designed stoves for cooking. When burnt in silk mantle lamps, it serves as a source of lighting. The biogas plays an important role in the utilization of the waste for the energy recovery thereby facilitating proper and efficient waste disposal. The waste disposal is a global environmental problem. Energy from waste as an alternative to fossil fuels provides an important contribution towards the reduction in landfill disposal and global warming.

Prasad et al. [3] developed a model for biogas production rate and a period for optimum temperature which depends on the temperature of the slurry. Renewable energy technologies were developed by Kandpal et al. [4] to make efficient domestic cooking from biofuels and to reduce carbon dioxide (CO_2).

Chandra [5] discussed a distributed energy systems based on renewable energy resources like solar, wind, hydro and bio-waste and compared on the basis of energy pay back time. Embodied energy of building materials in India had been presented and comparative analysis [6, 7] were also carried out to gauge the energy efficiency of the walling elements and to identify the most suitable option. Reddy et al. [8] developed an approach to reduce the size and cost of the biogas system. Venkataraman Reddy [9] described a brief history of building materials, energy consumption in manufacture and transportation of some common and alternative building materials. He also discussed its implication on environment.

Biogas plants may be classified in several ways depending upon the plant design and mode of working. Digesters can also be vertical and horizontal displacement types depending on the orientation of digester.

A life cycle analysis for each energy service analyzed will start with identification of the primary energy source and progress through the appropriate steps for energy conversion and transportation up to the final devices providing energy service [10].

In present study, an effort has been made to estimate the embodied energy from the building materials used in construction of the biogas plants [6]. The embodied energy is the amount of energy required to produce the materials in its present form [11]. Energy pay back time (EPBT) has been evaluated using embodied energy and energy output. Finally analysis of potential CO_2 mitigation using renewable energy and different biomass has been carried out.

2. METHODOLOGY

Based on average conditions, with cattle dung as feed it is possible to get yield of 0.4 m^3 gas/day/m^3 of digester volume of movable drum type plant [10]. The energy output annually for horizontal and vertical type biogas models at different digester capacities are mentioned in Table 1 [12, 13].

2.1 Assumptions

Following assumptions have been made in the analysis of biogas system:

1. Volume of biogas required per person for cooking = 0.40 m^3/day
2. Thermal efficiency of the system = 50%
3. Biogas required for lighting = 0.12 m^3/ hr
4. Each family has 4 members.
5. Each family requires a light for 6 hr a day.
6. The biogas is available for 300 days in a year.
7. Maintenance cost is 5% annually.

8. Average annual growth rate of population in India is 2%.

2.2 Embodied Energy

Embodied energy is calculated by the following relation:

$$\text{Embodied energy} = \sum m_i e_i \tag{1}$$

where m_i = mass of materials used in constructing biogas plants in kg

e_i = energy density of the material in MJ/kg

2.3 Energy Output Annually

Energy output in MJ /day is calculated as

$$\text{Energy output} = HV \times S \times G \tag{2}$$

where HV = Heating value of fuel in MJ/m^3

S = Digester capacity in m^3

G = Rate of gas production in m^3 /day per digester capacity (m^3)

$$\text{Energy output annually} = HV \times S \times G \times 300 \tag{3}$$

Energy pay back time (EPBT) can be calculated as [5]:

$$EPBT = \frac{\text{Embodied energy}}{\text{Energy output}} \tag{4}$$

The Table 1 shows embodied energy and EPBT in MJ and years respectively.

Table 1: Embodied energy, energy output and Energy Pay Back Time (EPBT) for Horizontal and Vertical digester type biogas plants.

Sl. no.	Digester capacity (m3)	Energy Output (MJ/day)	Horizontal Type Biogas Plants		Vertical Type Biogas Plants	
			Embodied Energy (MJ)	EPBT (years)	Embodied Energy (MJ)	EPBT (years)
1	2.83	22.66	31939.4	4.70	26412.91	3.89
2	4.25	34.0	37471.1	3.67	31122.91	3.05
3	7.08	56.64	45452.6	2.67	38374.09	2.26
4	14.02	112.16	86585.8	2.57	74734.20	2.22

3 NUMERICAL COMPUTATIONS

The daily biogas requirement per family, the energy Conservation and CO_2 mitigation are computed.

3.1 Biogas Requirement per Family

Gas required for cooking per family = 0.4×4 m^3/day

$= 1.6$ m^3/day (5)

The biogas required for lighting (6 hr) a day

$= 0.12 \times 6$ m^3/day

$= 0.72$ m^3/day/family (6)

The total gas required for cooking and lighting

$= 2.32$ m^3/day/family (7)

The total energy required per day

$= 2.32 \times 22$ MJ/family

$= 51.04$ MJ/family (8)

The annual primary energy required

$SPE_{annually}$ = 15312 MJ/annum/family (9)

3.2 Energy Conservation

If the biogas replaces the conventional fuels (coal /firewood /dung cake/agriculture residue etc.) for a single household, then amount of fuel saved per year is calculated from the following relation

$$m_f = \frac{SPE_{annually}}{H.V. \times \eta} \tag{10}$$

where m_f = mass of fuel saved per year, kg

H.V. = Heating value of the fuel, KJ/kg

η = Burning efficiency of the fuel device in %age

3.3 CO_2 Mitigation

By considering different fuels (firewood/dung cake/charcoal/kerosene etc.), the CO_2 emissions from each fuel is calculated. In order to estimate CO_2 emissions from different fuel for a single household energy ($SPE_{annually}$), the following expression is adopted [14] as:

$$Q_{CO_2} = m_f \times c \tag{11}$$

where c = Fraction of carbon contents multiplied by 44/12. From above relation CO_2 emission are calculated for different fuels are mentioned in Table 4.4 [14, 15].

4 PAYBACK PERIODS

The payback periods have been computed by considering the equivalent savings in alternate fuels, viz. firewood, coal, kerosene, liquid petroleum gas (LPG) and electricity. The payback periods have been calculated by considering the compound annual interest rate, maintenance cost and inflation in fuel prices and maintenance cost per year.

The payback periods, N have been computed by the following relation [16, 17]

$$N = \frac{\log[(E-M)/(a-b)] - \log[(E-M)/(a-b) - C]}{\log[(1+a)/(1+b)]} \qquad (12)$$

The payback periods have been calculated by considering the following annual cost: interest rate, a = 10%; maintenance M = 5% of cost of plant; inflation rate, b = 5%, where C is the cost of biogas plant [18] and E is the energy saving per year (Rs.). By considering the equivalent savings in alternate fuels, viz. firewood, charcoal, kerosene, liquid petroleum gas (LPG), dung cake and biogas, estimated payback periods are shown in Fig 4.

5 CARBON CREDIT

Carbon Credit Trading (Emission Trading) is an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. Carbon credits are a tradable permit scheme. A credit gives the owner the right to emit one ton of carbon dioxide. International treaties such as the Kyoto Protocol set quotas on the amount of greenhouse gases countries can produce. Countries, in turn, set quotas on the emissions of businesses. Businesses that are over their quotas must buy carbon credits for their excess emissions, while businesses that are below their quotas can sell their remaining credits. By allowing credits to be bought and sold, a business for which reducing its emissions would be expensive or prohibitive can pay another business to make the reduction for it. This minimizes the quota’s impact on the business, while still reaching the quota. Credits can be exchanged between businesses or bought and sold in international markets at the prevailing market price. European and Japanese Companies were the major buyers and China was the major seller of the carbon credits in 2005-06. Demand of carbon credits continued to soar in 2006-07, resulting in an increase in the treaded rate of carbon credits. The present market rate is fluctuating at € 20-22 in the European Climate Exchange (www.europeanclimateexchange.com) [19].

5.1 Population in Rural Areas

There are 602 districts and 127800 villages in India based on 2005 statistics and as per 2001 census. Each village has more than 1000 population. Most population of India lives in rural areas. Therefore total population of rural areas was 127.8 million in the year 2001.

Present population is given by the equation [20],

$$P_n = P_0 \times (1+i)^n \qquad (13)$$

where P_n is population in the nth year, P_0 population in the 0th year (the year 2001; P_{2001}=127.8 million) [20] and i is the annual growth rate in the population, which equals to 2%.

The rural population in the current year will be as

$$P_{2010} = P_{2001} \times (1+0.02)^9 = P_{2001} \times 1.1951$$

$$= 127.8 \text{ million} \times 1.1951$$

$$= 152.733 \text{ million}$$

Then total number of families in rural areas $= \frac{1}{4} \times 152.733$ million

$$= 38.18 \text{ million.} \qquad (14)$$

5.2 Energy Required in Rural Households

The total energy for rural households is computed using eqn. (9) and (14) as

$$= 15312 \times 38.18 \times 10^6 \text{ MJ/annum}$$

$$= 584612.16 \times 10^6 \text{ MJ/annum}$$

$$= 162392.3 \times 10^6 \text{ kWh/annum}$$

6 RESULTS AND DISCUSSION

The Energy pay back times (EPBT) of horizontal and vertical biogas plants have been determined and are plotted along with different digester capacities as shown in Figure 1 and Figure 2

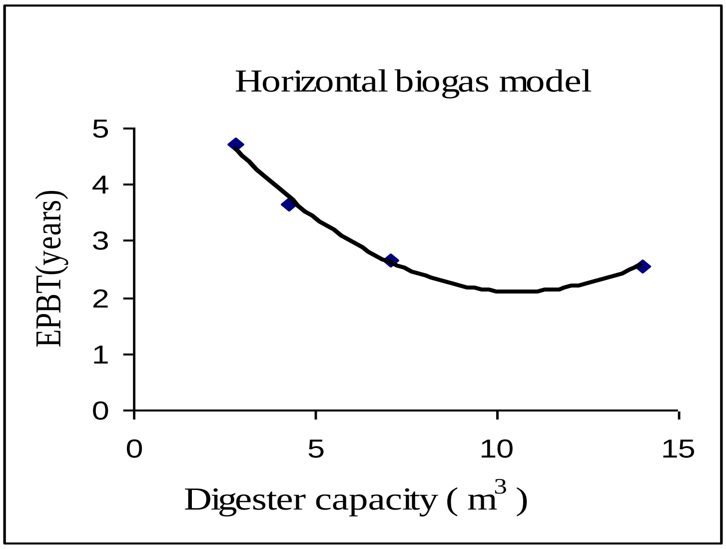

Fig. 1: **Variation of Energy Pay Back Time (EPBT) with digester size**

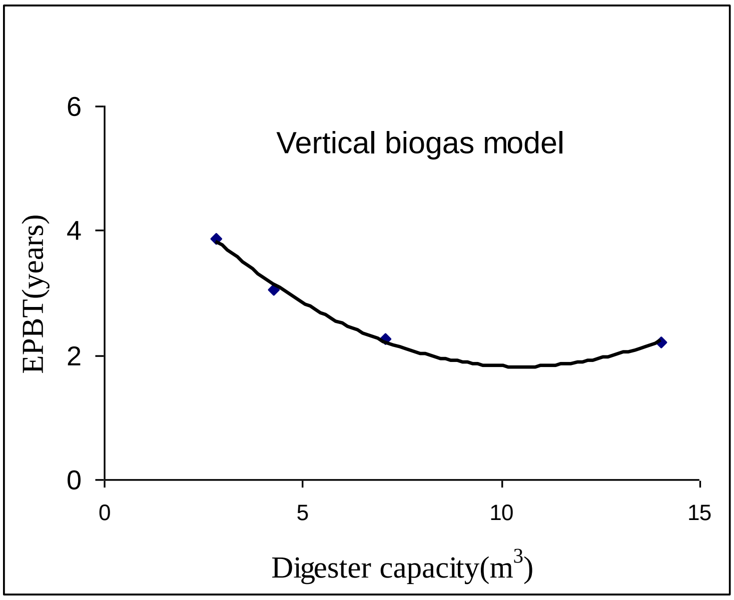

Fig. 2: **Variation of Energy Pay Back Time (EPBT) with digester size**

The Figures 1 and 2 show the variation of EPBT with digester size of biogas plant. From the graphs, it is observed that EPBT decreases significantly with increase in the digester capacities of plants.

Table 2 represents fuel saved, heating value of fuel, device efficiency, carbon contents in percents and CO_2 emission per annum for a single household.

Table 2: Fuel saved and Carbon dioxide (CO_2) emission

Types of Fuel	Heating Value	Device efficiency	Fuel Saved/yr	%Carbon contents	Amount saved	CO_2 emission
	kJ/kg	(%)	(kg or Litre)		per yr (Rs.)	(Kg/yr)
Firewood	19711	17.3	4490.32	48.68	13470.96	8014.92
Charcoal	29015	28	1884.74	85.20	18847.40	5887.93
Kerosene	38192	50	801.84	80.00	8018.40	2352.07
LPG	45560	80	420.11	83.45	10082.64	1285.47
Dung Cake	8606	15	11861.49	48.68	8896.12	21171.97
Biogas	22000	60	1160	42.24	12064	1796.60

From the results shown in Table 2, it is observed that it is observed that LPG is minimum CO_2 emitter followed by biogas and kerosene whereas biomass appeared to be highly polluted as far as CO_2 emissions are concerned.

There is a need to promote biogas technology in rural areas because of nonavailablity and costlier LPG. Therefore use of biogas as a fuel should be encouraged.

The exact payback periods have been computed from eqn. (12) with respect to different fuels and are shown in Figure 3. It is observed that the payback period is highest, i.e., 9.67 years, with respect to kerosene. The payback periods are in increasing order with respect to fuel: coal, firewood, LPG, biogas and kerosene.

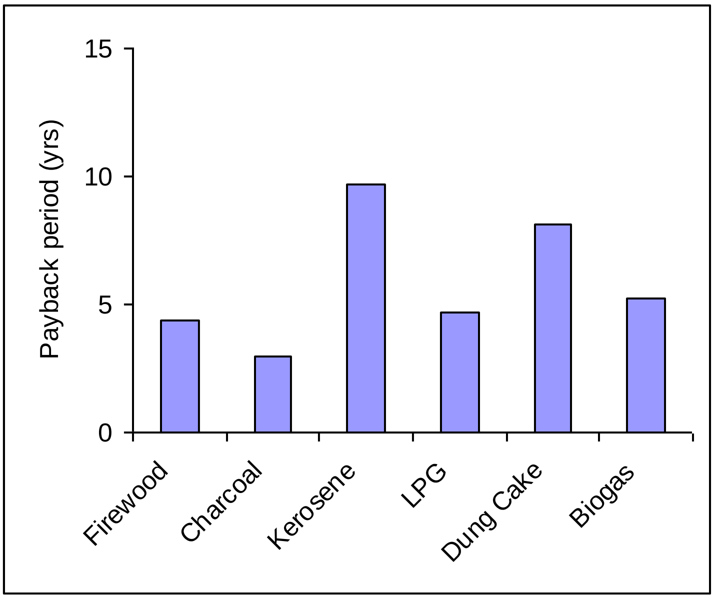

Fig. 3: Payback periods of biogas system

6.1 Carbon Credits Earned by Biogas System

The average CO_2 equivalent intensity for electric generation from coal is approximately 0.982 kg of CO_2 per kWh at source [21, 22]. However, 40% is transmission and distribution losses and 20% loss is due to the inefficient electric equipment used. Then the total figure comes to be 2.04 kg of CO_2 / kWh.

So, the CO_2 emission reduction = $2.04 \times 162392.3 \times 10^6$ kg = 331280.3×10^3 ton. If CO_2 emission reduction at present being traded @ € 20 / tons CO_2 [11], then CO_2 emission reduction by biogas system [11] comes to USD $(331280.3 \times 10^3 \times 20 \times 1.29202)$ = USD 8560.million per annum (where, 1€ = 1.29202 US dollar as on Jan 2012). Variation of carbon credit earned with household in rural areas is shown in Figure 4.

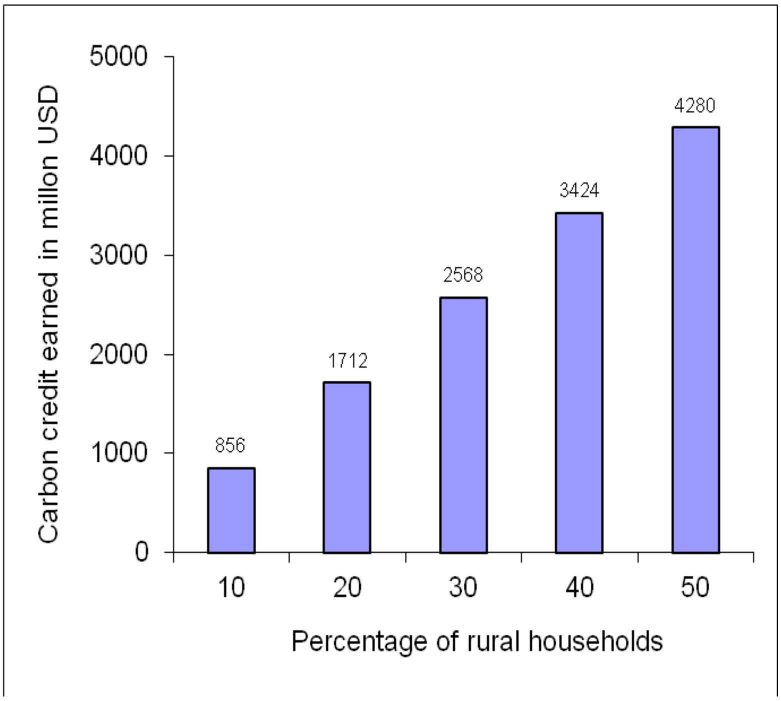

Fig. 4: **Variation of carbon credit earned with rural households.**

7 CONCLUSIONS

From the analysis the following conclusions can be drawn:

1. Biogas is environment friendly renewable source of energy (fuel).
2. The pollution caused by biogas is comparatively very less as compared to other biomass fuels.
3. Energy Pay Back Time decreases as the digester size of biogas plant increases.
4. Based on economic analysis, payback period is the least for coal, i.e. 2.93 years.
5. If this type of project is installed only in 20% of the Indian rural areas, then the carbon credit earned by the biogas system becomes Rs. 8900 crores annually.

REFERENCES

1. Garg H.P. Environment and Social Impact of Renewable Energy in India. Proceeding of 3rd International Conference on Solar Radiation and Day Lighting, 2007, p 544-53.
2. Ministry of New and Renewable Energy (MNRE; 2008a). "Estimated medium term {2032} potential and cumulative achievement as on 31.03.2008", www.mnes.nic.in
3. Prasad C.R. and Sathyanarayan S.R. Studies in biogas technology, Part III, Thermal analysis of biogas plants, Proceedings of Indian Acad. Sci., Part 3. 1979, p 377-386.
4. Kandpal T.C., Kumar A., and Purohit P. CO_2 mitigation potential of renewable energy technologies for domestic cooking in India. Proceedings of the National Conference on Advances in Contemporary Physics and Energy, 2002, p 390-401.
5. Chandra A. Distributed Energy Systems: Energy Pay Back Time and Environmental Benefits, Proceeding of 3rd International Conference on Solar Radiation and Day Lighting, 2007, p 269-277.
6. Chani P.S., Najamuddin and Kaushik S.K. Comparative analysis of embodied energy rates for walling elements in India, IE (I) Journal-AR, 87, 2003, p 47-50.
7. Das A., and Kandpal T.C. Energy Environment Implications of Cement Manufacturing in India, A scenario Analysis. Int. J. of Energy Research, 1997; 721(4): 299-308.
8. Reddy A.K.N., Prasad C.R., Rajabapaiah P. and Sathyanarayan S.P.C. Proceeding of Indian Acad. Sci. C, 1979; 2 (3): 387.
9. Venkatarama Reddy B.V. Sustainable building technologies, Current Science, 2004; 87(7): 890-907.
10. Tester J.W., Drake E.M., Driscoll M.J., Golay M.W, and Peters W.A. Sustainable Energy: Choosing Among Options, Prantice-Hall of India Pvt. Ltd. Publishing House, New Delhi, 2006.
11. Tiwari G.N. and Ghosal M.K. Renewable Energy Resources: Basic Principles and Applications, Narosa, 2005.
12. TERI, Source: Punjab Agricultural University, Ludhiana, 1982, p 38.
13. Mohd. Arif, Usmani J.A. and Chandra A. Energy Analysis of Biogas System, Proceeding of 1st International Conference on Advances in Energy Research, 2007, p 51-55.
14. Usmani J.A. Thermal Analysis, Performance Evaluation of Biogas System and Reduction of CO_2 emission, Ph.D. Thesis IITD, 1997, p 112-116.

15. Mohammad Arif and Avinash Chandra, “Energy, Environment and Economic Analysis of Biogas System”, International Research Journal of Material Sciences, 2008; 5 (2): 251-256.
16. Duffie J.A, Beckman W.A. Solar engineering of thermal processes. John Wiley & Sons; third edition. New York: 1991.
17. Bo¨er K.W. Payback of solar systems. Solar Energy, 1978; 20:225–232.
18. Mohammad Arif and Avinash Chandra. “Energy, Environment and Economic Analysis of Biogas System”. International Research Journal of Material Sciences.2008; 5(2): 251-256.
19. European Climate Exchange.www.europeanclimateexchange.com (accessed July 03, 2008).
20. Tiwari G.N. Solar Energy. CRC Press, New York, 2002.
21. Watt M, Johnson A, Ellis M, Outhred H. Life-cycle air emission from PV power systems. Progress in Photovoltaics Research Applications, 1998; 6: 127.
22. Nawaz I, Tiwari G N. Embodied energy analysis of photovoltaic (PV) system based on macro and micro level. Energy Policy, 2006 34: 3144.