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ECONOMIC IMPORTANCE OF BIOGAS IN INTEGRATED RURAL ENERGY SYSTEM

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ECONOMIC IMPORTANCE OF BIOGAS IN INTEGRATED RURAL ENERGY SYSTEM

ABSTRACT

This paper discusses the impact of dung availability and economic importance of biogas plants in Integrated Rural Energy System (IRES). Fixed Cost, maintenance cost, feed-stock cost and manpower costs of community biogas plant are presented. IRES selection for four villages using the Mixed Integer Linear Programming (MILP) optimization model is presented. Analysis of selection of IRES and energy costs with short term and long term policies of improving dung availability is given which highlights the importance of biogas plants in IRES and costs of energy to a village.

1. Introduction

The concept of Integrated Rural Energy Systems (IRES) is evolved out of the need to change from non-renewable to renewable energy sources and to promote change from energy dependence to energy autonomy at the village level. The main consideration, therefore, while designing IRES is to see that all the energy needs of the village are met with local resources and using renewable technologies. Thus one of the crucial consideration in selecting IRES is the resource endowment of a village since the locally available resources determine yhe type, scale and economy of the energy generating systems. As IRES meets energy needs of several end-uses, matching of local energy resources, i.e. energy supply with energy demand is crucial. The supply-demand gap if any may then be fulfilled by appropriate short term and long term strategies. The present paper discussed impact of availability of dung (i.e. biomass for biogas plant) in the selection of biogas plants and their economic importance in IRES.

2. Biogas Plant Costs

Fixed costs, maintenance costs, feedstock costs and manpower costs of three sizes of KVIC model community biogas plants are given below.

2.1 Fixed Costs

For three sizes of biogas plant fixed costs are as under :

Biogas Plant Size	Fixed Cost
25 m^3	Rs. 1,10,000
60 m^3	Rs. 2,20,000
85 m^3	Rs. 3,05,000

2.2 Maintenance Costs

Annual maintenance costs for three sizes of biogas plant are given below. These are estimated assuming that the biogas plants would require following periodic maintenance:

Nature of job		Frequence
a. Dome painting	:	Once in 4 years
b. Painting on pipes	:	Once in 3 to 4 years
c. Rubber tube replacement	:	Once in 4 years
d. Valve replacement	:	Once in 20 years
e. Main pipe replacement	:	Once in 2 years
f. Sludge cleaning	:	Once in 5 years
g. Leakage of holder	:	Once in 10 years
h. Leakage of inlet and outlet pipes	:	Once in 10 years.

The cost of above service would depend on the size of the plant. Table 1 indicates annual maintenance cost for biogas plants of sizes 25 m^3, 60 m^3, and 85 m^3.

Table 1

Annual Maintenance Cost of Biogas Plants

(Rupees)

Service	25 m^3	60 m^3	85 m^3
a. Dome painting	500	750	986
b. Painting on pipes	85	128	171
c. Rubber rube replacement	75	112	150
d. Valve replacement	250	400	500
e. Main pipe replacement	125	200	250
f. Sludge cleaning	400	700	900
g. Leakage of holder	900	1,100	1,950
h. Leakage of Input & output pipes	900	1,100	1,950
Total	3,235	4,490	5,857

2.3 Feedstock Costs

Feedstock costs for 3 sizes of biogas plants are given below. It is assumed that dung would be available at the rate of Rs. 0.02/kg. The daily requirement is estimated as 25 kg/m^3/day. Annual dung requirements and annual variable costs for different sizes of plants are as under :

Size	Annual Feedstock requirements	Annual Feedstock cost
a. 25 m^3	230 tonnes	Rs. 4,600
b. 60 m^3	550 tonnes	Rs.11,000
c. 85 m^3	775 tonnes	Rs.15,500

It is assumed that cost of water needed for mixing with dung is negligible.

.4 Manpower Cost

Labour is required in biogas plant operation for collection of dung, making slurry, feeding slurry and in collection of manure.

Besides there are some costs for periodic supervision and trouble shooting for different sizes of biogas plants. It is assumed that the community plant will be in operation through out the year and labour time required for 25 m^3, 60 m^3 and 85 m^3 plants respectively will be 3 hours, 5 hours and 7 hours per day. Considering labour rate of Rs. 2/- per hour and additional costs of supervision etc., the annual manpower cost will be as follows :

Plant size	Annual manpower cost
25 m^3	Rs. 2,500
60 m^3	Rs. 4,000
85 m^3	Rs. 5,600

4. Energy Resources, Systems and Needs

Energy in the village is required for different end-uses (needs). Various energy generating systems use energy resources to meet energy demand. Integrated energy system configuration at a village level must be decided on economic considerations, i.e. costs of different energy systems, level of resources available locally and energy needs. In Indian villages, major end-uses requiring energy are: (a) cooking, (b) water heating, (c) irrigation, and (d) electricity. Major local resources used for energy needs are fire-wood, agricultural waste and dung. Besides, solar and wind energy are also locally available. Energy resources such as kerosene, diesel and centralized electricity may also be available at a village. However, their costs are higher and they also result in drain on village surplus. As IRES aims at reducing energy dependence of village, in planning for IRES centralized resources should be considered only for fulfilling energy supply-demand gap not fulfilled by local resources. Figure 1 shows the energy resources, energy systems and energy needs relationship.

4. Economic Selection of Energy Systems

Integrated Energy System selection for four villages is considered here. A Mixed Integer Linear Programming (MILP) optimization model (Shukla and Moulik, 1984) is used for selection of energy systems and distribution of energy to different end-uses. The economic criterion used is minimization of annual cost, i.e., the sum of annual fixed costs, which includes depreciation, interest and maintenance cost, and annual running cost of the system. For each village optimal selection of energy system and distribution of energy is achieved by using MILP computer package (Land and Powell, 1973).

4.1 Energy Related Data

For the four villages considered, annual energy requirements and resource availability are given in Tables 2 and 3.

Figure 1 : Interrelationship of Energy Resources, Energy Systems and Energy Needs

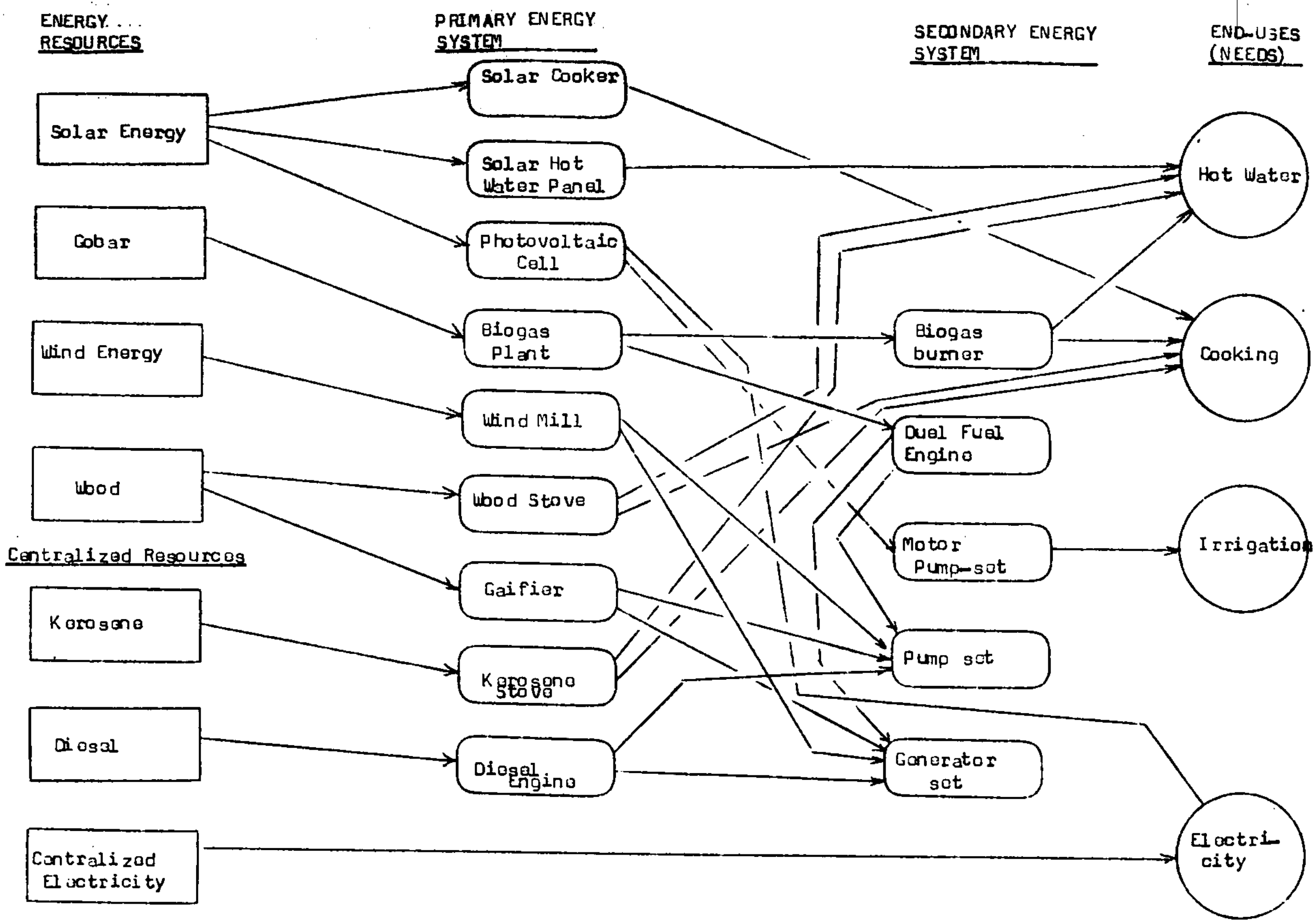

Table 2

Annual Energy Requirement (in KWh) for Four Indian Villages

End-use Type	Village			
	1	2	3	4
Cooking	210,000 (76.53)@	435,000 (74.49)	705,000 (73.55)	1,411,200 (74.83)
Hot Water	34,000 (12.39)	75,840 (12.98)	122,400 (12.77)	245,400 (12.03)
Irrigation	8,700 (3.19)	7,500 (1.28)	42,000 (4.38)	66,500 (3.53)
Electricity	21,675 (7.89)	65,670 (11.25)	89,100 (9.30)	160,200 (8.51)
Total	274,375 (100)	584,010 (100)	958,500 (100)	1,883,300 (100)

Note: @ Figures in brackets represent percentages of total energy requirement for a particular village.

Table 3

Annual Availability of Raw Materials (in KWh) at Four Villages@

Raw Material	Village			
	1	2	3	4
Dung	187,000	281,000	437,000	313,000
Wood	1,400,000	562,000	605,000	2,907,000

Note: @ The figures in this table represent the potential energy availability from a raw material. The actual energy availability at the demand level is then computed by considering efficiencies of the energy systems used.

Energy Systems

Energy systems are classified in two major categories - primary and secondary. Primary systems generate energy whereas secondary systems are sometimes used to supply energy produced by a primary system to a given end-use. Of the various energy systems available some were eliminated from consideration for the present application on the basis of their present high costs (e.g. photo voltaic system). A description of energy systems and sizes considered here and the end-uses supplied by them are given in Tables 4 and 5.

Table 4

Primary Energy Systems, Sizes and End-use

	Description	Size	End-use that can be supplied by the Energy System
1.	Biogas Plant	5 m^3 25 m^3 60 m^3 85 m^3	1, 2, 3, 4
2.	Solar Cooker	-	1
3.	Solar Hot Water Panel	250 Litres	2
4.	Wood Burner	-	1, 2
5.	Kerosene Stove	-	1, 2
6.	Wind Mill	3 KW, 10 KW	3
7.	Diesel Pump Set	5 KW, 10 KW	3
8.	Diesel Generator Set	5 KW, 10 KW	4
9.	Centralized Electricity	-	3, 4
10.	Gasifier	5 KW, 10 KW 25 KW	3
11.	Gasifier Generator Set	5 KW, 10 KW 25 KW	4

Table 5

Secondary Energy System and Sizes

Description	Size
1. Biogas Burner[a]	..
2. Dual-fuel Engine and Pump-set[b]	5 KW
3. Dual-fuel engine and Generator Set[c]	5 KW, 10KW
4. Motor and Pump-set[d]	5 KW

Notes: [a] Used for cooking when using biogas.

[b] Used for irrigation when using biogas and diesel.

[c] Used for electricity generation when using biogas and diesel.

[d] Used for irrigation when using centralised electricity.

Optimal Results

Optimal systems selection, energy allocation and costs under existing data (hereinafter called normal data) for the four villages are given in Tables 6, 7 and 8.

Analysing the optimal solution for four villages, we find that dung was used up in all four villages (i.e. constraint relating to dung had no slack at optimality) and wood was used up in all villages except village 1 where energy plantations are raised and hence wood is available in abundance. Scarcity of these local resources leads to use of costly fuels like kerosene and diesel (see Table 5) which results in substantial increase in unit variable costs for villages 2, 3 and 4 compared to village 1 (see Table 8). The implications of

Table 6

Energy Systems Selected for Four Villages (Normal Data)

Energy Systems	Number of Systems Village 1	2	3	4
Primary System				
1. Biogas Plant, 25 m^3	-	-	2	-
2. Biogas Plant, 85 m^3	1	2	2	2
3. Solar Cooker	102	309	419	754
4. Solar Hot Water Panels	7	17	28	56
5. Wood Burner	102	309	419	754
6. Kerosene stove	-	309	419	754
7. Diesel Pump-set, 5 KW	-	-	1	-
8. Diesel Pump-set, 10 KW	1	1	4	7
9. Diesel Genset, 5 KW	-	1	-	-
10. Diesel Genset, 10 KW	1	-	-	1
11. Centralized Electricity, 5 KW	1	4	6	10
Secondary System				
1. Biogas Burner	102	309	419	754

Table 7

Allocation of Energy for Four Villages (Normal Data)

End-use	Energy Systems	Annual Energy Consumption (KWh) Village 1	2	3	4
Cooking	Biogas	89,340	153,410	226,710	168,500
	Solar Cooker	70,000	145,000	235,000	470,400
	Wood Burner	50,660	35,130	37,810	181,700
	Kerosene Stove	-	101,460	205,460	590,600
Hot Water	Solar Hot Water	35,000	83,400	136,800	273,800
	Wood Burner	1,600	-	-	-
	Kerosene Stove	-	530	-	200
Irrigation	Diesel Pump-set	8,700	7,500	42,000	66,600
Electricity	Diesel Genset	6,675	5,670	-	10,200
	Centralized Electricity	15,000	60,000	89,100	150,000

Table 8

Costs Obtained Using Optimal Solution for Four Villages (Normal Data)

(Rupees)

Costs	Village 1	2	3	4
1. Fixed (capital) Cost	440,540	1,199,860	1,844,315	3,087,980
2. Total Annual Cost	153,175	424,259	760,934	1,426,368
3. Annual Variable Cost	43,040	124,297	245,855	654,373
4. Unit Cost of Energy (Rupees/KWh)	0.558	0.726	0.737	0.757

biomass (wood and dung) availability on selection of energy system and energy costs is reported elsewhere (Shukla and Moulik, 1986). In the following sections we consider the impact of dung (or any biomass usable as feedstock for biogas plant) availability and the significance of biogas plants in integrated rural energy systems.

5. Impact of Dung Availability

In considering the dung availability in villages in Table 3, it was assumed that only fifty percent of available dung could be collected. Also only dung was considered as suitable feedstock in these estimates of Table 3. In both these regards, appropriate policy of improved dung collection (in short-run) and developing alternate biomass as biogas plant feedstock (in long-run) can result in increased availability of dung. In the following we considered the importance of such policies on integrated energy system selection and energy costs to the village.

5.1 Improved Dung Collection (short-run policy)

Assuming that a short-run policy resulting in improved collection of dung may result in seventy-five percent dung collection rather than fifty percent as assumed earlier. The dung availability for four villages then would be as in Table 9.

Table 9

Annual Availability of Dung (in KWh) with Seventy-five Percent Collection

	Village			
	1	2	3	4
Dung	280,500	421,500	655,500	469,500

Considering dung availability constraint as per Table 9, and keeping all other data as before, the optimal results for the four villages are as in Tables 10 and 11.

Table 10

Energy Systems Selected for Four Villages with Improved (75%) Collection

Energy Systems	Number of Systems			
	Village			
	1	2	3	4
Primary System				
1. Biogas Plant, 5 m^3	-	-	1	2
2. Biogas Plant, 25 m^3	2	-	-	-
3. Biogas Plant, 60 m^3	-	2	1	1
4. Biogas Plant, 85 m^3	1	1	3	2
5. Solar Cooker	102	209	419	759
6. Solar Hot Water Panels	7	17	28	56
7. Wood Burner	-	309	419	759
8. Kerosene Stove	-	309	419	759
9. Diesel Pumpset, 5 KW	-	1	1	-
10. Diesel Pumpset, 10 KW	1	-	3	7
11. Diesel Genset, 5 KW	-	1	-	-
12. Diesel Genset, 10 KW	1	-	-	1
13. Centralized electricity, 5 KW	1	4	6	10
Secondary System				
1. Biogas Burner	102	309	419	754
2. Duel-fuel Engine with Pumpset, 5 KW	-	1	2	-

Table 11

Annual Costs and Savings for Four Villages with Improved (75%) Dung Collection

(Rupees)

	Village 1	2	3	4
Annual Cost	144,985	393,739	651,576	1,382,168
Annual Savings	8,190	30,520	109,358	44,200
Savings (%)	5.34	7.19	14.37	3.10
Unit Cost of Energy (Rupees/KWh)	0.528	0.674	0.680	0.734

Analysing the optimal results we find the following :

1. For all four villages increased dung available is also completely used up, i.e. the constraint relating to dung in all four villages has no slack at optimality. In energy system selection, comparing Table 10 with Table 6, we find that additional biogas plants replace some other energy systems. For example, for village 1, biogas replaces wood for cooking and water heating and for villages 2 and 3, dual-fuel engine with generator set is selected to supply part of the electricity requirements.

2. Comparing Table 11 with Table 8, we find that cost of energy for each village decreases, from about three percent for village 4 to fourteen percent for village 3.

3. Thus, increased availability of dung from fifty to seventy-five percent has significant impact on reducing the unit energy cost. All the dung is used up at optimality, it can be concluded that further improvement in dung availability will also result in additional saving. In the next section, we consider the impact of making dung availability unrestricted.

5.2 Developing Alternate Feedstock for Biogas Plants (Long-run Policy)

Considering that in long-run alternate biomass are developed as feedstock for biogas plant, the dung availability can then be taken as constrained. Removing the dung availability constraint and keeping all other data as before, the optimal results for the four villages are as in Tables 12, 13 and 14.

Comparative analysis of the optimal results with unrestricted dung availability given in Tables 12, 13 and 14 with optimal results with normal data given in Tables 6, 7 and 8 suggests the following:

1. Biogas supplies most of the cooking demand for all four villages. Use of kerosene is completely eliminated from all four villages.

2. Biogas replaces solar hot water panels to meet most of the energy demand for water heating.

3. For irrigation and electricity demand, all other systems are eliminated and only biogas based duel-fuel engines are used coupled with pumps for irrigation and generators for electricity.

4. Energy costs are reduced from twenty to forty percent for different villages. Unit energy cost reduces from about Rs. 0.72/KWh in most villages to about Rs. 0.48/KWh. This means that unrestricted availability of dung can result in significant reduction in energy costs to the village.

5. From the above observations it is clear that if dung is freely available it is optimal to supply most of the village energy needs through biogas-based systems.

6. Table 12 shows that with free availability of dung, decentralized and renewable energy systems are mainly selected for all villages inspite of availability of completing centralized energy systems.

Table 12

Energy Systems Selected for Four Villages with Unrestricted Dung Availability

Energy System	Number of Systems			
	Village			
	1	2	3	4
Primary System				
1. Biogas Plant 25 m^3	-	1	-	-
2. Biogas Plant 85 m^3	2	6	10	15
3. Solar Cooker	102	-	-	754
4. Wood Burner	102	309	419	754
Secondary System				
1. Biogas Burner	102	309	419	754
2. Dual-fuel Pump set, 5 KW	2	2	9	14
3. Dual-fuel Genset, 5 KW	-	1	-	-
4. Dual-fuel Genset, 10 KW	2	-	-	1
5. Dual-fuel Genset, 25 KW	-	2	3	5

Table 13

Allocation of Energy for Four Villages with Unrestricted Dung Availability

End-use	Energy Systems	Annual Energy Consumption (KWh) Village 1	2	3	4
Cooking	Biogas	86,060	349,500	475,545	740,133
	Solar Cooker	70,000	-	-	-
	Wood Burner	53,940	85,500	229,455	200,667
Hot Water	Biogas	24,000	41,100	122,400	72,200
	Wood Burner	10,000	34,940	-	173,200
Irrigation	Dual-fuel Engine Pump set	8,700	7,500	42,000	66,600
Electricity	Dual-fuel Engine Genset	21,675	65,670	89,100	160,200

Table 14

Annual Costs and Savings for Four Villages with Unrestricted Dung Availability

(Rupees)

Costs	Village 1	2	3	4
Annual Cost	121,973	144,695	251,455	581,953
Annual Savings	31,202	279,564	509,479	844,415
Savings (%)	20.37	34.10	33.04	40.80
Unit Cost of Energy (Rupees/KWh)	0.444	0.475	0.475	0.448

Before concluding, a caveat should be entered at this stage about various assumptions made in relation to large size community plants.

Firstly, given the hetrogeneity in relation to caste-class division in most of the Indian villages, operating a truly community-managed biogas plants often becomes an insurmountable problem. In fact, in most situations, clash of interests among various caste-class groups results in conflicts to a level when smooth operation of a large-size community plant becomes well-nigh impossible (Moulik, et. al., 1984). Instead it may be advisable to have medium-sized biogas plant (say, upto 15 m^3) serving a homogenous caste-class-wise neighbourhood or hamlet group. This means, a number of medium-sized neighbourhood plants in a village, depending on clusters of homogenous neighbourhoods.

Secondly, the assumption of dung price of Rs. 0.02/kg seems to be on a lower side. In fact, given the caste-class conflicts as mentioned above, the villagers generally tend to hike the price of dung once a large size biogas plant is established, eventhough they might have agreed to a much lower price before the plant is constructed. The realistic price of dung would be around Rs. 0.08 to Rs. 0.010 per kg. However, this would not affect the results discussed above since the higher price of dung will be off-set by higher price of slurry.

Thirdly, in our calculations we have assumed price-free water. The amount of water needed daily for a large-size plant is quite substantial. Many villages in India, particularly, in drought-prone areas, have serious scarcity of water. On the other hand, given the large quantity of water needed daily, the water sources should necessarily be near the plant site in order to avoid transportation cost. It would, therefore, be pragmatic to consider a price for water which may either be calculated on the basis of labour cost for transportation or the opportunity cost of water supplied to the biogas plant.

6. Conclusions

Nothwithstanding the caveat mentioned above, the results reported in this paper suggest that :

1. Decentralized and renewable energy systems are economically viable if local resources are made freely available. Availability of dung has considerable impact on the selection of energy systems and energy costs.

2. If dung is freely available, then biogas based systems are most economical. In such situations, in the economic selection of IRES, biogas systems shell supply significant portion of village energy needs.

3. The unit cost of energy of IRES with biogas based systems can be very low compared to centralized systems. Also, the centralized energy systems such as electricity require very high fixed costs and results in considerable drain on village surplus.

4. Developing alternate feedstock for biogas plant and programmes for improving dung availability have tremendous economical potential and deserves serious immediate attention from agencies planning for rural energy needs.

5. Besides developing alternate biomass resources, technological aspects like improvement in energy system technologies and managerial aspects like economical planning for growing energy demands, maintenance of IRES, etc. are also critical for the success of IRES.

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