A rural energy system based on energy forest and wood gasifier

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A decentralized electricity generation system using a 5 kW wood gasifier has been installed for electrification in a non-electrified village. All the 43 houses in the village are provided with two lighting points each in addition to eight street lights. An energy forest has been raised and an annual productivity of 6.4 tonnes per hectare has been recorded compared to an annual wood fuel requirement of 5.1 tonnes for the gasifier. A diesel substitution level of 73% has been achieved in the field. The use of electricity for lighting has saved 0.803 tonne of kerosene per year in the village. Economic analysis has been carried out for the wood-gas-based system. The study has demonstrated the technical feasibility of a decentralized electricity generation system based on renewable source of energy which has been accepted by the village community.

In remote rural settlements the basic energy needs, apart from energy for cooking, are electricity for lighting and shaft power for pumping water (drinking and irrigation) and flour milling. Such settlements are located away from the power grids and the loads would be low. Thus, in view of the long distance over which the electricity has to be transmitted to remote villages and the low loads involved, the approach of the centralized generation and grid transmission is inefficient and involves relatively higher transmission and distribution losses compared to supplies of large loads to nearby load centres[1]. The cost of transmission lines is also high (Rs 20,000/km of 11 kV lines). Thus, one of the options for meeting the energy needs of home electrification, pumping, flour milling, etc. in rural settlements could be to shift to decentralized electricity generation systems based on renewable sources of energy. There are several options like wood-gas, biogas and solar energy systems. In this paper, a wood-gas-based system is considered for village electrification. A small wood gasifier of 5 kW capacity has been developed at ASTRA, Indian Institute of Science[2]. A field experiment was undertaken with the following objectives: (i) To experiment with a decentralized electricity generation system using a small wood gasifier (of 5 kW) for electrification of a non-electrified village. (ii) To grow an energy forest to supply wood in a sustainable way and to make the energy system self-reliant. (iii) To study the performance of the wood gasifier and its technical feasibility and economic viability. (iv) To develop and implement a local management system involving the village community for the operation and maintenance.

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Hosahalli, a backward and non-electrified village in Tumkur district (100 km from Bangalore) with a population of 267, was selected. Group meetings were held with the village community and they agreed to the project proposal. They provided land for growing an energy forest and for the generator room. Using the project funds (i) an energy forest was raised, (ii) a generator room was built, (iii) wiring of all the households was carried out and (iv) two village youths were trained to operate the system. The woodgasifier–diesel engine–genset system has been in operation since May 1988.

Connected load

The village community agreed for two lighting points for each house and lighting for 4 to 5 h per day. Load in kW = 43 houses × (1 × 40 W flourescent tube + 1 × 15 W bulb) + 8 street lights × 40 W flourescent tube = 2.685 kW or 10.74 kWh/day considering 4 h of lighting. Considering a load of 2.685 kW a 3.7 kW diesel engine genset was installed.

Energy forest for sustainable supply of wood fuel

The basic concept was not to deplete the existing stock of local biomass or to import biomass. Given a load of 10.74 kWh/day and 1.3 kg of wood/kWh, the wood requirement is 14 kg/day and 5.1 t/year. Energy forest was planted on a plot of 2 ha of wasteland to supply wood in a sustainable way. The species composition and density are as follows:

Leucaena leucocephala	: 2023
Dalbergia sissoo	: 1357
Eucalyptus hybrid	: 1147
Cassia siamea	: 679
Acacia auriculiformis	: 580
Casuarina equisetifolia	: 814
Total trees per ha	: 6600

The annual and coppice productivity are given in Table 1. It has to be noted that the energy forest did not receive any irrigation, or fertilizer or weeding. The organic matter content of the topsoil is 1.8% and the total annual rainfall during the two years was 89 and 85 cm. To supply the annual requirement of 5.1 t of wood in a sustainable way for the given load, about 1 ha of energy forest is adequate.

Operation of the system

Two trained youths from a nearby village are operating the system. The operation of the gasifier involves obtaining small twigs from the energy forest and cutting them to 4 × 2 × 2 cm dimension. Labour required for procurement and preperation of 14 kg of wood chips required per day is 4 h in the total manual mode and 2.2 h using a 0.75 kW cutter. Thus, the operator can prepare wood during the 4 h of gasifier operation for lighting even in manual mode.

Operation cost

The operation cost is given in Table 2. When the diesel and labour cost are included the cost is Rs 1.22/kWh. Since wood is available from energy forest the operation cost to the village community is Rs 392/month or Rs 9/household/month. The villagers have agreed to pay Rs 6/household/month. However, the repair and replacement costs are not included.

Table 1. Productivity of the energy forest.

	Total productivity dry t/ha	Productivity dry t/ha/yr
At 12 months	6.96 t	6.96
At 24 months	12.90 t	6.45
Coppice yield between 12 and 24 months	—	4.50

Table 2. Operation cost of the wood-gas-based electricity generation system.

Inputs	Qty/kWh	Cost/kWh	Cost/month (Rs)
Diesel	130 ml	0.52	167
Labour for wood preperation and operation*	0.37 h	0.70	225
Total	—	1.22	392

*Even though 4 man hours are adequate for the operation of the system, currently more labour is employed in the field as the second phase of the project is still being implemented.

Performance of the wood gasifier

One of the aims of the project was to monitor the performence of the 5 kW gasifier over longer hours of operation in the field. For this purpose two gasifier units were installed and used alternatively. Performance results are shown in Figure 1 for 8 months during 1989.

1) Wood consumption for the 5 months out of 8 months is between 1.2 and 1.4 kg/kWh. During May to July it was slightly high due to the air nozzle failure. 2) The ratio of hours run in dual-fuel mode to total hours operated ranged between 71 and 91.8%. This shows that barring the first and last 15 min the diesel engine was run in dual-fuel mode for most of the time. 3) Diesel replacement averaged over the month range between 66.9% and 76.8% over a period of 8 months under consideration. 4) A problem in the form of gas valve failure in the damper was noticed. The major problem in the form of air nozzle failure was noticed after 825 and 790 h of operation of gasifier-1 and gasifier-2 respectively. The steel welding at the joint cracked. In response a new design to overcome the problem has been developed[3]. No other system problem was faced with respect to the gasifier.

Economic analysis of the wood-gas-based electricity system

The wood-gas system to be replicable must be economically viable. Economic analysis is carried out using the discounted cash flow (DCF) technique namely net present value (NPV) method. (NPV = Present value of life cycle benefits − Present value of total life cycle costs.)

The spread sheet used for the DCF analysis of a biogas system[4] has been used here. Total life cycle cost

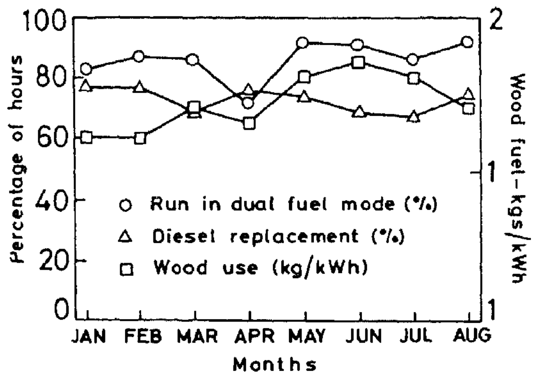

Figure 1. Wood use per kWh, diesel replacement and hours in dual-fuel mode.

is the sum of present values of all the costs throughout the life of the project. The life cycle benefits are calculated from the sale of electricity. The unit cost of sale of energy (Rs/kWh) is computed by setting NPV = 0 and solving for the unit cost of energy. The unit cost of energy is calculated taking a discount rate of 12% for the wood-gas-based system and is compared with a diesel-based system of similar capacity. The details of capital cost and operational cost are given in Table 3 and Table 2 respectively. The unit cost of energy (Rs/kWh) at different levels of capacity utilization is given in Figure 2.

At the current level of operation of 4 h/day, the wood-gas system would be economical only if electricity is priced at Rs 3.50/kWh. When the effect of different hours of operation on the unit cost of energy is considered, it can be observed from Figure 2 that the unit cost of energy decreases as the hours of operation increases for wood-gas as well as for diesel systems. Beyond 5 h of operation/day the unit cost of energy for wood-gas system becomes cheaper than that for the diesel system.

It has to be noted that the small wood gasifier design is still in its initial development stage and cost reductions are possible through design improvements. The economic viability could be improved further; (i) by matching the gasifier-diesel engine capacity (5 kW) with the generator capacity (5 kW) as currently a 3.7 kW generator is connected and (ii) by increased capacity utilisation through diversifying the use of gasifier system for meeting the other energy needs like pumping water and operating a flour mill leading to increased capacity utilization.

Table 3. Capital cost of 3.7 kW wood-gas-based and diesel system.

	Woodgas system	Diesel system
Gasifier	16,000	—
Engine + genset	28,600	28,600
Voltage stabilizer + accessories	6,000	6,000
Wood cutter	3,000	—
Building	5,000	5,000
Energy forest	5,000	—
Total	63,600	39,600

Life of the gasifier and engine is taken to be 50,000 h and 20,000 h respectively. The diesel engine has to be overhauled every 5000 h. Annual maintenance cost is taken as 5% and 10% for the gasifier and engine respectively at an operational level of 20 h/day.

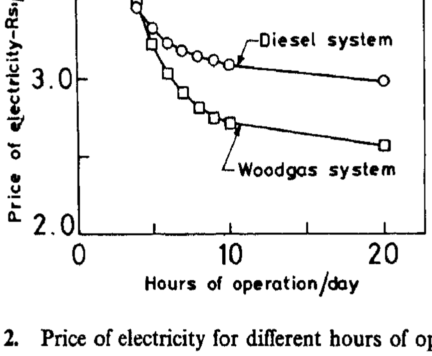

Figure 2. Price of electricity for different hours of operation.

Management of the decentralized system

The decentralized systems have to be managed at decentralized level. A committee consisting of four local members and a local government official has been formed. The functions of the committee are: (i) Protection of energy forest and generation units, (ii) Supervision of operation and operators, and (iii) Assistance for collection of charges and maintenance of accounts. The committee is partially managing the systems now.

Problems and prospects of decentralized system

The field experimentation has demonstrated the technical feasibility of the decentralized electricity generation system based on renewable source of energy. In addition, the Hosahalli experiment has demonstrated the following:

Acceptance by the community. Even though the neighbouring villages are connected to grid electricity, the Hosahalli Community has accepted the decentralized wood-gas-based system.

Equitable distribution. The whole community has accepted two lighting points equally for all houses irrespective of the economic or social status.

Sustainability. All the woodfuel required is being grown locally making the system self-sustainable and environmentally sound.

Saving kerosene. Reduction in kerosene consumption from a pre-electrification level of 1512 l/year to insifignificant level has been achieved. However 504 l of diesel is used annually for the dual-fuel engine. Thus annually there is a net saving of 0.803 t of oil, a non-renewable source of energy, in addition to improving the quality of lighting. (This point was made during the KSCST Seminar on Power Generation, 1989.)

Such decentralized systems have several obvious advantages over centralized generation and transmission systems especially for remote locations: (i) The cost of transmission lines for connecting the remote village to the grid is saved. (ii) The transmission and distribution losses (22 to 24%) are avoided especially in low load situations. (iii) Adverse environmental impacts associated with large centralized systems are avoided. (iv) Decentralized systems lead to local skill and employment generation and more importantly to self-reliance of the village community. (v) It is a renewable system as wood-gas system is based on wood fuel.

However some problems could be visualized for large scale replication of wood-gas-based electricity generation systems: (i) The land required for growing an energy forest may not be available in some situations. (ii) The village community may not always be enthusiastic about shouldering the responsibility of operation and management of the system and (iii) At present the system is not yet economically viable though possibilities exist for the near future.

Village community has demanded pumping drinking water and operation of a flour mill using the wood-gas system. This phase is in progress. It would lead to increase in hours of operation and further improving the economic viability. It is hoped that the community would take full responsibility in the management of the system after the completion of this phase. A similar decentralized electricity generation system based on biogas has been in operation since August 1987 in Pura village 8 km from Hosahalli[4]. Thus decentralized renewable energy systems for meeting all the village energy needs are becoming feasible options.

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2. Dasappa, S., Mukunda, H. S., Baliga, B. N. and Srinivasa, U., *Sadhana*, 1989, **14**, 187.
3. Dasappa, S., Ramesh, V. and Krishnan, V., Proceedings of the First National Meet on Recent Advances in Biomass Gasification, IIT, Bombay, 1989, pp. 138–149.
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ACKNOWLEDGEMENTS. We thank Prof. K. S. Jagadish for his support in the implementation of the project. We acknowledge the technical assistance provided by Prof. H. S. Mukunda and Dr U. Srinivasa for their comments on the earlier draft. We also thank Prof. A. K. N. Reddy and Prof. Madhav Gadgil for their comments and P. Balachandra for assistance for economic analysis. We thank CAPART for funding the project.