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Model for empowering rural poor through renewable energy technologies in Bangladesh

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Abstract

This paper proposes an integrated ecological, economic and social model to assist sustainable rural development in villages in Bangladesh. In the model, renewable energy technologies (RETs) create income-generating activities for male landless and marginal farmers and for women from such households, while reducing environmental problems, like deforestation and indoor air pollution from cooking with poor-quality fuels. Because of the high capital costs of RETs, the model proposes an extension of the well-known micro-credit approach developed by such NGOs as the Grameen Bank and BRAC. With the assistance of an External Agency composed of NGO, business, government and university representatives, such groups of villagers would form Village Organizations, comprising cooperatives or other forms of business, borrow money from a bank or large NGO, and purchase a RET based on biogas, solar or wind, depending upon location. By selling energy to wealthier members of the village, the Village Organizations would repay their loans, thus gaining direct ownership and control over the technology and its applications.

Keywords: Cooperative; Environment and development; Micro-credit; Renewable energy technologies; Rural poor; Sustainable development

1. Introduction

Renewable energy technologies (RETs) offer developing countries some prospect of self-reliant energy supplies at national and local levels, with potential economic, ecological, social, and security benefits. Some RET models have already been implemented in rural communities of developing countries such as India, Nepal, and China (Bajracharya et al., 1991; Venkataramana, 1992; Rajabapaiah et al., 1993; Shangbin, 1993). However, these models do not specifically allow the poorest peasants control over RETs and the income generated by them. A model for rural electrification in Pacific Island States has been implemented by the Australian NGO, APACE, addressing specifically Melanesian conditions for the rural poor (Bryce, 1997; McMurray, 1998). Philips recently developed a model for implementing hybrid renewable energy-based rural electrification for Indonesian rural co-operatives with revenue being collected through a rural bank (Phillips, 1998). The cooperative would manage electricity generation projects, and rural people would prepay for electricity purchased. Here, the cooperative acts as a manager rather than an income generator.

This paper proposes a model for more equitable development in rural Bangladesh, via income generation from RETs. The model may allow the landless and the more marginal rural peasants a mechanism for ownership of RET businesses by forming cooperatives or other forms of business with finance provided by banks and large NGOs.

Bangladesh is a small country of 143 thousand square kilometres. Its dense population (842 people/square kilometre) is increasing by 1.8% p.a. (FAO and WEC, 1999a,b). GDP per capita is low compared to that in other developing countries of the region. Although it has an agriculture-based economy, it imports 1.8 million tonnes of food p.a. along with fuels, chemicals and machinery (WFP, 1999). Jute, tea and leather are the main exports. Garments and fish have recently been popularised because of cheaper labour, but export

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income remains at around half the cost of imports (BBS, 1998). Rural Bangladesh is a focus of the country's socio-economic development plan. Whereas the agricultural sector contributes 36% of total GDP, it employs 65% of the total population (BBS, 1995), and about 85% of people live in rural areas, depending mainly on agriculture for their survival.

The agricultural output per family has declined in recent decades due to continuous fragmentation of land that arises from population pressure and the Muslim law of inheritance. The average family farm size declined from 1.43 ha in 1969 to 0.91 ha in 1984 (Chowdury, 1989). Under these circumstances, the income from crop production is not enough to allow marginal and small households[1] to subsist. They are 'deficit households', with expenditure on basic needs exceeding their agricultural income. To meet the deficits, they usually work as agricultural labourers in larger farms during the peak season and necessarily accept any other work at other times. Since hired agricultural positions are limited, exploitation accompanies a lack of bargaining power (Eusuf, 1997).

Alternatively, 'deficit households' sometimes establish credit relationships with the few 'surplus households', thus creating a mechanism for transferring land from poor to rich households. Their capital stock in land is mortgaged to wealthier people with loans to fulfil recurrent expenditure needs. Such a continuing marginalisation process pushes an increasing number into the ranks of the landless. It is evident that the percentage of rural people who are landless has increased from 25% in 1960 to 42% in 1977, to 46% in 1984 and to 50% in 1998 (Chowdury, 1989; FAO and WEC, 1999a,b). Land is increasingly accumulated by 'surplus households', whose agricultural output per hectare and economic returns to the rural sector are both low on account of inappropriate agricultural methods. About 8% of all rural households control almost 48% of all the cultivable land, and 50% of marginal land owners hold 3.7% of the total acreage (Blair, 1985).

Accordingly, social inequality is created between two groups: landless and marginal farmers on one hand, who depend heavily upon the other group, the rural rich (Jensen, 1986). The inequality of bargaining power produces wage levels inadequate for fulfilling the nutritional requirements of a poor family. Thus, many landless people migrate to urban areas where they again compete for scarce resources and limited opportunities (Chowdury, 1989).

[1] Households are classified as either landless, or marginal farmers (occupying areas between 0.02 and 0.39 ha), or small farm households (occupying areas between 0.4 and 0.99 ha), or medium farm households (occupying areas between 1.0 and 2.98 ha) or large farm households (more than 3.0 ha) (Haque, 1993).

This increasing social inequality is a national problem with wide-ranging implications. Waddell sees the key constituents of a sustainable economic development strategy as *meeting basic needs*, *decentralisation* and *appropriate technology* (Waddell, 1993). Moreover, sustainable development has interconnected economic, social and ecological facets: 'Sustainable development comprises types of economic and social development which protect and enhance the natural environment and social equity' (Diesendorf, in press).

Ecological imbalance is an important consequence of the poverty-directed spiral discussed above, as poor people depend increasingly on low-grade fuel for their subsistence. Appropriate technology elements of a solution need to address energy supply in the prevailing social and economic context.

According to UNDP (1995), poverty reduction, gender equity and sustainability are important objects for development. The most successful efforts in alleviating poverty have made efficient use of labour and have invested in the human capital of labour (Siddique, 1994). Accordingly, the technologies for income generation are best applied so as to empower rural poor, investing their indigenous skills and resources to meet their own and local needs.

Rural women suffer more from poverty[2] than men, due to social custom and religious belief (Siddique, 1996). Although women participate more than men in household and income generation activities, the customary system often leaves them economically dependent on men, even for the basic necessities of life. Any technology intervention to address this cycle of inequities must accordingly recognise specific gender needs and realities.

The next sections discuss the links between poverty and the rural energy system, the potential for renewable energy technologies in Bangladesh, and requirements for appropriate technologies. Then, a model is presented to show how a local business or cooperative approach to renewable energy technology could help create income-generating activities for rural landless and marginal farmers and also for women from these households. A hypothetical example, using the installation of a biogas plant, is described.

[2] About 48% of the rural population live below the absolute poverty line (i.e. each person of the family ingesting below 2122 calories per day). As a result, they suffer from malnutrition and inadequate health care. About one-quarter of the rural households fall into the severe category of poor who lack land as well as non-land assets. They live in deplorable housing conditions, and aggregate income earned is inadequate to ensure even 85% of their calorific requirements. They experience different categories of crisis — illness, death or loss of earners, natural digesters etc. (Siddique, 1994).

2. Poverty and the rural energy system

Next to food and water, poor rural people struggle for energy for cooking. Biomass fuel accounts for 76.3% of the total fuel in rural industries such as paddy parboiling, smithies, potteries, etc. and is the common fuel for the domestic rural sector (Eusuf, 1997). Wood fuel has become scarce over the last few years through deforestation. Its share as a percentage of total biomass fuel had decreased from 63% in 1981 to 22% in 1990 (Douglas, 1981; Islam, 1993). Invasion of the forest area by people's housing and demand for wood fuels and products in different sectors have combined to generate scarcity, and the price of wood fuel increased from 25 Tk per 100 kg in 1980 to 90 Tk in 1991. Corresponding increases in annual incomes of poor households have been relatively slow (Islam, 1980, 1987; Eusuf, 1997; Islam and Biswas, 1998), and the rural household budget for this fuel would now account for about half of the annual income of 50% of rural households. Consequently, women of these households have to gather lower-grade biomass fuels in the form of agricultural and animal residues. Use of these fuels has the following effects:

- As the calorific value of these fuels is low, they require a higher quantity to meet the same energy demand. Therefore, time spent on gathering these fuels is very high: 1–5 h per day (Biswas and Lucas, 1997a; Reddy et al. 1997).
- These fuels formerly supplied nutrients to the soil. Increased dependence on them results in an ecological imbalance.
- There is a range of health problems associated with this fuel cycle. Increased exposure to smoke during cooking can cause acute respiratory infection, chronic obstructive lung diseases, low birth weights and lung cancer and eye problems (Smith, 1990). Adverse health effects can further increase poverty by increasing medical-care expenditure and diminishing productivity. The whole family could be vulnerable to indirect health impacts from lack of fuel for proper cooking (i.e. malnutrition) and for boiling water (diarrhoea, parasites, etc.).
- There are equity issues of both gender and class. Poorer women put in more labour compared to women in rich households to meet the same energy demand. Women play a vital role in both cooking and energy management.

The prognosis for interventions with conventional energy supply technologies, or 'improved' conventional agricultural technologies, is not encouraging. The introduction of power tillers is one example: Bala found that they do not themselves enhance plant yield, but only replace cattle (Bala, 1998a,b).

There are only 125 000 irrigation pumps for 9 million hectares of cultivable land in Bangladesh (Bala, 1998a,b). Most of these are diesel-driven, because only 30% of villages could potentially be connected to electricity from the national grid (BCAS, 1998). Electrification of the remaining villages, by grid extension, may have a substantial short-term impact on the economy, since electrically operated irrigation pumps are cheaper and service a larger irrigated area per hour than diesel pumps. However, 85% of national electricity generation is sourced from natural gas, with 46% already used directly in agricultural production (Power Cell, 1998). Natural gas reserves may be exhausted by 2015 if the current trend of consumption is continued (Shajahan, 1993), and the National Energy Policy predicted that the country would need to import fuel to meet a deficit of 6.75% in electricity generation by 2000 and 47% by 2020. Currently, Bangladesh imports about 2 million tons of crude oil and petroleum products every year, which accounts for 9% of the total import costs and requires 15% of the total export earnings (Shajahan, 1993). Such import dependency will further lower national economic competitiveness. Consequently, the country is being unable to direct enough money to health, education and welfare. There may be ecological implications as well, from a further proliferation of pumps drawing subsurface water, in the absence of institutional controls.

Moreover, while fragmented land areas are insufficient to cope with food demand using traditional agricultural technologies, intensive high-input agricultural technologies are not energy-sustainable. Fertiliser factories are presently the second largest consumer (34.5%) of natural gas. Organic fertiliser is already accounted for, with about 80% of the total cow dung being used as cooking fuel in Bangladesh (Parikh, 1985).

It is therefore necessary to look at the context for alternatives in rural energy services and fertiliser substitution. A recent FAO and WEC (1999a) report emphasised three imperatives in improving on the limited progress of efforts to date in addressing rural energy poverty. Rural energy development must be

- afforded a higher priority by policy makers;
- decentralised to place rural people at the heart of planning and implementation;
- integrated with other measures dealing with agriculture, education, infrastructure and social and political factors.

The proposal and example below cover most of these potential avenues.

3. Role of RETs

Energy sources of wood fuel, agricultural waste, solar energy, animal power and wind energy are decentralised and can be considered renewable and environmentally friendly within demand limits.

In Bangladesh, the average solar radiation is 3.85 kWh/m^2/year, which is quite good for photovoltaic (PV) applications (Huq, 1997). Such radiation is unpredictable during the monsoon season, suggesting that a complete dependence on direct solar for electricity supply is unwise. However, the energy requirement for irrigation is less during the monsoon months and higher during dry months when insolation is higher and more predictable (Hossain, 1987). Simple and low-cost solar water heaters can preheat water up to 60°C for cooking and boiling predictable (Hossain, 1997). Solar dryers may potentially replace open crop drying, as about 10–25% of the crops of Bangladesh are spoiled each year (Bala, 1998a,b).

Only 10% of the rural population is connected to the electricity grid network (BCAS, 1998). Moreover, electricity is too expensive to use for cooking in rural areas. It is mainly used for lighting, radio and television. Villagers who do not have electricity use kerosene lamps, which provide poor illumination, inadequate working hours of rural people at night, seriously limiting educational attainment. Olfactory irritation and respiratory problems also result. The better illumination from photovoltaic systems may justify their higher cost provided that time is used more productively, since they are cheaper on a $/lux/day basis than kerosene lamps (WSS, 1993).

Some components of the biomass energy cycle are not well utilised at present. The open latrine system causes diarrhoea as pathogens get into nearby canals, which are usually the source of water of rural people, causing about 49 children per 1000 to die every year (ICDDRB, 1997). Open storage of cow dung in farmers' houses makes breeding grounds for mosquitoes. Both waste sources may potentially provide biogas energy more effectively and hygienically (Biswas and Lucas, 1997b; LGED, 1998a). Use of these technologies for cooking could help rural women who currently struggle for low-grade fuel for their subsistence.

Other than in coastal areas, Bangladesh does not have wind-power potential for electricity generation. Average inland wind speeds are only 3–5 km/h (Hussain, 1987). The speed is relatively high during the monsoon months when solar radiation is unpredictable, suggesting that a wind generator could be part of a hybrid system with PV for electricity generation. However, the cost of a combined PV–wind system would be prohibitive. Windmills alone will only be used for lifting water. RETs could thus be selectively applied to various rural applications, potentially generating income, improving health and educational quality, and increasing labour productivity. However, such potential benefits arising from RETs may be realised only through a process that appropriately harnesses the social and financial context of village life. There are practical implementations of RETs in other rural situations that have succeeded in catalysing endogenous development, including job creation (Bryce, 1997).

4. Appropriate RETs

For ready acceptance, RETs should preferably replace or complement energy sources or technologies currently used as necessities by the rural people. These must be simple, but give comfort, save resources (energy, time) and increase labour productivity. Schumacher stated that the 'non-violence of a technology' is an essential part of its appropriateness, suggesting that an appropriate technology is completely under human control, has no unintended side-effects and, in particular, social or environmental disruption (Schumacher, 1975). Is the proposed RET technically feasible, affordable, socially acceptable, institutionally sustainable, and replicable (Hope, 1996)? Technical criteria are:

- The *state of art* of these technologies, indicating where they have been used, at what capacities, for what purposes, and under what conditions.
- The *technical resource* of the site, indicating wind speed, solar radiation, availability of biomass.
- *The operating characteristics*, including requirements on local skills, understanding and maintenance procedures.
- *The level of local replicability*, including locally available materials and resources to manufacture these technologies.
- *Environmental implications* relative to existing technologies.

RETs should be *financially feasible*. Income generation due to use of RETs will need to enhance household budgets while covering O&M, administrative costs and payback of capital on a regular basis. In this case, *sectoral effectiveness* is important, as technologies could be used for different purposes in different seasons. For example, biogas technology could be used to generate electricity for irrigation in the dry season, while it could supply thermal energy for paddy parboiling in the rainy season when other biomass fuels get wet.

RETs need also to be *financially sustainable*. The project should be able to operate satisfactorily beyond the initial funding period. Necessary arrangements for monitoring, on-site services and spare parts supply would therefore be required to maintain customer satisfaction, following the wind-up of bank involvement when the capital cost is recovered.

The technologies should be *socially equitable* and should *harmonise culturally*, in a country where 88% of people are Muslim. These requirements raise issues of gender equity, discussed in Section 5. Additional income from RETs should help reduce *income disparities*, and preferably have *second round effects* on employment through RET applications such as the manufacture of biogas cookers, lanterns or holders.

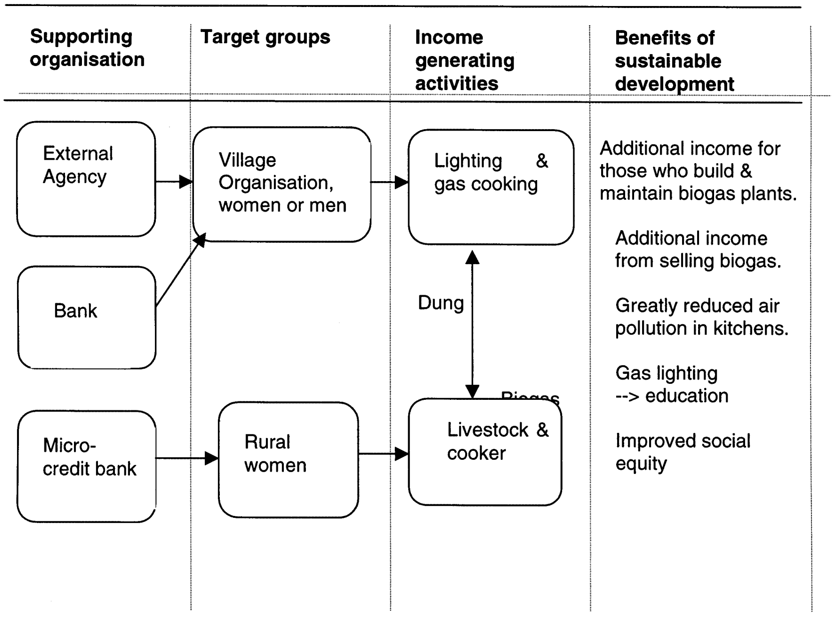

Fig. 1. Simplified system using biogas as a case study.

It is important also to assess *institutional capacity* to implement and support RETs.

RETs fulfilling the above-mentioned criteria of '*appropriateness*' may provide viable income generating opportunities for the target groups to approach sustainable development, with its social, economic and ecological facets.

5. Model for empowering rural poor through RETs

Fig. 1 represents a model for addressing inequities via RETs, in which facilitating organisations invest in human resources of the rural poor. The components of the model are described below.

The agricultural labour market is saturated, even during the peak season, and most landless and marginal farmers have no employment during the rest of the season. As discussed earlier, marginal farmers thus find themselves losing control over capital resources through forced sales of their land. Their abundant human resources may, however, be shifted from agricultural labour to a renewable energy technology business, where there is potential to improve the energy system of the village. At the same time, poor rural women could receive the services provided by such RETs to save time in household activities and accommodate more time for income generating activities. They could use their indigenous skill and resources to generate income by selling goods and services required by wealthier village people. Also, the use of labour-saving technologies can reduce drudgery of rural women and therefore increase their labour productivity (Barrett and Browne, 1994).

Lack of capital is the major constraint to such income-generating activities. Such activities (raising livestock, handicrafts, tailoring, etc.) that can be facilitated by a micro-credit loan distribution system have already been found more applicable to rural women than to men in rural Bangladesh. Men have tended to be involved in large-capacity development (irrigation, domestic supplies) works. Previously, BRAC, an NGO in Bangladesh, provided loans to landless groups for buying irrigation pumps so that they could sell water to the landed (Chowdury, 1989).

The model proposed in this paper includes an extension of the Grameen Bank's very successful method of generating income in villages by providing micro-credit (Hussain, 1987; Bornstein, 1996). The main objective of the Grameen Bank (GB) is to provide loans to rural people (landless and marginal farmers) to generate income and create employment. Currently, the bank forms small groups of about five villagers, who are usually women. Once formed, a group is closely monitored for a month to ensure that the members are conforming to the discipline of the GB rules. Two members of the group receive loans and, if they make their weekly payments for a period of several months, two more members of the group become eligible for the loan, and so on. Each member of a small group receiving micro-credit loans from GB carries out a separate income generating activity, based on purchasing a cow, poultry, hand tools, etc.

Because RETs are much more expensive than the usual kinds of goods purchased with micro-credit loans, they are not currently affordable by rural poor families. The Grameen Bank has formed a sister organisation, Grameen Shakti, involved in commercialising RETs with loans to solvent rural people with collateral, generally involving the wealthiest households. Unlike its parent, Grameen Shakti does not form groups of five, etc., although it is trying to make RETs available to middle peasants by marketing very small PV systems that can power just one or two lights. Similarly, BRAC launched its solar energy program in 1997. The program involved installing PV systems in its branch offices (training centres, schools, health clinics) and micro-enterprise projects (carpentry, tailoring shop, clothe dyeing, etc.) and in government-owned buildings (rest houses, cyclone shelters, weather-monitoring stations). A few systems have been set up for wealthier households. A limitation of this program is that it is mainly functioning within BRAC's project boundaries and, to some extent, with government departments.

Our proposed model deals with the problem of the capital intensity of RETs by assisting a group of village people, specifically from landless and marginal farm households, to form a business or a cooperative. The formation of this Village Organisation is facilitated by an External Agency comprising representatives of NGOs, universities, business and government with experience in rural development, management and the technologies of interest. This agency would be funded by national and international sources. Its role would be to:

- initiate the project in a particular village in close consultation with the villagers;
- assist in the formation of the Village Organisation;
- facilitate the creation of the institutional capacity, by training and guiding the Village Organisation in project/business management, accounting, operation and management of RETs that are appropriate to the region, and marketing of the RET product (electricity or gas) to other members of the village;
- liaise between the Village Organisation and the bank;
- move on to another village when the loan has been repaid, typically in 3 years or less.

RET projects run by a Village Organisation would provide a scale suitable for village-level economic synergies. This will help the unemployed rural landless and marginal farmers find part-time work in installation, operation, maintenance and administration of the RET. Because the size of the loans for RETs would be too large to be made by a micro-credit bank such as GB, it is envisaged that such loans would be made by Grameen Shakti or an ordinary bank or a large NGO. However, as discussed in the biogas case study, there is also a role in the model for micro-credit to provide loans to enable individual poor women to purchase animals, tools and appliances to make effective use of the RET.

During the payback period for the RET, all monetary transactions (investment, bill collection and allocation) would be carried out by the bank. Whereas much of the total bill collected would recycle to the target group of equity holders for operation and maintenance (O&M), the bank would organise a direct debit on the account of the borrowers' wages, for loan repayments. However, the choice of RET must be appropriate to the locality in order to sustain a local market.

Rural poor women need to be included within any equitable model, and this can present difficulties. 'Purdah' is one Islamic law that requires women to be fully occupied with work inside the household. Public meetings and the village market may be out of bounds in many contexts (White, 1992). In practice, Purdah is not enforced rigorously on rural women. They say, 'How could we run our household if we do not go out?' (adapted from White (1992)).

More specific constraints on women may arise, for example, when men may not be prepared to invest the capital required for a biogas plant to provide gas solely for cooking that primarily affects women, since it does not directly impinge upon men's area of responsibility (Stuckey, 1993). Therefore, to protect social equity (in this case, gender equity), it may be necessary that loans for the purchase of biogas plants should be made to groups of poor women only, for specific applications in rural areas where poor women have more freedom (see below). Indeed, the majority of loans for all RETs could be made to rural women, as in the case of the current micro-credit loans by GB and BRAC. The latter's large body of experience suggests that poor women can be involved in a business of producing goods and services for the wealthier village and town people, enabled in this case by drudgery-free, renewable energy consumption. However, men would normally do the heavy jobs run by RETs (e.g. irrigation), and so, delicate situations may arise when all-women Village Organisations have to hire men to perform such tasks.

Therefore, the feasibility of building Village Organisations that are composed entirely of women or entirely of men should be tested by means of pilot studies in the field under different social and religious circumstances. (The use of cow dung could be different for people from Islam and Hindu religions.)

Finally, an additional comment on institutional capacity. While several facilitating players have been mentioned as interlinking within a proposed model, their roles in financial and technical safeguards need to be balanced by capacity building at local level (Foley, 1995). In our model, this would be facilitated by the External Agency. Also, Government policies on energy pricing, taxes, laws and product standards on energy are important; at present, they constitute one of the main barriers to the dissemination of bio-energy projects in India, through high subsidies to conventional electricity and petroleum products (Ravindranath and Hall, 1995).

The present approach depends on the Village Organization being able to repay their loans by selling goods and services to a wealthier group. This may be considered to be an 'assisted market' model, where the assistance of the External Agency facilitates the operation of a market. However, not all of the villagers' needs (e.g. education, safe drinking water) can be necessarily met via a market at present. In order to meet these needs, humanitarian aid may be required.

It should be noted that an assumption of the model, treating a village as an entity, is a common assumption shared by multilateral, bilateral and non-government development agencies.

6. Hypothetical example: group-owned biogas plant

The following project model exemplifies the design issues above:

- The External Agency forms a Village Organisation, in the form of a cooperative or other form of business, involving a number of landless and marginal farmers, or LMF group, on the basis of their interest in the renewable energy technology business and their ability to find biogas buyers from rich and middle peasants' households. Relationships usually exist with wealthier households within the village through kinship, employment or business.
- The interested biogas consumers owning cows and poultry contribute dung as raw material to the biogas plant. They are recompensed with fertiliser produced by the biogas plant.
- The Village Organisation could require that its members make a commitment to purchase biogas for cooking from the organisation. Some portion of their income from selling gas to other members of the village will cover their own gas bills.
- The External Agency facilitates linkages for training, construction, operation, maintenance and management of the Village Organisation with NGOs or companies, research organisations or Government utilities.
- The Village Organisation and External Agency assess whether the dung from the households of biogas buyers is sufficient to meet the biogas demand of the consumers. If there is a scarcity of cows and poultry, they coordinate between a micro-credit bank and villagers to allocate more micro-credit loans for these animals, so that poor peasants can contribute dung. If this involves saturation of the milk and egg markets, it would not be wise to consider the installation of a biogas plant in this village without some modification of the model.
- Following assessment and training, the bank will finance the Village Organisation (VO) to construct the digester. (In a variation of the model, the External Agency borrows the money on behalf of the VO and loans the technology to the VO until the loan is paid off, when ownership of the technology is formally transferred to the VO.)
- Each member of the Village Organisation will take part in material procurement and construction with guidance from the training organisation. After construction, work will be distributed among the members of the Village Organisation, such as dung collection, gas distribution, bill collection, slurry distribution, repairing, etc. Members may subcontract some of these tasks to non-members.
- When the capital is recovered, the bank will wind up its involvement. By this time, the Village Organisation could expect to be well equipped with O&M and project management skills, while consumers would be getting more dependent on the products and services of RETs. Given that risk factors are managed, a (relative) excess of funds should be available for plant expansion or replication or extensions to secondary applications of the technology products.

Fig. 2 represents a cooperative biogas plant run by a Village Organisation and supported by a bank. Rural people contributing cow dung to the plant will get nutrient-rich fermented slurry back from the plant free of cost. The bank will collect gas bills from rich (x_1), middle (x_2), and poor peasants (landless and marginal households) (x_3) through one of the members of the group. At the same time, the poor group will also pay back the loan (Y) taken for income generating activities. The bank will allocate some portion (A) of the total bill ($x_1 + x_2 + x_3$) for wages of the members of Village Organisation, some for loan repayment of the digester (B) and the rest for operation and maintenance cost (C) and savings (D).

This example model has been checked for theoretical feasibility by using data from a rural energy project already carried out in Bangladesh (Biswas, 1995). The village contains 61 households from different land holding groups (three large farm households, 24 medium farm households, and 37 from small and marginal farm and landless households). The per capita energy consumptions for cooking by each household of these groups were 90, 54, 42 GJ/household/year, respectively. Stoves used for burning biomass have one mouth and allow cooking only one item at a time. Under this condition, the heat utilisation efficiency of biomass fuel is only 10%, and the actual energy demands by each household of these groups were 9, 5.4 and 4.2 GJ/year, respectively. Given that the heat utilisation efficiency of a biogas stove is 55%, large farm, medium farm and small and landless households require 16.4, 9.8 and 7.6 GJ of biogas energy per year, respectively, to meet the same cooking demand. The daily supplies of biogas for each of these households have been estimated as 1.3, 0.78, 0.61 m^3.

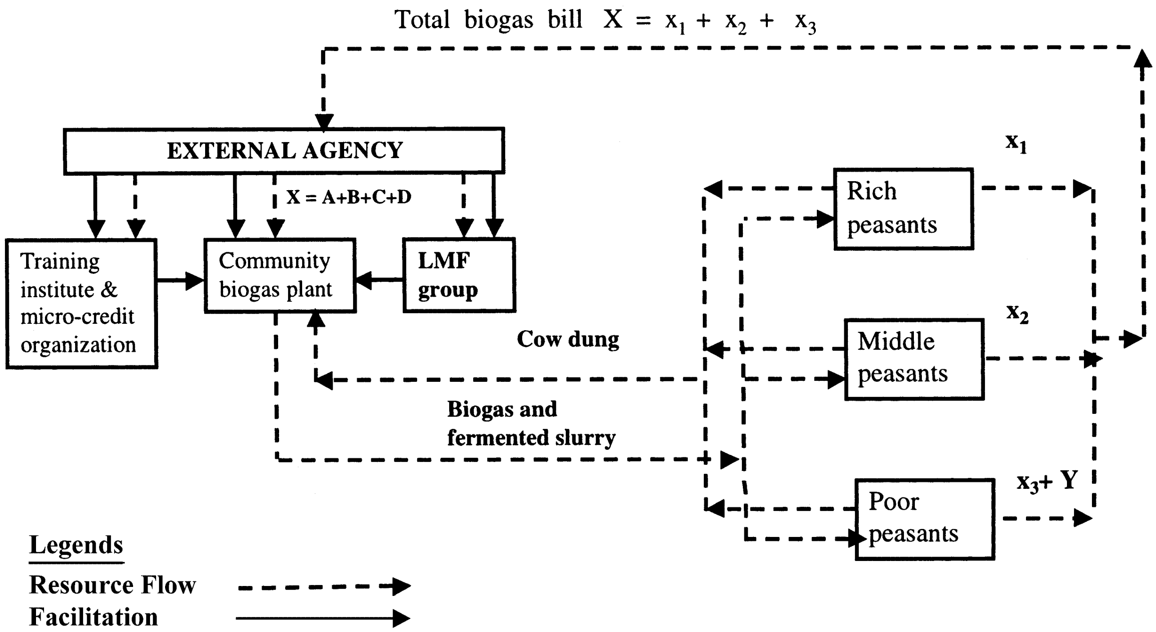

Fig. 2. Resources flow and facilities provided by actors in a cooperative biogas plant.

Table 1
Resources requirement for community digester

Number of households	Demand of gas per day (GJ)	Number of cows	Size of digester (m^3)	Investment[a] (Tk)[b]	O&M[c] (Tk)	Pay back period (years)
15	11	29	19	60 077	2922	0.9
31	22	56	38	91 060	4429	1.0
46	32	85	58	116 140	5649	1.2
61	43	113	77	138 021	6713	1.3

[a] Investment includes total construction cost and transmission (piping, cylinders, etc.) cost. The costs were taken from LGED (1998b).
[b] US$ = 49 Tk (1998).
[c] O&M costs do not include the wages. These include mainly costs of instruments, cement, etc.

Biogas digesters have been designed to meet the cooking energy demand for 25% (15 households), 50% (31 households), 75% (46 households) and 100% (61 households) of the total households of the village. The design is based on involved in providing technical support for biogas plants (LGED, 1998b). The temperature of the country varies from a minimum of 4°C in winter (very rarely) to a maximum of 42°C in summer. The gas generation rate from cow dung has been calculated at an ordinary temperature range (8–25°C) (Biswas, 1995).

Table 1 shows how many cows are needed to fulfil the biogas requirement for cooking for different classes of village household, the capital costs required to construct different sizes of biogas digesters, and the corresponding investment payback period.

Since the viability of the digester depends on the availability of cows in the village, the aggregate resource must match the biogas demand from the different ranges of households. Table 2 shows the annual bill collection equal to the summation of annual wages (A), loan repayment (B), O&M (C) and savings (D) for different options. It shows that the unit cost of biogas is lower for larger biogas plants. Required human resources vary from two persons for a small plant (for 15 households) to eight persons for a large plant (61 households). The wage of a labourer has been considered to be 1200 Tk/month[3] for all options, and this income would greatly assist in supplementing their basic needs during the time they remain unemployed in the slack seasons. A residual saving is considered at 10% of annual income, to allow future expansion of the

[3] Monthly expenditure varies from 1110 Tk for a landless family to 2373 Tk for a small farm household (Ullah et al., 1993). The proposed wage would enhance their income at the peak of job market and help to sustain them during the slack season when most are unemployed. The present study considers that members of the LMF group will not invest most of their time during the day for the cooperative biogas plant. There will remain some time for other household and income generation activities.

plant, cover risk factors in management, or as an allowance for illness or disability.

Bill defaults may occur for different reasons such as loss of crops or ill health. A risk analysis has been carried out to see the payback periods for different options at different percentage of bill collections. Fig. 3 shows that the digester with a smaller capacity has less risk compared to other options. For 60% of the total bill collection, the payback period for this digester is 2.1 years. For the large digester at a 60% collection rate, the payback period is close to the lifetime of the plant, at 8.2 years.

Use of the biogas plant would not only benefit the women who comprise the Village Organisation. It would benefit all village women who become biogas users, because they avoid the inhalation of cooking smoke. In one way, it would benefit poor women preferentially, since they would avoid spending hours each day collecting leaves and twigs, which account for about 50% of the total biomass fuel for cooking of the poor group (Bala et al., 1989; Biswas and Lucas, 1997a). Such collection is a particularly onerous task. However, in another way, it could possibly disadvantage poor women, e.g. if dung that they previously collected for fuel from common grazing areas becomes unavailable to them because it is being collected for the biogas plant. Under these circumstances, compensation for the loss of a common good (e.g. biogas in return for dung) would have to be paid. This equity concern would have to be investigated in field trials.

Poor women must have some income to afford biogas for cooking. The project could include the facilitation of individual loans from a micro-credit bank for poor women to carry out a poultry business (for example) and obtain a biogas cooker. According to the GB micro-credit loan system, she will receive 5000 Tk (4000 Tk for 50 chickens and 1000 Tk for cage and biogas cooker), and she will repay this capital at a 20% interest rate (6000 Tk) in 52 weeks. GB will collect eggs from her on daily or weekly basis and create a market

Table 2
Returns from the biogas plant

Number of households	Unit gas cost (Tk)[a]	Annual bill collection (Tk) (*X*)	Annual wages (Tk) (*A*)	Loan repayment (Tk) (*B*)[b]	O&M (Tk) (*C*)	Savings (Tk) (*D*)
15	19.86	110 556	28 800	67 779	2922	11 056
31	15.05	167 572	57 600	88 786	4429	16 757
46	12.8	213 726	86 400	100 304	5649	21 373
61	11.41	253 992	115 200	106 680	6713	25 399

[a] The lifetime of the plant has been considered as 10 years, and the discount rate is 10% p.a.
[b] Loan repayment = annual bill collection − annual wages − annual O&M − annual savings.

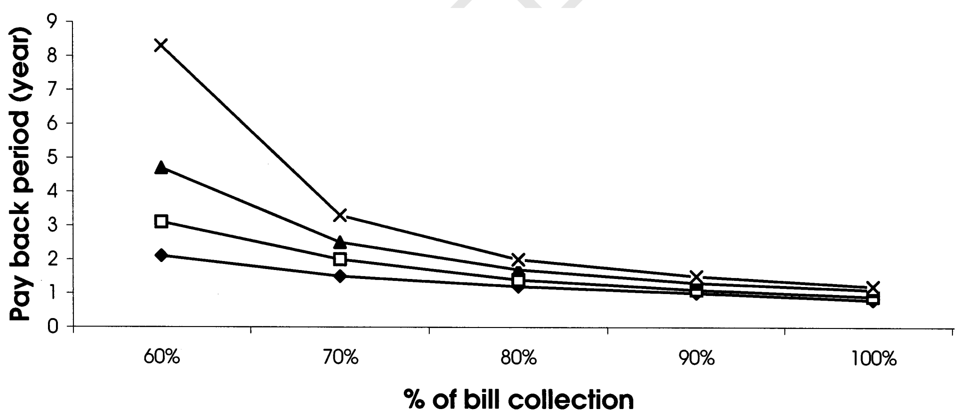

Fig. 3. Sensitivity analysis of payback periods of biogas plants at different percentages of the total bill collection.

Table 3
Cost and benefits from a poultry business (Tk)

Capital cost Chicken	Annual Income Cage	Annual biogas bill Cooker	Annual feed requirement	Loan repayment	Personal use		
4000	500	500	38 310	7250	21 900	6000	3160

Table 4
Benefits from the use of biogas for cooking by a household

Household type	Economic implications	Health	Environmental implications
Rich peasant	Use of firewood can be avoided each year which costs about 7445 Tk[a]	Women will not be exposed to smoke	The fire wood avoided in a year would be equivalent to 5.4 tonnes of standing biomass
Middle peasant	Use of firewood can be avoided each year which costs about 4467 Tk	Women will not be exposed to smoke	The fire wood avoided in a year would be equivalent to 3.2 tonnes of standing biomass
Poor peasant	Reduce drudgery as they would not gather leaves and twigs and would not be exposed to smoke	Use of 1.5 tonnes leaves and twigs by a family could be avoided in a year that gives 50 kg of nitrogen[b]	

[a] The cost of fire wood is 1.25 Tk/kg (Eusuf, 1997).
[b] 0.03 kg N/kg of dry leaves (Ravindranath and Hall, 1995).

infrastructure for selling these eggs. Table 3 shows that the annual income from the poultry business is equal to the total bill from gas, feedstock, loan repayment and personal expenditure. Out of these, the bank provides money for personal use and feedstock on weekly or fortnightly basis. The time saved through use of biogas fuel may be used for the poultry business, such as feeding and rearing chickens. About 2.5 kg of poultry droppings could be attained from 50 chickens a day, which could be used as raw material in the biogas digester.

The example assumes that the project, while providing less onerous cooking as well as income opportunities, does not add additional time burdens on poor women. Further study will be required to determine appropriate business opportunities for particular local contexts.

The expenditures on firewood by a large and a medium farm household are 7445 and 4467 Tk, respectively. The cost of firewood substitution by biogas has been found to be lower for large digesters (digester designed for 31–61 households) but higher for a small digester (15 households). The annual expenditure on biogas by these families would be 5442 and 3265 Tk, respectively for the larger digester, and 7181 and 4309 Tk, respectively, for the smaller digester. Table 1 shows the variation in gas unit cost with digester size. Table 4 shows how a large and medium farm household can avoid using about 5.4 and 3.2 tonnes, respectively, of standing wood biomass per year due to use of biogas. Poor households would avoid using lower-grade leaves and twigs, with around 50 kg of nitrogen per family per year available for return to nature, due to use of biogas.

However, these nutrients could otherwise have been taken up by the plants and therefore could maintain soil quality. Moreover, introduction of nitrogen-enriched fermented slurry from the biogas digester into the land would help substitute for chemical fertiliser. Only after the implementation of the model under various field conditions could a detailed quantitative study be performed of the actual flows of nutrients, and their availability to the poor.

Accordingly, the small cooperative biogas plant could generate additional income for landless and marginal farmers, provide improved cooking and domestic conditions for all families, reduce social, economic and possibly gender inequities, and protect the natural environment. The design of some small RET projects, such as rural electrification for domestic lighting and irrigation pumping, could be developed on principles similar to those outlined earlier in the paper.

7. Conclusions

If sustainable development is to occur in Bangladesh and similar countries, improvements are required in the rural areas that comprise the major part of the formal and informal national economy. Renewable energy technologies (RETs), used appropriately, may improve the quality of life of rural people and provide income-generating opportunities. Some of the issues required for successful dissemination of these technologies through an assisted market mechanism have been discussed. Sustainable development requires a model that specifically addresses social, economic and environmental issues. The suggested project model describes how RETs may provide these elements, creating income-generating activities while redressing social inequities and environmental impacts. The essence of the proposed model is to extend the successful models of the Grameen Bank and BRAC, which currently provide micro-credit to rural poor individuals, to larger loans to Village Organisations for RETs. Several key features of the proposed model have to be tested in the field, notably social equity and gender equity aspects of introducing the RETs, and what structure and gender composition of Village Organisations works best in various village societies. Such tests will enable the proposed model to be refined or discarded.

8. Uncited references

Hossain, 1988

References

Bajracharya, D., Nakarmi, A.M., Singh, K.M., 1991. Development of Micro-hydro System in Nepal: Problems and Prospects. Paper Presented in a Seminar on Rural Energy and Related Technologies, Jointly Organized by Agricultural Development Bank, Water and Energy Commission Secretariat, and Centre for Integrated Mountain Development, Kathmandu, Nepal, 26–27 March.

Bala, B.K., 1998a. Solar Drying Experience in Bangladesh. Proceedings, National Seminar on Solar Energy for Every Day Use, ANANDO, Banani, Dhaka 1213.

Bala, B.K., 1998b. Energy and Environment: Modelling and Simulation. Nova Science Publishers, New York.

Bala, B.K., Karim, M.M., Dutta, D.P., 1989. Energy use pattern of an electrified village in Bangladesh. Energy 14 (2), 61–65.

Barrett, H.R., Browne, A.W., 1994. Women's time, labour-saving devices and rural development in Africa. Community Development Journal 29, 203–213.

Bangladesh Bureau of Statistics, 1995. Statistical Year Book of Bangladesh. Ministry of Planning. Government Republic of Bangladesh, Dhaka.

Bangladesh Bureau of Statistics, 1998. Statistical Year Book of Bangladesh. Ministry of Planning. Government Republic of Bangladesh, Dhaka.

Bangladesh Centre for Advanced Studies, 1998. Diffusion of Renewable Energy Technologies. BCAS, Dhaka.

Biswas, W.K., Lucas, N.J.D., 1997a. Energy consumption in the domestic sector in a Bangladesh village. Energy — The International Journal 22, 771–776.

Biswas, W.K., 1995. Energy consumption and prospects of renewable energy technologies in a Bangladesh village. Unpublished M.Sc. thesis, Imperial College, London.

Biswas, W.K., Lucas, N.J.D., 1997b. Economic viability of biogas technology in a Bangladesh village. Energy — The International Journal 22, 763–770.

Blair, H.W., 1985. Participation, public policy, political economy and development in rural Bangladesh 1958–85. World Development 13, 1231–1247.

Bornstein, D., 1996. The Price of a Dream. The University Press, Dhaka.

Bryce, P., 1997. Enlightening the Poor: ODA and Rural Electrification. Development Bulletin. National Centre for Development Studies, Australia.

Chowdury, A.N., 1989. Let Grassroots Speak. The University Press Limited, Dhaka.

Diesendorf, M., in press. Models of Sustainability and Sustainable Development. International Journal of Agricultural Resources, Governance and Ecology.

Douglas, J., 1981. Supply and Demand of Forest Products and Future Development Strategies: Consumption and Supply of Wood and Bamboo in Bangladesh. Field Document 2, FAO/ UNDP/ BDG/78/010.

Eusuf, M., 1997. Dissemination of Biogas Technology in Bangladesh. National Seminar on Renewable Energy for Poverty Alleviation (NSREPA-97). Institute of Engineers, Bangladesh.

Food and Agricultural Organization and World Energy Council, 1999a. The Challenge of Rural Energy Poverty. World Energy Council, London.

Food and Agricultural Organization and World Energy Council, 1999b. Asia's Women in Agriculture, Environment and Rural Production: Bangladesh. United Nations Regional Office for Asian and Pacific, Bangkok.

Foley, G., 1995. Photovoltaic Applications in Rural Areas of the Developing World. World Bank Technical Paper No. 304, Energy Series. The World Bank, Washington, DC.

Haque, A.Z., 1993. An economic analysis of the process of land accumulation and diminution in a selected area of Bangladesh. Unpublished MSc. thesis, Faculty of Agricultural Economics, Bangladesh Agricultural University, Bangladesh.

Hope, K.R., 1996. Promoting sustainable development in developing countries: the role of technology transfer. Community Development Journal 31, 193–200.

Hossain, M.A., 1997. Renewable Energy for Poverty Alleviation — Bangladesh Perspective. Paper Presented at the National Seminar on Renewable Energy for Poverty Alleviation (NSREPA-97). Institute of Engineers, Bangladesh.

Hossain, M., 1988. Credit for Alleviation of Rural Poverty: The Grameen Bank in Bangladesh. Bangladesh Institute of Development Studies, Dhaka.

Hossain, M.A., 1987. Solar radiation in Dhaka, Bangladesh. Alternative Energy Sources 1, 81–86.

Huq, A.M.A., 1997. Solar Thermal Energy as Energy Option for Poverty Alleviation. Paper Presented at the National Seminar on Renewable Energy for Poverty Alleviation (NSREPA-97). Institute of Engineers, Bangladesh.

Hussain, M., 1987. Bangladesh energy sources and renewable energy prospects. Energy — The International Journal 12, 369–374.

International Centre for Diarrhoeal Disease Research, 1997. Bangladesh Annual Report. accessed at http://www.icddrb.org/ar97_cont.html.

Islam, M.N., 1980. Study of the Problems and Prospects of Biogas Technology as a Mechanism for Rural Development Study in a Pilot Area. Bangladesh University of Engineering and Technology, Dhaka.

Islam, M.A. (1987) Energy planning for rural Bangladesh: comparative assessment of energy situation in an electrified and a non-electrified village of Mymensingh District. Unpublished M.Sc. thesis, Bangladesh University of Engineering and Technology, Dhaka.

Islam, M.N., 1993. Environmental Assessment in Energy and Mineral Resources Sector of Bangladesh: Policies and Strategies for Sustainable Energy Development. Institute of Appropriate Technology, Bangladesh University of Engineering and Technology, Dhaka.

Islam, S.M.N., Biswas, W.K., 1998. Rural Energy Assessment and Utilisation in Hiron Union of the District Gopalganj. University Grants Commission, Bangladesh.

Jensen, E.G., 1986. Rural Bangladesh: Competition for Scarce Resources. Oxford University Press, Oxford.

Local Government Engineering Department, 1998a. Development of Biogas Technology. Technical Bulletin — 20. LGED, Dhaka.

Local Government Engineering Department, 1998b. Technical Manual of Biogas Technology. LGED, Dhaka.

McMurray, L., 1998. Rural Electrification — A Potential Solution to Urban Migration in Solomon Islands. Unpublished Master's thesis, University of New South Wales, Australia, 1998.

Parikh, J., 1985. Modelling Energy and Agriculture Interactions — I: A Rural Energy System Model. Energy — The International Journal 10, 793–804.

Phillips, J.S., 1998. A Hybrid Renewable Energy Based Rural Electrification Project for Eastern Indonesia. Village Power 98 Conference — Scaling Up Electricity Access for Sustainable Rural Development, Washington DC.

Power Cell, 1998. Status of Renewable Energy in Bangladesh. Draft Report. Ministry of Energy and Mineral Resources, Dhaka.

Rajabapaiah, P., Jayakumar, S., Reddy, A.K.N., 1993. Biogas electricity: The Pura Village case study. In: Johansson, T.B., Kelly, H., Reddy, A.K.N., Williams, R.H. (Eds.), Renewable Energy. Island Press, Washington, DC.

Ravindranath, N.H., Hall, D.O., 1995. Biomass, Energy and Environment — A Developing Country Perspective from India. Oxford University Press, New York.

Reddy, A.K.N., et al., 1997. Energy After Rio: Prospects and Challenges. United Nations Development Program, New York.

Schumacher, E.F., 1975. Small is Beautiful: Economics as if People Mattered. Harper & Row, New York.

Shajahan, M., 1993. Inaugural Speech Given at the International Symposium on Electrical Energy System, Jointly Organised by Bangladesh University of Engineering and Technology, Dhaka and Virginia Polytechnic Institute, USA, December 13–15.

Shangbin, G., 1993. Development of Biomass and Biogas Programmes in China. Paper Presented at the International Conference on Medium and Large Scale Biogas Plants in Developing Countries. DANIDA, Taastrup, Denmark.

Siddique, M.A.B., 1996. Gender Issues in Poverty Alleviation: a Case Study of Bangladesh. Discussion Paper 96.20. The University of Western Australia, Perth.

Siddique, M.A.B., 1994. The Government Poverty Alleviation: Selected Micro-economic and Selected Issues. The University of Western Australia, Perth.

Smith, K.R., 1990. Health effects in developing countries. In: Pasztor, Janos, Kristoferson (Eds.), Bioenergy and the Environment. Westview, Boulder, CO.

Stuckey, D.C, 1993. Technology Assessment Study of Biogas in Developing Countries. International Research Centre for Waste Disposal, Duebendorf, Switzerland.

Ullah, M.M., Karim, M.R., Elias, S.M., 1993. Income and expenditure distribution pattern of rural farm households of Bangladesh: a study with special reference to poverty alleviation. Farm Economy Journal 9, 161–166.

UNDP, 1995. Human Development Report. Oxford University Press, Oxford.

Venkataramana, P., 1992. Community Biogas System in Mathan, Gujrat — A Case of Study. Tata Energy Research Institute, New Delhi.

Waddell, R., 1993. Replanting the Banana Tree. APACE Publications, University of Technology, Sydney.

World Food Program, 1999. BGD 6043 — Emergency Assistance to Flood Victims. accessed at http://www.wfp.org/OP/Countries/Bangladesh/emop6043.html.

White, S., 1992. Arguing with the Crocodile: Gender and Class in Bangladesh. The University Press Limited, Dhaka.

World Solar Summit, 1993. Solar Energy and Health. UNESCO Headquarters, Paris, Document No. WHO/EPI/SOL/WP. 1.

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