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Biogas Plants Ease Ecological Stress in India's Remote Villages

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Introduction

Increasing human population growth and persistent poverty in developing countries continue to influence ecological degradation, especially of forests around the world. About 4.2% of the forest cover that stood in 1990 had disappeared by the end of the decade (FAO 2001). The Millennium Ecosystem Assessment (2005), determined that of the 24 ecosystem services examined, including freshwater, food, climate, and air quality, 15 (62.5%) are presently being degraded or used unsustainably. Similarly, an appraisal from the World Conservation Union (2004) on the status of global forest plant diversity showed that 45% of the plant species assessed, have been classified as endangered or critically endangered with the possibility of extinction.

In developing countries, wood is traditionally the main source of fuel for rural people who live adjacent to forest areas. About 2.5 billion people, mostly in Asia, use firewood or other biomass collected from forest for energy (Starke 2004). In India alone, over 80% of the total energy consumed in rural areas comes from biomass fuels such as firewood, crop residues and livestock dung (Ravindranath *et al.* 2000). The average person in the United States of America consumes five time more energy than the average global citizen, ten times more than the average Chinese, and nearly 20 times more than the average Indian (Starke 2004). With the on-going destruction of forests due to overuse and degradation, scarcity of wood has become increasingly common in Asia. Since livestock such as cattle, buffalo, sheep, and goat are common in villages of the developing world, animal dung is the most easily available and abundant biomass for fuel and the burning of dung is common in rural areas. Cow dung has been used as both fertilizer and fuel in many countries around the world for centuries (Hall and Moss 1983).

The need for affordable, clean and renewable energy to enhance sustainable development has been reiterated recently by the World Energy Council (2006) and the UN Commission on Sustainable Development (2007). Methane gas produced from organic matter can be utilized as fuel with less impact on natural forest ecology than the use of firewood. This paper presents data on household biogas plants successfully established by a non-profit agency in remote tribal villages of western India with an emphasis on their impact in enhancing local ecology and relieving economic stress in rural communities.

Study Area Description

The study site comprised the districts of Dahod (Gujarat State), Jhabua (Madhya Pradesh), Jhalawar and Banswara (Rajasthan State), where most household biogas plants were established in villages during 2001–2005. Dahod District in Gujarat State has an area of 3,642 km^2 with a population of 1,636,433 (Government of India 2001). It was created on 2 October 1997 and was formerly part of the neighboring Panchmahal District. This drought prone district is one of the poorest in Gujarat State. The predominant population (72%) belongs to the indigenous 'Bhil' (meaning 'bow') tribe. The district receives 860 mm of annual average

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rainfall with an inconsistent, unreliable pattern with longer dry spells resulting in drought every third year. About 24% of the district is covered with forest while 57% of the area is under cultivation. Jhalawar District (area 6,928 km^2) in Rajasthan State is one of the least developed in India. It supports a population of 1,180,342, the vast majority (86%) living in rural areas (Chopra 1988; Government of India 2001) and representing indigenous tribes. The district has 1,585 villages and only 40% of the total area has irrigation access for agriculture. Most villages in the district do not have public institutions with the exception of some primary schools. The Dag Block in Jhalawar district is the poorest in Rajasthan State with a predominant agrarian society. Banswara District in Rajasthan has an area of 5,037 km^2 and harbors rich flora and fauna. The Jhabua District in Madhya Pradesh State (area of 6,782 km^2) supports a population of 1,396,677 and 85% belong to tribal communities of which 47% are extremely poor. The literacy rate is 36.87%, with female literacy of only 4% (Government of India 2001).

Methods of Survey and Data Analysis

Between January and June 2007, 125 biogas plants in three states, namely Gujarat, Rajasthan and Madhya Pradesh, were visited to record data on their impact on the local ecology and community. The biogas plants were established between 2001 and 2005 by a local non-profit agency called ‘NM Sadguru Water and Development Foundation’, based in Chowsala village (Gujarat State, India). It is popularly known as ‘Sadguru’ (Sanskrit, meaning ‘true teacher’) and was created in 1974. It is India’s premier non-profit organization known globally for its contributions to community-based sustainable and equitable rural development, poverty alleviation and natural resource management (Agoramoorthy 2007a; Jagawat 2005).

Data on the cost of biogas plants, selection of households, and implementation of biogas plants in villages were pooled from the archives of Sadguru Foundation. Interviews were conducted with 125 households to record data on perspectives on biogas plants, impact of biogas plants on local ecology, usage of forest firewood, chemical fertilizer, and kerosene before and after the establishment of biogas plants, following the methods of Mikkelsen (1995). Although Sadguru has built a total of 1,292 biogas plants benefiting 7,752 people in remote villages in western India as of March 2007, only data on 125 biogas plants constructed between 2001 and 2005 were included in the statistical analysis (Table 1). Statistical Analysis System software was used for data analyses and all mean values are presented as ±1 standard deviation (SAS Institute 2000). A general linear regression analysis was used to estimate the cost (USD) according to the size of households and year.

Results

Selection of Households for Biogas Plants in Villages

Most villagers who live in the tribal drylands of western India traditionally engage in seasonal rainfed farming of crops such as maize, corn, wheat, pulses, grams, etc, on their own land. Livestock keeping in the drylands plays a crucial role in food security and as a risk aversion mechanism for sustaining rural families during times of crop failure related to drought and famine. Milk production from cow and buffalo is common in India and generates employment and income primarily for rural women. Domestic livestock are widespread across India’s drylands and provide an outstanding opportunity to establish biogas plants for sustainable rural development. With this in view, Sadguru’s staff approached villagers to establish household biogas plants to meet growing rural energy demands with minimal impact to local forest resources. Sadguru’s staff initially conducted rapid participatory rural appraisals during routine monthly field trips to villages with large

Table 1 Ecological, economic and human health benefits of household biogas plants in remote villages of western India between 2001 and 2005

State name	District name	No. of biogas plant	Household size	No. of domestic animals/household		Fuel saving (USD)/household/year			No. of visits to clinics due to health problems	
				Cattle	Buffalo	Wood	Kerosene	Fertilizer	Before biogas plant	After biogas plant
Rajasthan	Banawada	18	5.5±0.8	2.9±1.3	3.1±1.5	78.4±24.8	39.9±15.2	22.9±9.5	5.9±1.1	3.2±1.0
Gujarat	Dahod	90	6.3±2.1	3.6±1.5	2.7±1.3	54.7±23.6	36.9±19.5	21.9±16.0	6.3±1.1	2.6±0.9
	Panch Mahal	9	5.1±1.1	4.1±0.9	2.9±0.7	104.2±22.8	40.3±5.7	38.9±8.8	3.9±1.2	1.6±0.5
Madhya Pradesh	Jhabua	8	4.6±1.2	4.5±1.5	1.5±1.1	44.4±8.3	35.7±20.2	11.9±5.2	6.1±1.1	3.1±0.8
Mean ± SD		125	6.0±2.0	3.6±1.5	2.7±1.4	61.0±27.6	37.5±18.5	22.7±15.3	6.1±1.3	2.6±1.0

numbers of cattle and buffalo. During these field visits, the significance of household biogas plants to community and environmental health was emphasized. Since villagers traditionally use of cow dung as fuel and fertilizer, the concept of household biogas plants was well received.

The selection of households for the implementation of biogas plants included three basic requirements: (a) availability of cattle/buffalo (each household must own three or four cattle/buffalo that can produce 25 to 50 kg of dung daily), (b) availability of water (50 l of fresh water daily), and (c) access to land near the kitchen (area 4 m^2) to construct the biogas plant. When the above criteria were met, interested villagers were asked to submit written requests to Sadguru's office in Chowsala village (Gujarat State). Out of 250 such requests received annually, only 50 households were ultimately selected. The final selection process was based on the agreement that each beneficiary household had to pay 20% (USD 50) of the total cost of biogas plant construction (USD 250), and that the biogas plant must be used by the household for a minimum of 10 years. If the households fail to maintain the biogas plant for 10 years, they are obligated to return 80% of funds to the funding agency. After obtaining 10% of initial seed money as a down payment from the beneficiary, a supervisor was assigned to begin construction of the biogas plant. After completion of construction, the remaining 10% was paid by the beneficiary.

A household with four to six members usually requires a 2 m^3 plant, which will provide biogas for a total of 4 h daily. The biogas plant is divided into three basic units: (a) the inlet or mixing tank where an equal ratio of cow dung and water are mixed daily, (b) the digester, which connects the inlet and the outlet (main chamber where bacteria forms to produce methane gas by interacting with cow dung and water, and (c) the outlet tank connected to the digester, which receives the digested slurry as an organic manure. Thus building a biogas plant in rural setting is simple and cost-effective, and a plant could be constructed within three to four weeks (Fig. 1). During the last 10 years, the household biogas plants constructed by Sadguru in villages have not encountered any mechanical problems. However, natural calamities such as earthquakes and floods can damage the system. If the biogas plant is damaged due to natural calamities, a thorough clean-up and restart of the plant is necessary.

Impact of Biogas Plants on Local Ecology and Community

The average size of households in villages was 5.99±1.96 (Table 1). The annual average use of firewood was 638.34± 309.22 kg/household, which dropped drastically from 1,048.9 kg before launching the biogas plants to 410.6 kg afterwards. The size of household ($F_{1,119}$=5.24, $p<0.05$) and year ($F_{4,119}$=9.77, $p<0.001$) had significant effects on the total use of fuel before and after the establishment of household biogas plants in villages ($p<0.05$). The overall cost of fuel fell from 2001 to 2005 (Fig. 2). Each household's impact on the forest for firewood collection after construction of the biogas plant was reduced to 60.86% (0.638 ton/household). An annual total of 79.79 tons of firewood from the forest was saved by the 125 households. This clearly showed the enormous potential of household biogas plants in relieving ecological stress in forest areas of rural India.

After the launch of the biogas projects in villages, kerosene usage was also dramatically reduced by 62% (from an average of 120.68±50.8 to 46.33±24.71 l/year; Table 1). Kerosene usage was positively correlated to family size before and after the establishment of biogas plants ($p<0.05$; Pearson Correlation). Interestingly, chemical

Fig. 1 A household biogas plant under construction by Sadguru Foundation in a village in Gujarat, India. Photograph by G. Agoramoorthy

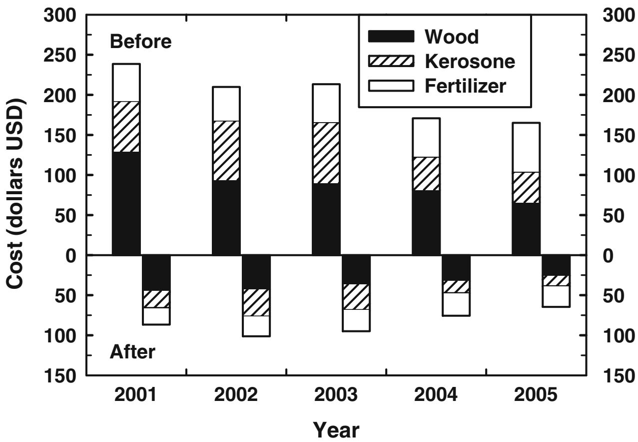

Fig. 2 Average cost of firewood, kerosene and fertilizer per household annually before and after the construction of biogas plants in villages in western India between 2001 and 2005

fertilizer usage was also significantly reduced by 50.1% (from an average of 472.24±159.77 kg/year to 235.48±94.52 kg/year), easing toxic pollutants in the soil and associated terrestrial ecosystem (Fig. 2).

Usage of firewood, kerosene and fertilizer after the biogas plants implementation was significantly reduced (paired t-test, $p<0.001$). The cost of firewood was reduced the most (61.02±27.60 USD), followed by kerosene (37.49±18.46 USD), and fertilizer 22.65±15.25 USD ($F_{2,372}=105.15$, $p<0.001$).

Furthermore, the household biogas plants enhanced hygiene and human health. For example, the average number of times people visited clinics for smoke-related illnesses such as eye infection, burns, respiratory problems, asthma, dizziness, headache, intestinal problems, and diarrhea fell from 6.10±1.25 to 2.62±0.97 after the launching of biogas plants (Table 1). People who live below the poverty line were exposed to higher rates of sickness significantly more (3.06±1.21; $n=18$; $p<0.05$ Wilcoxon Rank Test) than those who were above the poverty line (2.55±0.91; $n=107$), even after setting up of biogas plants. However, before the plants, there were no differences in the rate of sickness between the two groups.

Discussion

Mixed History of India's Biogas Plants

One of the earliest designs of biogas plant was reported in 1933, and used chopped corn straw in the digester to produce methane gas (Buswell and Boruff 1933). A total of 34 types of biogas plants using a variety of feeds and processes were tested or used globally prior to the 1970s globally and details on the evolution of biogas plants have been described by Van Brakel (1980). India's national father, Mahatma Gandhi's (1927) vision of utilizing the biogas in a scientific way was materialized in the 1930's when two scientists, S.V. Desai and N.V. Joshi of the Indian Council of Agriculture Research developed a simple device known as 'gobar gas plant' that produced biogas and manure. It mainly focused on the Sewage Purification Station at Dadar, south Mumbai. The early biogas plants were not only costly but also prone to burst (Sodhiya and Jain 1988). However, some of the later designs of small-scale biogas digesters created by J. Patel for use of farmers had longer life with minimal maintenance cost. The government of India became serious about implementing the biogas technology in rural areas only in 1981 when it initiated the National Project for Biogas Development as a result of the alarming shortage of fuel wood at the time (Sodhiya and Jain 1988).

The government-sponsored biogas plants in India faced several set-backs in the past since large proportions of the plants were not used at all or used insufficiently. Technical defects and maintenance problems were common till the early 1980s despite the fact that biogas technology was supported by the government. In 1982, the federal Ministry of Power and Non-Conventional Energy Sources started to supervise biogas dissemination across rural India to increase the efficiency of biogas plants usage and management. The ministry continues to amend guidelines on financial support for biogas technology in rural areas and also promotes research and development of cost-effective designs. The actual implementation of biogas plants in rural areas, however, has been carried out by individual state government agencies, public corporations such as Khadi and Village Industries Commission, and non-government agencies such as the Sadguru Foundation.

Seven types of biogas plants have been officially recognized by the Ministry of Power and Non-Conventional Energy Sources. They are (a) floating-drum plant with a cylindrical digester (KVIC model), (b) fixed-dome plant (Janata model), (c) floating-drum plant with a hemisphere digester (Pragati model), (d) fixed-dome plant with a hemisphere digester (Deenbandhu model), (e) floating-drum made of angular steel and plastic foil (Ganesh model), (f) floating-drum plant made of reinforced concrete, and (g) floating-drum plant made of fiberglass reinforced polyester. The above types, which do not exceed gas production of 10 m^3/day with a 30 m^3 digester, can apply for subsidies from the government. However, other types can also be implemented subject to the approval of the respective state government agencies.

Biogas Plants Enhance Local Ecology, Economy and Human Health

Extensive use of firewood in rural areas was known to cause forest decline in many developing countries and it was reported to account for nearly 54% of all global harvests annually with a direct role in forest loss (Osei 1993). In India, rural consumption of firewood accounts for nearly 87% with demand exceeding supply (Hall *et al.* 1982). Tribal communities that live in remote parts of India rely on forest resources, with 90% of the local population using biomass as a major energy source (Bhatt and Tomar 2002). If the intensity of deforestation in India and other countries in Asia increases in near future, the implementation of biogas plants in rural areas could certainly save enormous amounts of forest trees and biodiversity. India's state forest departments should implement the subsidized biogas plants in forest areas managed by the community and government under the joint forest management program (Poffenberger and McGean 1998; Singh and Ballabh 1996). Village communities take responsibility to manage forest resources in these areas, so that the household biogas plants can easily succeed.

Before the establishment of biogas plants in villages, the cost of firewood and kerosene in most households exceeded the annual salary of a rural Indian family. Thus people were often forced to harvest firewood from the forest illegally. Biogas plants, being an eco-friendly technology, safeguard local ecological and forest resources. The negative impacts of chemical fertilizers on soil and ecology are well known (Hall and Robarge 2003). After the biogas plants were established in villages, the need for chemical fertilizers was reduced and farmers were seen increasingly using the organic slurry as natural fertilizer for crops that enhances top soil health in agricultural areas promoting healthy agricultural and terrestrial ecosystems in villages. The organic manure helps in retaining soil fertility and productivity, especially in the ecologically fragile drylands of western India.

Fumes from household cooking pose health hazards to villagers especially women and children in rural areas. Fuel which consists of firewood, dried dung and straw in primitive stoves often fails to burn completely and therefore produces poisonous pollutants such as carbon monoxide. When women and children inhale the smoke regularly, they become vulnerable to acute respiratory problems such as asthma and chronic bronchitis sometimes even leading to lung cancer. The World Health Organization estimates that the scale of the problem is massive in India, where 650 million people depend on traditional stoves for cooking and 400,000 deaths occur annually related to indoor air pollution in rural areas (WHO 2005). The present study shows that the incidence of smoke inhalation related diseases drastically fell as a result of the biogas stoves in rural areas. When firewood is used for cooking, utensils, rooms, and roofs are fragmentally damaged by smoke and carbon deposits. Women and children who often stay in-doors are most commonly affected by toxic smoke inhalation. But the biogas kitchen provides a clean, hygienic and healthy environment for cooking in rural settings. Also, women can prepare food and drinks anytime when guests arrive, which was not possible before due to longer cooking times required by traditional methods. After the establishment of household biogas plants, rural women were able to save 2.5 h/day on average that was spent earlier in collecting firewood in forest and preparing cow dung cakes to be used as fuel. Rural women are able to devote the extra time to other income generating work such as tailoring, farming, and producing handicraft items.

Future Potential for Biogas Use and Ecological Protection in Rural India

India's renewable energy sources account for 33% of primary energy consumption with traditional biomass contributing a major share, followed by electricity from hydro-electric power plants. Therefore India has policy initiatives to promote renewable energy in rural areas with an emphasis on mini-hydropower, wind power, biodiesel, ethanol, fuel wood plantation, electricity from wood gasification, biogas plants, solar/thermal water heaters, solar/thermal power plants, and solar photovoltaics. If these sustainable development initiatives are implemented efficiently across rural India, it would improve the quality of life for the rural poor and lead to poverty alleviation.

India harbors one of the largest domesticated bovine populations (294 million) in the world including cows, bullocks, buffalo, and calves (Ravindranath *et al.* 2000; Tata Energy Research Institute 1997). Based on the mean annual average dung yield (fresh weight) of 4.5 kg/day for cattle and 10.2 kg/day for buffalo, total dung production is estimated to be 659 tons annually, with cattle dung accounting for 344 tons and buffalo dung accounting for 315 tons (India's Animal Husbandry 1997). Only about 40% of dung collected is usually used as fuel in rural areas. The quantity of dung used annually in the existing 2.7 million family type biogas plants is estimated to be 22 tons. Thus bovine dung use for biogas has enormous potential in future since only 22% of the total potential for biogas plants is being utilized (Ministry of Non-conventional Energy Sources 1998).

The potential for household biogas units in India is 12 to 17 million. However, only 3.7 million biogas plants had been installed by 2003. Thus the impact of household biogas plants in sustainable development is yet to be fully realized in rural India. Firewood collected from forest areas still serves as the main fuel consumed in India and peoples' dependency on firewood is a major set back for local ecology due to the unsustainable removal of natural forest vegetation. Energy use projections indicate that India's rural communities will continue to use bio-fuel (firewood, dried dung, and biogas), while urban areas will switch to LPG, kerosene and electricity (Ravindranath *et al.* 2000; Sarma *et al.* 1998).

Asia and the Pacific have 23% of the world's land area but 58% of its people (Agoramoorthy and Hsu 2001; Brown *et al.* 1999). Patterns of unsustainable resource use and conflicting policies are already causing continued loss of forest and biodiversity in Asia, including the biological hotspots of India (Agoramoorthy 2006; Agoramoorthy and Hsu 2002; Mittermeier *et al.* 2000). Although forest biodiversity has been given significance in India, the scientific basis of knowledge on forest ecology and ways of adding values to it are unfortunately still weak (Agoramoorthy 2007b). Forests play a crucial role in climate regulation by storing carbon. Continued degradation aggravates the already precarious state of the remaining forests in Asia since the demand for forest products cannot be satisfied by sustainable harvests. The diversity of plants and animals are declining, carbon emissions are above the earth's carbon-fixing capacity, and human population pressure is exceeding the population of all species of non-human primates combined (Brown *et al.* 1999). Thus human survival depends on the future wise and ethical management of natural resources.

The majority of India's indigenous tribal populations (70%) has been concentrated in the vast drylands roughly 1,500 km long and 500 km wide that stretch across central India starting from Dungarpur in the west to Dumka in the east, representing one of the largest concentrations of rural poverty in Asia (Jagawat 2005), with little access to public services in health, education or commerce. From the government point of view, a single tribal settlement is too small to economically justify a school or a health center, and the poor infrastructure in villages makes facilities elsewhere difficult to access. Furthermore, the low density of the tribal populations and lack of purchasing power make village businesses not at all feasible. Within the rankings of the traditional Indian caste system, tribals (locally known as *adivasi*, meaning 'original people') are beneath even untouchables, thus the most downtrodden (Agoramoorthy and Hsu 2006). The Indian constitution of 1949 singled them out for preferential treatment, in a kind of permanent affirmative action plan, but the government's efforts has not made significant impact in helping the tribal people for nearly half a century. Most of India's 70 million tribals are illiterate with a shorter life expectancy than other castes. No strategy of rural development can succeed that neglects India's ignored tribal communities (Jagawat 2005).

Conclusions

To overcome degradation of natural resources in developing countries such as India, that harbors over 1 billion inhabitants, is not easy (Bluffstone 1998). Therefore, India's politicians and policymakers must promote efficient ways to meet rural peoples' needs and to reduce pressures on natural forest ecology. One way to achieve this is to implement simple and cost-effective biogas technology highlighted in this paper across rural India. This provides an alternative renewable energy source, which has the potential to significantly reduce pressure on forest, soil and associated terrestrial ecosystems. Therefore this environment-friendly biogas technology deserves attention and it should be promoted aggressively throughout the world, including the most and least developed countries.

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