BIOGAS TECHNOLOGY AS A SUSTAINABLE DOMESTIC ORGANIC WASTE MANAGEMENT MEASURE FOR DEVELOPING COUNTRIES

Athira Ravi and Subha Vishnudas

Division of Civil Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, Kerala, India

ABSTRACT

Solid waste management especially residential organic waste management is one of the most important problems after the water quality in developing countries all over the world. There are many waste management techniques for the disposal of these wastes. Attaining sustainability goals is the challenge faced by each of these techniques. This paper presents the evaluation study of the biogas technology as a sustainable domestic organic waste management measure. The evaluation method is detailed and the perception of the biogas users with respect to different aspects of sustainability is presented here. The technological benefits and bottle necks were also reviewed in this paper.

KEYWORDS

Sustainability, domestic organic waste management, conceptual framework, biotechnology, Kochi city.

1. INTRODUCTION

Increasing population levels, booming economy, rapid urbanization and the rise in community standards have greatly accelerated the municipal waste generation rate in developing countries (Minghua et al., 2009). As compared to the western countries, MSW differs greatly with regard to the composition and hazardous nature, in developing countries like India. (Gupta et al., 1998; Shannigrahi et al., 1997; Jalan and Srivastava, 1995). MSW contains compostable organic matter (fruit and vegetable peels, food waste), recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), and soiled waste (blood stained cotton, sanitary napkins, disposable syringes) (Jha et al., 2008; Reddy and Galab, 1998). Among these, the residential organic wastes make the urban waste management in a worse situation. The wastes generated in communities are the reflection of their ways of life, wealth and culture (UNCHS, 1989). There are many waste management techniques for the assimilation of these wastes. One of the most important techniques which is getting attention in developing countries like India is biogas technology. Interest in biogas technology is growing in India, because of the increasing awareness of the importance of the renewable energy sources and their potential role in decentralized energy generation. The rate of growth of biogas technology is expected to accelerate in the future given the moderately high potential, mounting concerns on environmental protection and waste minimization. Whatever the technology it must be sustainable in all means. This paper evaluates the biogas technology as a measure of sustainable domestic organic waste management for urban residential areas in developing countries like India.

2. METHODOLOGY

The evaluation of the biogas technology practiced in the study area - Kochi city was carried out through a questionnaire survey conducted in households who are using this technology inside the city and outskirts. The questions in the survey were framed based on the conceptual framework developed for sustainable domestic organic waste management (Ravi and Vishnudas, 2017). The various aspects of sustainable domestic organic waste management were

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studied in detail. Then measurable factors were identified for each aspect of sustainable domestic organic waste management and based on this the question were framed. The overall objective of the evaluation study was to get an idea of existing biogas plants constructed over the past ten years, which will help to formulate guidelines for the sustainable domestic organic waste management in the city. The structured questionnaires were discussed in a panel of experts from various organizations involved in biogas promotion and extension in the city prior to the field testing. An interactive approach rather than a question and answer session with the respondents during the field survey process was adopted to enhance the quality of data and information collected.

2.1. Sustainable domestic organic waste management (SDOWM)

To achieve sustainable and effective waste management, development strategies must go beyond purely technical considerations to formulate specific objectives and implement appropriate measures with regard to political, institutional, social, environmental, economic and technical aspects of solid waste management (Schubeler et al., 1996) For sustainable domestic organic waste management, the waste management system should be socially and economically acceptable to all groups of the society. The environmental impacts of such systems should be minimum or negligible. The system should be preferably locally manufactured, should have maximum efficiency, durable and of good quality. The system should be adaptable and affordable to all sections of the society, simple and easy to operate, low initial and maintenance cost, energy efficient etc. Thus, the study defines sustainable organic waste management as the 'domestic organic waste management system which is environmentally friendly, technically feasible, economically viable and socially acceptable with adequate institutional/organizational support'. The various aspects of SDOWM were identified and the conceptual framework was outlined as shown in Figure 1 (Ravi and Vishnudas, 2017).

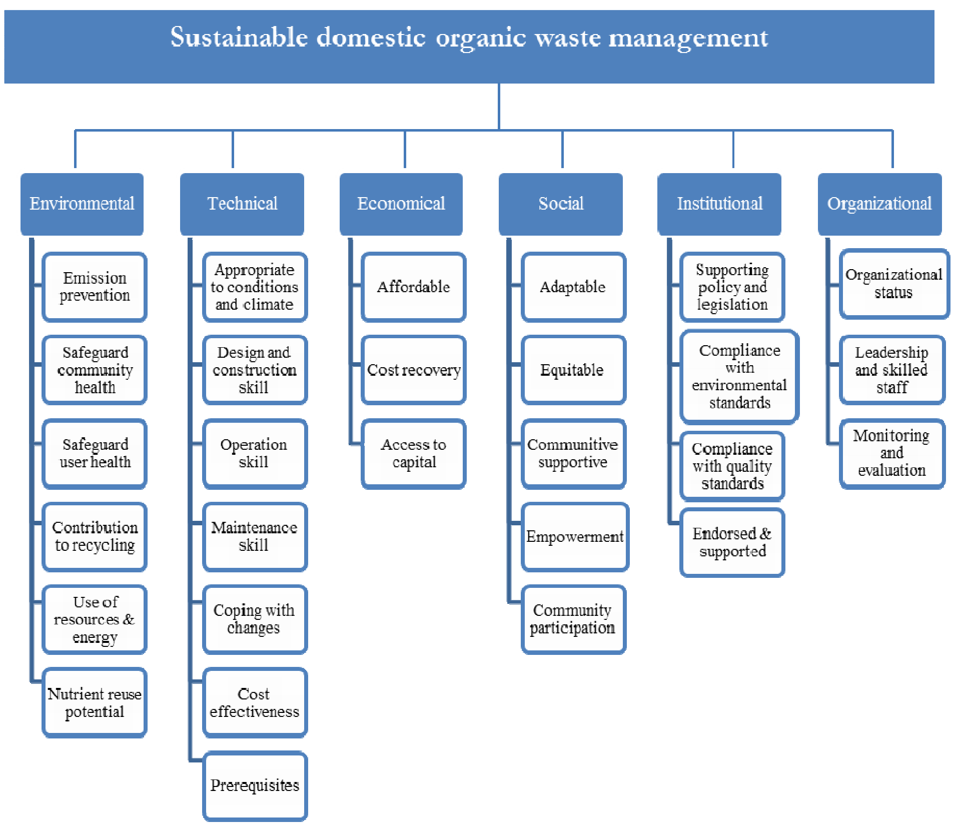

Figure 1 Conceptual framework for sustainable domestic organic waste management

The various measurable factors with respect to biogas technology were identified for each of the factors of the aspects of sustainable domestic organic waste management. These are presented in Tables 1 – 5 for evaluating the biogas technology. Table 1 describes the factors identified to measure the environmental aspects of sustainable domestic organic waste management. The various aspects are emission prevention, safeguard of community health and user health, contribution to recycling, use of resources and energy and nutrient reuse potential which measure the environment friendliness of the system (Zurburgg et al., 2014, Yang et al., 2012, ISSOWAMA, 2011).

Table 1. Factors identified to measure environmental aspects

Sl.No.	Environmental Aspect	Measurable factors identified
1	Emission prevention	Air pollution status in the kitchen
2	Safeguard community health	Complaints from neighbours regarding smell or other issues
		Mosquito breeding
3	Safeguard user health	Infections after the installation of the plant
		Diseases after the installation of the plant
4	Contribution to recycling	Percentage reduction in the amount of organic waste
5	Use of resources and energy	Daily availability of biogas
		Purpose of the gas
6	Nutrient reuse potential	Use of bio slurry

Factors which measure the technical aspects are appropriateness to conditions and climate, design and construction skill, operation skill, maintenance, coping with changes, cost effectiveness and prerequisites (Table 2) which measure the technical feasibility (Hazeltine and Bull, 1999; Akubue, 2000, Baetz et al., 1995). Affordability, cost recovery and access to capital are the factors identified to measure economic aspects (Table 3) (Zurburgg et al., 2014, Cellini and Kee, 2010, Nelson and Yudelson, 1976).

Table 2. Factors identified to measure technical aspects

Sl.No.	Technical Aspect	Measurable factors identified
1	Appropriate to conditions and climate	Working condition of the plant
2	Design and construction skill	Who constructed the plant
3	Operation skill	Who operates the plant
		Is this operable by all members of the family
4	Maintenance	Frequency of repairs
		Ease of repair
5	Coping with changes	Cope with the amount of waste produced
6	Cost effectiveness	Perception of the user for cost effectiveness
7	Prerequisites	What are the prerequisites required

Table 3. Factors identified to measure economic aspects

Sl.No.	Economical Aspect	Measurable factors identified
1	Affordable	Income range of people who uses the plant
2	Cost recovery	Cost recovery in terms of LPG cylinder numbers
		Cost recovery in terms of fertilizer purchase
3	Access to capital	Source of fund

Adaptability, equitability, community support and participation and empowerment are the factors identified to measure the social aspects (Zurburgg et al., 2014, Luthi et al., 2011) of sustainable domestic organic waste management. (Table 4). These aspects measure both social and economic sustainability.

Table 4. Factors identified to measure social aspects

Sl.No.	Social Aspect	Measurable factors identified
1	Adaptable and equitable	Educational status of people
		Gender equity
		Occupation of the people
2	Community support & participation	Is the plant shared by neighbours
3	Empowerment	Time saved after the installation of the plant
		Involvement in other activities after the installation of the plant

Table 5 describes the factors which measure the institutional/organizational aspects (Morgan and Taschereau, 1996) of sustainable domestic organic waste management. Supporting policy and legislation, compliance with environmental standards, quality standards, leadership and skilled staff, monitoring and evaluation and endorsement and support of any agency are the factors identified.

Table 5. Factors identified to measure institutional/organizational aspects

Sl.No.	Institutional/Organizational aspect	Measurable factors identified
1	Supporting policy and legislation	Whether any policy standards available?
2	Compliance with environmental standards	Whether any environmental standards available?
3	Compliance with quality standards	Whether any quality standards available?
4	Endorsed and supported	Is the institution/enterprise endorsed/supported by any agency?
2	Leadership and skilled staff	Details of skilled staff
3	Monitoring and evaluation	Is there is frequent monitoring and evaluation?

2.2. The study area – The Kochi city

Kochi city (formerly known as Cochin), lies between 9°48’ and 10°50’ latitude and 76°5’ and 76°58’E longitude, Kerala, South India. It is the commercial capital of Kerala, ‘The God’s Own Country’ and is in the Ernakulam district of Kerala. The Kochi Municipal Corporation extends to an area of 94.88 sq.km. As per census of India 2001, the population of Kochi Corporation is 5,95,575 and as per census 2011 the population is 6,01,574. The density of the city is 6,340 persons per sq. km against a density of 819 persons per sq. km in Kerala, 382 persons per sq. km in India and a world average of 46 persons per sq. km in 2011 (Census, 2011).

3. FINDINGS AND DISCUSSIONS

3.1 General Aspects

The study on household size revealed that the average household size of the respondents using the biogas plant is 4.3. The plant is used more by households of medium household size (3 - 4) followed by households with sizes more than four and least by the 0 – 2 size household group. The study revealed that the size of the land holdings is not a criterion for owning the biogas plant. The plant works almost equally in the land holdings of the size of less than five cents and above twenty cents. The plant is seen more in households with small land holdings. Only 3% of the samples reported livestock farming in their house. 97% own a plant of size 1m3. The installed plants were of the age two to more than five year. The survey revealed that the service providers decide the size of the plant and the respondents are not aware of the capacity determination. The non-availability of other fuel sources especially LPG and as a solution to reduce the organic waste mainly motivated the respondents to install the plant. The users also responded that they were motivated to install the plant by their friends/ relatives who are well-wishers of the technology. 74% of the households who own the plant have a vegetable garden in their home which provides them with the essential needy vegetables for their diet. This will help to attain self-reliance on organic vegetables rather than depending on the other states. Most of the respondents were doing some sort of organic farming even in small parcel of land.

3.2 Social Aspects

The various social aspects for a sustainable management can be measured by the educational status of the people (whether the plant can be operated by people of different educational status), gender equity (operable or handy by both male and female), occupation. The community support and participation aspects can be measured by use of a single plant by multiple families or houses. The empowerment aspect can be measured by the time saved after the installation of the plant and utilization of time saved by involvement in other activities after the installation of the plant.

3.3 Economical Aspects

The economical sustainability was measured mainly by the factors like the income range of the people who uses the plant, measuring the cost recovery aspect in terms of the number of LPG cylinders, fertilizer purchase etc. and by measuring the access to capital in terms of source of fund.

The total monthly income of the households includes the income of the respondent and the family members from all sources. 40% reported that their income falls in the Rs.10K to 15K category. Income category Rs.15K to 20K constituted 33.33% and more than 20K group constituted 26.67%. The study reads that the plant is not accessible to the low income groups but accessible to the middle income groups due to the high initial cost. Almost all of them were able to afford the cost of the plant themselves. Only 13.33% of the households responded that there is no reduction in the number of LPG cylinders in a year whereas the rest of the households responded that there is considerable reduction in the number of LPG cylinders in terms of 1-4 or even more than 4 numbers. 53% of the households reported that they not even purchase fertilizer before or after the installation of the plant. 33% reported that there is reduction to some extend in the purchase of fertilizer where as 13% responded that there in considerable reduction in the purchase of fertilizers.

3.4 Technical Aspects

The technical aspects of sustainability is assessed by the factors like working condition of the plant in all climate and location, design and construction skill, operation skill of the family members irrespective of age, gender or any other discrimination, maintenance skill, ability of the plant to cope with the changes in the amount of wastes, cost effectiveness and the prerequisites required. Most of the plants were constructed outside the house (90%) whereas two households constructed inside the house and one outside the plot. 93% reported that the plant is working normal in all climates.

The female members are more sensitive to use the plant than the male members. 73% of the households answered that female member mostly operates the plant, while 13% answered male member mostly operates the plant and 13.33% answered both men and women operates the plant. The amount of gas production in biogas digester depends upon the quantity of feeding added to it daily provided the plant is technically all right. Kitchen waste and other household wastes were the two major feeding materials used. Majority of the respondents (93%) used kitchen waste as the feeding material. 3.33% used cow and buffalo dung in addition to the kitchen waste. Another 3.33% used the poultry droppings from their farm and nearby areas to feed the plant.

The response of the households were also taken regards the latrine connection to biogas plants. Few people responded that people are hesitant to handle bio-slurry from latrine-attached plants. 53% answered that the quantity of wastes produced is adequate for the production of gas whereas 47% answered that the feed is not sufficient for the working of plant. All the plants were installed by the service provider itself and the respondents were not aware of the standards and quality controls insisted during the design and construction. The 87% of households responded that the initial cost of the plant and its installation is quite expensive and 13.33% responded that the cost is reasonable. 87% responded that water is an essential prerequisite for the functioning of the plant. 7% each responded that land and agricultural land is also a prerequisite for the functioning of the plant.

3.5 Environmental Aspects

The measurable factors identified for the assessing the environmental aspect of sustainability are emission prevention by means of air pollution status in the kitchen, safeguard of community health by means of complaints from neighbours regarding smell or any other menace like mosquito breeding, safeguarding user health by means of enquiries about infections and diseases after the installation of the plant, contribution to recycling by measuring the percentage reduction in the amount of organic waste, use of resources and energy by measuring the daily availability of biogas and the purpose of gas, nutrient reuse potential by means of the use of bio slurry.

All the households do not find any pollution in their kitchen after the installation of the plant. Most of the respondents reported that with the installation of biogas, cooking using firewood has decreased and this has reduced the smoke due to firewood stoves in the kitchen after the installation of biogas plant. The households were asked to report whether there are any complaints from neighbours regarding smell or any other thing after the installation of biogas. All of the respondents reported that no such complaints have been raised by the neighbours. Households were asked whether increase in mosquito breeding has noted after the installation of the plant. 40% reported that there is considerable increase in the breeding of mosquitoes are noted after the installation of the plant since the plant is of floating type and the bio slurry is exposed. 60% have managed the mosquito menace by preventive measures. The following preventive methods looked essential to avoid mosquito breeding: covering the whole plant with net; using guppies which feed on mosquito larvae; using bacillus thuringiensis as a biological control agent for killing larvae; and by means of kerosene or oil dropped in the bio slurry.

All the households reported that no infections or diseases have been affected after the installation of the plant. 87% confirmed that there is 100% reduction in the percentage of organic waste after the installation of the plant whereas 13% reported 75% reduction of organic waste. No accidents due to fire or burning from biogas have been reported by the households. 73% reported that the daily availability of biogas is up to one hour and 8% reported that they are getting 1-2 hours daily (See Table 10.4). Single burner gas stoves were installed in all the biogas-households. When asked about the reasons for lesser gas production, the respondents felt that it was small-sized plant; under-fed plants (more the fish waste more gas is produced); lack of timely repair and maintenance work; and some others replied that they are not aware of the reason. Biogas produced was used only for cooking purpose in all the households. 87%

households reported that they effectively use the bio slurry produced from the plant. Of this 87% use this as organic fertilizer without composting, 10% give out to others and 3.33% drain to water course or drain. 13.33% reported that they do not use the bio slurry as it is difficult to use (40%) and no land to use (60%) then effectively.

3.6 Institutional/Organizational Aspects

The factors identified for measuring the organizational or institutional aspect of sustainability are the stress on policy standards, environmental and quality standards set for the plant, whether the institution is endorsed or supported, details of skilled staff who installed the plant and the details of monitoring and evaluation. The study findings revealed that biogas plants were installed by the service provider themselves. The respondents (43%) are not aware of the standards set by their service providers or government. Though of the plant owners felt that some technical standards were set by the service providers as regards the quality of construction materials and construction methods, 47% of the respondents did not know about those standards. The rest of the respondents (10%) believed that no such standards were set. All of the respondents revealed that, only the spot instruction with palm lets from mason/company/supervisor etc. was received. Regarding the after sale services 90% reported that they had not even requested for services and 10% reported that the services have been availed on call.

4. Benefits and Bottle Necks Of Biogas Technology

4.1 Benefits

Biogas is an odourless and colourless flammable gas which burns with a clear blue flame similar to that produced by Liquified Petroleum Gas (LPG). It is produced from the bacterial decomposition and fermentation of organic matter in a bio-digester. The process is enabled by the addition of water to the organic matter and happens within an optimal temperature range of between 35 and 40 degrees Celsius (Parker, 2007; Sathianathan, 1975).

One of the main attractions of biogas technology is its ability to generate a flammable gas from organic waste which is freely available in most communities. Biogas produced from the controlled bacterial decay of organic matter in a bio-digester largely consists of methane and carbon dioxide, with these gases constituting two thirds and one third of the total gas output respectively. Small amounts of nitrogen, hydrogen and hydrogen sulphide are also produced (Fulford, 1988; Parker, 2007). The calorific value of biogas is roughly 20 Mega Joules per m3 and it usually burns with 60% efficiency in a conventional biogas stove (Fulford, 1988). Apart from the flammable gas produced as primary output, bio-digesters also produce a secondary product as the digestion process readily converts organic waste into bio-manure. This by-product, also known as sludge, carries an added advantage in its potential application as a highly nutritious fertilizer (Parker, 2007, Savola, 2006).

Austin (2003) states that biogas holds wide ranging potential at the household level in its domestic application to meet heating needs and to provide energy for cooking, lighting, running water pumps and even generating electricity through internal combustion processes. Akinbami et al. (2001) furthermore report that biogas has equally positive agricultural applications in its use for drying crops, pumping water for irrigation and providing a steady supply of fertiliser as by-product.

In its role as a way to conserve soil nutrients and also to manage organic waste, countries such as Finland and Sweden have already formally adopted biogas technology. Moreover, biogas has many useful applications in small-scale industrial operations. Apart from its benefits in terms of electricity production, biogas energy can be used wherever industrial heating applications are required, such as in the case of scalding tanks and drying rooms. In addition to the above, biogas production is associated with significant advantages in the field of environmental health and environmental management.

Biogas production promotes environmental sanitation by transforming biodegradable organic waste from a potential public health liability in the form of pathogens and groundwater pollution into something with positive environmental utility in the form of useful organic fertilizer and a sustainable and in expensive form of energy. The latter of course aids air quality by displacing wood and fossil fuels such as charcoal and diesel, thereby reducing deforestation, greenhouse gas emissions as well as air pollution with its negative consequences for human health and respiratory function (Engler et al, 1999).

When using biogas, people can involve more additional activities, and social benefits such as village self-reliance, local employment and skill generation will occur (Ravindranath, 1992). The daily time spent in feeding a small biogas digester could be as little as 15 minutes compared to several hours with the collecting of biomass. Time consumed cleaning vessels and other kitchen equipment can also be lowered since biogas produces less soot than biomass generally does. Most importantly, the more economical use of time, results in more time available for education. (Gautam et al, 2009)

Varma (2007), analyzed various technological options, their salient features, environmental implications, cost norms and suitability to the biophysical environment of Kerala and concluded that windrow composting, vermi composting and biomethanation (anaerobic composting for biogas) are the most appropriate techniques for organic waste management as far as Kerala is concerned.

Some of the health related benefits achieved from the implementation of biogas plants in Nepal include: reduced smoke exposure in the indoor environment, reduced acute respiratory infections on population of all ages, improved infant mortality rates, reduced eye ailments, reduced concentrations of carbon monoxide, formaldehyde and suspended particles in indoor environments (Pandey, 1984).

A properly managed compost operation promotes clean and readily marketable finished products, minimizes nuisance potential and is simple to operate (World Bank, 1997). There is a reduction in landfill space where composting is operated as waste management technique (He et al., 1992, Awomeso et al., 2010). There is also a reduced surface and groundwater contamination, which is a phenomenon in landfill. According to WHO, 900 million people experience diarrhoea or contact diseases such as typhoid and cholera through contaminated water (WHO, 2008). Through composting waste blocking of rivers, canals, drainages could be reduced (World Bank, 1997). As a flexible waste management, composting enhances recycling of materials, low transportation cost. In composting there is a minimal emission of greenhouse gases with subsequent effect on climate change and global warming (Seo et al., 2004). Moreover, addition of compost to soil reduces soil erosion as well as improvement of soil's structure, aeration and water retention. The use of chemical fertilizer could lead to groundwater pollution. But the use of compost discourages this water pollution.

In short the advantages and benefits of biogas technology can be listed as follows

- Provides a non-polluting and renewable source of energy thereby conserve energy in an efficient manner.
- Saves women and children from drudgery of collection and carrying of firewood, exposure to smoke in the kitchen, and time consumed for cooking and cleaning of utensils. This meets the most popular worldwide objective of women empowerment.

- Produces enriched organic manure, which can supplement or even replace chemical fertilizers.
- Leads to improvement in the environment, and sanitation and hygiene, a source for decentralized power generation and employment generation in the rural areas.
- The technology is cheaper and much simpler than those for other bio-fuels, and it is ideal for small scale application.
- Anaerobic digestion inactivates pathogens and parasites, and is quite effective in reducing the incidence of water borne diseases.
- Environmental benefits on a global scale: Biogas plants significantly lower the greenhouse effects on the earth's atmosphere. The plants lower methane emissions by entrapping the harmful gas and using it as fuel.

4.2 Bottle Necks

Biogas production is however also challenged by limitations. Balsam (2006) explains, firstly, that the process of digestion in bio-digesters can be relatively slow. Thus, for biogas to be delivered at useful rates, a fairly large volume of organic waste as input material would be required. Secondly, biogas cannot be easily bottled for transportation and use at a relatively large distance away from the source of production. It is therefore only useful if bio-digesters are located fairly close to the end-users. In view of such limitations, Balsam states that it is important that decision-makers understand what biogas production entails if it is to be effectively produced and if its advantages are to be enjoyed by people.

A biogas plant is said to be defective if it does not yield the expected gas as per the specifications of the plant. This may be due to the operational problems or shortcomings in the accessories and inputs such as stove, pipeline, valve and feeding rate and installation problems due to deviation from the standard specification of construction such as using quality, dimensions and trained masons.

According to Khoiyangbam et al.(2011) the problems faced by biogas technology include high cost of construction, corrosion of gas holder, leakage of digester tank, defective pipeline, accumulation of water in pipeline, low biogas production in winter and at high altitude, slurry comes through the pipeline, plenty of gas inside the plant but will not come in the stove or lamp, slurry level would not rise in the displacement chamber / outlet pipe, low pH, fluctuation of gas pressure, carbon dioxide reducing the calorific value, hydrogen sulphide leading to corrosion, gas does not burn, improper combustion, elongated yellowish flame, flames lifts off, flame extinguishes, flame too small and too big.

5. CONCLUSIONS

The paper evaluated the sustainability of the biogas technology system practised in Kochi city and the major findings are as follows. When measuring the social aspects of sustainability, the evaluation study reveals that the respondents who have installed the plant are mainly government/salaried and self-employed. A noticeable percentage of daily wage and other occupation groups also installed the plant. The plants have been installed by the people having different educational status ranging from school education to post graduation and above. Sharing of the plant with the neighbours has not been seen during the study except for some cases. 53% revealed that time is saved in kitchen due to the availability of extra fuel which increase their involvement in organic farming and gardening activities in their houses. Apart from this, the technology is used as an alternate for waste disposal. The decision to install the plant has been done mainly by the female member and after discussion in the family. These findings show that the technology is affordable and equitable. In addition it has adequate community support and participation and promotes women empowerment.

While measuring the economic aspects, the study point out that the system is affordable to all income groups and almost all of them afforded the cost of installation themselves. The majority of respondents experienced a reduction in the number of LPG cylinders in one to four numbers in a year and also reported that there is economic gain in terms of fertilizer purchase also. Even though the initial capital cost is high it is economical in the long run in terms of saving of other fuels used in kitchen. These findings reveal that the system is economically sustainable.

Regarding the technical aspects the study assessed that the plant is adaptable to climate and location and is easily operable, but mostly female members operates it. The plant feeds on kitchen waste in most cases but also accommodates dung, poultry droppings, leaves etc. Most of the households responded that the quantity of their feed is sufficient for the functioning of the plant and almost all the plants are installed by the service provider. This explains the technically feasibility of the plant.

The plant is free from emission, foul smell or any other menace. It was observed that preventive measures are done for controlling mosquito breeding. The user or community health is safe and cases of contagious disease were not reported after the installation of the plant. The majority of the respondents reported that there is 100% reduction of organic waste. The availability of gas is about one to two hours. The produced gas is used only for cooking purpose which can be expanded to many energy saving options like lighting. Apart from this, the nutrient reuse potential of bio slurry can be efficiently utilized by means of vegetable gardens or for sale the bio slurry to others. This highlights the environmental friendliness of the system.

The plant is installed by service providers who are mainly NGOs or installation supervisors. The respondents were given on the spot instruction and through palm lets. This is adequate for majority of respondents but the training for regular maintenance of the plant is felt not adequate. The after sale services is satisfactory among the respondents. Even though the technical sustainability is not at par with standards and other aspects of sustainability, the installation and maintenance of the plant can be promoted through local bodies to make it more sustainable.

In general, the biogas technology system is socially acceptable, economically viable, environmental friendly, technically feasible and institutionally stable apart from some minor issues. The issues include improper operation and maintenance, improper segregation of waste for feeding the plant, improper application of slurry, optimal use of biogas etc. The key to proper operation of biogas plant is the daily feeding with mix of right proportions of the wastes and water, frequent draining of condensed water in the pipeline through the water outlet, cleaning of stoves and lamps, oiling of gas valves and gas taps, cleaning of overflow outlet, checking of gas leakage through pipe joints and gas valves and adding of organic materials to slurry pits. As long as these tasks are carried out reliably and carefully the plant will function properly.

From the technical review it has been strengthened that biogas production process has become attractive as its technology has been successfully tested through experience on both small- and large-scale projects. Therefore, it is concluded that feeding upon renewable resources and non-polluting in process technology, biogas generation serves a triple function: waste removal, sustainable management of the environment, and energy production.

REFERENCES

[1] Minghua, Z., F. Xiumin, A. Rovetta, H. Qichang, F. Vicentini, L. Bingkai, A. Giusti, L.Yi. (2009), *Municipal solid waste management in Pudong New Area, China.* Waste Management, 29, 1227-1233.

[2] Gupta, S., K. Mohan, R. Prasad, and A. Kansal (1998) *Solid waste management in India: options and opportunities*. Resources, Conservation and Recycling, 24, 115-137.

[3] Shannigrahi, A.S., N. Chatterjee, and M.S. Olaniya (1997) *Physico-chemical characteristics of municipal solid wastes in mega city*. Indian Journal of Environmental Protection, 17, 527-529.

[4] Jalan, R.K., and V.K. Srivastava (1995) *Incineration, land pollution control alternative - design considerations and its relevance for India*. Indian Journal of Environmental Protection, 15, 909-913.

[5] Jha, A.K., C. Sharma, N. Singh, R. Ramesh, R. Purvaja, and Gupta (2008) *Greenhouse gas emissions from municipal solid waste management in Indian mega-cities: A case study of Chennai landfill sites.* Chemosphere, 71 , 4119-4130.

[6] Reddy, S., and S. Galab (1998) *An Integrated Economic and Environmental Assessment of Solid Waste Management in India - The Case of Hyderabad, India*, Centre for Economic and Social Studies, Andhra Pradesh India.

[7] UNCHS, (1989), *Solid waste management in low income housing projects*, United Nations Centre Human Settlement Programme, Nairobi, 46.

[8] Ravi. A., and S. Vishnudas (2017) *Conceptual Framework for Evaluating the Sustainability of Domestic Organic Waste Management Techniques.* International Journal of Civil Engineering and Technology, 8, 283 –289.

[9] Schubeler P., K. Wehrle, and J. Christen, and SKAT (1996) *Conceptual Framework for Municipal Solid Waste Management in Low-Income Countries*, Swiss Centre for Development Cooperation in Technology and Management, Switzerland.

[10] Zurbrugg, C., M. Caniato, and M. Vaccari (2014) *How assessment methods can support solid waste management in developing countries - a critical review*. Sustainability, 6, 545-570.

[11] Yang, L., Z. Chen, T. Liu, Z. Gong, Y. Yu, J. Wang (2012) *Global trends of solid waste research from 1997 to 2011 by using bibliometric analysis*. Scientometrics, 1, 1-14.

[12] ISSOWAMA (2011) *Relevant Potential Impacts and Methodologies for Environmental Impacts Assessment Related to Solid-Waste Management in Asian Developing Countries*, ISSOWAMA.

[13] Hazeltine, B., and C. Bull (1999) *Appropriate Technology: Tools, Choices, and Implications*, Academic Press, New York.

[14] Akubue, A. (2000) *Appropriate technology for socioeconomic development in third world countries*. Journal of Technology Studies, 26, 33-43.

[15] Baetz, B.W., and R.M., Korol (1995) *Evaluating technical alternatives on basis of sustainability*. Journal of Professional Issues in Engineering Education and Practice, 121, 102-107.

[16] Cellini, S.R., and J.E. Kee (2010) *Cost-Effectiveness and Cost-Benefit Analysis. In J. S. Wholey, H. P. Hatry, & K. E. Newcomer (eds.),* Hand book of practical program evaluation (3rd Ed.), 493-530, San Francisco.

[17] Nelson, L., and J. Yudelson (1976) *Criteria for an Appropriate Technology*, California Office of Appropriate Technology, Los Angeles.

[18] Luthi, C., A. Morel, E. Tilley, and L. Ulrich (2011) *Community-Led Urban Environmental Sanitation Planning (CLUES)*, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dubendorf.

[19] Morgan, P., and S. Taschereau (1996) *Capacity and Institutional Assessment: Frameworks, Methods and Tools for Analysis*, Canadian International Development Agency (CIDA), Policy Branch.

[20] Census Provisional Population Totals (2011), India, Ministry of Home Affairs, Government of India, New Delhi.

[21] Parker, N. (2007) *Integrated Biogas Solutions*, Agama Energy, Cape Town, South Africa.

[22] Sathianathan, M.A. (1975) *Biogas: Achievements and Challenges, Association of Voluntary Agencies for Rural Development*, New Delhi.

[23] Fulford, D. (1988) *Running a Biogas Programme: A handbook*, Intermediate Technology Publications London.

[24] Savola, H. (2006) *Biogas Systems in Finland and Sweden: Impact of Government Policies on the Diffusion of Anaerobic Digestion Technology*, Master’s Thesis, Lund University, Lund, Sweden.

[25] Austin, G. (2003) *Biogas Energy and Sanitation in South Africa*, ESI Africa, South Africa.

[26] Akinbami, J.F.K., M.O. Illori, T.O. Oyebisi, I.O. Akinwumi and O. Adeoti (2001) *Biogas energy use in Nigeria: current status, future prospects and policy implications*. Renewable and Sustainable Energy Reviews, 5, 97-112.

[27] Engler, C.R., E.R. Jordan, M.J. McFarland, and R.D. Lacewell (1999) *Economics and Environmental Impact of Biogas Production as a Manure Management Strategy*. Proceedings of the 1999 Texas Animal Manure Management Conference, USA.

[28] Ravindranath, N. H. (1992) *Biomass Gasification: Environmentally Sound Technology for Decentralized Power Generation, A Case Study from India,* ASTRA and Centre for Ecological Sciences, Indian Institute of Science, Bangalore.

[29] Gautam, R., S. Baralb, and S. Heart (2009) *Biogas as a sustainable energy source in Nepal: Present status and future challenges.* Renewable and Sustainable Energy Reviews, 13, 248-252.

[30] Varma, A. (2007) *A database on solid wastes of Kerala for initiating programmes for prevention of land pollution and upgradation of environment*. Proceedings of National workshop for Fertility Evaluation for Soil Health Enhancement, Soil Survey Organization, Govt. of Kerala. 330-338.

[31] Pandey, M.R. (1984) *Domestic smoke pollution and chronic bronchitis in a rural community of the hill region of Nepal.* Thorax, 39, 337-339.

[32] World Bank (1997) *Expanding the Measure of Wealth:* Indicators of Environmentally Sustainable Development, Washington D.C.

[33] He, X.T., S.J. Traina and T.J. Logan (1992) *Chemical properties of municipal solid waste composts.* Environmental Quality, 21, 318-329.

[34] Awomeso, J.A., A.M. Taiwo, A.M. Gbadebo and A.A. Arimoro (2010) *Waste disposal and pollution management in urban areas: A workable remedy for the environment in developing countries.* American Journal of Environmental Science, 6, 26-32.

[35] WHO (2008), *Safe Water and Global Health,* World Health Organisation, Geneva.

[36] Seo, S.A., T. Aramaki, Y. Hwang and K. Hanaki (2004) *Environmental impact of solid waste treatment methods in Korea.* Environmental Engineering, 130, 81-89.

[37] Balsam, J. (2006) *Anaerobic Digestion of Animal Waste: Factors to Consider,* National Centre for Appropriate Technology.

[38] Khoiyangbam, R.S, S. Kumar, M.C. Jain, N. Gupta, A. Kumar, and V. Kumar (2004) *Methane emission from fixed dome biogas plants in hilly and plain regions of northern India.* Bioresource Technology, 95, 35-39.

Authors

Athira Ravi is currently a part time research scholar in the Division of Civil Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, Kerala, India. Also she is the Deputy Town Planner, Town and Country Planning Department, Government of Kerala, India. She received Master of Planning (Housing) from the College of Engineering, Thiruvananthapuram in 2007. Her current research interests include sustainable development, urban planning, solid waste management, footprint analysis etc.