Energy Policy 112 (2018) 361–370

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Barriers to biogas dissemination in India: A review

Shivika Mittal[a,*], Erik O. Ahlgren[a], P.R. Shukla[b]

[a] Division of Energy Technology, Department of Energy and Environment, Chalmers University of Technology, SE - 412 96 Göteborg, Sweden
[b] Public Systems Group, Indian Institute of Management, Vastrapur, Ahmedabad 380015, Gujarat, India

ARTICLE INFO

Keywords:
Biogas
Barrier identification
Decomposition analysis
Expert interviews
Literature review
Bioenergy policies

ABSTRACT

Biogas has emerged as a promising renewable technology to convert agricultural, animal, industrial and municipal wastes into energy. Biogas development can be integrated with strategies to improve sanitation as well as reduce indoor air pollution and greenhouse gases. Currently, the total biogas production in India is 2.07 billion m^3/year. This is quite low compared to its potential, which is estimated to be in the range of 29–48 billion m^3/year. Hence, this study aims to identify both technical and non-technological barriers impending biogas dissemination in India. Biogas dissemination is affected by various waste, renewable energy, and urban policies. Barriers were therefore identified individually for rural and urban biogas systems existing in India using decomposition analysis. The results show that type and importance of barriers vary strongly between biogas systems due to the difference in technology maturity, feedstock availability and quality, supply chain, awareness level and policy support.

1. Introduction

Biogas is a renewable energy source that is generated through anaerobic digestion of biodegradable organic feedstocks i.e. municipal and industrial wastes, animal and agricultural residues. Biogas contains high methane content (40–70%) that can further be upgraded to natural gas quality (75–99% methane content). The upgraded biogas can be injected into a natural gas grid or used as a transport fuel.

Anaerobic digestion of biodegradable organic wastes, besides providing energy and manure, offers several social and environmental benefits. Biogas contributes in reducing negative externalities associated with organic wastes such as groundwater and soil contamination, emission of local air pollutants like dioxins and furans as well as methane, a potent greenhouse gas (Kumar and Sharma, 2014; Lewis et al., 2017). Replacement of fossil fuels and untreated traditional solid biomass by clean fuel like biogas for cooking, lighting and electricity generation would also help in curtailing GHG emissions as well as indoor air pollution (Pathak et al., 2009). The nitrogen content in the slurry after anaerobic digestion enhances compared to untreated animal manure, thus can be used as organic fertilizer. Bio-fertilizer use in agricultural land would partly or fully offset the need for chemical fertilizers which itself have high energy demand during production (Katuwal and Bohara, 2009). Even though environmental, health and social co-benefits from biogas production are commonly recognized, there are several barriers to the deployment of biogas technologies that need overcoming.

Family-type small biogas systems predominantly exist in the rural areas with capacities ranging from 1 to 10 m^3 biogas per day. Animal manure and agricultural wastes are primarily used as feedstocks in household biogas digesters, producing biogas and bio-slurry that can be used as organic fertilizers. Mostly small-scale plants are managed by individual households to generate energy for self-consumption. On the other hand, large and industrial-scale biogas plants with capacity above 5000 m^3 biogas per day largely utilize municipal or industrial organic wastes to generate biogas which can further be utilized for electricity generation, heat and transport fuel. Family-type biogas plants are managed by the individual households requiring financial investment but only yielding non-monetary benefits i.e biogas used as cooking fuel substituting gathered fuelwood, whereas large-scale commercial biogas plants, managed by entirely private or public-private partnership aim to yield financial benefits by selling end-products i.e electricity, transport fuel or heat. Factors such as the macro environment, scale of production, utilization area and feedstock type differ widely between two biogas systems in India (He et al., 2013; Song et al., 2014). Given the differences between two biogas systems, it would be essential to carry out a comparative assessment of barriers to biogas dissemination at different scales.

Several support schemes such as the National Biogas and Manure Management Program (NBMMP), off –grid biogas power generation program, waste to energy program have been implemented by the government for biogas development in India (MNRE, 2015; Shukla, 2007). Regardless of these efforts, diffusion of biogas technologies is

* Corresponding author.
E-mail address: mittal.shivika86@gmail.com (S. Mittal).

http://dx.doi.org/10.1016/j.enpol.2017.10.027
Received 13 January 2017; Received in revised form 22 August 2017; Accepted 14 October 2017
Available online 05 November 2017

constrained by several financial, social and institutional factors (Rao and Ravindranath, 2002; Schmidt and Dabur, 2013). Few researchers have looked at the barriers to bioenergy diffusion in rural India (Rao and Ravindranath, 2002; Ravindranath and Balachandra, 2009; Vijay et al., 2015); while others have focused on stakeholder perspectives (Hassan et al., 2015; Zyadin et al., 2015) and bioenergy potential (Chandra et al., 2006a; Hiloidhari et al., 2014; Kumar et al., 2015; Rao et al., 2010). Several case-studies have also been carried out in the rural context to assess the success of biogas development programs (Bhat et al., 2001; Raha et al., 2014; Reddy, 2004). However, there is no study focusing on the barriers impeding the commercialization and diffusion of biogas technologies in urban areas at large and industrial scale.

Previous research studies have identified various barriers to biogas dissemination in different countries, for instance, UK (Adams et al., 2011), Europe (McCormick and Kaberger, 2007), Sweden (Lantz et al., 2007), China (Chen et al., 2012) and Thailand (Prasertsan and Sajjakulnukit, 2006), some from a stakeholder perspective (Adams et al., 2011), some from a system perspective (Lantz et al., 2007) and some from a multi-level perspective (Kamp and Bermúdez Forn, 2016) but none of these studies have compared the barriers prevailing in different biogas systems functioning at different scales. He et al. (2013) compared the performance of centralized and decentralized bioenergy systems in rural China and found that the costs of centralized bioenergy systems outweigh the overall benefits from the system. Barriers to biogas technologies diffusion in different countries stemming from previous studies are summarized in the Tables S.1 and S.2. The barriers mentioned in the literature have been classified into barriers affecting biogas dissemination in developed and developing economies.

Based on the review, it was found that barriers differ in different regions depending on the degree of market maturity and availability of natural resources like biomass, land, and water. Barriers such as low ambient temperature and water unavailability in arid regions are area specific (Shane et al., 2015) whereas others are specific to technological scale like lack of distribution infrastructure hindering the biogas expansion in a centralized system (Lantz et al., 2007). Socio-cultural barriers like objections towards using animal and human waste as raw material are very specific to the local values and culture (Rupf et al., 2015). Technical and informational barriers such as lack of technical capacity for construction and maintenance, competition from freely available firewood and lack of awareness mainly exist in rural areas in developing countries (Rao and Ravindranath, 2002; Rupf et al., 2015). Some barriers are specific to its utilization i.e transport fuel or heat production. High variation in the seasonal demand for heat acts as a barrier for utilization of biogas for heat production whereas a limited number of filling stations acts as a barrier for utilizing biogas as vehicle fuel (Lantz et al., 2007; Poeschl et al., 2010). This indicates that barriers to biogas penetration differ based on utilization area, substrate, resource potential, technological maturity, and scale. These factors may also vary among countries or regions.

To fill this gap, a comparison is done in this paper between the barriers to small-scale biogas technology dissemination in rural areas and large-scale biogas technology dissemination in urban India. The choice of India as a case is due both to the immense size of the country, the long history of a biogas policies, and the clear existence of biogas challenges at the rural (small scale) and the urban (large scale) biogas systems. Comparative analyses can then be used to propose strategies or policy interventions to deal with biogas development barriers specific to each system. Thus, this paper aims to address the following elicited questions. First, what are the barriers involved in the dissemination of biogas technologies in India? Second, are there any differences in the type of barrier among rural and urban biogas systems? Third, what changes in policy architecture are required to overcome the barriers in the respective biogas systems? This paper identifies the barriers to biogas dissemination in India based on an extensive literature review complemented by expert interviews.

The structure of the remaining paper is as follows. The first section highlights the history of biogas development policies in India to delineate the underlying drivers behind the current biogas development. The next section presents the methodology used to identify and analyze the barriers. Then we present the identified barriers followed by discussion and policy implications.

2. Evolution of biogas policies in India and their current status

Programs for promoting biogas technologies have been running since the 1970s. The first oil crisis in early 1970's made evident to the Indian policymakers that commercial energy would remain outside the economic reach of the rural as well as the urban poor (Deo et al., 1991). India was a net importer of oil products. The combination of global energy crisis together with the local energy shortages heightened the national energy security risk from rising costs of energy imports as well as the pressure on the national budget to meet the rising energy subsidy for domestic fuels, especially kerosene, used by the rural and urban poor for very basic cooking and lighting needs.

By the late 1970's, it was evident to the Indian policymakers that the traditional local energy resources such as agriculture waste, animal waste,and fuel-wood were no more freely available in many rural areas and there was a need to conserve and augment local resources. Several rural programs such as National Biogas and Manure Management program and off–grid biogas power generation program for providing renewable energy for cooking and lighting use. The biogas development program in 1981 was a part of a multi-prolonged approach adopted to alleviate the rural energy crisis (Shukla, 2007). Growing concerns towards solid waste management and climate change are the key drivers behind these policy initiatives to increase the biogas development in the urban areas. Fig. 1 represents the policy timeline specifying various initiatives taken by the government in last three decades to boost the waste to energy and biogas sector. Programs and initiatives for boosting the waste-to-energy sector from municipal solid waste and industrial wastes are of more recent origin; so it is difficult yet to determine the influence of new policies on the biogas technology deployment in the urban areas.

The rate of biogas dissemination is low in rural areas and the share of biogas in the fuel mix in rural households is insignificant. Around five million family biogas plants (40%) have been installed under the biogas development program against the total potential of 12 million domestic biogas gas plants estimated by the MNRE (CSO, 2014). In addition to family type biogas plants, 400 biogas off-grid power plants have been set up with a power generation capacity of about 5.5 MW (MNRE, 2015). The share of anaerobic digestion in biological waste treatment in urban areas is presently very low due to high capital cost and low revenue growth prospects compared to other competing waste treatment technologies. Currently, there are only 56 operational biogas based power plants in India, the majority of them are located in three states, Maharashtra, Kerala, and Karnataka (CPCB, 2013).

3. Methodology

A qualitative and systemic approach was used to identify barriers to biogas penetration in India. The following steps were taken to extract the relevant literature. First, a systematic search was conducted of research and review articles published after 1990 in the Scopus database. Fig. 2 presents the overview of the research protocol. Search terms used for identifying the relevant articles are mentioned in Table 1. Technical, potential and futuristic scenario studies on biogas were excluded after a manual screening (Table S.3). The gray literature related to biogas was also searched through Google and government portals(Table S.4).

As mentioned in the Section 1, few researchers have looked at the barriers impending large-scale biogas dissemination in urban India. Therefore, as a complement to the literature review, in-depth interviews with selected stakeholders were conducted to get insights needed to understand the root cause of each barrier particularly for biogas

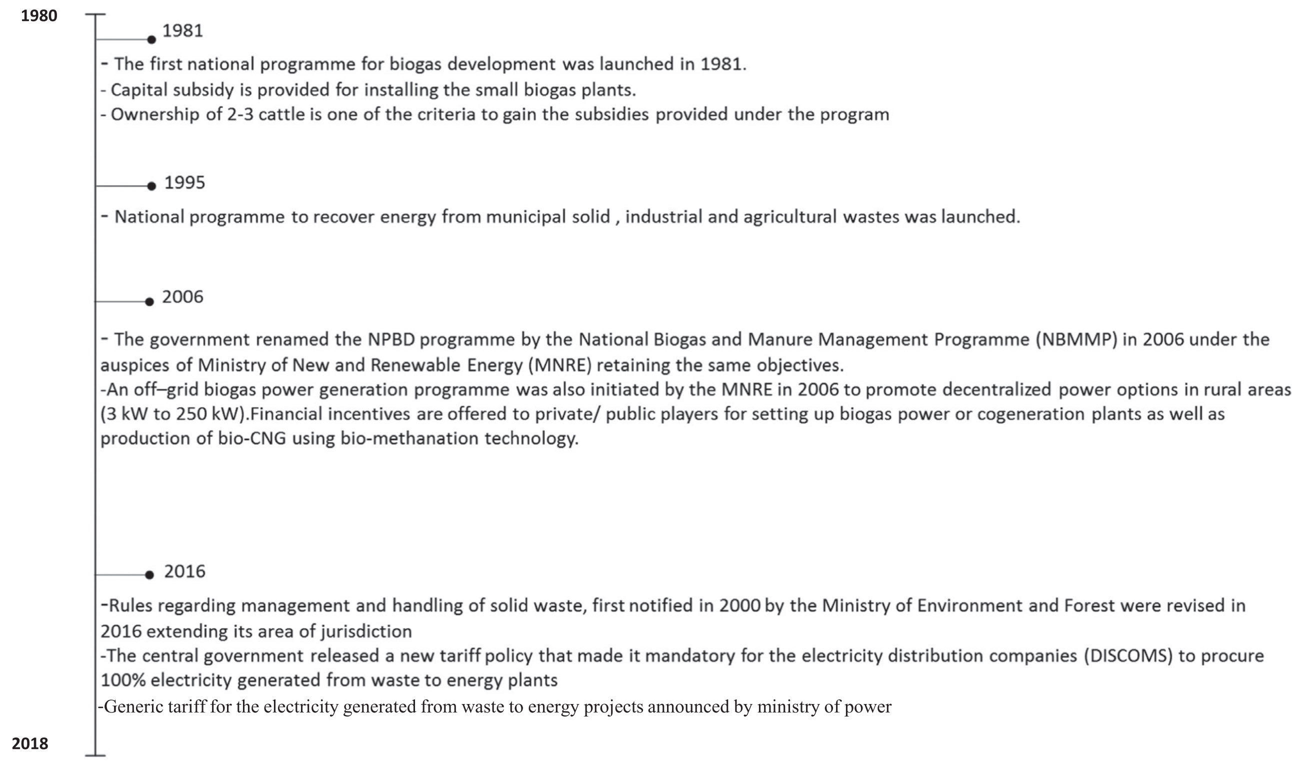

Fig. 1. Policy timeline.

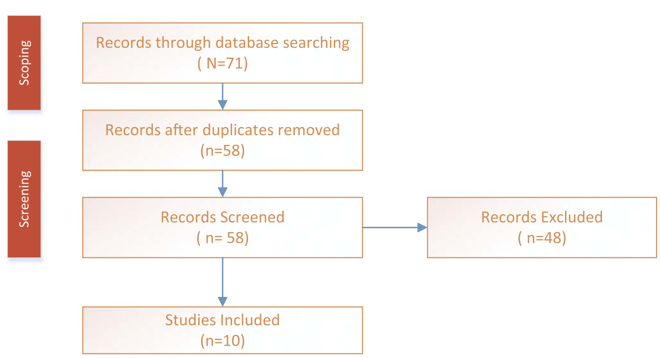

Fig. 2. Literature review plan.

Table 1
Search terms used to identify the literature.

Search terms	No of articles	Relevant articles
"Biogas" and "challenges" and "India"	13	1
"Biogas" and "constraints" and "India"	13	2
"Biogas" and "barrier" and "India"	10	6
"Biogas" and "obstacles" and "India"	3	0
"Bioenergy" and "challenges" and "India"	17	0
"Bioenergy" and "constraints" and "India"	5	0
"Bioenergy" and "barrier" and "India"	9	1

dissemination in urban areas (details are provided in Table 2). Interviews were carried out using a semi-structured questionnaire developed based on the barriers identified during the literature review. The broader review of studies addressing biogas barriers in developed and developing countries was conducted to understand the barriers to biogas dissemination at different scales. Open-ended questions related to barriers and biogas policies were asked in a hierarchical manner based on overall literature review. Consultants and academicians involved in biogas projects at different scales were selected for the interviews for the understanding of key market and technology related barriers existing in India. Officials involved in policy-making processes related to biogas at different governmental levels i.e. national, state and local were interviewed to understand the current policy landscape and level of coordination between the national and subnational governments. As Gujarat was the first state in India to announce waste to energy policy, policymakers at the state level and municipal level in this state were selected for the interviews (Table 3).

Decomposition and logical problem analysis tools were used to analyze the barriers to biogas dissemination in India identified after literature review and expert interviews. These tools are widely used in barrier identification studies (Lantz et al., 2007; Nygaard and Hansen, 2015; Painuly, 2001). Painuly (2001) developed a framework for identifying the barriers impending renewable energy penetration. In this study, barriers were decomposed at four levels: 1) broad barrier categories 2) barriers within each category 3) elements of the barriers and 4) dimension of the barrier elements. Barriers were analyzed up to the first three of these levels in this study. Multi-level cause-effect paths were created based on the stakeholder interviews for the construction of a problem tree diagram for each biogas system.

The classification approaches chosen in previous studies are region and context specific. As biogas can be produced from different feedstocks and can be utilized for different energy services, some studies have classified barriers into two categories; 1) barriers affecting the production from different raw materials (organic household waste, organic industrial waste, and dedicated energy crops) and 2) barriers affecting the utilization of biogas (CHP production, heat production and vehicle fuel production) (Lantz et al., 2007; Poeschl et al., 2010). Some studies used an agent-based approach, and identified barriers based on stakeholder perspectives, considering how various stakeholders are involved at different stages of the biogas project implementation like feedstock supplier, developer, policy maker and end-user (Adams et al., 2011; Nilsson et al., 2007). Adams et al. (2011) found that suppliers and developers are concerned by the production cost and end-users are primarily influenced by the final fuel purchase cost borne by them.

As mentioned in the introduction section, factors constraining

Table 2
Overview of interviews conducted.

Referenc code		Details	No. of Interviews	Interview date
A	Government official	Official at Ahmedabad Municipal Corporation (AMC)	1	29-03-2016
B		Official at Gujarat Energy development agency (GEDA)	1	30-03-2016
C		Official at Ministry of national and renewable agency (MNRE)	1	06-04-2016
D	Consultants	Consultant at Norwegian Embassy	1	05-04-2016
E		Consultants at India biogas association	2	03-04-2016
F		Consultant at UNDP	1	15-04-2016
G	Academicians	Professors at National universities	2	27-03-2016
H	Financial Institution	Official at the national financial agency (IREDA)	1	05-04-2016

biogas penetration vary among biogas systems existing in different countries. Therefore, a taxonomy providing a clear distinction between two biogas systems (i.e. rural and urban biogas system) existing in India was adopted. Then, the barriers within each group were explored at three different levels. At the top level, barriers were divided into broad categories: (i) Financial/economical, (ii) Market, (iii) Social and cultural, (iv) Regulatory, (v) Technical & infrastructural, (vi) Information. Then at the second level, different barriers were specified within each broad category and at the final level, elements associated with each barrier existing in each system were stated. In addition to the decomposition analysis, a logical problem analysis tool was used to explore the interactions between different barrier elements and to find measures to overcome these barriers.

4. Results

4.1. Barriers to biogas technologies in rural areas

The key barriers identified based on the literature review and expert interviews are discussed in detail in this section. Table 4 summarizes the barriers to biogas technologies dissemination in rural areas in India.

4.1.1. Financial and economic barriers

High capital cost is one of the key barriers to biogas technologies for rural applications (Rao and Ravindranath, 2002). The upfront costs such as construction, labor & equipment cost of installing a biogas plant are quite high for rural households. The total installation cost of family biogas plants varies with size, location, and model. The average cost of installing a family size biogas plant of capacity 1 m^3 of biogas per day is around $348 (Samar et al., 2016). The government provides a subsidy of around $123–$200 for family biogas plants depending upon plant capacity ranging from 1 to 6 m^3 i.e 20–40% of the total installation cost. It is evident from the Table 3 that monthly household expenditure of more than half of the rural population in India is less than $150 (MOSPI, 2015).[1] This indicates that the upfront installation cost of biogas plant is significantly higher than the monthly household expenditure of low-income households in rural areas. This makes it difficult for the low-income households in rural areas to afford biogas plant even after receiving the capital subsidy. Bansal et al. (2013) also stated lack of purchasing power among the rural households as one of the barriers hindering adoption of renewable energy technologies in India.

Moreover, procedural delay in the release of capital subsidies increases the overhead costs adding an extra burden on the beneficiaries of the program (Chandra et al., 2006b; Rao and Ravindranath, 2002). In addition to the high initial cost, limited access to easy credit for installation of a biogas plant also acts as an impediment for low-income household to utilize biogas for cooking applications (Ravindranath andBalachandra, 2009).

[1] https://rbidocs.rbi.org.in/rdocs/PressRelease/PDFs/IEPR1409R0311.pdf Accessed on 13th July 2017.

4.1.2. Market barriers

Biogas faces intense competition with other fuel substitutes available in the market. Several factors like the assurance of fuel supply, ease of procurement, fuel price, and household income have an influence on household fuel choices (Bansal, Saini and Khatod, 2013). In rural areas, biogas competes with cheaper alternatives like traditional solid biomass, firewood, and cow dung, which are locally available for cooking applications (Rao and Ravindranath, 2002). The negative externalities associated with the use of traditional biomass i.e time consumed in firewood collection, indoor air pollution, loss of forest resources, are not taken into calculation by these households. In contrast, assurance of fuel supply and ease of procurement are two critical factors for high-income households. Bhat et al. (2001) cited limited accessibility to liquid petroleum gas (LPG) as one of the reasons for the high rate of biogas dissemination in Sirsi area. However, biogas faces competition with LPG in areas with better LPG distribution network.

4.1.3. Social and cultural barriers

There are several social-cultural barriers hindering the uptake of biogas technology in rural areas. First, people and plant owners are reluctant to the use of night soil/human excreta in biogas plant due to the attached social stigma (personal communication E). Second, women are primarily responsible for cooking in rural households and primarily exposed to the indoor air pollution caused by burning solid fuels. The status of women in the rural society is very low and they have very limited decision making power which acts as a critical factor in the low penetration of clean fuels (personal communication G).

4.1.4. Regulatory and institutional barriers

A top-down approach is adopted in the NBMMP program initiated by the central government. The program is inefficiently targeted as ownership of 2–3 cattle is one of the criteria to gain the capital subsidies provided under the program to install a biogas plant. Since the majority of low- income households in rural areas does not own 2–3 cattle, it is very difficult for them to get a capital subsidy which hinders the adoption of biogas technologies (Raha et al., 2014). Therefore, low-income households rely on locally available biomass for cooking. Multiple agencies are involved in the implementation of the national biogas development program. Lack of coordination and competition between them for the incentives has been identified as one of the reasons for the poor performance and low dissemination of the biogas technology in rural areas (Bansal et al., 2013; Kaniyamparambil, 2011).

4.1.5. Technical and infrastructural barriers

Adequate supply of water and substrate are two crucial factors for the effective functioning of biogas plant. Under-feeding of inputs or feeding in wrong ratios either results in suboptimal performance of biogas plant or formation of scums, making installed plant completely dysfunctional (Rupf et al., 2015). These failures create a negative perception about the biogas technologies that discourage the potential users.

Minimum ownership of 2–3 cattle does not fully ensure the reliable supply of substrates to the biogas plant. There are several factors that

Table 3
Monthly household expenditure in rural areas in India.

Decile class[a]	p10	p30	p50	p70	p90	P95
Monthly household expenditure in rural areas (US dollar)	91	111	130	153	203	221
Monthly per capita expenditure	16	22	27	34	51	65
Household size	5.7	5.15	4.85	4.49	3.95	3.41

[a] kth percentile of the distribution of persons by Monthly per capita expenditure (MPCE), that is, the MPCE level below which k% of the population lie.

could lead to inadequate substrates supply to biogas plant. Cattle roam around grazing and working in the fields resulting in under-collection of cattle dung which eventually leads to improper functioning of the biogas plant due to under-feeding. Moreover, the collection of cattle dung at disaggregated places increases the transition cost. Water and cattle dung is required to be mixed in equal ratios in the biogas plant. Shortage of water was one of the reasons for the non-functionality and low penetration of installed biogas plant in drought-prone and deserted areas like Rajasthan or Rann of Kutch (Bhatia, 1990). In dry areas, women spend several hours to fetch and transport the water needed for cooking and drinking purposes. Thus, a large amount of water needed for proper functioning of biogas plants is one of the reasons for the low uptake of biogas technologies in dry and drought-prone areas (Samar et al., 2016).

Temperature is also a crucial factor influencing the rate of biogas production. During winters in cold areas, the production of biogas decreases considerably due to low temperatures that inhibiting methanogenesis. The hydraulic retention time also increases to around 120–150 days at temperatures below 15 °C (Zeeman, 1991; Daxiong et al., 1990, Kalia and Kanwar, 1998). The biogas production during the winter season is not sufficient for cooking which forces the users to switch to other fuels. In addition to these challenges, the- absence of trained manpower to repair technical faults occurring during biogas operation acts as another barrier deterring the penetration of biogas technologies in rural areas (Kaniyamparambil, 2011).

4.1.6. Information barriers

Lack of awareness about the technology, its associated benefits as well as incentives provided by the government has also been identified as one of the reasons for low usage of biogas as their primary fuel for cooking (Blenkinsopp et al., 2013; Rao and Ravindranath, 2002). Insufficient cattle head to supply substrate is primarily considered as the main issue for low adoption of biogas technology in rural areas. People are not aware regarding other feedstock alternatives that can be used in the digester (Raha et al., 2014).

A logical problem tree is constructed to assess the linkages between barrier elements. Fig. 3 represents a problem tree for rural biogas system in India. Low adoption of biogas technologies among rural households is considered as a core problem even after government dissemination programs running for several decades. The direct causes and effects are placed below and above the core problem respectively in the Fig. 3. Several technical, informational and infrastructural barriers such as unavailability of cattle dung, lack of user awareness as highlighted in the problem tree result in improper functioning of biogas technology. Suboptimal performance of biogas technology discourages the use of biogas technology in rural areas which eventually leads to the low adoption of the biogas technology in the rural areas. When the supply of biogas is inadequate to match the household's daily or seasonal energy requirements for cooking, rural households need to switch to other available fuels. This indicates that the adequacy and reliability of biogas plants are crucial to the adoption and use of biogas technology among the rural households.

Financial and economic barriers such as high transaction cost, high installation cost along with social and cultural barriers hinder the adoption of biogas technologies in the rural areas.

4.2. Barriers to biogas technologies in urban areas

There are various barriers listed in Table 5 that are required to be overcome to increase the dissemination rate of biogas in urban areas. In urban areas, biogas produced from municipal and industrial wastes is primarily considered for generating electricity or for transportation fuel. The description of the different elements under each barrier category is discussed below.

4.2.1. Financial and economic barriers

Financial barriers like high capital cost, unavailability of long term financing options, high interest rate and high-risk perception by financial institutions are identified as the most prominent barriers to biogas dissemination in urban areas. The high capital cost and low revenue accrual act as entry barriers for small private players/developers. Lack of access to long-term financing and high interest rate (12–14%) affects the economic viability of the biogas projects (low

Table 4
Barriers to biogas technologies in rural areas.

S. No	Barrier categories	Barriers	Barrier element	Reference
1	Financial/ economical	High investment cost	High up-front installation cost	Rao and Ravindranath (2002), Bansal et al. (2013)
		High transaction cost	High level of bureaucracy	Kaniyamparambil (2011)
			Procedural delays in getting financial support	Bansal et al. (2013), Rao and Ravindranath (2002)
2	Market	Competition from other fuels	Freely available fuelwood in the local area	Ravindranath and Balachandra (2009), Bansal et al. (2013)
3	Social and cultural	Social biases	Lack of social acceptance for biogas from substrates like night soil, human excreta, dead animal carcass	Interview, Rupf et al. (2015)
		Gender participation	Low involvement of women in decision- making process	Interview
4	Regulatory barrier	Top-down policy approach	Strict policy criteria	Raha et al. (2014), Kaniyamparambil (2011), Bhat et al. (2001)
			Lack of coordination between different government agencies	Bansal et al. (2013)
5	Technical & infrastructural	Inadequate supply of feedstock	Mixing of water and substrate in incorrect ratios	Interview
			Scattered dropping of cattle during gazing	Interview
			Low output for two – three months in winters	Rupf et al. (2015)
		Lack of technical services	Access to skilled workers for construction and repairs	Kaniyamparambil (2011), Bhat et al. (2001), Bansal et al. (2013)
6	Information	Lack of awareness	Poor dissemination of information regarding the technology and incentives given by the government	Rao and Ravindranath (2002), Ravindranath and Balachandra (2009)
			Lack of awareness regarding substrates other than cattle dung for biogas generation	Raha et al. (2014)

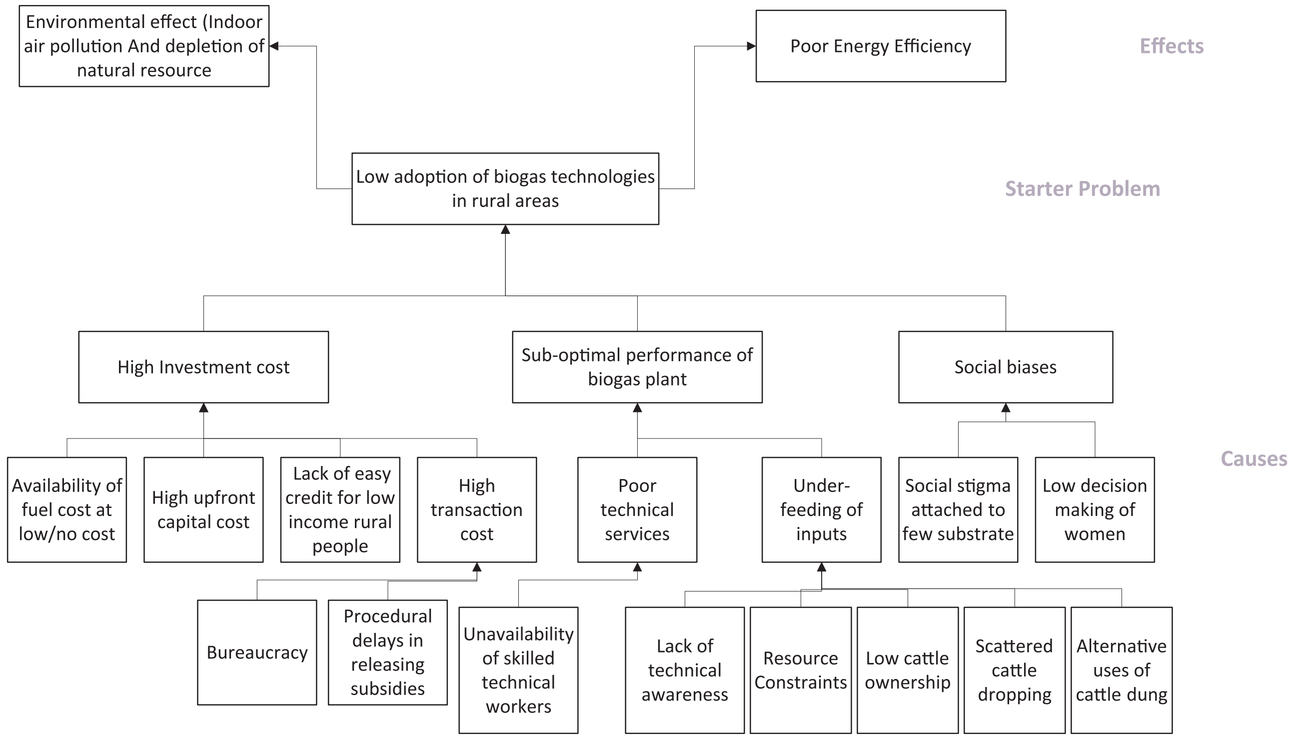

Fig. 3. Logical problem tree for biogas related barrier in rural areas.

internal rate of return) (CDM-SS-PDD, 2006; Schmidt and Dabur, 2013). The government initiated a demonstration program to test the economic and technical viability of the bio-methanation technology (Deodhar and Akker, 2005). Even after the program, there is no well-established commercialized biogas technology functioning at the industrial scale for heterogeneous waste in urban India. Based on the interview with an officer working for a financial institution, it was indicated that they are reluctant to give the credit for biogas projects in absence of a well-established technology and high failure ratio (personal communication H).

4.2.2. Market barriers

The competitiveness of biogas technologies for electricity is limited due to the availability of low-priced electricity from coal and natural gas-fired power plants. The operation and maintenance costs of biogas based power plants are quite high compared to thermal power plants (as evident from Table S.5).

The electricity from other renewable sources like solar, hydro and wind is also cheaper than anaerobic digestion based power generation technology due to government support like fixed feed-in tariffs and renewable power obligations. As also evident from Table 5, biogas based power plants cannot compete with large-scale coal power plants. The electricity price paid by the consumers is lower than the cost of electricity from anaerobic digesters or co-digesters. Even though the feedstock is free in case of an anaerobic digester the cost of handling and transporting the waste over long distances is high negatively affecting the power plant economics. In absence of a government electricity mandate specific for biogas based power, it is difficult to sell

Table 5
Barriers to large-scale biogas plants in urban areas.

No	Barrier categories	Barriers	Barrier element	Reference
1	Financial/ Economical	High investment cost	High up-front installation cost	Interview, Planning Commission (2014)
		Lack of financing mechanism	High risk perception by financial institutions	Interview, CDM-SS-PDD (2006)
			High Interest rate	
			Long term financing options	
		High transaction cost	Long lead time in getting approval	Vijay et al. (2015)
			No legal standards	Vijay et al. (2015)
2	Market	Price Competition from other fuels	Tariff from renewables and fossil based electricity is low	Interview, Planning Commission (2014)
		Competition from other technologies i.e RDF, compositing		
3	Technical & Infrastructural	Lack of access to technology	Dependence on the foreign technology for setting large scale projects	Interview
			Nonexistence of proven technology	Interview
		Poor quality of feedstock	Inadequate segregation of waste at source	Interview, Planning Commission (2014)
		Lack of waste storage and treatment facilities		Interview, Ojha (2010), Planning Commission (2014)
4	Institutional	Limited urban municipal capabilities		Interview, Ojha (2010), Bag et al. (2016), Planning Commission (2014)
		Lack of coordination between national and subnational government	Non-alignment of National policies and state policies in terms of feed-in tariff	Interview, Ojha (2010),
		Low private player involvement		Interview

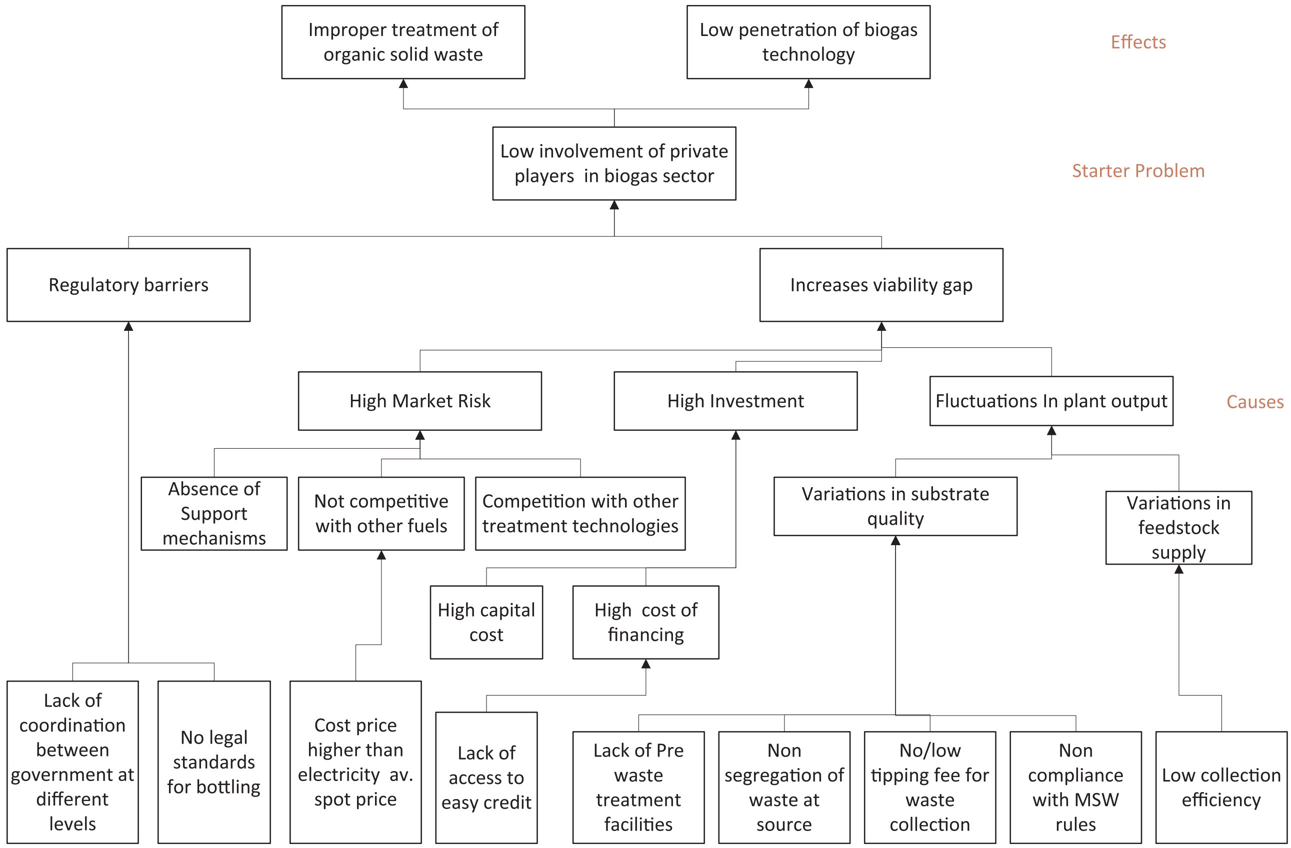

Fig. 4. Logical problem tree for biogas related barrier in urban area.

electricity generated from biogas plants to the off-takers and maintain a continuous revenue stream. It would be difficult for the biogas technologies to be competitive in the electricity market without considering social and environmental externalities associated with different generation technologies into final electricity prices. The slurry from the digester can be used as organic fertilizer and can be regarded as another revenue source but here also, the organic fertilizer has to compete with heavily subsidized chemical fertilizers (Mate, 2010). The anaerobic digestion technology faces competition from other waste treatment technologies such as compositing, vermi- composting, and waste to pellets that can also be used for treating organic municipal and industrial waste. Preference for low cost treatment method like composting also acts as a constraint resulting in lower uptake of biogas digesters for waste management in urban areas (personal communication A)

4.2.3. *Regulatory and Institutional barriers*

Incentives like guaranteed feed-in tariffs and regulatory power purchase obligations (RPPOs) are necessary for diffusion of the technology in the relatively immature market. This is evident in the case of the solar and wind technologies in India where strong political will and investment-friendly policies provided by the government which has driven the growth of renewables in the last decade. Government incentives like feed-in tariffs, long-term financing, capital grants, viability gap funding & tipping fee for waste collection and handling are currently not in place (Personal communication B). In absence of these government policies, biogas projects are not economically viable at large scale that discourages private investment in this sector (Ojha, 2010). There are uncertainties related to feedstock supply and quality due to inefficient supply chains and low collection efficiency in India. Fluctuation in feedstock supply and quality can hamper the production efficiency of the plant that affects the plant profitability in the long run.

Municipal corporations are responsible for the waste management in the urban areas. Due to limited financial and technical capabilities, it is challenging for the municipal corporations to manage the growing solid waste amounts in an integrated manner without the involvement of private players (personal communication A). There is a lack of coordination between national and subnational governments. A generic tariff for the electricity generated from biogas and waste to energy projects has been announced in 2016 as highlighted in the Fig. 1 (MOP, 2016). However, state electricity regulatory commissions (SERCs) still have not fixed a generic tariff for electricity from anaerobic digestion based power plants. In absence of the fixed generic tariff, it is difficult to assess the project viability at the pre-investment assessment stage due to unpredictability related to the power purchase agreement prices determined by the SERCs (personal communication B, E). Risks associated with revenue streams, technology, and feed supply are primarily borne by the private players (personal communication F). This deters private players´ participation in the sector.

Biogas can be upgraded, bottled and utilized as a transportation fuel. Compressed and bottled bio-methane can easily be used in CNG vehicles without modification. But there are no legal standards or guidelines issued by the government neither for using biogas as a transportation fuel nor for injection in the natural gas grid (Vijay et al., 2015). In absence of proper legal standards, project developers need regulatory approval for grants and permissions from different government departments like Petroleum Explosives Safety Organisation (PESO) and Ministry of Environment and Forest. These regulatory requirements hinder the growth of upgraded biogas sector in India.

4.2.4. *Technical and infrastructural barriers*

The segregation of organic and non-organic waste is not done in urban households resulting in the low-quality organic feedstock (personal communication A). Due to improper segregation, dust and inert material are also exist to varying degrees in the feedstock. In this case, sorting of wastes needs to be done before digestion at the plant which further increases the overall generation cost and complexity. Moreover, poor collection and unorganized transportation of wastes especially in medium–small size cities increase the supply chain disruption risk. Failure to supply the committed quantity of waste to plant by municipal authorities was identified as one of the reasons for the closure of waste-to-energy plants (Planning Commission, 2014). Proper technologies/ strategies for waste segregation, collection and transportation are not placed in the cities which is one of the main reasons for the slow growth of the waste-to-energy sector in India. Process standardization is challenging due to large variations in waste characteristics across different regions hindering the large-scale diffusion of biogas technology.

Fig. 4 represents links between the barriers hindering adoption of biogas technologies in urban areas. As mentioned before, urban municipal bodies have constrained financial resources and limited technical capabilities. Thus, the private sector has a key role to play in increasing biogas technology deployment for organic waste treatment. Low involvement of private players in the biogas sector in urban areas is pointed out to be the core problem from the literature review and interviews in case of the urban biogas system. High cost of investment and market risks are two critical factors affecting the viability of large-scale biogas production projects in urban areas. Market associated factors such as strong competition from other fuels and from other waste treatment technologies affect the dissemination of biogas technologies. In addition to these factors, factors such as non-segregation of municipal solid waste, low tipping fee for waste collection, and non-compliance with MSW rules make it difficult for developers to obtain a continuous supply of high-quality substrates. Inferior quality substrates affect the plant productivity and ultimately result in lower electricity generation. The risks associated with biogas technologies are enhanced by uncertainties associated with waste quality and quantity of supply. These risks are borne by the private players even in case of public-private partnership (PPP) modes which eventually discourages private investment in this sector.

5. Comparison between the barriers affecting the two biogas systems

The analysis in previous sections pointed to key barriers affecting the biogas dissemination in India. The results obtained from the decomposition analysis (Table 6) show that barriers vary across biogas systems in urban and rural areas of India. The social and cultural barriers such as reluctance to use certain substrates such as night soil and lower female participation in decision-making exist largely in the case of rural biogas system. Infrastructural and regulatory barriers also vary across two systems because of different policy approaches and history. As commented by Raha et al. (2014), a target-oriented approach is followed under NBMMP to deploy decentralized biogas technology in rural households and technology is not adapted based on agro-climatic conditions and rural households' requirements. As mentioned in the previous Section 2, several government policies such as pilot programs and financial subsidies are targeted to push the installment of biogas plants in rural areas. But in urban areas, the strong policy push for treatment of organic wastes has continued to lag compared to the pace of rising urban waste treatment problem. It is only recently that the government has set a long-term target for increasing electricity generation capacity based on urban and industrial wastes (MNRE, 2011). The government is considering the enhanced response to climate change by adding a 'waste-to-energy mission' to India's 'National Action Plan on Climate Change' (Sinha, 2015).

The National Rural Biogas Development Program has a longer history than policy measures taken for promoting biogas technology diffusion in urban areas. The biogas market is still immature in the urban areas compared to in the rural areas. There are several success stories indicating a certain level of technological maturity at the household scale using cattle dung as feedstock in biodigesters (Bhat et al., 2001; Bond and Templeton, 2011). However, significant technological risks persist regarding steady biogas production from municipal and industrial organic wastes as highlighted by the experts in the interviews. The analysis indicates that the in rural biogas system, feedstock availability is one of critical factor affecting the adoption of biogas technologies whereas in urban areas, factors like inferior quality of feedstock, improper waste segregation and weak supply-chains influence the biogas production. Besides this, in urban areas, biogas technologies compete with other waste treatment technologies such as those for the treatment of organic urban and industrial wastes. Financial barriers like high initial cost and limited access to credit appear in both the systems. Regulatory standards required to inject biogas into the natural gas grid are not in place which hinders the utilization of current natural gas infrastructure for biogas. These regulatory barriers do not impede the expansion of decentralized biogas in rural areas. These results imply that contextual factors should be taken into consideration for developing effective technology dissemination strategies.

6. Conclusions and policy recommendation

The key conclusions of the paper are: 1) several financial and non-financial barriers exist resulting in the low penetration of biogas technology in India 2) barriers vary strongly between biogas system in urban and rural areas due to difference in technology maturity, feedstock availability and quality, supply chain, awareness level and policy support; Another key contribution of the paper is the identification of key areas of improvements in existing policies as well as strategies to

Table 6
Barrier comparison.

Category	Barriers	Rural	Urban
Financial & Economical Barrier	High initial investment	✓	✓
	High transaction cost	✓	✓
	Lack of financing mechanism		✓
Market Barriers	Competition from other fuels	✓	✓
	Competition from alternative technologies/ uses	✓	✓
Social and cultural barrier	Social biases	✓	
	Gender participation	✓	
Regulatory and institutional barrier	Top down policy approach	✓	
	Limited urban municipal capabilities		✓
	Lack of coordination between different stakeholders	✓	✓
	Low private player involvement		✓
Technical & Infrastructural barriers	Lack of technical services	✓	
	Lack of waste treatment and storage facilities		✓
	Feedstock of poor quality		✓
	Unavailability of sufficient feedstock	✓	
Information	Lack of awareness about the policies, technology and its benefits	✓	

overcome the existing barriers.

Based on our findings, several policy recommendations are drawn for overcoming these barriers. The greater need for clean and affordable energy in rural areas is for the overwhelming population belonging to low and middle-income rural households. The key barrier to the deployment of the rural biogas plants among these households is the upfront installation cost of the biogas plant. Presently, under the NBMMP, the financial incentive for installing biogas plant is targeting the households having adequate cattle ownership. Such a categorization excludes a sizable fraction of the middle and lower-income rural households. A bottom-up approach should be adopted to increase the dissemination of biogas in rural areas. The socio-economic characteristics like household size & income, agro-climatic conditions should also be considered while developing policies for biogas dissemination in rural areas. Greater inclusiveness, therefore, requires broadening the selection criteria and at the same time ensuring that households not having enough cattle for running the individual plant can receive a subsidy for installing community biogas plants or easy loans for purchasing cattle. Provision of microfinance options for cattle purchase could be an option as this can enhance income as well as access of dung by rural households. The biogas system installation cost barrier can also be reduced by providing low-cost credits like interest-free loans or subsidized loans or cheap technology like low-cost polythene biogas plants that are used in Nepal & Uganda. Greater penetration of information and communication technologies in rural India, now provides an opportunity to streamline the process of approval and transfer of subsidies to the beneficiaries via digital technologies and integration with other government programs to reduce the transaction costs of operating the NBMMP.

As mentioned in the Section 4.1.5, a steady supply of substrate is essential for smooth functioning of biogas plants. Therefore, subsidy for cattle insurance also helps to reduce the risk of supply disruptions. There are also other substrates like food and flower waste, agricultural residues, poultry and pig manure which are used in a small fraction as digester feedstocks along with cattle dung. Evidently, the appropriate mix of substrates such as kitchen or agriculture waste along with the primary substrate even helps to enhance the biogas yield (Li et al., 2009). Co-digestion and dry anaerobic digestion could also be potential options in areas of cattle dung and water scarcity. Therefore, technology type and scale should be adapted based on the local conditions for the smooth functioning of biogas plants. Techniques such as predigestion using microbial additives and mechanical pretreatment for biogas production enhancement exist in the literature (Gupta et al., 2012; Yadvika et al., 2004), but the awareness and use of these production enhancement techniques are as yet absent (Raha et al., 2014). Another barrier to accessing organic biomass feed-stock in villages is the absence of local markets for these feedstocks. The government should create an enabling environment for greater involvement of private players in the biogas sector in rural areas. This would help in developing the local markets for feedstocks and technologies. The competition between the private players would also help to bring down the biogas technology prices.

Closing the information and implementation gap through demonstration programs and participation of rural organizations can deliver sizable benefits of affordable and clean energy access to rural households. Furthermore, the sustained benefits of biogas deployment require targeted policies and financial support to strengthen training programs for rural technicians and setting up post installment maintenance and repair centers. Besides financial and technical support, the programs to create awareness about the short-term and long-term health effects of indoor air pollution generated by traditional biomass fuels are vital to have households include the external costs in their energy choices and make an early shift towards clean energy use. Knowledge sharing among different states related to innovative dissemination strategies and success stories would also help to increase the biogas technology diffusion in India.

The biogas market is immature in the urban areas and strict policy measures are required to increase the biogas production from municipal and industrial wastes. As mentioned before, municipal corporations are primarily responsible for waste management in urban areas but they have limited financial capacities, therefore public-private partnerships should be encouraged to increase private investment in the waste to energy sector in India. However, factors like high upfront cost of technologies and difficulty in getting easy credit from banks are some of the causes for the low involvement of private players in this sector. Therefore, financial support from central and state governments is thus required to bridge the viability gap and make biogas projects economically viable. Financial incentives like accelerated depreciation and tax holidays would also help to attract big private players in this sector.

Policy lessons should be learnt from developed countries like Germany & Sweden to promote the dissemination of biogas technologies in urban areas. For instance, the government ban on disposal of municipal solid wastes to landfills has changed the waste management scenario in Germany and augmented the demand of biogas plants for managing organic wastes (Poeschl et. al, 2010). Government should enforce strict waste management rules to stop the disposal of organic wastes to landfills to avoid water and air pollution. Participation of biogas project developers in waste collection, segregation, and transportation within the cities would help in achieving better control over the substrate quality. Awareness campaigns through television and newspapers regarding the need for waste segregation should be conducted in the short-term to bring the change in people's behavior. In the long-term, proper regulations regarding organic and inorganic wastes segregation should be enforced on the generators to help to reduce the variations in feedstock quality which could eventually lead to standardization of technologies for a certain quality and composition of the waste. Moreover, integration of waste pickers working in the informal waste management sector to streamline the whole supply chain would help improve their working conditions as well as socio-political integration. Financial measures such as tipping fee or collection fee would generate the funds to co-finance and maintain the biogas projects.

Biogas technologies face competition from other renewable electricity generation technologies like solar & wind. Market risks faced by the biogas electricity generators can be reduced by providing either price based (preferential tariffs) or quantity based (minimum purchase quota) support from the government in the initial development phase. As the quality of the feedstocks is currently not consistent resulting in the suboptimal biogas production. To reduce the producers' losses in the initial stages of operations, the biogas based plants could be exempt from scheduling and unscheduled interchange charges till feedstock quality are not assured.

Acknowledgements

The authors are grateful to anonymous reviewers for their valuable comments. This research was supported by the CLEANS project funded by Swedish Energy Agency Strategic Energy System Research Programme(Grant Number- P39929-1) .

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2017.10.027.

References

Adams, P.W., Hammond, G.P., McManus, M.C., Mezzullo, W.G., 2011. Barriers to and drivers for UK bioenergy development. Renew. Sustain. Energy Rev. 15, 1217–1227.
Bag, S., Mondal, N., Dubey, R., 2016. Modeling barriers of solid waste to energy practices: an Indian perspective. Glob. J. Environ. Sci. Manag.
Bansal, M., Saini, R.P., Khatod, D.K., 2013. Development of cooking sector in rural areas in India – a review. Renew. Sustain. Energy Rev. 17, 44–53.
Bhat, P.R., Chanakya, H.N., Ravindranath, N., 2001. Biogas Plant Dissemination: Success

Story of Sirsi. Energy for Sustainable Development, India.
Bhatia, R., 1990. Diffusion of renewable energy technologies in developing countries: a case study of biogas engines in India. World Dev. 18, 575–590.
Blenkinsopp, T., Coles, S.R., Kirwan, K., 2013. Renewable energy for rural communities in Maharashtra, India. Energy Policy 60, 192–199.
Bond, T., Templeton, M.R., 2011. History and future of domestic biogas plants in the developing world. Energy Sustain. Dev. 15, 347–354.
Planning Commission, 2014. Report of the Task Force on Waste to Energy (Volume I). In: Commission, P. (Ed.). New Delhi.
CDM-SS-PDD, 2006. Biomethanation Project of Baramati Agro Limited in Maharashtra, India. Project Design Document.
Chandra, R., Vijay, V.K., Subbarao, P.M.V., 2006a. A study on biogas generation from non-edible oil seed cakes: potential and prospects in India. In: Proceedings of the 2nd Joint International Conference on Sustainable Energy and Environment. Bangkok, Thailand.
Chandra, R., Vijay, V.K., Subbarao, P.M.V., 2006b. A study on biogas generation from non-edible oil seed cakes: potential and prospects in India. In: Proceedings of the 2nd Joint International Conference on Sustainable Energy and Environment. Bangkok, Thailand.
Chen, L., Zhao, L., Ren, C., Wang, F., 2012. The progress and prospects of rural biogas production in China. Energy Policy 51, 58–63.
CPCB, 2013. Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) Rules, 2000. In: BOARD, C.P.C. (Ed.), Ministry of Environment Forests & Climate Change, New Delhi.
CSO, 2014. Energy Statistics. In: Office, C.S. (Ed.), Ministry of Statistics and Programme Implementation, New Delhi.
Daxiong, Q., Shuhua, G., Baofen, L., Gehua, W., 1990. Diffusion and Innovation in Chinese biogas program. World Dev. 18, 555–563.
P. Deo S. Modak P.R. Shukla 1991.*Decentralized energy planning,* New Delhi, India, Oxford and IBH Publishing Co. Pvt. Ltd.
Deodhar, V., Akker, J.V.D., 2005. Development of High Rate Biomethanation Processes as Means of Reducing GHG Emissions India. UNDP/GEF.
Gupta, P., Shekhar Singh, R., Sachan, A., Vidyarthi, A.S., Gupta, A., 2012. A re-appraisal on intensification of biogas production. Renew. Sustain. Energy Rev. 16, 4908–4916.
Hassan, M., Natarajan, K., Pelkonen, P., Zyadin, A., Pappinen, A., 2015. Perspectives of feedstock supply for biomass-based energy plant development in India: views from an expert survey. Challenges 6, 71–87.
He, G., Bluemling, B., Mol, A.P.J., Zhang, L., Lu, Y., 2013. Comparing centralized and decentralized bio-energy systems in rural China. Energy Policy 63, 34–43.
Hiloidhari, M., Das, D., Baruah, D.C., 2014. Bioenergy potential from crop residue biomass in India. Renew. Sustain. Energy Rev. 32, 504–512.
Kamp, L.M., Bermúdez Forn, E., 2016. Ethiopia's emerging domestic biogas sector: current status, bottlenecks and drivers. Renew. Sustain. Energy Rev. 60, 475–488.
Kalia, A.K., Kanwar, S.S., 1998. Long term evaluation of a fixed dome janata biogas plant in hilly conditions. Bioresou. Technol. 65, 61–63.
Kaniyamparambil, J.S., 2011. A Look at India's Biogas Energy Development Program – After Three Decades, Is it Useful (Doing What it Should) and Should it be Continued? School of Engineering Practice McMaster University.
Katuwal, H., Bohara, A.K., 2009. Biogas: a promising renewable technology and its impact on rural households in Nepal. Renew. Sustain. Energy Rev. 13, 2668–2674.
Kumar, A., Sharma, M.P., 2014. GHG emission and carbon sequestration potential from MSW of Indian metro cities. Urban Clim. 8, 30–41.
Kumar, A., Kumar, N., Baredar, P., Shukla, A., 2015. A review on biomass energy resources, potential, conversion and policy in India. Renew. Sustain. Energy Rev. 45, 530–539.
Lantz, M., Svensson, M., Björnsson, L., Börjesson, P., 2007. The prospects for an expansion of biogas systems in Sweden—incentives, barriers and potentials. Energy Policy 35, 1830–1843.
Lewis, J.J., Hollingsworth, J.W., Chartier, R.T., Cooper, E.M., Foster, W.M., Gomes, G.L., Kussin, P.S., MacInnis, J.J., Padhi, B.K., Panigrahi, P., Rodes, C.E., Ryde, I.T., Singha, A.K., Stapleton, H.M., Thornburg, J., Young, C.J., Meyer, J.N., Pattanayak, S.K., 2017. Biogas stoves reduce firewood use, household air pollution, and hospital visits in Odisha, India. Environ. Sci. Technol. 51, 560–569.
Li, R., Chen, S., Li, X., 2009. Anaerobic co-digestion of kitchen waste and cattle manure for methane production. Energy Sources Part A: Recov. Util. Environ. Eff. 31, 1848–1856.
Mate, N., 2010. Biogas for Sustainable Development, Bioenergy. Winrock International India, New Delhi.
McCormick, K., Kaberger, T., 2007. Key barriers for bioenergy in Europe: economic conditions, know-how and institutional capacity, and supply chain co-ordination. Biomass Bioenergy 31, 443–452.
MNRE, 2011. Strategic Plan for New and Renewable Energy Sector for the Period 2011-2017. In: ENERGY, M.O.N.A.R. (Ed.), New Delhi.
MNRE, 2015. Annual Report, 2015–16. In: Energy, M.O.N.A.R. (Ed.), New Delhi.
MOP, 2016. Tarriff Policy. In: Power, M.O. (Ed.). Ministry of Power, Government of India, New Delhi.
MOSPI, 2015. Energy Sources of Indian Households for Cooking and Lighting, 2011–12, In: Ministry of Statistics and Programme Implementation. G.O.I. (Ed.), New Delhi.
Nilsson, H., McCormick, K., Ganko, E., Sinnisov, L., 2007. Barriers to Energy Crops in Poland—From the farmers' Perspective. I. pp. 207–215.
Nygaard, I., Hansen, U.E., 2015. Overcoming Barriers to the Transfer and Diffusion of Climate Technologies. TNA Guidebook Series, UNEP DTU Partnership.
Ojha, K., 2010. Status of MSW management system in northern India – an overview. Environ. Dev. Sustain. 13, 203–215.
Painuly, J.P., 2001. Barriers to renewable energy penetration; A framework for analysis. Renew. Energy 73–89.
Pathak, H., Jain, N., Bhatia, A., Mohanty, S., Gupta, N., 2009. Global warming mitigation potential of biogas plants in India. Environ. Monit. Assess. 157, 407–418.
Poeschl, M., Ward, S., Owende, P., 2010. Prospects for expanded utilization of biogas in Germany. Renew. Sustain. Energy Rev. 14, 1782–1797.
Prasertsan, S., Sajjakulnukit, B., 2006. Biomass and biogas energy in Thailand: potential, opportunity and barriers. Renew. Energy 31, 599–610.
Raha, D., Mahanta, P., Clarke, M.L., 2014. The implementation of decentralised biogas plants in Assam, NE India: the impact and effectiveness of the National Biogas and Manure Management Programme. Energy Policy 68, 80–91.
Rao, K.U., Ravindranath, N.H., 2002. Policies to overcome barriers to the spread of bioenergy technologies in India. Energy Sustain. Dev. VI (3).
Rao, P.V., Baral, S.S., Dey, R., Mutnuri, S., 2010. Biogas generation potential by anaerobic digestion for sustainable energy development in India. Renew. Sustain. Energy Rev. 14, 2086–2094.
Ravindranath, N.H., Balachandra, P., 2009. Sustainable bioenergy for India: technical, economic and policy analysis. Energy 34, 1003–1013.
Reddy, M.K.N., 2004. Lessons from the pura community biogas project. Energy Sustain. Dev. VIII.
Rupf, G.V., Bahri, P.A., de Boer, K., McHenry, M.P., 2015. Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal. Renew. Sustain. Energy Rev. 52, 468–476.
Samar, K.K., Sharma, D., Meena, E., 2016. The Solid State Biogas Plant: A Boon for Water Scarce Areas Akshay Urja Ministry of New and Renewable Energy. 2016 Government of India, New Delhi, India.
Schmidt, T.S., Dabur, S., 2013. Explaining the diffusion of biogas in India: a new functional approach considering national borders and technology transfer. Environ. Econ. Policy Stud. 16, 171–199.
Shane, A., Gheewala, S.H., Kasali, G., 2015. Potential, barriers and prospects of biogas production in Zambia. J. Sustain. Energy Environ. 6.
Shukla, P.R., 2007. Biomass Energy Strategies for Aligning Development and Climate Goals in India. Netherlands Environmental Assessment Agency.
Sinha, A., 2015. Four New Missions to Boost Response to Climate Change. The Indian Express, New Delhi.
Song, Z., Zhang, C., Yang, G., Feng, Y., Ren, G., Han, X., 2014. Comparison of biogas development from households and medium and large-scale biogas plants in rural China. Renew. Sustain. Energy Rev. 33, 204–213.
Vijay, V.K., Kapoor, R., Trivedi, A., Vijay, V., 2015. Biogas as clean fuel for cooking and transportation needs in India. In: Ravindra, P. (Ed.), Advances in Bioprocess Technology. Springer International Publishing, Cham Switzerland, pp. 257–275.
Yadvika, Santosh, Sreekrishnan, T.R., Kohli, S., Rana, V., 2004. Enhancement of biogas production from solid substrates using different techniques – a review. Bioresour. Technol. 95, 1–10.
ZEEMAN, G. 1991. Mesophilic and Psychrophillic Digestion of Liquid Manure. PhD, Agricultural University.
Zyadin, A., Natarajan, K., Chauhan, S., Singh, H., Hassan, K., Pappinen, A., Pelkonen, P., 2015. Indian farmers' perceptions and willingness to supply surplus biomass to an envisioned biomass-based power plant. Challenges 6, 42–54.