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The implementation of decentralised biogas plants in Assam, NE India: The impact and effectiveness of the National Biogas and Manure Management Programme

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HIGHLIGHTS

- In India, biogas policy is supply-driven and based on technology implementation.
- NBMMP policy needs revision to engage with market forces to drive down costs and improve services and delivery.
- Community empowerment, awareness, training and education, particularly of women, plays a critical role in accelerating the deployment of biogas technology.

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ABSTRACT

The Indian Government's National Biogas and Manure Management Programme (NBMMP) seeks to deliver renewable energy services to households across the country by facilitating the deployment of family-sized ($<6\ m^3$) anaerobic (biogas) digesters. NBMMP policy is implemented at three levels, from government and state nodal agency, via private contractors to households, creating multiple institutional arrangements. We analysed the scheme in Assam, north-east India, focusing on how policy was implemented across two districts and interviewing stakeholders in rural households, state and non-state institutions. The top-down, supply-side approach to policy enables government to set targets and require individual states to deploy the scheme, which benefits households who can afford to participate. NBMMP delivered improved energy service outcomes to a majority of households, although the level of knowledge and understanding of the technology amongst users was limited. Training and education of householders, and particularly women, is needed in relation to the maintenance of digesters, feedstock suitability and the environmental and potential livelihood benefits of digestate. A revised bottom-up approach to policy, which highlights the contextual and demand-side issues around adopting the technology, may deliver monetary benefits from market competition and enable development of community-focused microfinance schemes to improve the affordability of biogas systems.

1. Introduction

In naming 2012 as the ‘International Year of Sustainable Energy for All’ the United Nations drew attention to the inextricable link between energy, sustainable development and the eradication of poverty (Bhanot and Jha, 2012). India has 17% of the world's population, however it accounts for only 4% of the world's primary energy consumption (553 kWh consumption per capita) with renewables being a small share in the total energy usage (18,655 MW equivalent to 11% of the total renewable energy capacity as on 31.12.2010; IEA 2011; MNRE, 2011; Pillai and Banerjee, 2009). India's approach to increasing its renewable energy mix has involved funding research and development, subsidising demonstration projects, providing financial incentives for private sector participation, and, more recently, adopting comprehensive legislative reforms led by the Ministry of Renewable and New Energy aimed at increasing the proportion of renewables in the share of total energy consumption (Sawhney, 2013).

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These new policies have encouraged the provision of affordable and accessible modern energy to both rural households and the urban poor (Reddy and Srinivas, 2009).

Universal energy access is influenced by political and economic drivers and energy for cooking has been given less political backing in comparison to access to electricity (Rehman et al., 2012). India's energy policies have set targets for delivery of a renewable energy power generation capacity of 18.5 GW by 2017 and an additional 30.5 GW generated by 2022 (Government of India, 2012). These policies reflect a target-oriented approach to significantly increasing power generation from clean, renewable resources coupled with a reduction in the carbon emissions associated with electricity production (Sawhney, 2013). While there has been considerable backing for new electrification policies (Chaurey et al., 2012) efforts related to cooking and off-grid energy services have concentrated on schemes enabling the adoption of cleaner cookstoves, anaerobic (biogas) digesters for cooking and lighting services and public distribution systems for kerosene (Rao, 2012) and liquefied petroleum gas (LPG) (Bansal et al., 2013; Rehman et al., 2012). The National Biogas and Manure Management Programme (NBMMP) is one such scheme which started in 2005 as the result of the merger of the National Project on Biogas Development and a manure management initiative. A number of other Government of India rural energy schemes are linked to this programme including the National Biomass Cook Stove Initiative launched in 2009 by the Ministry of New and Renewable Energy to promote clean and efficient energy cooking for poorer sections of the country. The success of these energy service schemes is strongly influenced by the socio-cultural context in which they are developed and implemented (Mondal et al., 2010) and despite the government adopting new policies to enable improvements in energy supply, there has been little work undertaken to assess the success of the schemes at the user level. Here we seek to address this lack of understanding by analysing how the NBMMP is implemented in a case study region in Assam, north-east India, in order to establish how a multi-level hierarchy of rural householders, policy makers and technicians engage with the scheme and how policy implementation impacts upon the uptake, delivery and success of the scheme across these different stakeholder groups. With an increasingly target-oriented approach to developing renewable energy policy (Sawhney, 2013) and a focus on clean renewable resources (Government of India, 2012) the role that implementation plays in the delivery of government policy is critical to enabling both a security of supply and a reduction in energy poverty.

2. Background

In India, the complex network of energy service, demand and supply, is influenced by the formal and informal activities of people, the technologies available ('traditional', 'low quality', 'polluting' vs 'improved', 'modern' or 'clean' options) and the disparity between urban and rural lifestyles and incomes (Bhattacharyya, 2010). For successful uptake, a new technology needs to be tailored towards local circumstances and designed with an understanding of local needs (Mondal et al., 2010). In developing countries, cooking and heating water are major consumers of energy (Urban et al., 2009) and a lack of access to efficient technologies and clean cooking fuels presents particular challenges (Bansal et al., 2013). Rural populations depend upon biomass for fuel often due to diminished access to modern alternatives, driven in part by family income (Assaduzzaman et al., 2010). The heterogeneity of cultural practices, which determine the cooking patterns found in rural households are also important (Foell et al., 2011; Pachauri, 2011). The Indian Government has initiated a number of different programmes (National Project on Biogas Development in 1981; National Programme for Improved Chulhas (cookstoves), NPIC in 1986; National Biomass Cook Stove Initiative in 2009, Venkataraman et al., 2010) to replace biomass cooking with alternative cleaner fuels such as biogas (Bansal et al., 2013). A majority of rural households use firewood as a primary source for cooking with leaves, twigs, cowdung and coal also common (Bansal et al., 2013; Khandker et al., 2012; Reddy and Srinivas, 2009). Though the government of India provides subsidies for LPG to encourage its use for cooking, the low rural population density and poor road infrastructure has limited its distribution (Bansal et al., 2013). To bridge the energy access gap it has been suggested that a change in the top-down implementation of energy policy is needed in order to create improved delivery mechanisms (Balachandra, 2011) since centralised models result in high installation and infrastructural costs, and challenges of affordability, quality, and availability (Rehman et al., 2012) are further complicated by existing socio-cultural perceptions (Bansal et al., 2013) which may vary between states due to geopolitical differences (Schmid, 2012).

The National Project on Biogas Development was set up in 1981 for the promotion of biogas plants using cattle dung and other biomass waste to generate methane for household cooking and lighting (Bond and Templeton, 2011). In 2005, as part of the Government's 11th Five Year Plan (2007–2012), the scheme was renamed the National Biogas and Manure Management Programme in an attempt to address a failure of the target-oriented, top-down approach in which a large number of agencies competed for incentives associated with implementation of the National Project on Biogas Development. The Government of India Integrated Energy Policy (2006) report highlighted the fact that unhealthy competition among the implementing agencies led to: (a) sub-standard quality of construction and materials; (b) the overlooking of eligibility and sustainability criteria associated with the scheme; (c) double-counting and over reporting of achievements and; (d) lack of accountability for failure /non-functionality. The new NBMMP scheme (MNRE, 2009), which aims to encourage people in rural areas to adopt biogas technologies to meet their household cooking and lighting needs, involves Khadi and Village Industries Commission concrete and plastic floating dome plants and cheaper, concrete, fixed-dome Janata and Deenbandhu plants (Singh and Sooch, 2004). The floating dome system, fed with animal manure and other organic wastes is arguably more popular in south India, while the fixed dome system fed only with animal manure more common in the north of the country (Balachandra, 2011).

NBMMP household plants were designed to be multifunctional and to: (a) reduce dependency on LPG and kerosene for cooking and lighting purposes; (b) produce waste digestate fertiliser which can help reduce the use of chemical fertilisers; (c) remove the need for collection of firewood which reduces the drudgery on rural women and children who undertake his task (Kanagawa and Nakata, 2007), as well help preserve forests; and (d) improve sanitation in villages by linking sanitary toilets with biogas plants. Subsidies and financial assistance were provided centrally to each state based on its economic profile (MNRE, 2009).

3. Material and methods

Assam is the largest of eight states in north-eastern India[3] and is economically important for tea production and tourism. It is rich in natural and mineral resources and sustains large sub-tropical forest reserves (Jhajharia et al., 2012; Lele et al., 2008) but has poor

[3] Official website Government of Assam http://assam.gov.in/ accessed on 2nd April 2013.

provision of energy services in both urban and rural areas (Kanagawa and Nakata, 2008). Nearly 76% of the state′s population depends on agriculture (Bhattacharyya et al., 2001; Baruah and Bora, 2008) and biomass materials (wood, plant stems, leaves, twigs) are routinely used for cooking, lighting and housing construction (Kanagawa and Nakata, 2007) since most rural areas in Assam fall within or on the periphery of forest conservation areas where supply is abundant. We undertook surveys of 60 households with biogas plants in eight villages[4] across two districts (Kamrup and Morigaon) of Assam to establish the benefits and challenges of using biogas from the perspectives of the householder and the state nodal agency responsible for implementing the NBMMP. Our primary data was supplemented with reference to secondary information from 146 biogas households[5] (Biogas Development Training Centre Annual Report, 2011–2012). All of the villages were classified as peri-urban or rural villages by the Assam Department of Environment and Forests and village occupants spanned different socio-economic and occupational backgrounds, with three of the five villages in the Boko region of Kamrup district currently non-electrified (i.e. off-grid). This study undertook a range of data collection methods: (i) semi-structured interviews were conducted and recorded with householders including men and women family members; (ii) ethnographic observations and pictorial evidence were collected; (iii) semi-structured interviews were conducted with institutional actors in the region including senior officials of the Department of Environment and Forests which is the State Nodal Agency for NBMMMP in Assam, the Assam Energy Development Agency, the Biogas Development Training Centre and private contractors employed by the State Nodal Agency. Interviews were undertaken in the months of January to February 2013, and interview recordings were then transcribed, coded and themed for analysis.

4. Results

We looked at three groups involved in the implementation of the NBMMP and sought to understand the dynamics between them including how policy was understood, deployed and responded to at each point in the implementation chain from Central Government to the State Nodal Agency (the Assam Department of Environment and Forests) and its institutional employees responsible to Ministry of New and Renewable Energy for ensuring that NBMMP targets were met; the private contractors employed by the Assam Department of Environment and Forests to construct the biogas plants; and the individuals and householders in each village participating in the NBMMP.

4.1. Central government policy

The Ministry of New and Renewable Energy Strategic Plan (2011–2017) has set yearly targets for the installation of biogas plants at both individual household (usually $<6\ m^3$) and community level ($>25\ m^3$) in the small electricity capacity generation range of 3 kW to 250 kW and these are devolved to the State Nodal Agency to implement. The benefits of the government scheme were recognised by the Senior Officer of the State Nodal Agency, the Department of Environment and Forests, who argued that adopting biogas technology minimised the exploitation of forest areas for fuel wood. Though it is an offence to collect firewood from these conservation areas, he stated that it remains a problem. The Senior Officer acknowledged that the environmental benefits from conserving the forests were poorly understood by local people and that there was also low general awareness of the known economic, health and digestate related benefits of using biogas technologies (Sovacool and Drupady, 2011). His knowledge of the technology was good and he was keen to install a large-scale community unit for electricity generation (Winkler et al., 2011) and to act as a municipal waste management programme (Poeschl et al., 2010). Indeed the NBMMP aims to improve sanitation in villages by linking sanitary toilets with biogas plants (MNRE, 2009) yet despite studies which show that human waste is full of nutrients (Lamichhane and Babcock, 2013) and can successfully employed generate biogas (Rajagopal et al., 2013) there are no biogas plants in Assam using human waste. Evaluation of the commercial, small-scale, biogas systems in Kerala using faeces and kitchen waste reported that though the performance of the biogas linked to toilets were good, people′s acceptance of these systems varied, due to self-constraints, cultural and religious beliefs (Estoppey, 2010). The Senior Officer believed that people in Assam would not agree to link their sanitation outlets with anaerobic digesters since for a range of religious and cultural reasons obtaining fuel for cooking that has been generated from human waste is likely to be considered both impure and unhygienic.

To deploy the technology, the Ministry of New and Renewable Energy mandates that four meetings should be held annually with the implementing agencies, Biogas Development and Training Centres, manufacturers and technology providers in order to improve the development, implementation and monitoring of NBMMP (MNRE, 2009, 2011). The Assam Department of Environment and Forests were allocated central subsidy funds from the Ministry of New and Renewable Energy directly through the NBMMP and targets set from central government for each financial year. The Central Financial Assistance agency (CFA) then authorise the release of funds to the relevant State Nodal Departments, State Nodal Agencies and other implementing agencies. The Ministry of New and Renewable Energy (2009) provided a central subsidy towards a total installation cost of Rs. 24,300 for 2 m^3 biogas units, and Rs. 35,025 for 4 m^3 systems, and Rs. 10,000 per 2–4 m^3 biogas; units of this size have been estimated to require between 50 and 100 kg of feedstock per day which is equivalent to the amount of dung produced by 4–12 head of cattle (MNRE, 2009).

There is a three-tier system of target allocation, monitoring, and evaluation of the NBMMP which involves (a) the state nodal agency; (b) physical inspections and verification by the administrative levels of District and block (officials); (c) third party inspections by the regional biogas training centre i.e. the Biogas Training and Development Centre located at Guwahati. Each level is expected to create a report each financial year based on the functional and non-functional status of the biogas plants at the household level and these reports should be made available to the Ministry of New and Renewable Energy separately for triangulation of information from the field. Other than the biogas plants installed, the report is also required to present a list of certificates issued for training and turn-key course attendance.

Training and education is delivered by the Biogas Development and Training Centres who provide the technical support for NBMMP. Biogas Development and Training Centres undertake biogas research and development, they also deliver consultancy services and organise training programmes for private contractors, turn-key workers and masons who build the biogas plants, as well as staff of the state nodal departments and implementing agencies to enable them to carry out field testing and demonstrations of new biogas plant models. The Biogas Development and Training Centre is required to undertake survey inspections of the biogas

[4] The eight villages where fieldwork was conducted are (in two districts of Kamrup and Morigaon): Amarigog, Kamarkuchi, Amlighat (described as 11th Mile region), Sukunia Hasi, Pukhuripara, Singra, Kaithalkuchi and Dirma (described as Boko region).

[5] Out of the 146 biogas households surveyed by the Biogas Development Training Centre – 143 functional biogas plants and 3 non-functional plants.

plants installed in the region and provide a detailed report to Ministry of New and Renewable Energy. The north-eastern region Biogas Development and Training Centre is located in a university (the Indian Institute of Technology Guwahati) offering some academic prestige to the programme providing training.

4.2. Intermediaries: the state and private contractors

The Department of Environment and Forests engaged a private contractor, who they paid to undertake the biogas installations and who was also formally responsible for the maintenance of the biogas units post-installation. The contractor was paid in full only when the Ministry of New and Renewable Energy released the funds at the end of the year to the State Nodal Agency. The private contractor we interviewed had previously worked with Khadi and Village Industries Commission as a biogas installer under the earlier National Programme for Biogas Development scheme; the changed focus of NBMMP meant that the bulk of the central government targets were assigned to the State Nodal Agency so with his previous expertise in biogas technology, the contractor joined the Department of Environment and Forests. The private contractor must hold a 'Renewable Energy Technician' (RET) or 'Turn Key Worker' certificate to be identified as a trained technician who is qualified to undertake NBMMP biogas installation. There are two ways the contractor earns a profit: (1) buying material in bulk from the wholesale market and making a marginal profit on the material costs apportioned by Ministry of New and Renewable Energy bas part of the NBMMP; (2) employing a mason who does not spend the full time designated to build each biogas plant; this provides additional profit where the salary of the mason is cheaper than that allocated by the Government. During the interviews, household members stated that it took between three to five days to build one biogas plant, five days less than the allocated ten days assigned to build one plant as per the Ministry of New and Renewable Energy prescribed procedures. This time-saving potentially comes back to burden the household where due to the rapid construction, faults may appear causing biogas units to either underperform in terms of the amount of biogas produced and/or to leak.

The contractor argued that it is common to be given large targets (i.e. the number of units he is required to install) by the Department of Environment and Forests (the Ministry for New and Renewable Energy targets for the State) and very little time to meet them. He explained that these targets are released in May or June at the Ministry of New and Renewable Energy and take a month to be communicated to the Department of Environment and Forests (arriving sometime in July) and in any case June to December is the monsoon season in Assam when construction activities cannot be undertaken due the wet conditions. The contractor argued that he had only January to March to complete the annual target allocation (which for 2012 was 6000 biogas plants in all districts of Assam). The large target and short building timescale results in rapid installation practices which can increase problems with defective construction. Where it works well in other developing countries, target setting is realistic (Zheng et al., 2012; Rehman et al., 2012) involving the promotion and engagement of private investment and local governance systems.

The village contact is responsible for identifying the households that match the NBMMP prerequisite characteristics. These individuals usually comprise educated, unemployed men who chose the households based on their own social networks and who interact only with the men of the households. They often have additional unpaid/informal/part time jobs and tend not to undertake the required monitoring and evaluation of the installed biogas plants.

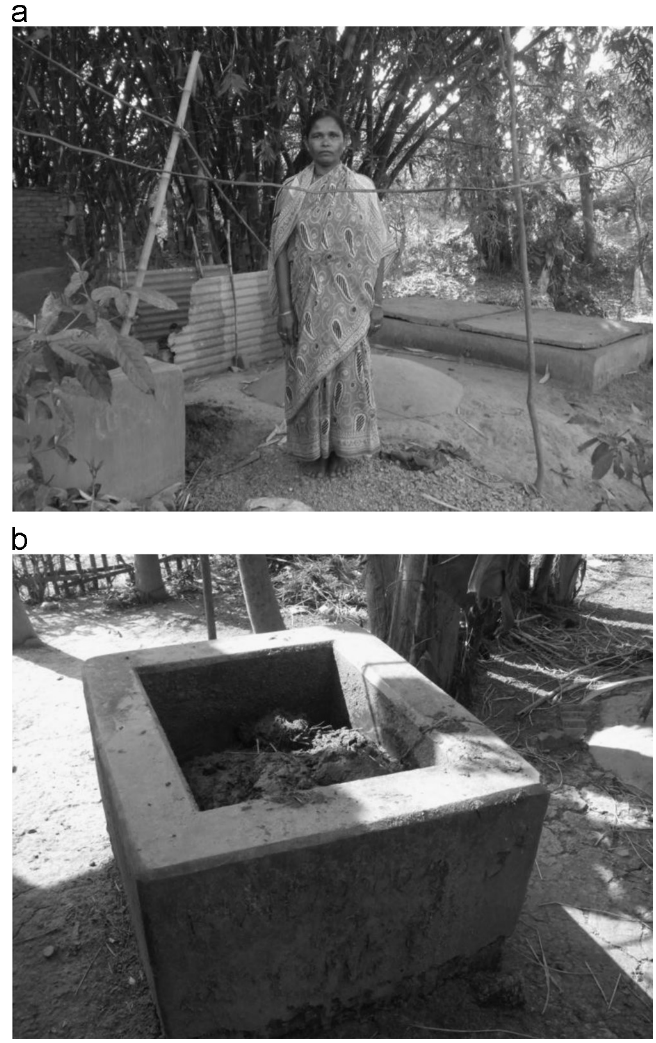

Fig. 1. (a) A household beneficiary of the fixed-dome (3 m^3 concrete) Deenbandhu biogas model and (b) view of the feedstock inlet.

4.3. Householders

All the biogas units in the villages surveyed were found to be 3 m^3 concrete, fixed-dome Deenbandhu models (Fig. 1) which required a minimum of 35–50 kg of cow-dung feedstock per day; cow-dung was the only feedstock used. Fifty-two of the biogas units were installed by the Department of Environment and Forests and eight were installed by KVIC. Most of the installed plants were 10–15 years old, with 5 plants $>$20 years old installed in 1990 and 19$<$2 years old, installed in 2012 (Table 1). Of the households surveyed 20% stated that they had non-functional units. There were different reasons provided for failure including the presence of a construction defect, a broken digester dome (enabling gas escape), or lack of maintenance (Fig. 2). Although it was evident that the units had four-year guarantees, neither the village contact, nor the private contractor had visited the household post-installation to assess or monitor the plant. Units were constructed on-site in three days (despite an allocation of ten days per plant for this work by the Ministry of New and Renewable Energy) and despite the fact that the mason undertaking the construction had suggested ways to maintain the plant, no-one had visited to undertake a post-installation assessment. The NBMMP provides 50% of the rate of central subsidy as a financial support for repair and maintenance of family type biogas plants to householders where units are at least five years old, as well as to

Table 1
Status of the NBMMP biogas units at the households interviewed including date of installation, feedstock input quantity and normal gas output and household size. All units were 3 m^3 concrete fixed-dome units fed only with cow manure feedstock. The households with missing data comprise non-functional (NF) biogas units.

Respondent	Family size (individuals)	Date of unit installation	Quantity of feedstock (kg day^{-1})	Cooking time from biogas (max **hours**)	Use of digestate
1.	7	2010	50	4	Thrown away
2.	8	2008	65	5	Thrown away
3.	10	2010	55	4	Thrown away
4.	5	2011	30	2	Thrown away
5.	9	2012	25	2	Thrown away
6.	5	2003	30	2	Thrown away
7.	7	2006	45	3	Thrown away
8.	3	2010	50	3	NF
9.	5	2012	60	3	Thrown away
10.	4	2003	60	3	Thrown away
11.	6	2006	70	3	Thrown away
12.	6	2012	60	3	Used for cultivation
13.	8	2013	30	2	Used for cultivation
14.	7	2012			NF
15.	4	2012			NF
16.	3	2001	60	6	Thrown away
17.	5	2006	65	5	Used for gardening
18.	2	2003	40	3	Used for gardening
19.	6	2000	90	7	Thrown away
20.	6	2003	90	7	Thrown away
21.	5	2003	80	6	Thrown away
22.	6	2003	60	6	Thrown away
23.	5	2005	90	6	Thrown away
24.	6	2004			NF
25.	6	1998	60	0.3	Used for cultivation
26.	6	1999	65	5	Used for cultivation
27.	6	2005	80	3	Used for cultivation
28.	2	2001			NF
29.	4	2005	30	0.5	Used for cultivation
30.	5	2008	60	5	Thrown away
31.	4	2003	65	3	Thrown away
32.	11	2008	65	2	Thrown away
33.	4	1997	40	1.5	Used in banana plantation
34.	5	2003	70	8	Used in banana plantation
35.	6	2003	50	4	Used in banana plantation
36.	3	2003	60	6	Used in banana plantation
37.	5	1996	60	5	Used for cultivation
38.	6	2002	80	6	Used for cultivation
39.	2	2004	70	5	Used for cultivation
40.	5	2002	70	6	Used for cultivation
41.	5	2002	70	4	Used for cultivation
42.	3	2010	50	2	Sold for profit
43.	4	2010	50	3.5	Used in banana plantation
44.	5	2011	60	4	Used for cultivation
45.	8	1990	60	3	Used for cultivation
46.	7	2004	25	1	Thrown away
47.	4	2012	40	3	Used for cultivation
48.	5	2012	50	3	Used for cultivation
49.	4	2012	30	3	Used for cultivation
50.	6	2012	20	4	Used for cultivation
51.	5	2012			NF
52.	7	2012	35	3	Used for cultivation
53.	3	2012			NF
54.	8	2012	25	3	Used for gardening
55.	4	2012			NF
56.	5	2012			NF
57.	7	2012			NF
58.	5	2012	50	5	Used for cultivation
59.	6	2012			NF
60.	4	2012			NF

enable structural repairs to be undertaken where the units have stopped functioning. We found that neither the private contractor nor the household beneficiaries had been made aware of this subsidised provision in the NBMMP.

On average, the functioning units delivered one to three hours per day of biogas for cooking and heating water; the staple diet in Assam is rice and this is traditionally cooked three times a day for the households (ranging from 2 to 11 people), requiring at least three hours of daily gas supply. To be eligible for the NBMMP scheme the household must complete a pre-determined questionnaire designed by the Ministry of New and Renewable Energy to assess the socio-economic profile of the household and the number of cattle owned. We found that participation in the NBMMP was influenced by both the social networks of the village contact and the householders' willingness to invest in the cost of the plant. Evidence from the households which have biogas unit installed

Fig. 2. Non-functional biogas unit at household number 12 (see Table 1) which has not been repaired for 6 months.

indicated that family income and number of cattle (and hence feedstock) were the most important considerations for participating in the NBMMP. These issues are explored in detail below.

4.3.1. Supply of feedstock

In the Amlighat region, the village of Amarigog focused on dairy farming and households commonly owned an average of 5–20 cattle with the result that cow-dung was abundantly available for use as digester feedstock. Excess cow-dung that was not utilised by a household was either discarded or provided free of charge to be used by neighbours with fewer cows to feed their own biogas units. All households in this village who had NBMMP units were dairy farmers owning 4–25 head of cattle. Respondents from Amarigog stated that using cow-dung feedstock provided sufficient biogas for 3–4 h cooking with excess gas (2–3 h daily) used for preparing 'home-mixed feed' for cattle consisting of different types of millets (maize, oilseeds, grass, and sorghum) mixed in rice-bran, which is then boiled in a large vessel. In other villages in the Amlighat region populated by both dairy farmers and cultivators, there were fewer cattle and feedstock was limited. As a result of lower livestock numbers, these NBMMP units delivered lower average gas production.

4.3.2. Income and costs

Householders belonging to higher income groups (those having additional household income from non-agricultural sources) preferentially installed the NBMMP units. All of the villages surveyed were within 20–25 km of the state capital, Guwahati, making access to urban employment possible. In the Assam study villages the households who had either functional or non-functional biogas plants ranged from landless farm workers to marginal farmers (average landholding varied between 0 and 5 bigha; where 1 Assamese bigha = 1337.8 m^2 which also included the homestead building plot) although most households with biogas units had alternative income sources to agriculture (for example, petty business, carpentry, service occupations). The Government of India Planning Commission (2002) stated that 60% of households engaged in the NBMMP thought financial subsidy was not an important factor in adopting the technology because family-type biogas plants are being adopted by farmers. However we found that a key element in adoption of new technologies at the household level is the perceived cost advantage of the alternative energy options provided (Rehman et al., 2012) compared to the existing energy expenditure. The direct monetary cost of subsidised LPG, kerosene, or biogas appears higher for households compared to the non-monetary cost of biomass or wood fuel for cooking (Balachandra, 2011; Bhattacharya, 2011; Rehman et al., 2012) where time and effort for collection by women and children and loss of forest resource is not considered in the calculation. While women identified biogas as beneficial to them, the availability of sufficient feedstock to maintain a steady gas supply was the main impediment found with its use. This problem was discussed with the State Nodal Agency and the private contractors who argued that those households with insufficient cattle to qualify for a biogas unit make promises to buy more cattle if the scheme is awarded to them. However, once a biogas unit is awarded, for whatever reason, they do not fulfil their promise of purchasing more cattle and thus the available quantity of cow dung is insufficient for good gas production. In these circumstances, the monetary outlay associated with the purchase of the digester may make buying additional cattle unaffordable. A standard amount (15% of the Ministry of New and Renewable Energy assessed costs for installation of the biogas plant, including a four year guarantee for maintenance work) is paid to the contractors, however the investment for the household is anything between Rs. 1000 and 8000 as the household have to provide sand and bricks as building materials needed for the mason to construct the biogas unit. As stated above the NBMMP scheme provides a Central Financial Assistance turnkey job fee to private contractors for setting-up of biogas plants with the provision of five years free maintenance and the subsidy to the State Nodal Agency for bearing the costs of building the biogas plant so the investment by the householder is already heavily subsidised.

The climatic conditions of Assam and the seasonal variation of gas production was highlighted by the households in relation to the overall cost. During winter months the cool temperatures meant that households with insufficient cow-dung faced issues of low gas-production and they were thus were forced to substitute some of their energy service needs with secondary fuel sources for cooking (e.g. fuel wood or LPG). The cost of fuel wood varied between Rs. 10–15 for a two to three kg bunch. Few households bought kerosene at the market value of Rs. 17 per litre from the public distribution system shops despite the availability of government subsidised LPG and kerosene; only 7 out of 60 households used LPG as most used fire wood (Fig. 3) for additional cooking needs due to the high cost of Rs. 475 per LPG cylinder. The Government provide a cap on subsidised LPG in the open market to nine cylinders per household, necessitating additional costs as high as Rs. 1200 for groups requiring more than their maximum subsidised allowance.

Fig. 3. Cooking undertaken using firewood collected from nearby forest areas.

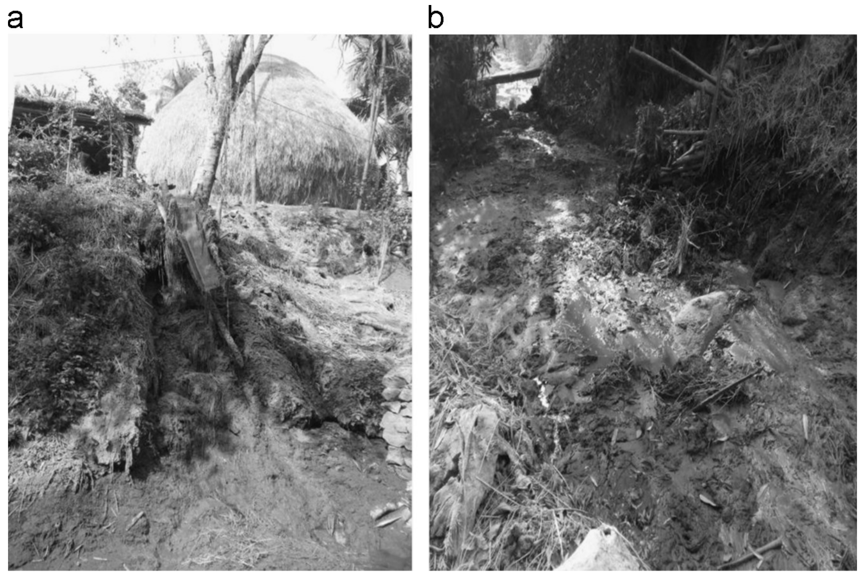

Fig. 4. (a) The digestate outlet showing unmanaged slurry flowing downhill from a household biogas unit in Amirigog village. View upstream towards the farmstead. (b) View downstream from the same location showing the pollution potential for local water supplies.

The benefits gained from the provision of low-cost fuel for cooking are the main reasons householders cited for adopting biogas plants; nonetheless secondary reasons included seeing others in the village having one installed suggesting some evidence of peer-related competition. For families with only a few cattle, the challenge of insufficient feedstock meant adopting biogas technology was out of reach and these households had opted to remain with fuel wood that was supplemented with kerosene.

4.3.3. *Labour, maintenance and training*

In rural areas, gender division of labour allocates tasks such as cooking and collection of fuel-wood to women and older children (IRADE, 2009). The family members we interviewed identified women as the main household cooks and cleaners. Women were also considered responsible for feeding, cleaning and maintaining the biogas units. However, when questioned it was apparent that only the men had received training from the contractors. In winter months when ambient air temperatures drop, gas production is also affected, compelling women to collect firewood from in and around the household, and it was also women who collected excess cow-dung from neighbours as feedstock. During interviews a number of women asked if using other organic materials like kitchen wastes, which were commonly fed to pigs, could be used as biogas feedstock since relatives living elsewhere (in both India and Nepal) had spoken of fibre-glass units fed by different types of feedstock. This lack of knowledge and understanding raised issues of adequate education and training since the lower status of women in rural society means that they tend to be excluded from knowledge-based activities and have to rely on second-hand information or work by trial and error.

4.3.4. *Digestate and additional income opportunities*

An essential element of the NBMMP scheme is the value-added perspective of using the waste digestate as an organic fertiliser, which can reduce a rural household′s dependency on chemical fertilisers and provide economic and environmental benefits to rural communities. 27 households out of the 49 households (i.e. 55%) with functional biogas units surveyed were using the digestate waste in their fields or kitchen gardens. For those not using the digestate as fertiliser the main reason was lack of awareness – most households had not been informed what to do with the digestate and its liquid state made it difficult to apply to the fields. The lack of alternate income-generating activities through potential sale of spare feedstock and the related market linkages for digestate products is unfortunate. In China biogas programmes which promote the financial rewards from digestates have been shown to work well (Jiang et al., 2011).

In Amarigog village, which was located on a hillside, we found that digestate was considered a waste product with no obvious value and as a result it was thrown outside the houses creating a ‘river’ of slurry running from the top of the hill to the bottom (Fig. 4). In the monsoon season, this is likely to cause a health-hazard since pathogens and nutrients could leach from it into the river systems and ground water, ultimately impacting on the quality of local drinking water. In households where the digestate was used but was found to be too liquid to handle easily, householders left it to air dry and then mixed it with straw then applied the mixture as a garden mulch. Some householders had an option to sell their digestate to a local organisation which used it in the production and marketing of vermicompost. The Department of Environment and Forests officials were interested in promoting vermi-composting as an entrepreneurial activity for forest villages, and viewed digestate as useful alternative income-generating product for forest village households. Despite support from the State Nodal Agency it is clear that there is a lack of communication around income-supplementing opportunities and more needs to be done to educate householders as to the options available to them to add value from operating biogas systems.

5. Discussion

The Government of India is committed to providing its population with universal energy access (Sawhney, 2013). While the conventional models of providing energy access (i.e. grid extension) have had limited success in reaching may rural communities (Bhattacharyya, 2006, 2013), there have been innovative technological and institutional solutions that have shown an alternative path to providing energy access in a reliable and successful manner (Chaurey et al., 2012). The NBMMP is a national scheme but its effectiveness nationally or within individual states is currently unknown; ours is the first study analysing its implementation. In Assam, the State Nodal Agency, the Department of the Environment and Forests, has installed 26908 biogas units

(2007–2012) in rural villages across Assam and these appear to be working well; the official Biogas Development and Training Centre survey of the villages found $>99\%$ of the installed biogas units operational compared with 82% of the households we interviewed. Surveys in various regions of India have found the proportion of functional plants to vary from 40% to 81% (Bhat et al., 2001) though digester age was found to be a significant factor in performance, with, on average, higher functionality being associated with younger digesters as well as more recent designs (Tomar, 1995; Bond and Templeton, 2011).

The relationship between NBMMP uptake and sufficient head of cattle to provide manure feedstock for the digester was an issue in Assam and proved to be a limiting factor for the technology. Although biogas digesters can be fed with a range of feedstocks including poultry manure and pig slurry (Nasir et al., 2012), toilet waste (Katukiza et al., 2010; Rajagopal et al., 2013), food waste (Zhang et al., 2007), flower waste (Singh and Bajpai, 2012), dairy waste (Campbell and Sallis, 2012) and agricultural residues (Parawira et al., 2008; Chen et al., 2012), cattle dung is known to be particularly suitable since methanogenic bacteria are naturally present in the stomachs of ruminants (Bond and Templeton, 2011). Villagers in Assam seem unaware of possible alternative feedstocks for their digesters or the potential benefits of mixing them; co-digestion of a range of wastes has been shown to improve biogas yield (Gupta et al., 2012). It has been previously reported that rural households in India require four to five cattle to feed a 2 m^3 biogas plant (Dutta et al., 1997) and this view is pervasive as other sources of possible fuel are apparently not considered to be relevant.

Where biogas was produced from the anaerobic digestion of cow dung, participants were provided with improved access to clean, renewable and sustainable energy although the full benefits of the technology were not always accessed, particularly in relation to income generation opportunities. We found that implementation of the NBMMP occurs via a complex series of multi-institutional actions where an individual's gender, economic position, community status, personal networks, knowledge of and access to available feedstock will determine their ability to participate in, and benefit from, biogas technology. Below we analyse how these institutional arrangements and individual attributes impact on the delivery of NBMMP and consider how issues of affordability, available financial support and viable business models (including public–private partnerships) (Sovacool, 2013) as well as technology management, community ownership, capacity building and training and wider livelihood improvements and poverty reduction (Chaurey et al., 2012) can play an important role in improving delivery, uptake and impact of the scheme.

5.1. Technology management

The NBMMP requires a top-down approach to delivery of the scheme with targets set by the central government, which are then translated to the state implementing agencies. The prescribed structure is designed around adoption of the technology with low consideration of people's needs particularly in rural households. Though the NBMMP programme lists a number of agencies i.e. banks, Indian Renewable Energy Development Agency, financial institutions, self-help groups, cooperatives and NGOs, in addition to State Government Nodal Departments/Implementing Agencies and the Khadi Village Industries Commission, which should be involved for policy implementation, there are very few examples of these agencies playing an active role in the villages we visited in Assam.

Energy governance and local participation are clearly essential for successful implementation of the NBMMP by the state nodal agency in rural areas. Evidence from this study has indicated that for households, socio-economic characteristics and local community networks are important determinants of technology adoption behaviour. The performance and technology management of NBMMP installations in Assam were found to be successful in a majority of the households surveyed. Policy implementation may have benefitted from some of the lessons learned through previous Ministry of New and Renewable Energy schemes in other Indian states. Studies are limited but a survey of 24,501 biogas plants in Madhya Pradesh installed under the National Programme for Biogas Development found only 53% functional, with failures due to technical and operational defects and 21% resulting from incomplete installation (Tomar, 1995). However Bhat et al. (2001) reported that of 187 household floating dome plants in eight villages in Sirsi block of the Uttara Kannada district, Karnataka state, 100% were found to be operating satisfactorily. The success of the Sirsi scheme has been put down to number of contextual and inter-related conditions (Bond and Templeton, 2011) which highlight the importance of market forces and socio-economic status in additional to technological factors in making a biogas scheme operate well. In the Sirsi example, drivers of success included: the availability of free servicing; the presence of competing entrepreneurs who assisted householders in all phases of plant construction, installation, and the procurement of subsidies; a high demand for biogas plants (i.e. more applicant households than administered subsidies); warranties for plant performance; and above national-average household incomes, literacy rates and availability of cattle manure (Bhat et al., 2001; Bond and Templeton, 2011). Community behaviour, free market competition and the availability of microfinance and affordable business schemes clearly have the potential to enhance the effectiveness of local energy service schemes and are unfortunately missing from the way that the NBMMP is currently implemented in Assam.

5.2. Finance and business models

Sovacool (2013) argues that pro-poor, multi-institutional, partnership models, which include end-user microfinance, cooperatives and community funds are needed to overcome the high start-up costs associated with renewable energy technologies. In Assam, only the Biogas Development and Training Centre and the Department of Environment and Forests were active in the biogas scheme. The subsidies provided by the NBMMP required individual households to invest Rs 6000–8000 towards the cost of sand and bricks which was a significant financial outlay for most rural families that we interviewed. As poorer households have no access to micro-finance, the NBMMP was perceived as only for those with money and cattle – the central government subsidy for biogas installation was deemed unattractive and unaffordable to many in the context that most householders were able collect readily available fuel wood or biomass wastes that do not engage a market value – the drudgery and personal cost to women who undertake these tasks for up to 5 h a day is not considered as part of the outlay (Chaurey et al., 2012; Khandker et al., 2012; Pachauri, 2011).

Multi-actor platforms based on partnerships between the public and private energy institutions can enable wider biogas implementation (Landi et al., 2013), for example Chaurey et al. (2012) suggest a 'pro-poor public–private partnership' model that takes into account energy along with other rural development programmes and this seems a good model for biogas in Assam going forward. Public–private partnership models (Balachandra, 2011) focused on community partnership to deliver energy services have been raised as a mechanism to enable a bi-directional policy delivery mechanism instead of a uni-dimensional process (Sovacool, 2013). It has also been suggested that the Indian government requires a more focused approach to the promotion of small-scaled entrepreneurial strategies for encouraging people to adopt renewable energy technologies (Pillai and Banerjee, 2009). The inclusion of multiple stakeholders in the initial program design as well as implementation and evaluation is likely to enhance the efficacy of renewable energy policy (Sovacool, 2013).

The Grameen Shakti initiative in Bangladesh (Barua, 2001) provides a range of different economic models for financial assistance to rural households to adopt renewable energy technologies (Mondal et al., 2010). The government encourages and partners with NGOs, micro-finance institutions and international donor agencies which enables a wider reach to rural households and provides improved financial and implementation strategies with the Bangladesh Rural Advancement Committee (an NGO) promoting household biogas plants, replacing the 'technology push' approach of the government and involving local expertise and leadership options (Sovacool and Drupady, 2011). The importance of providing the right financial mechanisms to circumvent the challenges of policy incentives, maintenance of the biogas plants, and lack of people's motivation to change their traditional practices has been reported from national household size biogas programmes in Nepal (Gurung and Oh, 2013), Cambodia (Buysman and Mol, 2013), China (Jiang et al., 2011) and Bangladesh (Mondal et al., 2010). Local and central government policies which have focused on alternative income generating activities have also been recently successful (Chen et al., 2012; Gosens et al., 2013). Thus there is a need for India to revise its institutional arrangements to consider the wider context of biogas implementation and refocus away from a simple narrative based on technology deployment.

5.3. Community ownership, capacity building and training

Capacity building initiatives to finance 'energy related entrepreneurship' and go beyond dependency on public energy access may provide an important mechanism to facilitate uptake of the NBMMP particularly if there is collaboration with financial and private institutions for the investment (Rehman et al., 2012). Community-level biogas initiatives are currently absent in Assam (although promoted by NBMMP) and could include providing energy services to restaurants, tea stalls, and bakeries. These kind of entrepreneurship initiatives often create self-help groups and cooperatives (Sovacool and Drupady, 2011) which can act as vehicles for micro-credit and income generating activities. These 'energy entrepreneurs' can then further invest in the establishment of small businesses (e.g. poultry rearing) which enable improved quality of life and livelihood options (Krishnaraj, 2007).

Community stakeholders play an important role when considering the adoption of new technology (Yadoo and Cruickshank, 2010). One approach to improving energy access is to establish demand-side indicators for improved monitoring and evaluation of existing biogas schemes and their adoption and use at the community level (Rehman et al., 2012). The Indian Government has taken a 'technology-push approach' (Singh and Sooch, 2004) without consideration of the relevant contextual factors which operate at village level and ignoring the unwillingness of some householders to move away from traditional methods (Mondal et al., 2010). The involvement of local stakeholders (end-users and opinion leaders) through capacity building, monitoring, and regulating and training should encourage a more 'demand-driven' approach.

As noted above in relation to the Sirsi biogas scheme in Karnataka (Bhat et al., 2001) contextual factors have an important influence on the implementation of energy policies in rural areas (Pachauri, 2011) and non-economic factors which influence the adoption of family-sized biogas digesters include age, education and gender of the household head as well as size of land holding, number of cattle and household income (Walekhwa et al., 2009; Kabir et al., 2013). Women and men within the households have different roles in the energy system (IRADE, 2009) and the role biogas affords in empowering women (Parveen, 2008) is a key factor that should encourage the adoption and maintenance of this technology (Kabir et al., 2013). Women in rural communities undertake non-market economic activities (Choudhary and Parthasarathy, 2007) which are commonly undervalued, due to their lower status and the absence of roles for women which involve decision-making (Sidh and Basu, 2011). However women benefit disproportionately by the adoption of biogas through improved health outcomes (Dohoo et al., 2012, 2013), educational opportunities provided by labour saving (Sovacool et al., 2013) and diminished drudgery (Fig. 5). In addition to agricultural work including transplanting, weeding and harvesting (Sidh and Basu, 2011), women often travel long distances and are responsible both for cooking, heating water and collecting cooking fuel (wood, leaves, twigs, cow-dung) (Barnes et al., 2012).

The Government of India (IRADE, 2009) reported that only 12.67% of the budgetary allocation of the Ministry of New and Renewable Energy benefited women at the household level which is clearly insufficient given that traditional roles require them undertake majority of the energy-related household chores (Batliwala and Reddy, 2003).

Successful implementation of any energy scheme necessitates consideration of the users' knowledge and expertise to maintain and undertake repairs to the technology (Barua 2001; Mondal et al., 2010) and issues around identification of functional problems and maintenance are clearly important for longer term success. In Assam our household survey showed that in general people felt they were given little assistance in understanding how to operate and main the biogas plants and, as pointed out by the private contractor, if a technical problem affecting the gas production occurred, the entire biogas unit (inlet and outlet) needed to be cleaned out and restarted. Training should to be tailored to recipients educational needs; placing the Biogas Development and Training Centres in elite universities provides educational leadership but more could be done to encourage participation by poor, rural dwellers using grassroots or community-based organisations which may increase awareness in a more accessible and locally-appropriate form, especially to women. In Bangladesh, women are trained to act as energy service technicians and can earn incomes from this role through servicing and training other users (Sovacool and Drupady, 2011). Given gender dynamics and traditional roles, this women-centric approach to training and delivery fosters empowerment and allows women to take charge of the technology that in practice they already operate. An additional benefit is that women technicians can enter village households to train other women which would be inappropriate for men outside of the immediate family to do. Giving women access to training not only therefore facilitates improved status but been shown to accelerate the deployment of biogas technology (Sovacool, 2013). Empowering women through energy services also has educational and community cohesion benefits (Sovacool et al., 2013).

5.4. Livelihood improvements

Improving energy access is seen critical for rural sustainable development yet the inclusion of energy access within the United Nations Millennium Development Goals is not solely about the provision of energy infrastructure (Bhanot and Jha, 2012) but requires policy makers to shift from a focus on technical factors towards the needs of end users (Chaurey et al., 2012). Adopting biogas technology has been shown to help improve rural livelihoods by: reducing costs associated with the purchase of firewood and chemical fertilisers; improving air quality (Khalequzzaman et al., 2011) and health outcomes (Dohoo et al., 2012, 2013) by

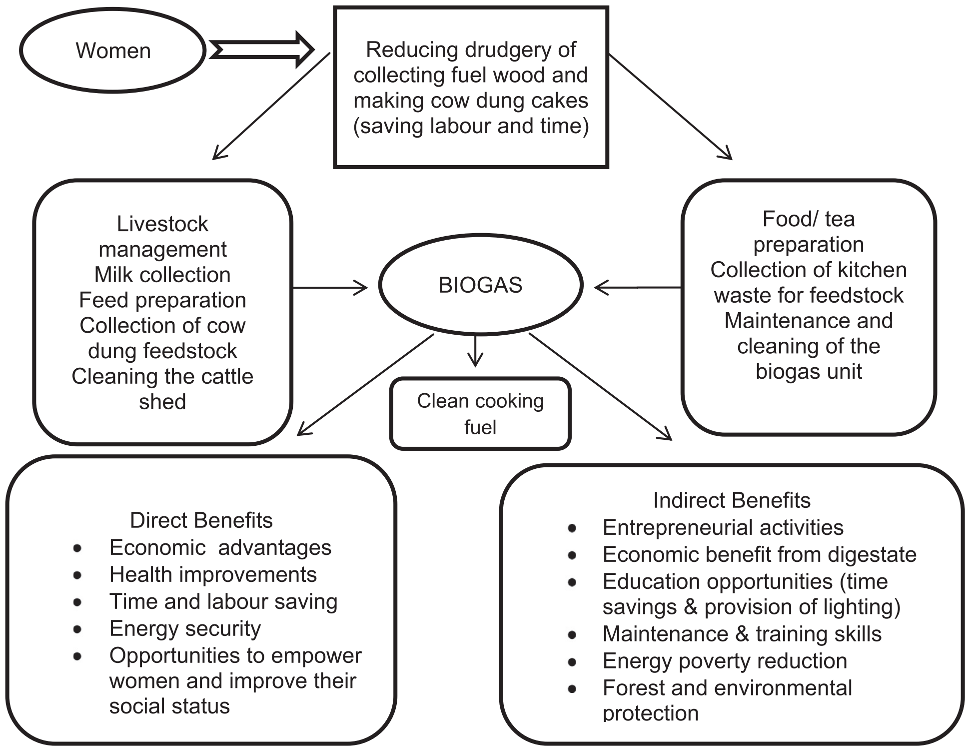

Fig. 5. The role of women in feeding, maintaining and using household biogas systems: workloads and potential benefits

reducing smoke from cooking and minimising emissions from burning biomass; reducing the workload of women who no longer need to collect firewood, tend fires and clean the soot from cooking utensils; and diminishing manure smells where animal housing is located (Keovaliv, 2012). The villagers we spoke to in Assam understood many of the health and task related benefits but did not necessarily weigh them above apparent household socio-economic advantages.

6. Conclusion and policy recommendations

Based on our survey it is clear that the NBMMP delivers improved energy service outcomes to a majority of households in Assam where biogas units have been installed. The use of biogas for cooking and heating water provides household monetary savings in the cost of fuel wood to power biomass stoves as well as forest conservation benefits, improved indoor air quality and associated health benefits which are particularly notable for women and children who regularly spend hours in kitchen areas close to polluting cookstoves (Larson and Rosen, 2002). Despite the apparent success of the scheme, there is much that could be done to improve its impact and uptake. The top-down approach to developing policy enables government to set targets and require individual states to roll-out the scheme which benefits households able to afford to participate. However our survey showed that few participants had sufficient knowledge and understanding of the technology to make the most of their digester both in terms of utilisation of a range of feedstocks for improved biogas yield as well as the added-value environmental and monetary benefits of the digestate output. Indeed sufficient cattle manure feedstock (and a lack of understanding of the available options for alternative organic feedstocks) appeared to be an important limiting factor in the ability of individual households to adopt biogas technology. The NBMMP does not explicitly deliver education and awareness programmes and the lack of additional roles for NGOs and associated stakeholders leaves the burden on the contractor appointed by the State Nodal Agency to install the units, who is likely to be ill-equipped to take up the challenge. Training of the users is also inadequate since biogas units are mostly operated and maintained by women who are disenfranchised in the top-down male-orientated delivery of the NBMMP, despite statements in the policy to the contrary. This is an area where the Government of India would do well to learn from successful schemes elsewhere in developing nations where gender empowerment can lead to improved uptake of biogas and other renewable energy schemes (Sovacool and Drupady, 2011; Sovacool et al., 2013).

The NBMMP is hierarchical in design and operation and misses opportunities to foster competition amongst contractors and enable market forces to penetrate the scheme to the benefit of potential customers. State Nodal Agencies directly appoint contractors to deliver a target number of unit installations in a given year (and thus be paid) and, to make a profit further down the delivery chain, the contractor is therefore obliged to seek savings in time and materials. A more clearly articulated bottom-up approach to highlight the contextual and demand-side issues around adopting the technology may deliver benefits such as competition for enrolment the scheme which could attract local commercial entrepreneurs to become involved. We recommend that the NBMMP policy is adapted to increase competition amongst contractors and enable development of more community-focused microfinance schemes and business models. Attracting public–private partnerships (Sovacool, 2013), banks, NGOs and small businesses to participate more explicitly in the scheme would benefit all stakeholders and particularly low income households (since household contributions require up-front payments raising issues of affordability).

In this paper we have shown how the NBMMP is a three-tiered hierarchical system linking central and state government with private contractors to deliver biogas to rural households. We recommend that NBMMP policy is revised paying particular attention to the appointment of private contractors by State Nodal Agencies. Revisions should enable greater stakeholder engagement, market competition to deliver new microfinance options such as low interest loans through government institutions, farmer cooperatives, banks and NGOs, and the new policy should seek to involve community education, training and awareness campaigns which focus on inputs and outputs, particularly in relation to the benefits of using digestate as an alternative to expensive chemical fertilisers. At State level in Assam, the role of the non-governmental organisations and research institutions needs strengthening. In addition the policy aspects dealing with the repair and maintenance processes of already installed biogas plants need to be streamlined to ensure that non-functioning systems are either repaired or replaced. Finally, biogas implementation cannot be gender blind and needs to explicitly incorporate the key role that women have in feeding, operating and maintaining biogas systems and their influencing capacity within households and communities.

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