Groundwater for Sustainable Development 7 (2018) 239–249

Contents lists available at ScienceDirect

Groundwater for Sustainable Development

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

Research paper

Integrated approach for provision of clean energy and water in rural Bangladesh

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ARTICLE INFO

Keywords:
Poly-generation
Biogas
Cooking fuel
Electricity
Water

ABSTRACT

The ultimate goal of this paper is to explore ways to upgrade energy and water services in rural areas of Bangladesh while improving resource recovery. The study analyzes the potential of a poly-generation system using locally available biomass resources (cow dung and agriculture residue) for providing cooking energy, electricity, and drinking water to a rural community. A questionnaire survey was conducted in Pani Para village with 52 households to investigate demand patterns and estimate the resource potential and amount of biogas needed in the poly-generation system. A poly-generation system with 150 m^3 biogas digester and a 10 kWe generator is required to meet cooking energy, electricity and water demand in the village. Co-digestion of available resources including cow dung and agriculture residues can provide 48,250 m^3 biogas/year, which is sufficient to supply electricity and clean drinking water to all households in the village. In addition, around two thirds of the households can use biogas for cooking. The sensitivity analysis shows that if the amount of agriculture residues is increased by 15%, also cooking gas can be provided to all households. The results indicate that such integrated solutions are worth further exploration.

1. Introduction

Bangladesh is one of the poorest and most densely populated countries in the world. Eighty percent of the population in the country lives in rural areas, and approximately half has access to electricity (Asaduzzaman et al., 2010). Kerosene lamps (hurricane and kupi) are the most used appliances for lighting (National Institute of Population Research and Training NIPORT, 2013). Currently, about 90% of the rural dwellings use traditional stoves and low-grade solid fuels for cooking (National Institute of Population Research and Training NIPORT, 2013; Mainali et al., 2014). Biomass resources used for energy purpose include agricultural waste and residues, cow dung and fuel wood (Jashimuddin et al., 2006). Inefficient combustion in traditional cooking stoves results in huge energy losses, indoor air pollution and widespread respiratory diseases particularly among women and children. Yearly, about 4.3 million premature deaths in the world, of which 46,000 in Bangladesh are associated with household air pollution (WHO, 2009a). Another alarming issue in the country is arsenic contamination of drinking water. Nearly 92% of the rural areas are affected by arsenic contaminated water (Biswas, 2011). The long-term use of contaminated water leads to different types of skin diseases, cancer, children's mental health and cardiovascular diseases (Loutatidou et al., 2017; Annaduzzamana et al., 2018). Thus, energy, water and health problems are intertwined in rural Bangladesh. Solar PV technologies, expansion of grid lines have been in practice for expansion of rural energy access while various water treatment technologies viz. filtration, membrane separation and Ion exchange are used for cleaning the water in Bangladesh. However, such efforts focus on one dimension of rural problems at a time, missing the potential benefits of synergies and integration. Developmental challenges are complex and need to be addressed in a holistic manner. In this context, there are reasons to explore synergies in the implementation of Sustainable Development Goals (SDGs) viz. energy access (SDG 7), good health and wellbeing (SDG 3) and clean drinking water (SDG 6).

The ultimate goal of this paper is to explore ways to upgrade energy and water services in rural areas of Bangladesh while improving resource recovery. More specifically, we evaluate the potential use of an integrated poly-generation system in a village of Bangladesh for providing clean energy and water. The idea is to explore synergies and opportunities offered by innovative solutions for managing local resources to promote sustainable development. A techno-economic analysis of the poly-generation system was carried out in a previous study Khan et al. (2014). In this paper, we explore the possibility of implementing such a system in a typical village of Bangladesh. The

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https://doi.org/10.1016/j.gsd.2018.06.009
Received 21 May 2018; Received in revised form 18 June 2018; Accepted 20 June 2018
Available online 21 June 2018
2352-801X/

insights are expected to inform on local conditions and the extent to which the technology can be disseminated to address multiple objectives in rural areas of the country. Following this introduction, Section 2 describes the methodology used in the study, also presenting the biogas poly-generation system and the village Pani Para that was chosen for the case study. Section 3 presents the estimation of energy demand in Pani Para. Section 4 discusses the socio-economic attributes affecting clean energy and water service choices in the village. Total biogas potential available and amount needed to supply the village with energy and water is estimated in Section 5. Final conclusions are presented in Section 6.

2. Methodology and data source

The methodology used for this research comprises literature review and field survey. The field work provided opportunity for close contact with the community, and direct observation of characteristics of the local rural life. The technical solution uses locally available biomass resources (e.g. animal dung and agricultural waste) as input. Therefore, the site visit and survey were important for assessing the local availability of biomass resources, as well as the demand for energy and drinking water. In addition, the survey served to analyze energy use patterns in relation to income and other characteristics of the 52 households in the village. The perception and preferences of different socio-economic groups could be observed and linked to the potential adoption of the poly-generation technology.

For the purpose of our analysis, we selected a typical poor village in Bangladesh. The Pani Para village is located in the Faridpur district and was selected in consultation with a local partner organization, the Grameen Shakti.[1] The criteria adopted for site selection were: (i) village without access to electricity or clean cooking fuels; and (ii) located in the arsenic affected zone. Easy access to the site was also taken into consideration while choosing the village as, if proven attractive, the study could lead to a demo project to showcase the solution.

A semi-structured questionnaire was used to carry out a survey in Pani Para village. The questionnaire was designed in consultation with local experts from Grameen Shakti to gather socio-economic data, determine the energy demand and use patterns among different income groups, and identify potential biomass sources for biogas production in the village. Household energy was estimated based on the collected information and used to verify the viability of the poly-generation system proposed. Rapid rural appraisal (RRA) technique was used to extract information regarding the socio-economic conditions, and fuel preferences. RRA is an effective technique to get information about social, economic and environmental conditions of a rural location in close collaboration with community members. The idea was to involve the community in all aspects of the data collection (Takasaki and Braham, 2000; Freudenberge, 2011). The principle of triangulation and search for convergence in the data collected from various sources was applied for crosschecking data quality. Data were also collected on the agriculture waste and animal dung available in each household, and then used to estimate the biogas potential.

We wanted to identify the types of biomass available in the village that can potentially be used for biogas production. In addition, we wanted to calculate if the available resources are sufficient to meet the village's demand for cooking energy, electricity and arsenic free drinking water when using a poly-generation technology.

The researchers spent 3 weeks in the field and collected data with the support of local staff from Grameen Shakti. It was important to incorporate women's perception in the survey, as they are typically responsible for collecting firewood, drinking water and cooking. However, women in Bangladesh are often reluctant to speak to outsiders. To overcome that, the team had a female Bengali native language speaker in the field work. As a result, the ratio of male to female respondents achieved was almost equal (51% male and 49% female). Rapport building is important when collecting reliable information from the respondent (Chambers, 1994; Luo and Liu, 2014). The facilitation role of the personnel from Grameen Shakti's local office throughout the survey contributed to the positive attitude and openness of the local population.

2.1. Proposed poly-generation system for provision of clean energy and water

The poly-generation system considered in this study comprises a biogas digester unit, an electricity generator unit and a membrane distillation (MD) unit for water purification. As implied in the term, poly-generation includes the generation of multiple outputs. This system uses low value products such as agricultural waste and animal dung to produce multiple high value outputs viz. electricity, clean water and cooking gas. If implemented in rural areas within favorable institutional and market conditions, this technical solution can bring significant improvements to life quality, as shown in the techno-economic analysis previously carried out for the system (Khan et al., 2014).

Fig. 1 illustrates the flows and functionalities of the poly-generation system. Cattle dung and agriculture residues (viz. rice straw, wheat straw, vegetable waste) available in the village can be used in an anaerobic digester to generate biogas. The plug flow digester can efficiently handle large volumes of substrate, and operate under mesophilic conditions (temperatures above 35 °C). The main advantages of the plug flow digester are: (i) simple construction, (ii) lower cost compared to other digesters, and (iii) possibility of using different mixes of substrate with high percentage of solid content (Jewell and Dell-Orto, 1981). As proposed here, part of the produced biogas will be distributed for cooking purposes, and the other part will be used in a biogas generator for electricity production. A thorough technical description can be found in Khan et al. (2014).

In principle, biogas is suitable for combustion in any type of engine, including gas engines (Otto engine), diesel engines, gas turbines and Stirling engines (Khan et al., 2014). However, biogas-based internal combustion engines are the most commonly used for small-scale electricity generation because of the low upfront cost, and relatively easy operation and maintenance in comparison to other types of engines (Dimpl, 2010). The electricity generated can be used for electrifying rural households.

In the combustion process, the average efficiency of the engine is only about 30%. Thus, around 70% of the energy is lost in the form of flue gas. A part of the low-grade heat in the flue gas can be extracted using a heat exchanger, and utilized in a membrane distillation unit to purify arsenic contaminated water. The arsenic contaminated water gets heated in the heat exchanger and passes through the membrane distillation unit. The membrane distillation (MD) is a thermally driven separation process, and only vapor phase volatile compounds pass through a porous hydrophobic membrane, being condensed on the cooling side. The MD unit achieves separation through the vapor pressure differences that exists between the porous hydrophobic membrane surfaces to purify the water. At the end of this process, arsenic and bacteria-free clean water is obtained. The amount of arsenic found in the water purified using this process is 0.4 µg/l, meaning that it is safe for drinking (Khan et al., 2014; Kullab and Martin, 2011). The permissible maximum amount of arsenic in drinking water as recommended by World Health Organization is 10 µg/l (Khan et al., 2014; Chakraborti et al., 2010). The process operates at lower temperature below normal water boiling temperature and the hydrostatic pressure in the MD unit is lower in comparison to conventional pressure-driven membrane processes like reverse osmosis (RO) (Alkhudhiri et al.,

[1] Grameen Shakti is a well-established NGO organization focusing on development work in Bangladesh (http://www.gshakti.org). The founder Muhammad Yunus is a Nobel Prize Laureate. The organization is well-known to the rural population throughout the country not least due to the dissemination of energy technologies such as biogas.