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Off-grid electricity generation using mixed biomass compost: A scenario-based study with sensitivity analysis

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HIGHLIGHTS

- Viability of waste gasification based off-grid electricity generation.
- LCOE depends largely on plant loading and capacity factor.
- Varying feedstock mixture has marginal impact on LCOE.
- Estimated LCOE is considerably high without governmental investment.
- Sensitivity analysis showed capital cost and operational hours as vital parameters.

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ABSTRACT

The aim of the study is to investigate the viability of waste gasification based off-grid electricity generation utilizing mixed biomass composts (mixture of rice hulls with cow/poultry manure compost). The economic viability is studied on the different scenarios with considerations of (1) levels of electricity demand and utilization, (2) costs of variable biomass mix, (3) combined domestic and cottage industry business model, and (4) influence of governmental investments. The levelized cost of electricity (LCOE) is used as an indicator to measure the competitiveness of gasification based off-grid electricity generation. The plant loading and the capacity factor have been used to assess the impacts of different scenarios. A sensitivity analysis of key parameters based on variations in annual operational hours, plant efficiency, plant cost and biomass supply cost is conducted. Based on levels of electricity demand and utilization, the LCOE ranged between 40 US cents/kW h and 29 US cents/kW h based on the plant loading and the capacity factor. The business revenue would not change considerably despite better plant utilization and reduced levelized cost of electricity if all the consumers, both basic or medium, are charged with the flat tariff. The part load operation will be costly despite considerably low capital investment per kW in comparison with PV or solar based plants. There is a large potential of off-grid electricity generation but the estimated off-grid electricity price is found to be higher in all scenarios than average grid-based electricity tariff. Moreover, the challenges for the implementation of the real off-grid electricity generation plant are discussed.

1. Introduction

The availability of electricity to a rural community drives the economic growth that leads to improvement in the agriculture, education, health, gender equality together with the sustainable development [1,2]. There is a widespread consensus that the electricity distribution to rural and decentralized population needs an approach which could utilize indigenous biomass resources for off-grid electrification options [3]. Since the biomass energy is distributed, there is a large potential to utilize various technologies, e.g. thermo-chemical methods etc., for off-grid electricity generation in order to promote local employment, reduce CO_2 emissions and less dependence on the national-grid at limited capital investments [4]. Despite such significance, more than 25% of world's population is deprived of electricity [5]. In the South Asian countries such as Pakistan, majority of the rural population is not connected to the electric power grid. The main reason for the absence of rural grid electrification is complex geography of certain rural areas, relatively low power demand and high costs of long distribution

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Nomenclature

AR	agriculture residues
CHP	combined heat and power
CI	cottage industry
d.a.f.	dried ash free basis
DESI	Decentralized Energy Systems India
GHG	greenhouse gas
GI	governmental investment
HH	household
HPS	Husk Power Systems
IC	internal combustion
LCOE	levelized cost of electricity
LHV	lower heating value
MC	moisture content
NGO	non-governmental organization
O&M	operation and Maintenance
PV	photovoltaic
SAARC	South Asian Association for Regional Cooperation
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme

networks. In addition, the rural areas that are connected to the grid face electricity shortages for up to 18 h a day especially during the summer season.

It is vital to utilize indigenous biomass resources efficiently in order to meet growing energy demands and reducing greenhouse gas (GHG) emissions [6,7]. The off-grid electricity generation through the utilization of indigenous resources could help to reduce electricity deficits and also provide electricity to the rural areas which do not have connected national grid [8–11]. Among various biomass resources, the agricultural wastes represent substantial share in the renewable energy mix especially in the countries with large agriculture sector, e.g. agriculture wastes account for over 30% of global agricultural productivity [12]. The agriculture sector in the South Asian countries plays an important role in their economy [13,14]. As per United Nations Environment Programme (UNEP), it is estimated that a single district of a South Asian country produces about 2.5 million tons of agricultural wastes such as wheat straw, rice hulls, rice straw etc. [15]. The agricultural residues, such as rice husk, rice straw and wheat straw, are usually used as domestic solid fuel and as supplementary fuel in the combustion process by small scale mills but around 50% of the residues are un-utilized that still go as waste [16–19]. The agricultural wastes combined with locally available cattle manure composts offer potential for off-grid electricity generation using the gasification process. Since the resources are widely distributed and locally available, off-grid electricity could be generated by private corporate entities, non-governmental organizations (NGO), or individuals at any suitable location [20–23]. The off-grid electricity generation could offer good solution for energy self-sufficiency at rural areas.

A number of concerted efforts have been made in past for off-grid electricity generation, e.g. off-grid PV, diesel mini-grids, biomass combustion & gasification etc. Table 1 shows few studies on off-gird electricity generation options in the developing countries including South Asian region.

The studies on the economic analysis show that the costs of off-grid electricity generation using local resources represents viable option for scattered rural areas [24,25]. Delavan et al. (2011) evaluated the economic viability of rice straw based combustion projects of different capacities to produce electricity. The evaluation showed that the cost of electricity varies between 7 and 9 US cents per kW h based on the plant capacity, 20–5 MWe respectively [26]. In Thailand, the cost of electricity (0.38–0.61 Baht/MJe or 0.011–0.017 USD/MJe) using rice straw for combined heat and power (CHP) production was not found to be competitive with coal based electricity (0.30 Baht/MJe or 0.009 USD/MJe) [27]. However, the cost was relatively comparable with other local biomass, i.e. 0.013–0.015 USD/MJe. A report from the United Nations Development Programme (UNDP) presented different business models of biomass gasification based electricity generation in India [28]. The report characterized the study in different criteria, i.e. off-grid, grid connected and captive criteria. A number of barriers were identified including the financing of off-grid electrification projects, technology acquisition, biomass resource management, electricity tariff and influence of governmental policies. The study concluded that the efforts from the government could create a conducive environment in order to ensure the investors that can build large plants both connected to the grid and off-grid mode. Similarly, Bergqvist et al. (2008) investigated the economical usage of rice husk for electricity production in Vietnam and concluded that the profitability was influenced based on electricity supply directly to the rice mill or to the national grid [29].

For short term perspectives, the emphasis on gasification based off-grid electricity generation is on evaluating the business viability, design, and demonstration of dispersed systems. In India, the rice husk has been used for off-grid electricity generation under biomass gasification projects, e.g. Husk Power Systems (HPS) and Decentralized Energy Systems India (DESI) power [30,31]. However, the off-grid electricity generation through mixed biomass compost (mixture of agricultural wastes including rice hulls with

Table 1
Studies on off-grid electricity generation options with conclusive findings.

Study, year	Objective	Tech. adapted	Conclusive findings	LCOE (US cents/kW h)
Bano and Rao, 2015 [44]	Effects of interest rate, inflation rate, depreciation on LCOE based on plant capacity	Solar PV	– LCOE increase with inflation & interest rate – Lower LCOE at high capacity	9–18
Ramamurthi et al., 2016 [45]	Rice residue based decentralized electrification in Ghana	Combustion & gasification	– Off-grid LCOE is lower than diesel mini-gird – Potential to meet 7% of un-electrified areas in Ghana	5–53
Zubi et al., 2016 [39]	Techno-economic assessment of off-grid PV system in developing countries	Off-grid PV solution	– Solution will be favorable at reduced costs of PV technology, batteries and electric appliances	39–67
Kemausuor et al., 2014 [46]	Electrification costs for rural communities	Diesel mini-grid Solar PV	– Off-grid and mini-grid solutions shall be utilized in addition to extension of national grid	57–102
Bhattacharyya, 2014 [41]	Viability of rice husk based off-grid electricity supply	Gasification	– High electricity use improves the financial viability – Large plants bring down LCOE	15–48

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