Bioresource Technology 173 (2014) 429–438

Contents lists available at ScienceDirect

Bioresource Technology

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

Logistics cost analysis of rice residues for second generation bioenergy production in Ghana

Pooja Vijay Ramamurthi [a,*], Maria Cristina Fernandes [a], Per Sieverts Nielsen [b], Clemente Pedro Nunes [a]

[a] CERENA/DEQ, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

[b] DTU Climate Centre, Systems Analysis, Department of Management Engineering, Technical University of Denmark, Denmark

HIGHLIGHTS

- Techno-economic potential of rice residue as a bioenergy resource in Ghana is studied.
- Capital costs contribute to 66–72% of straw supply costs to a combustion plant.
- Staff (40%) and O&M costs (46%) dominate for husk supply cost to a gasifier.
- Baling was the major processing cost for straw logistics (46–48%).
- Scale of the combustion plant did not impact straw supply costs significantly.

ARTICLE INFO

Article history:
Received 10 July 2014
Received in revised form 18 September 2014
Accepted 19 September 2014

Keywords:
Rice residues
Logistic operations
Cost analysis
Bioenergy
Ghana

ABSTRACT

This study explores the techno-economic potential of rice residues as a bioenergy resource to meet Ghana's energy demands. Major rice growing regions of Ghana have 70–90% of residues available for bioenergy production. To ensure cost-effective biomass logistics, a thorough cost analysis was made for two bioenergy routes. Logistics costs for a 5 MWe straw combustion plant were 39.01, 47.52 and 47.89 USD/t for Northern, Ashanti and Volta regions respectively. Logistics cost for a 0.25 MWe husk gasification plant (with roundtrip distance 10 km) was 2.64 USD/t in all regions. Capital cost (66–72%) contributes significantly to total logistics costs of straw, however for husk logistics, staff (40%) and operation and maintenance costs (46%) dominate. Baling is the major processing logistic cost for straw, contributing to 46–48% of total costs. Scale of straw unit does not have a large impact on logistic costs. Transport distance of husks has considerable impact on logistic costs.

1. Introduction

In Ghana, economic growth, rapid urbanisation and rural electrification have recently resulted in an 8% annual increase in its national electricity demand (Power Systems Energy Consulting, 2010). Although the Ghanaian government has been making efforts to meet these demands, 50% of rural households still do not have access to electricity. In order to fulfil an objective of electrifying the whole country by 2020, the government proposed the National Electrification Scheme (NES) in 1989 (Kemausuor et al., 2011). In 2005, to hasten this process, the Ghana Energy Development and Access Project (GEDAP) was introduced with a focus on strengthening the management, encouraging innovative technologies and promoting higher institutional collaboration within the power sector (Mahama, 2012). However, the electricity sector in Ghana still faces many challenges and at the current pace of electrification, it will not be possible to achieve full electrification by 2020 as planned (Kemausuor et al., 2011). One of the main causes for this failure in meeting electrification goals has been the emphasis on expanding central grid systems. Remote locations of rural areas and low income of rural population make the extension of centralised grids uneconomical (Mohammed et al., 2013). Hence, there is a pressing need to implement alternative decentralised solutions to ensure a reliable and sustainable energy supply to these under-served rural populations (Duku et al., 2011).

Modern bioenergy, which refers to the conversion of biomass into electricity and transportation fuel using sophisticated technology, has been globally recognised as a promising path to address today's growing energy challenges. This is because it is capable of serving as a decentralised solution which can increase access to reliable, affordable, efficient and clean energy services as well

* Corresponding author at: Center for Study of Science, Technology and Policy, # 18, 10th Cross, Mayura Street, Papanna Layout, Nagashettyhalli, RMV II Stage, Bangalore 560094, India. Tel.: +91 8762715670.

E-mail address: pooja@cstep.in (P. Vijay Ramamurthi).

http://dx.doi.org/10.1016/j.biortech.2014.09.102
0960-8524/

as promote social, agricultural and economic growth in a sustainable way (Global Bioenergy Partnership, 2011; Lim et al., 2012). Today, commercial production of modern bioenergy is dominated by first generation or second generation bioenergy (SGB) techniques (Nigam and Singh, 2011). First generation techniques involve fermentation of sugar and starch (cereal, grains and sugar crops) to bioethanol and transesterification of vegetable oils to biodiesel. As the feedstock utilised in these processes is traditionally used for food production, first generation biofuel production could lead to rising food prices, food shortages and unsustainable changes in land use patterns. These problems associated with first generation bioenergy have raised interest towards SGB production as the feedstock used in SGB processes is mainly lignocellulosic waste matter such as agricultural, forestry and municipal wastes (Shie et al., 2011). Therefore, in this particular study, only SGB processes have been considered for production of bioenergy.

In the Ghanaian context, rice is an important commercial crop, with an annual production of almost half a million tonnes, covering a cultivation area of 180,000 ha (Amanor-Boadu, 2012). Thus, one of the agricultural wastes available in Ghana is rice residues (mostly burned) and it has been shown to offer a considerable potential for energy production (5.65 TJ/year) (Duku et al., 2011). However, lack of official sources of information on utilisation of residues as an energy source has prevented any efforts for its useful development and implementation. It is thus, worth exploring the potential of rice residues as an easily available, low-value, resource that can be exploited in order to harness bioenergy to meet rural energy demands. One of the key economic and technical barriers in production of bioenergy is biomass logistics (Fan et al., 2013). In order to minimise overall energy generation costs and ensure reliable supply of biomass, it is essential to develop a sound supply chain management system (Kurian et al., 2013; Iakovou et al., 2010; Judd et al., 2012). Seasonal availability, scattered distribution and low energy density of rice residues demand that special attention be paid to their handling, transport and storage (Singh et al., 2010; Delivand et al., 2011). Previous analysis of rice residue logistics management have been made in countries such as the United States of America, India, Thailand and Vietnam (Kadam et al., 2000; Singh et al., 2010; Delivand et al., 2011; Diep et al., 2012), however they are scarcely to be found for the African subcontinent. This paper aims at quantifying the techno-economic potential of rice residues (straw and husk) to serve as a bioenergy resource in major rice growing regions of Ghana. SGB technologies for the conversion of rice residues to bioenergy were assessed to see which best suited the Ghanaian context and logistics analyses for the chosen technology pathways were made to evaluate their economic feasibility. Scale of the bioenergy plant could also have an impact on costs of transportation and handling of feedstock (Delivand et al., 2011; Diep et al., 2012). Hence, in order to identify the key factors affecting logistics costs, this study seeks to determine per unit cost of delivery of dry rice residues based on local transportation conditions as well as facility sizes that are suitable for the selected conversion technologies.

2. Methods

2.1. Rice residue distribution and availability for bioenergy production

Regional distribution of rice production was obtained from production estimates stated by the Ministry of Food and Agriculture (2013) in Ghana. The amount of rice straw and husk produced was calculated using a Residue to Product Ratio (RPR) of 1.55 and 0.25 respectively (Table 1). RPR indicates the amount of residue available from each tonne of product. It was found that the Northern (including the upper East and West), Volta and Ashanti regions had highest rice production. Field visits were made to these regions and interviews were conducted with local farmers, research institutes and rice mills to determine the percentage of rice residues that were freely disposed in order to calculate the actual amount of residue available for bioenergy production in these regions (calculations shown in Table 1). Table 1 shows that in the three regions considered, majority of rice residue was freely disposed (open burning or dumping in landfills), indicating its availability for utilisation as a bioenergy resource.

2.2. Technology options

The choice of a suitable bioenergy conversion process depends on many factors such as type and availability of biomass, socio-economic conditions and end-user applications (Caputo et al., 2005). For potential implementation in Ghana, four SGB technologies were initially investigated with respect to rice residue application. These can be classified into two types, namely bio-chemical and thermo-chemical processes. Bio-chemical processes included fermentation for bioethanol production and anaerobic digestion for biogas production. Thermo-chemical processes included direct combustion and gasification for electricity production. It was found that thermo-chemical routes of bioenergy production were most suitable for the Ghanaian context.

Anaerobic digestion is best suited for wet feed (moisture content >50%) (Caputo et al., 2005) and therefore rice residues which typically have a moisture content of about 10–30% (Lim et al., 2012; Chiueh et al., 2012; Fock et al., 2012) are not very ideal for this process. Additionally, anaerobic digestion requires resources like water and animal dung for inoculums. Water is scarce in the Northern region with considerable water shortages due to the long dry season and the topography of the region which causes rivers to dry up. Distribution of cattle is uneven in Ghana, with the Central part of the country having very few cattle, making dung hard to get there. Due to lack of water in the Northern region, and lack of inoculums in the Central region, anaerobic digestion is not an

Table 1
Annual production of rice and rice residues for 2012.

Region	Output[a] (kt/year)	Average yield[a] (t/km^2)	Straw diposed[b] (%)	Rice straw[c] (kt/year)	Husk diposed[b] (%)	Rice husks[d] (kt/year)	Average growing season[e] (days)
Northern regions (including Upper East and Upper West)	292.49	230	80–90	385.37	95	69.47	160–180
Volta	82.55	326	65–90	99.16	90–100	19.61	240–250
Ashanti	27.75	270	100	43.01	95–100	6.59	240–250

[a] Values from Ministry of Food and Agriculture (2013).
[b] Values from personal interviews.
[c] Value calculated by taking a straw to grain ratio of 1.55, the average between values mentioned at Kwame Nkrumah University of Science and Technology , Ghana and Mohammed et al. (2013) and the average straw disposed as 85%, 77.5% and 100% for the Northern, Volta and Ashanti regions respectively.
[d] Value calculated by taking a husk to grain ratio of 0.25 as mentioned by Soil Research Institute in Ghana and the average husk disposed as 95% in all the regions.
[e] Values from Ministry of Food and Agriculture (2011).