Applied Energy 135 (2014) 299–308

Contents lists available at ScienceDirect

Applied Energy

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

Rice straw supply chain for electricity generation in Malaysia: Economical and environmental assessment

S.M. Shafie [a,b,*], H.H. Masjuki [b], T.M.I. Mahlia [c,d]

[a] School of Technology Management and Logistics, College of Business, University Utara Malaysia, Sintok 06010, Kedah, Malaysia
[b] Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[c] Department of Mechanical Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
[d] Department of Mechanical Engineering, Syiah Kuala University, Banda Aceh 23111, Indonesia

HIGHLIGHTS

- Logistic cost, ready at the power plant between RM 39.95 and RM 65.80 per bale.
- Life cycle emission of logistic system is between 0.0234 t CO_{2-Eq} ± 0.11 percent per bale.
- Power plant less than 10 MW, the number of collection centre is not significant.
- Number of collection centre effect the total cost at higher plant capacity.

ARTICLE INFO

Article history:
Received 16 March 2014
Received in revised form 18 August 2014
Accepted 26 August 2014

Keywords:
Supply chain
Economic
Environment
Rice straw
Power generation
Malaysia

ABSTRACT

Rice straw supply costs were estimated and the supply potential was analyzed to determine the optimum amount of recourses and rice straw power plants. The logistic cost consists of rice straw collection, transportation to collection centre, collection centre cost and transportation to power plant. The total logistic cost, ready at power plant is found to be between RM 39.95 per bale and RM 65.80 per bale. The carbon emission and the environmental impact are analyzed throughout the life cycle involved in each process. Life cycle emission of logistic system is between 0.0234 t CO_{2-Eq} ± 0.11 percent per bale, ready at 10 MW power plants. Climate change has a significant impact on environment compared to other parameters like toxicity and acidification. For a small power plant having a capacity of less than 10 MW, the number of collection centres is not significant with respect to the total transportation cost parameter.

1. Introduction

Most of the biomass use occurs in rural areas of developing countries and about half of the world population has been depending on lignocellulosic biomass as their primary energy source [1]. Lignocellulosic biomass for bioenergy and biomaterials production include agricultural and horticultural residues, forest residues, municipal solid waste, live stock manure, perennial grasses, bioenergy crops, aquatic plants, and paper and cotton wastes [2,3]. Lignocellulosic biofuels are expected to contribute to 5% of total UK energy consumption by 2020 [4]. Parallel to this, about 67.24% of biomass based electricity generation is established in European countries [5].

Fig. 1 shows the percentage of world and Asia paddy residue production consisting of rice straw and rice husk. About 90% of paddy production are from Asian countries, and among them Southeast Asian countries provide 29% of the paddy production. Malaysia is enriched with biomass resources. The main sources of biomass in Malaysia are from plantation and agricultural residue [6]. One of the most potential and available agricultural residue is rice straw. Fig. 2 shows the total paddy residue production in Malaysia. It is forecasting that by 2020, the paddy residue production will increase to 7 million tonne per year.

Abundance of paddy residue creates a major problem for agriculture waste management. According to Shafie et al. [7], open burning of rice straw is common practice applied in the many countries of the world, especially in the Asian countries. However, these biomass resources can be used for generating electricity and

* Corresponding author at: School of Technology Management and Logistics, College of Business, University Utara Malaysia, Sintok 06010, Kedah, Malaysia. Tel.: +60 4 9287038/+60 17 499 4562.

E-mail address: shafini@uum.edu.my (S.M. Shafie).

http://dx.doi.org/10.1016/j.apenergy.2014.08.101
0306-2619/

Nomenclature

A_S	area served (km^2)
BRS	number of rice straw bale require
CC_{PG}	capital cost of power generation (RM)
CD	driver cost (RM/km)
CH_{4RSC}	CH_4 emission (kg/bale)
CP_{T1}	personnel cost lorry driver (RM/bale)
DR	discount rate (%)
C_{T1}	transportation cost of rice straw to collection centre RM
C_{T2}	transportation cost of rice straw to power generation (RM)
$d_{a,T1}$	average distance to collection centre (km)
$d_{a,T2}$	average distance to power generation (km)
DPC1	driver personnel cost
E_O	electrical output (MW)
F	fuel price (RM/l)
h	plant operating hours
L_{AS}	average salary
LC_{PG}	labour cost of power generation (RM)
LHV_{RS}	low heating value of rice straw (MJ/kg)
η	plant efficiency
NPV	net present value
P_P	paddy production in tonne
PPC	power plant capacity in MW
Q_{RS}	rice straw quantity in ton
RS_{AD}	annual demand of rice straw (tonne/year)
RS_Y	rice straw yield
TC_1	truck capacity of rice straw to collection centre (baler/lorry)
TCC	total collection centre cost (RM)
TCC_{RS}	total of rice straw collection cost (RM)
TPC	total plant cost (RM)
TTC	total transportation cost (RM)
W	the load (kg)

heat and also be used in transportation sector. Unfortunately, the main barriers in utilizing these resources for energy supply are the high cost of the respective supply chain [8] or logistic constraints [9,10]. Even though, numerous biorefinery schemes and conversion technologies exists which transforms biomass into usable energy forms, they are neither cost-efficient nor economically viable to compete with the existing petroleum-refinery technologies. The major cost is involved in the distribution networks and processing of high-moisture content biomass [11].

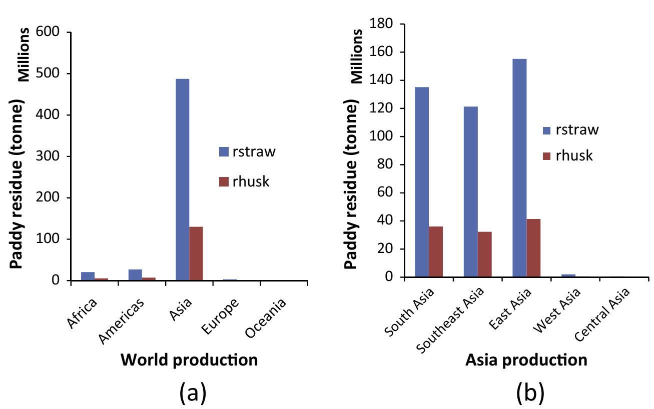

Fig. 1. Percentage paddy production (a) world production and (b) Asia production.

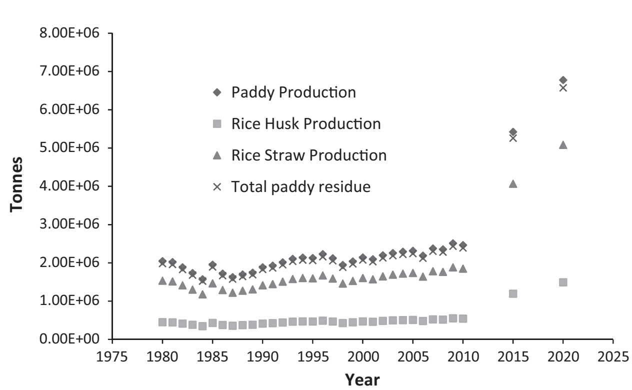

Fig. 2. Total paddy residue production in Malaysia.

In addition to the expense, the handling and transport of biomass resource to the power plant induces a variety of economic, energy and environment implication [10]. The larger fraction of cost in biomass energy generation originates from the logistics operations [12], especially from low density biomass fuels like straw [13]. The logistics of biomass agricultural community consist of multiple harvesting, storage, pre-processing and transport operation [14]. The long-term availability of biomass, the cost of generated energy, and environmental impacts of biomass are among the important factors that need to be assessed in the feasibility study of a bioenergy project [15]. However, the detailed cost analysis of logistics operations of rice straw in developing countries is scarce [16]. Rice straw power plants in China is shutting down due to logistic issues of fuel supply which proves that the logistic study is important in any feasibility project. According to Gold and Seuring [17], about 12.9% of research regarding the logistic issues are focusing in Asian countries. Table 1 lists the biomass logistic issues in prior studies [16–19,8,20,21].

The optimum design of the bioenergy power plant become the key element for success for the future projects. In Sweden, the optimum location of straw based ethanol plant is decided to raw material supply of that region [22]. The overall result obtained from Barua and Moraes [23] indicate that, the adoption of technology in biorefineries could potentially lead to profit from energy, environmental and economic perspectives by optimizing the plants in terms of sustainability.

It seems there are only a few papers focusing on the economical and environmental assessment in their study. Most of the studies are focusing on the economical aspect of the logistic issues. Although, there is a research on logistic biomass supply, eventually there will be a need for specific local study in this region due to spatial distribution of crop residue are varied for other countries and agriculture residue propriety as energy resources should be different as well [24].

This study aims to (a) analyze the economical and environmental supply chain of rice straw logistics in rice straw based power generation in Malaysia, (b) identify the optimum design based on above parameter, (c) analyze the costs and emissions of rice straw logistic supply chain to the variation collection centre number.