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# Life cycle assessment of rice straw-based power generation in Malaysia

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

[a] Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] School of Technology Management and Logistics, College of Business, Universiti Utara Malaysia, 06010 Sintok, 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

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ABSTRACT

This paper presents an application of LCA (Life Cycle Assessment) with a view to analyzing the environment aspects of rice straw-based power generation in Malaysia. It also compares rice straw-based power generation with that of coal and natural gas. GHG (Greenhouse gas) emission savings were calculated. It finds that rice straw power generation can save GHG (greenhouse gas) emissions of about 1.79 kg $CO_2$-eq/kWh compared to coal-based and 1.05 kg $CO_2$-eq/kWh with natural gas based power generation. While the development of rice straw-based power generation in Malaysia is still in its early stage, these paddy residues offer a large potential to generate electricity because of their availability. Rice straw power plants not only could solve the problem of removing rice straw from fields without open burning, but also could reduce GHG emissions that contribute to climate change, acidification, and eutrophication, among other environmental problems.



## 1. Introduction

Malaysia energy industries largely depend on fossil fuel resources in the electricity generation sector. From 1990 until 2004, total $CO_2$ emission increased by 221% in Malaysia, and it expected to increase up to 328 million ton $CO_2$-eq in 2020 [1] whereas fossil-fuel consumption contributed more than half of the total increments in $CO_2$ emission [2].

As a tropical country, Malaysia has an abundance of biomass resources that could be utilized for reducing fossil fuel consumption. The commitment of government to the development of RE (Renewable energy) is by introducing the Five Fuel Diversification Policy in 1999 by addition of RE as the fifth source of fuel in Malaysia [3]. Currently, the government of Malaysia encourages the utilization of biomass resources to attain the energy independence through its National Green Technology Policy [4]. In 2010, Malaysia introduced the National Renewable Energy Policy. Even though, the development of RE in Malaysia is still in the early stage, it estimated that by utilizing only 5% of renewable energy in the energy mix could save the country RM5Billion over a period of 5 years [5]. One potential green application uses paddy residue to generate electricity. The potential of electricity generation from paddy residue is 5652.4 GWh that is 5.4% from total electricity demand in Malaysia. Unfortunately, development of paddy residue for electricity generation remains low in Malaysia. Rice husk-based power generation only amounted to 1.38 MW in 2009 [6]. While, rice straw consumption as fuel in biomass energy plants is still unavailable not only in Malaysia but in Southeast Asia [7]. Utilization of rice straw for generating electricity remains in the discussion phase in Malaysia with plans on the drawing board for 12 MW capacity of electricity using rice straw as a fuel [8]. The use of rice straw as a fuel requires a knowledge of its heating value [9]. There are a lot of studies regarding the model of predicting the ultimate and proximate analysis. Table 1 listed the studies related to rice straw heating value model.

Even though the moisture content of straw is usually more than 60% on wet basis, Malaysian dry weather can quickly dry down the straw to its equilibrium moisture content of about 10–12% [6].

Worldwide development of straw utilization for energy conversion has been studied for more than 10 years; research has examined adapting straw technology from a small scale (<200 kW) to a large scale (>100 MW) and looked at ways to improve the combustion efficiency and reduce the pollutant emissions [18].

* Corresponding author. School of Technology Management and Logistics, College of Business, Universiti Utara Malaysia, 06010 Sintok, Malaysia. Tel.: +60 49287038/+60 174994562; fax: +60 49287070.
*E-mail address:* shafini@uum.edu.my (S.M. Shafie).

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**Nomenclature**

| | |
|---|---|
| $A$ | activity level |
| $A_{RS}$ | rice straw availability (tonne) |
| AF | availability factor |
| $BF_C$ | burning fraction of carbon |
| $C_T$ | carbon content of diesel for transportation |
| $CA_{RS}$ | rice straw catchment area ($km^2$) |
| DC | diesel oil consumption (L/ha) |
| $E_{BRS}$ | avoided GHG emission from burning rice straw in the fields |
| $E_{COAL}$ | avoided GHG emission from displaced coal power production |
| $E_P$ | emission pollutant ($CH_4$ or $N_2O$) |
| $E_{RS}$ | GHG emission from rice straw-based power generation |
| $E_{POWER, CO_2}$ | power plant emission of $CO_2$ |
| $EC_{RSC}$ | energy consumption for rice straw collection (MJ/ha) |
| $EO_{RS}$ | electricity output power from rice straw (MW) |
| $EU_D$ | energy unit of diesel oil (MJ/L) |
| $E_{T, CO_2}$ | transportation emission of $CO_2$ |
| $EF_{P, S}$ | emission factor ($CH_4$ or $N_2O$) |
| $F_{VT}$ | volume of diesel combusted for transportation |
| FF | farmland factor |
| $FO_T$ | fraction oxidized of diesel for transportation |
| $HC_T$ | heat content of diesel for transportation |
| $HHV_{RS}$ | rice straw high heating value, MJ/kg |
| $LHV_{RS}$ | rice straw low heating value, MJ/kg |
| $MW_C$ | molecular weight of carbon |
| $MW_{CO_2}$ | molecular weight of $CO_2$ |
| $\eta$ | overall efficiency of the plant |
| $\eta_C$ | collection efficiency |
| $P_C$ | carbon content in rice straw |
| $P_{RR}$ | rough rice production (k tonne/ha) |
| $R_{GHG}$ | GHG emission reduction |
| $RS_{avai, yr}$ | annual availability of rice straw, tonne/year |
| $Q_{RS}$ | quantity of rice straw (k tonne/ha) |
| SGR | Straw-to-Grain Ratio |
| $T$ | plant operating hours |
| $Y_{RS}$ | straw yield ($tonne/km^2$) |

In recent years, approximately 130 straw power plants have been established in Denmark, whereas the construction of these power plants is even high when we take into account the other European countries. The UN has enlisted the power generation based on straw as a fundamental element when it especially comes to combating environmental setbacks [19].

In 2011 the production of rice straw in Malaysian fields was 1,933,889.3 tonnes [20]. Unfortunately, the burning of rice straw remains the current cultural practice of disposal in Malaysia [21]. One major problem of open-field straw burning is atmospheric pollution because about 1521.53 kg $CO_2$-eq is produced from the open burning of one tonne of crop residue. This burning causes reduced air quality and human respiratory ailments [22]. Besides the potential to reduce problems associated with air quality, there is another advantage that is a move from fossil feedstock to rice straw for power production would result in a reduction of GHG (greenhouse gas) emissions [23].

One significant way to assess these concerns is through LCA (Life Cycle Assessment) which is a process that evaluates the environment impact for entire period of its life cycle [24].Some papers use the life cycle to analyze the different indicators regarding rice straw based power generation and therefore the literature of rice straw based energy production has been listed in Table 2.

A few studies carried out to evaluate the life cycle of rice straw based power generation for ethanol and electricity production. The majority of biomass electricity life cycle assessments has been prepared in a European context, where Asian countries only contribute 5% from the total studies [31]. However, there are significant differences of environmental performances among the existing bio-fuel production system due to local condition management practice [32]. For this study, it uses life cycle analysis of energy consumption and environment impact to the global warming potential of rice straw based power production in Malaysia. The environmental aspect of rice straw-based power generation is important to analyze because that aspect is a key consideration for technology investment. Information on environmental aspect should be disseminated to fully understand the direction of Malaysia future energy [33]. Rice straw-based power generation potential can be assessed with respect to both environmental and economic concerns based on the Malaysian situation before a pilot study is conducted.

According to [34], application of the LCA method is helpful in analyzing (and helpful in decreasing) environment effects. This paper presents an application of LCA in calculating the environment impact and energy consumption of rice straw-based power generation in Malaysia. The emissions saving from rice straw

**Table 1**
Listed the studies related to rice straw heating value model.

| Calorific value (MJ/kg) | LHV (MJ/kg) | HHV (MJ/kg) | References |
|---|---|---|---|
| 10.24 | | | [10] |
| | 15.03 | | [11] |
| | 14 | | [12] |
| | | 14.71<br>Experimental on California rice<br>15–17 | [13] |
| | HHV−212.2H (%W)−0.8 (O (%W) + N (%W)) | | [14] |
| | 34.8c + 93.9h + 10.5s + 6.3n−10.8o−2.5w (in %)<br>14 | | [12] |
| 14.97<br>Crushed rice straw in China | | | [15] |
| 16.1<br>smash rice straw in China | | | [16] |
| | | 17.8 in Denmark | [17] |

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