PADDY RESIDUE AS FEEDSTOCK IN ELECTRICITY GENERATION: REDEMPTION OF LIFE CYCLE EMISSIONS AND COST ANALYSIS

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ABSTRACT

Malaysia has an abundance of biomass resources that can be utilised for power generation. One of them is paddy residue. Paddy residue creates a huge potential in the power generation sector. The consumption of paddy residue can help Malaysia become less dependent on conventional sources of energy, mitigate greenhouse gas (GHG) emission, offer positive feedback in the economic sector, and at the same time, provide the best solution for waste management activities. The forecast data for 20 years on electricity generation was used to calculate the GHG emission and its saving when paddy residue is used for electricity generation. The government's cost saving was also identified when paddy residue substituted coal fuel in electricity generation. This paper can provide forecast information so that Malaysia is able to move forward to apply paddy residue as feedstock in energy supply. Hopefully, the data achieved can encourage stakeholder bodies in the implementation of paddy residue in electricity generation since there is a positive impact towards cost and emission saving.

Key words: *Paddy residue; Electricity generation; Malaysia; Emission saving; Cost saving*

INTRODUCTION

Development in the agriculture industry provides a positive impact towards paddy production. The world paddy production in the recent ten years is moving in an increasing pattern. This will increase the production of paddy residue, whereas rice husks from milling waste and rice straw are left in the field. Figure 1 shows the origin process of paddy converted to residue. Meanwhile, Figure 2 shows the world paddy residue production with the average ratio value waste generated: 0.22 for rice husk and 1.1 for rice straw (Aditiya et al., 2015). It seems that Asian countries are the dominant sector in paddy production. The Malaysian paddy production also shows an increasing pattern recently. Paddy residue creates the potential for power generation in Malaysia. Towards 2020, paddy residue is forecasted to increase to 7 million tonnes per year due to emerging technology development in the agriculture industry.

Open burning of paddy residue is the most current practice among farmers across the world (Bhattacharyya & Barman, 2017; Lohan et al., 2018; Shafie, Mahlia, & Masjuki, 2013; Sarma, 2018) due to the easy disposal method and lower awareness towards environmental issues. However, these will create negative impacts to the environment.

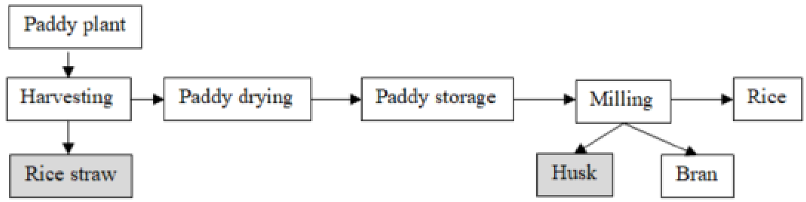

Figure 1 Paddy residue production process

Figure 2 World paddy residue production

The abundance of this residue will generate problems in handling and waste management. However, the utilisation of paddy residue for power generation can benefit the environment and economy in the future. According to Shafie, Masjuki, and Mahlia (2014), the utilisation of paddy residue can reduce CO_2 emission by 1.79 kg CO_2-eq per kWh. At the same time, this may become a stepping stone in the movement towards sustainable energy and less dependence on coal consumption. The strengths of biomass power are attributed to its feedstock availability—agricultural and forestry residues—and the socio-economic benefits, such as secure energy supply, employment creation, and regional income increments for developing countries. Many researches have been conducted regarding biomass as fuel in electricity generation, which is found to be beneficial in terms of economic and environmental saving (Wang, Zhang, Chang, & Pang, 2015; Sebastián , Royo, & Gómez, 2011). According to Yemane Weldemichael Weldu & Wondimagegnehu, 2015), the utilisation of biomass for energy production can save up to 11% to 15% of the total greenhouse gas (GHG) emissions. In 2012, about 87% of electricity generation in Malaysia is from coal and natural gas combustion (Energy Commission, 2014). Figure 3 illustrates Malaysia's forecasted electricity generation mix from 2012 until 2030 (Energy Commission, 2011). It indicates that by 2025, Malaysia will become less dependent on fossil fuel consumption, and other renewable energy will take part in the electricity generation sector.

The utilisation of paddy residue can provide variety in Malaysia's electricity generation mix in Malaysia. At the same time, this can reduce energy dependency on fossil fuel with sustainable energy generation. This study attempts to estimate the environmental and cost saving for the next 20 years if paddy residue is used for power generation in Malaysia.

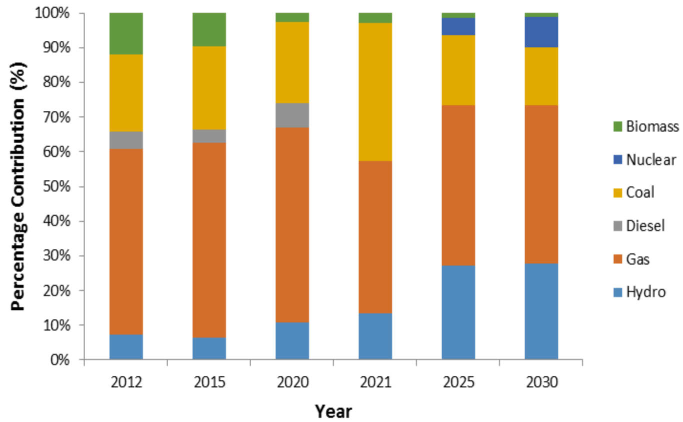

Figure 3
Malaysia's forecasted electricity generation mix from 2012 until 2030

METHODOLOGY

The data used for this study includes the paddy production, electricity generation, and coal consumption in electricity generation in Malaysia. Table 1 shows the collected data for paddy production, electricity generation, and coal consumption in Malaysia (Jabatan Pertanian, 2014; Suruhanjaya Tenaga, 2018). The electricity energy sector in Malaysia is forecasted to grow, and the demand for electricity has increased from 91,539 GWh in 2007 to 140,184.60 GWh in 2015 (Chandran, Sharma, & Madhavan, 2010; Energy Commission, 2015; Koh & Lim, 2010; Suruhanjaya Tenaga, 2018). Accordingly, it is projected that by 2020, the final energy demand in Malaysia will reach 116 mtoe based on the annual growth rate of 8.1% (Keong, 2005).

Table 1
Paddy production, electricity, and coal consumption data

Year	Paddy production (tonne)	Electricity generation (ktoe)	Coal consumption (ktoe)
1990	1884984	1979	513
1991	1926354	2283	599
1992	2012732	2521	672
1993	2104447	2987	487
1994	2138788	3362	598
1995	2127271	3909	712
1996	2228489	4421	727
1997	2119615	4977	740
1998	1944240	5220	767
1999	2036641	5609	608
2000	2140904	5955	991
2001	2094995	6112	977
2002	2197351	6384	1086
2003	2257037	6748	1212
2004	2291353	7075	1305
2005	2314378	7108	1348

2006	2187519	7740	1335
2007	2375604	8385	1361
2008	2353032	8423	1713
2009	2511043	9091	1613
2010	2464831	9791	1826
2011	2515689	10746	1759
2012	2538574	11562	1744
2013	2542517	12054	1539
2014	2848559	12629	1709

The polynomial curve fitting method was used to estimate and predict the long time series. With this method, the correlation between variable x as a function of available data and response y can be illustrated. This method seeks to find a smooth curve that best fits the data but does not necessarily pass through all the data points. Mathematically, a polynomial of order k in x is an expression in the following form:

$$y = c_0 + c_1 x + c_2 x^2 + \cdots + c_k x^k \quad (1)$$

Thus, Equation (1) is used to predict the potential of paddy residue-based power generation trend. The same concept also applies to determine the energy, environment, and economic saving projection. This method is a well-known application for data prediction (Mahlia, 2002; Shekarchian, Moghavvemi, Mahlia, & Mazandarani, 2011). The same concept is being used by several researchers to estimate the production data (Mahlia, 2002; Shekarchian et al., 2011).

The total potential of paddy residue-based power generation is predicted by applying the polynomial curve fitting method as shown in Equation (1) with the assessment of existing historical data from 1980 to 2014. Based on the listed historical data of Malaysia's paddy production in Figure 4 (Mahlia, 2002), and by using Equation (2) to determine the potential of electricity generated, the paddy residue-based electricity generation is projected by the following polynomial equation and the graph is illustrated in Figure 4; where y represents the potential of paddy residue-based electricity generation and x represents the number of years. Figure 5 shows the potential of paddy residue-based power generation.

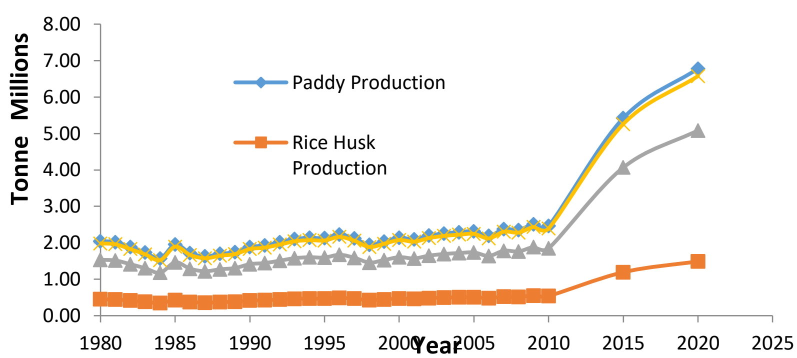

Figure 4

Malaysia's paddy and paddy residue production, 1980–2014

$$y = 706.6x^2 - 1109x + 2 \times 10^6 \quad (2)$$

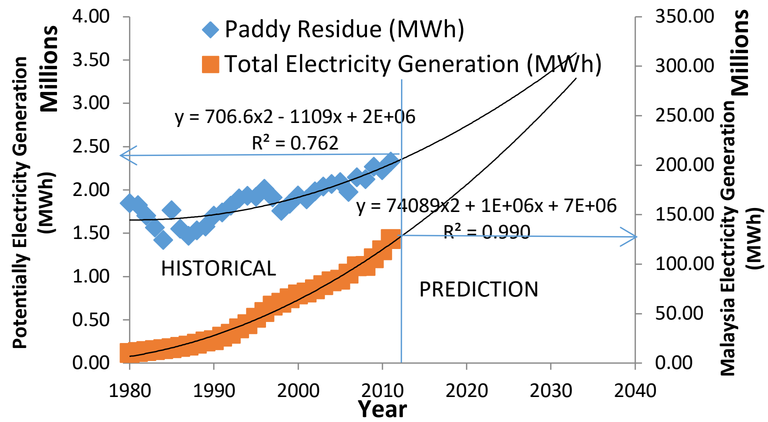

Figure 5

Potential of paddy residue-based power generation

The prediction of total electricity generation in Malaysia is estimated using Equation (3), with the historical data adapted from MEIH (2011) with an R^2 value of 0.99. Here, *y* represents Malaysia's electricity generation and *x* represents the number of years.

$$y = 74089x^2 + (10^6x) + (7 \times 10^6) \quad (3)$$

Figure 5 shows the graph of global warming potential (GWP) saving from rice straw open burning and coal-based power generation and Malaysia's total CO_2 emission from electricity generation. Malaysia's CO_2 emission from the electricity generation sector shows an exponentially increasing pattern each year.

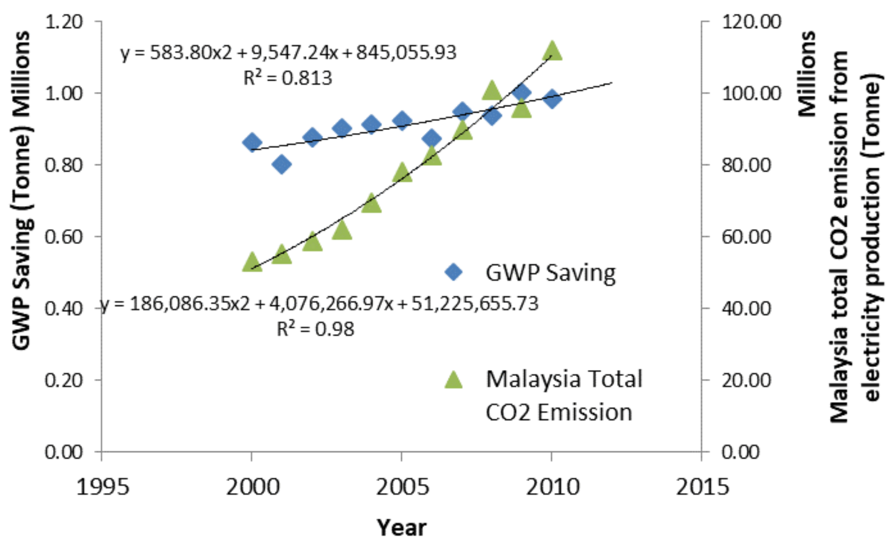

Figure 6

Global warming potential saving from rice straw-based power generations and total CO_2 emission from Malaysian electricity production

The forecasting of GWP saving due to the combustion of rice straw-based electricity generation is estimated using Equation (4), obtained from Figure 6. The overall electricity sector contributing to CO_2 emission is predicted by using Equation 6.

$$y_3 = 583.8x^2 + 9547x + 845055 \quad (4)$$
$$y_4 = 18608x^2 + 4076266.97x + 51225655.73 \quad (5)$$

RESULTS AND DISCUSSIONS

The impact of paddy residue consumption towards energy saving is discussed in this section. Electricity generation from paddy residue is assumed to be able to replace the contribution of coal mix electricity generation in Malaysia. The prediction of coal consumption in power generation used the data from Figure 2. Table 2 shows coal saving and energy saving after consumption of paddy residue for power generation. Until 2033, the consumption of paddy residue for electricity generation could replace 34.73 million tonnes of coal used for power generation in Malaysia.

Table 2
Prediction of energy and fuel saving

Year	Prediction coal mix generation ($\times 10^6$ MWh)	Coal saving ($\times 10^6$ tonne)	Energy saving ($\times 10^9$ MJ)
2014	56.00	20.60	41.00
2015	63.60	21.30	41.70
2016	66.60	21.60	42.50
2017	69.70	22.70	43.20
2018	72.80	23.20	44.00
2019	76.00	23.60	44.80
2020	77.50	23.90	45.60
2021	70.60	24.60	46.40
2022	73.50	25.30	47.20
2023	76.50	26.30	48.10
2024	79.50	27.20	49.00
2025	83.40	28.00	49.90
2026	86.60	28.80	50.90
2027	89.90	29.70	51.80
2028	93.20	30.70	52.80
2029	96.60	31.50	53.80
2030	80.20	32.60	54.80
2031	83.00	33.60	55.80
2032	85.80	1.94	56.90
2033	88.70	1.98	58.00

The impact of paddy residue substituted into the Malaysian electricity generation mix is predicted in this section. The forecasting of GWP saving due to the combustion of rice straw-based electricity generation is estimated using Equation 4, obtained from Figure 5. The overall electricity sector contributing to CO_2 emission is predicted by using Equation 5. Thus, the GWP saving and CO_2 emissions are presented in

Table 3. Up until 2033, Malaysia could save global warming potential about 29.22 million tonnes of CO_{2EQ}.

Table 3

GWP saving and CO_2 emission

Year	GWP saving (×10^6 tonne)	Total CO_2 emission (×10^6 tonne)
2013	1.07	135.66
2014	1.09	144.76
2015	1.12	154.23
2016	1.15	164.08
2017	1.18	174.30
2018	1.21	184.89
2019	1.23	195.85
2020	1.26	207.18
2021	1.30	218.89
2022	1.33	230.96
2023	1.37	243.41
2024	1.41	256.24
2025	1.44	269.43
2026	1.48	283.00
2027	1.52	296.94
2028	1.57	311.25
2029	1.61	325.93
2030	1.65	340.99
2031	1.70	356.41
2032	1.74	372.21
2033	1.79	388.39

However, the required paddy production will be increased to 6.19 tonnes per hectare in 2033 with a 67.3% increase from 2012. This is a realistic target due to the government policy to improve the productivity of paddy to 9-10 tonnes per hectare by 2020 (NCER, 2007). Thus, using the high yielding seeds and gazing at the core granary area to protect the paddy lands are some initiative ways to achieve the target.

Using paddy residue as a fuel source in boilers can reduce the cost of coal-based power generation by slashing the import of coal. Table 4 shows the coal saving cost and certified emission reduction (CER) after substituting coal with paddy residue for electricity generation. The total saving from substituting coal with paddy residue is RM1.96 billion up to the year 2033.

Table 4

Coal cost saving

Year	Coal Price (×10^{-3}RM/kg)	Coal Saving (×10^6RM)	CER (×10^6RM)	Total Saving (×10^6RM)

2013	14.99	20.60	50.19	70.80
2014	15.20	21.30	51.38	72.70
2015	15.20	21.60	52.62	74.30
2016	15.68	22.70	53.92	76.60
2017	15.72	23.20	55.28	78.50
2018	15.70	23.60	56.68	80.20
2019	15.66	23.90	58.15	82.10
2020	15.84	24.60	59.67	84.30
2021	16.00	25.30	61.24	86.60
2022	16.32	26.30	62.87	89.20
2023	16.54	27.20	64.55	91.70
2024	16.73	28.00	66.29	94.30
2025	16.91	28.80	68.08	96.90
2026	17.14	29.70	69.93	99.70
2027	17.35	30.70	71.84	102.00
2028	17.51	31.50	73.79	105.00
2029	17.74	32.60	75.81	108.00
2030	17.98	33.60	77.87	111.00
2031	18.17	34.60	79.99	115.00
2032	18.34	35.60	82.17	118.00
2033	18.52	36.60	84.41	121.00

For the next 21 years, the average potential of paddy residue-based electricity generation is 1.79% from Malaysia’s total electricity generation. Thus, the GWP saving from this generation is 5254.76 million tonnes CO_2-Eq. However, the required paddy production will be increased to 6.19 tonnes per hectare in 2033 with a 67.3% increase from 2014. This is a realistic target due to the government policy to improve the productivity of paddy to 9-10 tonnes per hectare by 2020 (NCER, 2007). Thus, using the high yielding seeds and gazing at the core granary area to protect the paddy lands are some initiative ways to achieve the target. Using paddy residue as a fuel source in boilers can reduce the cost of coal-based power generation by slashing the import of coal.

Paddy residue-based electricity generation on breakeven cost

Figure 7 shows the cost of energy (COE) and subsidy needed as functions of plant capacity. A small plant capacity size (less than 100 MW) needs a higher amount of subsidy from the government between RM 0.17/kWh and RM 0.07/kWh to compete with the conventional plant generation. However, a plant capacity greater than 400 MW provides lower COE, and the cost is the same as the conventional plant. Lower plant capacity generates higher error value, which is RM 0.02/kWh. However, increasing the plant capacity can reduce the error value to RM 0.01/kWh.

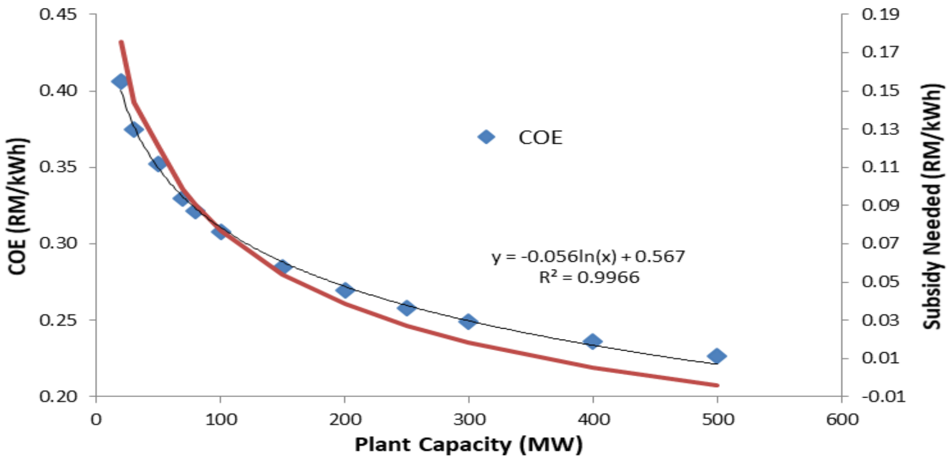

Figure 7
COE and subsidy needed as functions of plant capacity

Even though paddy residue-based power generation needs subsidy from the government to compete with conventional plants, in the long term, it gives more profit in terms of environmental preservation and ecosystem. Table 5 shows the comparison on paddy residue and conventional subsidy needed in Malaysia. Conventional subsidy refers to fuel subsidy for 2014; as the projection, if fossil fuel price increases, the pattern of subsidy should also increase, therefore the amount of government support for fuel will be higher than in Table 5. The Malaysian government could save RM13.02 million from subsidy saving. The trend continuously increases the government's savings from providing incentive in the energy sector. Thus, the government can generate more income by using paddy residue and simultaneously reduce environmental degradation.

Table 5
Paddy residue and conventional subsidy forecast in Malaysia

Year	Conventional Subsidy ($\times 10^4$ RM)	Paddy Residue Subsidy ($\times 10^4$ RM)	Different Saving ($\times 10^4$ RM)
2014	56.20	5.20	51.10
2015	57.20	5.20	52.00
2016	58.20	5.30	52.90
2017	59.20	5.40	53.80
2018	60.30	5.50	54.80
2019	61.40	5.60	55.70
2020	62.50	5.70	56.70
2021	63.60	5.80	57.80
2022	64.80	5.90	58.80
2023	66.00	6.00	59.90
2024	67.20	6.20	61.00
2025	68.40	6.30	62.20
2026	69.70	6.40	63.30
2027	71.00	1.90	69.10
2028	72.40	1.90	70.40
2029	73.70	1.90	71.80

2030	75.10	2.00	73.10
2031	76.50	2.00	74.50
2032	78.00	2.10	75.90
2033	79.50	2.10	77.30

CONCLUSION

In general, the utilisation of paddy residue in generating electricity provides a positive impact towards the environment and the economic sector. For the next 21 years, the average potential of paddy residue-based electricity generation is 1.79% from the total electricity generation in Malaysia. The total saving from substituting coal with paddy residue is RM1.96 Billion up to the year 2033. About 29.22 million tonnes CO_{2EQ} is saved by replacing fossil fuel with paddy residue as a feedstock in power plants. This could help to develop the nation as a more sustainable country in the future. It is hoped that this result will serve as a motivation in the implementation of paddy residue-based electricity generation in Malaysia. Malaysia has the potential to fully utilise its biomass resources as feedstocks in boilers in terms of economic and environmental issues. In addition, the findings of this study could serve as an alternative source of information for the government and other interested bodies in supporting the utilisation of paddy residue in electricity generation.

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