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ELECTRICAL ENERGY POTENTIAL OF RICE HUSK AS FUEL FOR POWER GENERATION IN INDONESIA

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ABSTRACT

This study was conducted to determine the potential of electrical energy of rice husk as fuel for power generation in Indonesia. The estimated potential of rice husk in each province of the country was calculated using the statistical data of rice production from 2011. The estimated annual potential of rice husk development was calculated using statistical data from 2001 to 2012. The results indicate that the development potential of rice husk, potential for electrical energy and economic potential increased by approximately 36.8% over 12 years; an average of about 3.1% per year. In 2011, the 33 provinces had rice husk potential of around 10.52 million tons, which is equivalent to about 5.24 million tons of coals, providing electrical energy and electrical power potentials of about 39,272 GWh and 4, 481 MW, respectively. About 26 provinces had potential rice husk electrical energy greater than 100 GWh, providing a total electrical energy potential of approximately 39,076 GWh, and electrical power of around 4, 460 MW. This potential could be turned into fuel for small power plants with mono-combustion applications. The other seven provinces had very small rice husk potential and should apply co-combustion with other fuels for very small power producers. Use of rice husk as fuel for power plants could overcome the shortage of electrical energy, reduce the use of coal and decrease negative environmental impacts in Indonesia.

Keywords: rice husk, fuel, energy potential, electrical energy, power generation.

INTRODUCTION

Rice is one of the most widespread crops in the world and is a staple food for more than half of the world's population (Calvo *et al*., 2004). Indonesia is the third biggest rice producing country in the world after China and India (Umadevi, 2012) and is the fourth most-populated country in the world after China, India and the United States (Population Reference Bureau, 2012). The country experiences problems of shortages of electric energy. The electrification ratio and the availability of electrical energy are low, especially outside Java. The national electrification ratio (NER) varies for each province in Indonesia. It is generally around 40% to 60% but there are four provinces in which it is only about 20% to 40% (PT PLN - Persero, 2010). Many people in these rural areas do not use electricity and in urban areas, rolling blackouts occur frequently. This is due to the limited capacity of the power plants to meet the increasing demands of society and industry.

In Indonesia, steam power plants generally use coal as their primary energy source because it is available in large quantities; around 61,365.86 million tons and reserves of approximately 6,758.90 million tons (Research and Development Center for Mineral and Coal Technology, 2006). However, it will run out in the near future if its consumption in large quantities continues. Furthermore, using coal as fuel damages the environment. The negative impact on the environment results both from the mining and from its combustion. However, Indonesia has a huge potential source of renewable biomass energy

in the form of rice husk (RH). The biomass potential in Indonesia is around 146.7 million tons/year, which is equivalent to 470 GJ/year. The largest biomass energy potential derives from rice residues, which is around 150 GJ/year (Hasan *et al*., 2012).

RH is an important source of energy for generating electricity (Kapur *et al*., 1996). Several researches on RH have being done to convert into energy sources (Yusof *et al.*, 2008, Islam and Ani, 2000, Islam and Ani, 1998). The use of RH by direct combustion has been applied largely for efficiency and environmental reasons (Roy, 2013). Emissions of CO_2, SO_X and NO_X produced by burning RH are much less than those produced by combustion of coal and oil (Shafiea *et al*., 2012). Asian countries, such as Indonesia, contribute more than 92% of RH with a calorific value (CV) of approximately 12-18 MJ/kg, while European countries contribute only about 0.5% (Gómez *et al*., 2010). The potential of RH in Indonesia extends to every province but it has not been used optimally to produce electrical energy; it is just discarded as waste that pollutes the environment.

In addressing the problems of electrical energy shortages and environmental pollution in Indonesia, an alternative course of action is to exploit the potential of RH as fuel for power plant. Thus, this study was conducted to gain an overview of the energy potential of rice husks (EP_{RH}) available in Indonesia as fuel for power plants. It was expected that the results would indicate that RH is an alternative fuel that could be used in Indonesia's power plants to overcome the shortages of electrical

energy, reduce the use of coals and minimise negative environmental impacts.

MATERIALS AND METHODS

Study area and electrification ratio in Indonesia

Indonesia is a unitary republic comprising thousands of small islands and six large islands: Sumatra, Java, Kalimantan, Sulawesi, Papua - Irian, and Bali - West Nusatenggara - East Nusatenggara. The NER of each province is generally low, i.e., less than 60% except for Java Island, which is greater than 60% (PT PLN - Persero, 2010). These data indicate that, in general, every province in Indonesia still lacks electrical energy, especially outside Java Island. However, each province has RH potential that could be used as fuel for power generation to overcome the shortages of electrical energy without relying on coal.

Indonesia comprises 33 provinces, about 27 of which produce more than 100,000 tons of rice per year. There are only about six provinces with rice production (RP) of less than 100,000 tons/year, i.e., Maluku, North Maluku, West Papua, Bangka Belitung, Jakarta and the Riau Islands (Statistic of Indonesia, 2013). In Indonesia, there are about 14 provinces for which the NER exceeds 60% (only Jakarta has reached 100%) and another 14 for which it is around 41% to 60%. In fact, there are five provinces for which the NER is very low, only about 20% to 40%: West Nusatenggara, East Nusatenggara, Papua, West Papua (Irjabar), and Southeast Sulawesi. The data indicate that Indonesia lacks electrical energy, especially outside Java.

Proximate and ultimate analysis of rice husks

A proximate, ultimate and calorific value analyses were performed to determine the quality of RH as fuel for power plants. Proximate analysis was conducted to ascertain the moisture, ash, volatile matter and fixed carbon. Whereas ultimate analysis was performed to determine the carbon, hydrogen, oxygen, nitrogen and sulphur contents. A calorific value (CV) analysis was undertaken to determine the amount of energy contained in RH. The content of energyor CV is an important criterion for assessing the quality of fuel that can be used for power plants (Dear, 2013). The proximate analysis was performed under the ASTM D 3172 - 3175 and ISO 565 standard procedures, while the ultimate analysis was performed under the ASTM D 3176, ASTM D 4239 and ASTM D 5373 standard procedures. The testing of the CV of RH was based on the ASTM D.5865 standard procedure using a Bomb calorimeter. This method is in line with previous studies (Maiti *et al*., 2006 ; Patel and Kumar, 2009).

Estimated energy and economic potential of rice husk

An estimation of RH potential was undertaken to establish the development of RH potential over 12 years. For this, RP data from 2001–2012 were analysed (Statistic of Indonesia, 2013). The data of RP in 2011 were used to determine the RH potential distribution in each province. The potential of RH available in each province was calculated with reference to the production of RH and the value of husk-to-grain ratio (H_{GR}); this is about 0.2 (Blasi *et al.*, 1997; Daifullah *et al.*, 2003; Dasappa, 2011; Hiloidhari and Baruah, 2011; Thao *et al.*, 2011) but it can reach 0.23 - 0.33 (Lim *et al.*, 2012). Accordingly, RP will produce around 20% to 33% RH. Ideally, it is assumed that all RH generated from RP is used as fuel. Therefore, the potential of RH could be determined by using the equation $RH = H_{GR} \times RP$. However, some RH is lost during the milling process. It is assumed that the volume of lost RH is about 20%. This means that the potential of RH that could be used as fuel is only about 80% of RP. Thus, the potential of RH that can be used as a fuel is calculated by the equation:

$$RH = C_E \times H_{GR} \times RP \tag{1}$$

where C_E = collection efficiency of RH = 80%, RP = rice production, H_{GR} = husk-to-grain ratio = 20%.

The EP_{RH} and electric potential energy (EE_{RH}) can be estimated with reference to the methods of (Gómez *et al.*, 2010) and (Yokoyama, 2009). The EP_{RH} can be determined using the equation:

$$EP_{RH} = W_{RH} \times CV_{RH} \tag{2}$$

where W_{RH} = the amount of RH and CV_{RH} = the calorific value of RH, taken as 13.44 MJ/kg.

The EE_{RH} generated can be calculated using the equation:

$$EE_{RH} = \frac{EP_{RH}}{C_F} \tag{3}$$

where C_F = conversion factor from joules to watt-hours. Thus, the electrical power potential of rice husk (PP_{RH}) can be obtained using the equation:

$$PP_{RH} = \frac{EE_{RH}}{C_{FP}} \tag{4}$$

where C_{FP} = conversion factor to obtain electrical power potential..

The economic potential of RH asfuel for power plantscan be determined usingthe equivalence of energy content of RH with the energy content of coal. The equivalentvalue of RH with coal (Eq_{Coal}) can be determined using the equation:

$$Eq_{Coal} = \frac{EP_{RH}}{CV_{Coal}} \tag{5}$$

where CV_{Coal} = calorific value of coal, taken as 27.0 MJ/kg.

RESULTS AND DISCUSSIONS

Calorific value of rice husk

The low calorific value (LCV) of RH obtained by experiment was 13.44 MJ/kg, which was used to determine the EE_{RH}. The LCV was in the range of values established in previous studies, i.e., 12.34 MJ/kg (Kuprianov *et al.*, 2006), 13.30 MJ/kg (Rozainee *et al.*, 2010), 13.42 MJ/kg (Sadhu *et al.*, 1993), 13.48 MJ/kg (Butt *et al.*, 2013) and 14 MJ/kg (Ahiduzzaman, 2007). Clearly, the LCV of RH determined in previous studies varies from about 12.34 to 14 MJ/kg. The higher calorific values (HCV) of RH also varies from about 14.61 MJ/kg (Martínez *et al.*, 2011), 14.98 MJ/kg (Madhiyanon *et al.*, 2009), 15.84 MJ/kg (Lim *et al.*, 2012), 16 kJ/kg (Chen and Wu, 2009), 16.05 MJ/kg (Kwong *et al*., 2007) and 16.59 MJ/kg (Yoon *et al*., 2012).The CV of RH and some types of fuel are presented in Figure-1.

Proximate and ultimate analyses

The proximate and ultimate analyses illustrate the characteristics of RH as fuel. Table-1 presents the proximate and ultimate analyses obtained from the test results, which are within the range of results of previous studies *(Kuprianov et al., 2006; Ghani et al., 2009; Rozainee et al., 2010; Chungsangunsit et al*., 2013). The values of the proximate and ultimate analyses vary because of different species of rice and different condition. The CV about 12.34 - 13.50 MJ and the ash content is high, about 12.99- 24.3%, but can be used as raw material for brick industry. Thus, suitable combustion techniques should be adopted for RH power plants.

The analysis and estimation of the potential ofRH for 12 years (2001-2012) were performed using Equation. (1). The energy potential development was as curtained using Equation. (2) with an LCV of 13.44 MJ/kg. The EE_{RH} was calculated using Equation. (3), PP_{RH} determined using Equation. (4) and the economic potential analysed using Equation. (5). The results of the analysis of the energy and economic potentials of RH are presented in Table-2. It can be seen that the RP increased annually over the 12years (2001-2012), except in 2011 when it decreased by approximately 1.1% (it then increased by approximately 5% in 2012). In general, the RP and RH potential increased by approximately 36.8% over the 12 years, or by an average of approximately 3.1% annually. These data indicate that the increase of RP will enhance the energy potential ofRH.

Table-2 presents the electrical energy and economic potential of RH in 2001. It can be seen that it was around 8.07 million tons with an EP_{RH} of around 108, 448 TJ. This is equivalent to an EE_{RH} of approximately 30.14 TWh, or equivalent to a PP_{RH} of about 3.44 GW. In 2012, the potential of RH increased to 11.05 million tons with an EP_{RH} of around 148, 485 TJ. This is equivalent to an EE_{RH} of about 41.25 GWh, or equivalent to a PP_{RH} of approximately 4.71 MW. The potential increased by approximately 36.8% over 12 years; an annual increase of approximately 3.1%. The economic potential of RH in Indonesia can be obtained by comparison with the economic value of coal (Eq_{Coal}). The Eq_{Coal} can be estimated based on the CV of coal about 27 MJ/kg (United Nations Environmental Programme, 2009) and the price of coal (CP), taken as USD 84 per ton (Ministry of Energy and Mineral Resources Republic Indonesia, 2012).
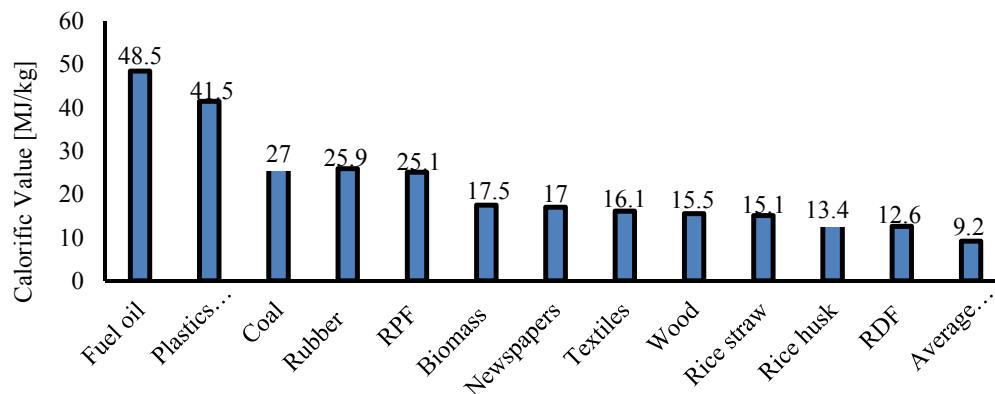
Electrical energy and economic potential of rice husk

Figure-1. Calorific values of some types of fuel.

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Table-2. Electrical energy and economic potential of rice husk.

No	Year	RP (10^6ton)	RH (10^6ton)	Eq_{Coal} (10^6 ton)	EP_{RH} (TJ)	EE_{RH} (TWh)	PP_{RH} (GW)	CP (10^6 USD)
1	2001	50.46	8.07	4.02	108,488	30.14	3.44	510.23
2	2002	51.38	8.22	4.10	110,530	30.70	3.50	520.40
3	2003	52.14	8.34	4.15	112,143	31.15	3.56	527.51
4	2004	54.09	8.66	4.31	116,337	32.32	3.69	547.84
5	2005	54.16	8.66	4.31	116,444	32.34	3.70	547.84
6	2006	54.46	8.72	4.34	117,197	32.55	3.72	551.90
7	2007	57.16	9.14	4.55	122,895	34.14	3.90	578.34
8	2008	60.33	9.66	4.81	129,777	36.05	4.11	610.86
9	2009	64.40	10.30	5.13	138,486	38.47	4.39	651.51
10	2010	66.47	10.63	5.30	142,894	39.70	4.53	672.86
11	2011	65.74	10.52	5.24	141,389	39.27	4.48	665.74
12	2012	69.05	11.05	5.50	148,485	41.25	4.71	698.26

Table-3. Electrical energy and economic potential of rice husk for each province in Indonesia in 2011.

No.	Province	RP (10^3ton)	RH (10^3ton)	Eq_{Coal} (10^3ton)	EP_{RH} (TJ)	EE_{RH} (GWh)	PP_{RH} (MW)
1	West Java (Jabar)	11,634	1,862	927	25,020	6,950	794
2	East Java (Jatim)	10,577	1,692	842	22,741	6,317	721
3	JCentral Java (Jateng)	9,392	1,502	748	20,192	5,609	640
4	South Sulawesi (Sulsel)	4,511	722	358	9,698	2,694	307
5	North Sumatra (Sumut)	3,607	577	287	7,752	2,154	246
6	South Sumatera (Sumsel)	3,382	541	269	7,268	2,019	230
7	Lampung	2,941	470	234	6,322	1,756	201
8	West Sumatera (Sumbar)	2,279	365	182	4,903	1,362	155
9	West Nusatenggara (NTB)	2,067	330	165	4,441	1,234	141
10	South Kalimantan (Kalsel)	2,038	326	163	4,387	1,218	139
11	Banten	1,950	312	155	4,194	1,165	133
12	Aceh	1,773	284	141	3,817	1,060	121
13	West Kalimantan (Kalbar)	1,374	220	110	2,957	822	94
14	Central Sulawesi (Sulteng)	1,039	166	83	2,237	622	71
15	Bali	858	138	69	1,850	514	58
16	Yogyakarta	843	135	67	1,817	505	58
17	Jambi	647	103	51	1,387	386	44
18	Central Kalimantan (Kalteng)	611	98	49	1,312	365	42
19	North Sulawesi (Sulut)	596	95	47	1,279	356	40
20	NusatenggaraTimur (NTT)	591	94	47	1,269	353	40
21	East Kalimantan (Kaltim)	554	89	44	1,194	331	38
22	Riau	536	86	43	1,150	319	37

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23	Southeast Sulawesi (Sultra)	492	78	39	1,054	293	34
24	Bengkulu	483	78	39	1,043	290	33
25	West Sulawesi (Sulbar)	366	58	29	785	218	25
26	Gorontalo	274	44	22	591	164	18
27	Papua	123	20	10	269	74	9
28	Maluku	88	14	7	194	54	6
29	North Maluku (Malut)	61	10	5	129	36	4
30	West Papua (Papubar)	29	5	2	65	18	2
31	Bangka Belitung (Bangbel)	15	2	1	32	9	1
32	Jakarta	10	2	1	22	6	1
33	Kepulauan Riau (Kepri)	1	0	0	0	0	0
	Total	65,742	10,518	5,236	141,369	39,272	4,481
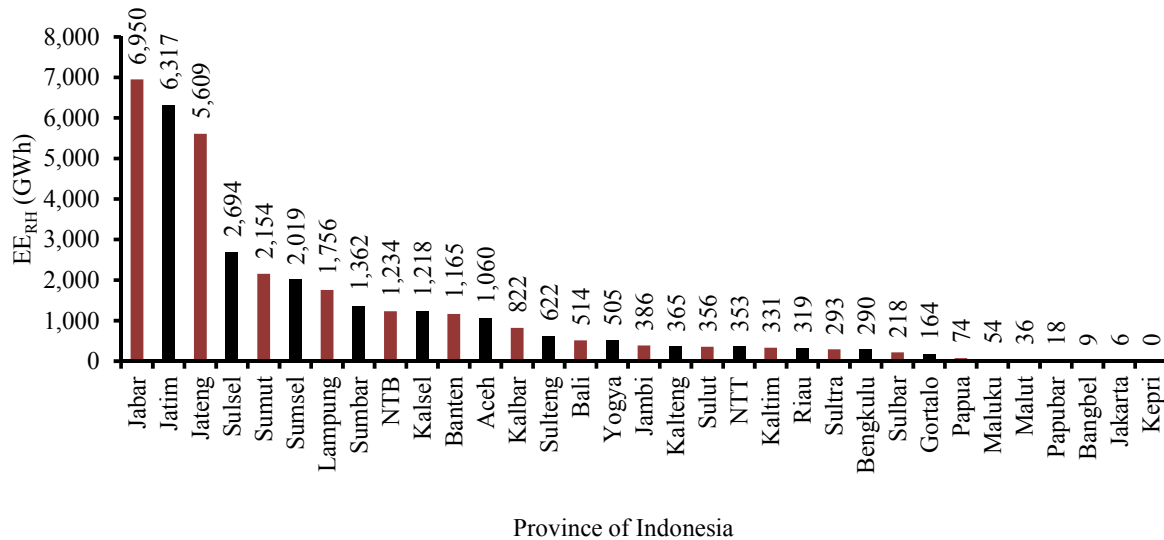
Figure-2. Potential of electrical energy by rice husk in each province in 2011.

Electrical energy and economic potential of rice husk

The energy and economic potential of RH in every province in Indonesia in 2011 can be obtained using Equations. (1) to (5), as presented in Table-3. It is shows the RP, potential of RH, Eq_{Coal}, EP_{RH}, EE_{RH} and PP_{RH} in the 33 provinces. In Indonesia, 26 provinces have PP_{RH} greater than 10 MW and 7 provinces have PP_{RH} less than 10 MW. The EE_{RH} in the 33 provinces is around 39,272 GWh and the PP_{RH} is about 4,481 MW. Ideally, 26 provinces could support the operation of power plants, i.e., those provinces that produce more than 20,000 tons of RH per year, or have PP_{RH} greater than 10 MW. Actually, the electrical energy generated by a power plant should take into account the overall thermal efficiency of the power plant. Biomass power plants generally have an overall thermal efficiency of around 20% to 27%, depending on the capacity (Delivand *et al.*, 2011).

Figure-2 shows that the potential of EE_{RH} in the 33 provinces of Indonesia; the largest is West Java (Jabar), which is about 6,950 MWh and the smallest is about 6 MWh in Jakarta. EE_{RH} could be used to generate electricity, especially in those areas that still lack electrical energy, i.e., those with an NER of around 20% to 40%:

a. West Nusatenggara (NTB) and East Nusatenggara (NTT) that has an NER of approximately 31.99% with an available EE_{RH} of around 1,234 GWh/year.

b. East Nusatenggara (NTT) that has an NER of approximately 24.24% with an available EE_{RH} of around 353 GWh/year.

c. Southeast Sulawesi (Sultra) that has an NER of approximately 38.21% with an available EE_{RH} of around 293 GWh/year.

d. Papua and West Papua that has an NER of approximately 32.05% with an available EE_{RH} of around 92 MWh/year.

Exploiting the potential of RH energy is expected to increase the NER to about 40% to 60%.

The available PP_{RH} in each province of Indonesia varies (Table-3). It can be seen that the largest is West Java (Jabar) at about 1, 033 MW and the smallest is Jakarta at about 1 MW. These data can be the basis and reference for conducting feasibility studies regarding the construction of power plants in each province in Indonesia, particularly those provinces that still have an NER below 60%. As a comparison, Thailand has developed small power producer for capacity of 10 - 90 MW and very small power producer for capacity of less than 10 MW programs to meet the target of 1,600 MW in 2012 (Suramaythangkoor and Gheewala, 2010). If Indonesia refers to these projects, then there are 26 provinces in Indonesia, from Gorontalo to West Java, which could support small power plant projects, while the other 7 provinces (Papua, Maluku, North Maluku, West Papua (Papubar), Bangbel, Jakarta and Riau) could support very small power plant programs using co-combustion with other biomass.

Projected electrical energy need in Indonesia

The electrical energy need in Indonesia is projected to increase annually from 2010 to 2019.

The energy needed will be provided by various types of fuel source, of which coal is the biggest. The use of coal appears to increase significantly each year; since 2011, the energy supplied by coal was greater than 50% (PT PLN - Persero, 2010). This percentage ofcoal use,which tends to increase annually, suggests that the generation of electrical energy in Indonesia is fully focused on the use of coal, without appreciating the negative impacts this might cause.

Table-4 shows that the use of coal is the primary source of energy in Indonesia. In 2011, coal accounted for approximately 54% of the energy total or about 62% of the energy needs in Indonesia. Utilization of gas fuel is the largest energy source after coal is about 45.753 GWh or approximately 25% of the total energy. The percentage utilization of some types of primary energy sources is shown in Figure-3. Coal utilization since in 2010-2014 has increased every year and is projected to increase until 2019, as shown in Figure-4. These conditions will continue to increase drastically if it is not anticipated by utilizing renewable energy sources as an alternative to coal. Utilization of biomass, especially RH is an alternative way of replacing coal with regard to the potential that is available and has been used as a source of electrical energy in other developing countries. The study shows that RH have characteristics that meet the eligibility as fuel in power plants (Anshar *et al*., 2015). RH has not been considered seriously as a source of energy despite the huge potential of around 39,700 GWh, 39,270 GWh and 41, 250 GWh in 2010, 2011 and 2012, respectively, as shown in Table-2. These values constitute almost half of the energy produced by coal in 2011. Thus, the use of RH as a fuel source could reduce the use of coal significantly.

Table-4. Composition production of electrical energy needs (GWh) by fuel type in Indonesia.

| Year	HSD	MFO	Gas	LNG	Coal	Hydro	Geother-mal	Total energy	Energy demand
2010	22,811	5,095	43,239	-	78,453	9,771	10,318	169,687	147,100
2011	13,035	5,194	45,753	-	99,312	10,296	10,672	184,261	160,500
2012	9,550	3,968	55,247	5,266	104,055	10,145	12,627	200,858	176,400
2013	6,740	1,836	63,387	5,365	111,976	10,894	19,347	219,546	192,700
2014	6,667	1,196	61,998	5,441	123,842	11,332	30,016	240,970	212,700
2015	6,158	1,007	62,600	5,508	141,848	11,613	35,108	264,486	230,800
2016	6,488	1,095	63,425	5,585	160,984	12,735	38,924	289,961	256,300
2017	6,751	971	61,430	10,727	180,469	13,808	42,220	317,454	275,300
2018	7,952	975	67,868	13,456	194,376	15,328	45,524	346,903	306,900
2019	8,642	958	67,492	13,482	220,410	16,506	49,853	378,493	327,300
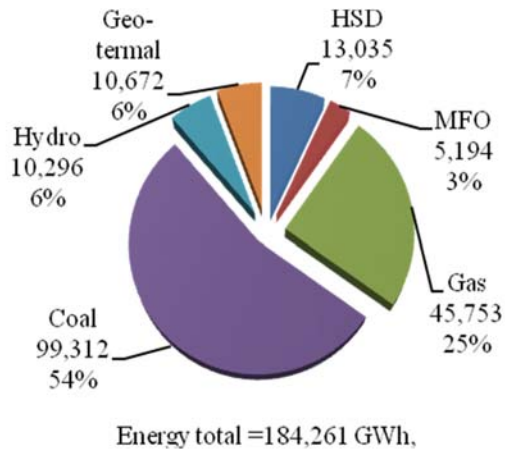
Figure-3. Percentage use of fuel type in Indonesia, 2011 (Anshar *et al.*, 2014).
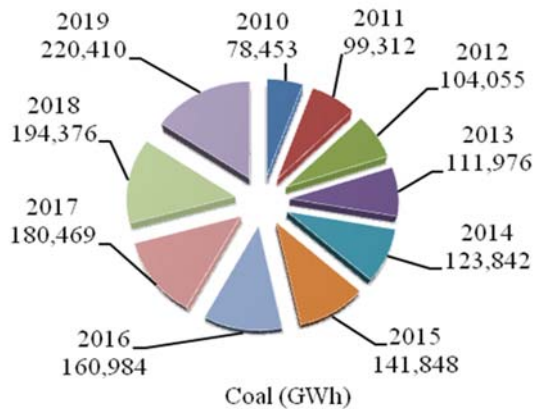

Figure-4. Projected use of coal in 2010-2019 (Anshar *et al.*, 2014).

CONCLUSIONS

Indonesia has huge energy and economic potentials from RH, which increased by approximately 36.8 % over 12 years, or by an average of approximately 3.1% annually. In 2011, 33 provinces had RH potential that reached around 10.52 million tons, which is equivalent to about 5.24 million tons of coal. This equates to an electrical energy potential of approximately 39, 272 GWh and electrical power potential of around 4,481 MW. Twenty-six provinces had an electrical energy potential from RH that was bigger than 100 GWh, offering a total electrical energy potential of approximately 39,076 GWh and electrical power potential of around 4, 460 MW. This potential could be exploited as a mono-combustion fuel for the implementation of small power producer projects. The other seven provinces have very small potential of RH, such that it could only support the implementation of very small power producer projects based on co-

combustion with other fuels. The use of RH as fuel for power plants could overcome the shortage of electrical energy, decrease the use of coal and reduce the negative environmental impacts in Indonesia.

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