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COMPARISON STUDY ON CARBON INTENSITY OF BIOCHAR WITH COAL IN POWER PLANT

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Abstract* – *Major shifts in the global energy scene since 2015 toward a low carbon economy such as adoption of solar and biomass are only adding the power capacity instead of replacing the large scale power of the coal. Life Cycle Analysis (LCA) specifically on carbon intensity assessment was performed to evaluate the potential of minimising the carbon emissions related to coal fuel. The assessment was carried out by calculating the carbon intensity (kg of CO_2 per kWh of energy consumed) of biochar from literatures and were compared with coal for three boundary conditions, i.e. feedstock production, logistic used to deliver feedstock to power plant and the feedstock's stationary combustion. The carbon emission of feedstock production for empty fruit bunch (EFB) biochar in pyrolysis plant used was 0.046 kg CO_2-equiv. kg^{-1} EFB yr^{-1} meanwhile the carbon emission emitted from coal extraction and mining was 0.116 kg methane Million BTU^{-1} coal yr^{-1}. The carbon emission for logistic was calculated for a scenario of 14,000 metric tons (MT) of dry feedstock (coal) shipped from the departure port, Samarinda port, Kalimantan, Indonesia to the receiver port, Jimah coal power plant, Malaysia, with carbon emissions of 10 g CO^2/MT/km distance. The carbon emission generated from feedstock combustion used was taken from a study on bioenergy crop, Miscanthus with carbon intensity of 113 kg CO_2/MWh. The CO_2 emission of sub-bituminous coal combustion was referred to Intergovernmental Panel on Climate Change (IPCC) default emission factors of 1,676 kg CO_2/ton. The LCA on three boundary conditions have suggested that biochar has big impact on environmental benefits when considering coal substitution with biochar as to minimize the lifecycle carbon footprint in which a noteworthy saving of 62.1% of carbon intensity can be achieved when biochar is replaced with coal as solid fuel in power plants.

Keywords: Biochar, Carbon intensity, Coal, Pyrolysis, Solid fuel

I. INTRODUCTION

Coal is one of the primary energy sources which has been helping the nation's need as depicted by over 50 % growth of world's coal demand over 2003-2013. Coal can be identified as a brownish to black sedimentary rock. It is formed under high temperature and pressure from plants and other organic matter that lived millions of years ago through a geologic process known as coalification. There are four main types of coal, classified according to the amount of available heat energy. The types of coal include Anthracite, Bituminous, Sub-bituminous and Lignite. The amount of carbon, hydrogen, and oxygen in the coal are the main factors that determine the amount of heat released during combustion. The carbon content determines the amount of carbon dioxide (CO_2) emissions from each type of coal [1].

In recent years, coal power plants are faced with critical issues as they are responsible for 44 % of global CO_2 emissions which has led to massive air pollution that has caused health impacts with 17 % of the nation's annual deaths in China alone [2]. Major shifts in the global energy scene have been happening since 2015 by the countries of the top coal producers such as United States of America (USA) and China for mitigating the climate change issues.

For instance, the coal demand in the Organization for Economic Cooperation and Development (OECD) regions have already experienced a drop by 8 % over 2003 - 2013 and is expected to decline by 2040 by almost 15 % [1],[3]. Reducing carbon emissions, in the context of increasing use of energy in growing economies, will be a challenge. In USA, Clean Power Plan was introduced to expedite the closure of the older coal power plants in the effort to reduce CO_2 emissions. However, the shutting down of existing plants requires large capital investment for modification works, premature decommissioning cost of the power plant and remediation of the site. Meanwhile, the current policies resolved around adopting renewables such as solar is only adding power capacity rather than replacing the existing capacity from the coal [4]-[5].

In Malaysia, the Feed-in Tariff (FiT) mechanism has been implemented since 1 December 2011 and biomass has become one of the fuel input to the power plants [6]. With this, Malaysia has committed to achieving 50 % of renewable energy in the energy mix by 2050 [3]. However, the small scale power generation with biomass still does not offer an immediate solution. In 2013, biomass contributes 0.3 % (297 ktoe) from the total energy mix compared to the coal with the bigger contribution, 1.9 % (1824 ktoe) [7]. Moreover, based on Academy of Sciences Malaysia (2013),

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the production capacity of biomass by 2030 will be 1340 MW which is still less than coal's contribution in 2013. The limited utilization of biomass is also related to the quality of feedstock due to various reasons such as low value heating value (HV), high ash and mineral content. These issues may cause operational problem in the boiler such agglomeration, molten slag and others [8].

A better approach for the long-term solution by utilizing a low carbon and sustainable fuel which has the similar specification to the coal such as biochar is necessary to represent global solution as to curb costs arise from the closure of the plants [4]. According to International Energy Agency (IEA), 1% increase in efficiency of coal power plants can reduce 2-3 % of CO_2 emissions immediately. This is an initial step toward other than carbon capture, utilization, and storage. Improving the coal-fired power plants' efficiency means reducing the amount of coal consumption for the same amount of energy needed [9]. Therefore, adopting biochar as solid fuel or coal-blend source can potentially be considered as one of the options for upgrading the efficiency of coal power plants.

In the study conducted by Ghani et al. [10], the coal-blend was done with biomass in which the biomass sources from agricultural residues (rice husk and palm kernel) were co-fired with coal in fluidised bed combustor. The combustion efficiency of co-combustion of a mixture of coal-blend increased up to 20% depending upon excess air levels and the carbon monoxide levels fluctuated between 200 and 900 ppm with the addition of coal. This has suggested that efficient co-firing of biomass with coal can be achieved with minimal modifications to existing coal-fired boilers, therefore the same trend is expected for replacing biomass with biochar as a blend source.

Biochar is a stable form of carbon substance, rich with carbon content (65 to 90 %) that is produced when biomass is heated under oxygen-limited condition and at relatively low temperatures ($T < 700$ °C) [8], [11]-[12]. Biochar has attracted many parties to discover more about its potential and some literature supported the correlations between biochar's physical and thermochemical properties that have potential in the energy production [8], [11], [13]-[14]. In order for opting sustainable solution, biomass is often regarded as the world's most widely available natural resource and sustainably produced with Malaysia's palm oil industry alone produced over 83 million dry tonnes of solid biomass per annum [15].

There are several thermal methods to produce biochar which include direct combustion, conventional or slow pyrolysis, fast pyrolysis and gasification which involve different pyrolysis temperature, feed's burning rate and residence time [16]-[19]. For instance, a biochar production facility in Selangor, Malaysia which adopted slow pyrolysis particularly on EFB required at least 4 h residence time with pyrolysis temperature between 350–450 ◦C [20]. Meanwhile Ariffin et al. (2014) in his study depicted that gasification process run at feeding rate 126 kg/h and syngas flow rate 362 m^3/h on EFB briquettes produces minimal production of 6% EFB biochar [21]. Hence, pyrolysis is most desirable method as it produces high biochar yield. The pyrolysis is a process of breaking down (lysis) of a substance by thermal assistance, heat (pyro). The development of pyrolysis method was improved with the introduction of microwave energy as a heating medium in a pyrolysis condition. The energy transfer by dipole rotation and ionic conduction causes the energy readily converted into heat inside the particles. Microwave energy targets straight into the area of interest when is heated, thus a rapid process is achieved and faster than the conventional pyrolysis (>50%) [22], consequently microwave technology created greater attentions for exploration in thermo-chemical treatment of waste materials. Some advantages of applying microwave pyrolysis can be seen from a study by Abas and Ani (2014) in which concluded that the quality of EFB biochar derived from microwave pyrolysis is superior to the conventional pyrolysis with the carbon content of EFB biochar derived from microwave pyrolysis recorded higher than the conventional heating which was correspondingly are 69.28% and 59.62% [23], while 45% is reported by Harsono et al. (2013) on conventional slow pyrolysis [20].

Carbon emissions intensity which can be agreed as carbon emissions per unit of economic output [24] is become one of the tools to measure the carbon emission, with one of the big elements is emission generated from shipping. This was evidenced by over the period of 2007 to 2012, the total ships accounted for approximately 1 billion tonnes of greenhouse gases (GHGs) emissions. GHGs was contributed from the fuel consumption, operational efficiency, energy use, installed power, cargo carrying capacity, operating hours, distance travelled, and operating speed [25]. The emissions from shipping will be kept incline if there is no measures and initiatives to combat the emissions as shown from the total shipping emitted CO_2 emissions from 2013 to 2015 which has increased from 910 million tonnes to 932 million tonnes (+2.4%) [26]. Therefore, based on the outstanding values possessed by the biochar from the literatures, a comparison study was undertaken to evaluate the environmental impacts of biochar as green alternative to coal substitution through carbon footprint assessment within the defined boundary conditions.

II. METHODOLOGY

The assessment on total carbon intensity (kg of CO_2 per kWh of energy consumed) of biochar in general was calculated to offer strategy in minimising the carbon footprint related to coal. In this study, the Life Cycle Analysis (LCA) specifically on carbon intensity was assessed and the boundary was divided into 3 conditions namely the total carbon intensity of feedstock production, the total carbon intensity of logistic used to deliver feedstock to power plant and the total carbon intensity of stationary combustion of feedstock [27].

A. Calculation of Carbon Intensity of Feedstock Production

The net CO_2 emissions of biochar was based on a study of direct empty fruit bunch (EFB) biochar production in pyrolysis plant in Selangor, Malaysia which was account for 0.046 kg CO_2-equiv. kg^{-1} EFB yr^{-1}. The emissions include EFB production in the mill, transport of EFB to the pyrolysis plant, electricity generation from the grid, biochar production via slow pyrolysis, transport of EFB biochar to warehouse and transport of biochar to plantation [20].

Meanwhile, carbon intensity of coal extraction and mining was taken from a study in U.S. which recorded about 0.116 kg methane Million BTU^{-1} coal yr^{-1}. Where, 1 kg of CH_4 is equivalent to 25 kg of CO^2. During the extraction phase, the emissions include the burning fuel to run the mining equipment [28].

B. Calculation of Carbon Intensity of Logistic

An assumption was made in which biochar production plant is located adjacent to one of the coal-fired power plant in Malaysia, Jimah Coal Power Plant, Port Dickson as Malaysia has abundance of biomass and it is more viable to reduce the logistic use. Therefore, emissions can be avoided for this scenario. However, this scenario does not include the emissions generated from the use of other machineries to transport biochar to the coal plant. In terms of coal delivery, CO_2 emissions generated from sea shipping was constructed from a literature which is 10 g CO^2/MT/km distance [29]. A scenario of 14,000 metric tons (MT) of dry feedstock supply to Jimah Coal Power Plant which is based on typical weight per shipment [30] was studied with approximately 1,266 nautical miles (2,342.1 km) distance from the departure port for imported coal supply, Samarinda port, Kalimantan, Indonesia to the receiver port, Jimah Coal Power Plant, Malaysia [31].

C. Calculation of Carbon Intensity of Feedstock's Stationary Combustion

The data was based on the stationary combustion of biochar originated from bioenergy crop, *Miscanthus* with carbon intensity of 113 kg CO_2/MWh [32]. To our knowledge, there was no study on the stationary combustion of biochar from palm biomass wastes. On the other hand, the stationary CO_2 emission of sub-bituminous coal was chosen to compare with the biochar. The stationary CO_2 emission of sub-bituminous coal was referred to Intergovernmental Panel on Climate Change (IPCC) default emission factors of 1,676 kg CO_2/ton [33].

III. RESULT AND DISCUSSION

Table I and Figure I present the simulation scenario of carbon intensity of biochar and coal within three boundary conditions. In parallel to Malaysia's Low Carbon Cities Framework and Assessment System (LCCF) to reduce 40% of carbon intensity per GDP by 2020, the present study addressed on one of the elements which is the transformation of the stock using available knowledge and tools for cost minimal and energy optimal solutions over their whole lifecycle [27].

For feedstock production or extraction, based on the preliminary calculation based on literatures, EFB biochar production has less carbon intensity (537.7 kg CO_2/kWh) than that of coal extraction (849.7 kg CO_2/kWh). In this case the avoided emission intensity achieved is 36.7% when EFB biochar production substitutes with the coal extraction. This can be explained by the high emission intensity of coal extraction from mining activities which generate massive methane emissions [28]. LCA study on the logistic used to deliver the feedstock to the power plant based on the current practice [30] has shown that one shipment of imported coal generates about 0.004 kg CO_2/kWh. On the other hand, the carbon intensity for biochar delivery was not calculated with the assumption that it is imperative to construct locally biochar production plant close to the power plant. Therefore, the assessment for this condition is nearly 100% carbon emission can be mitigated from biochar substitution regardless of emissions generated from other machineries. In terms of stationary combustion of feedstock, the calculations used from the literatures has clearly reputed that biochar is 62.1% less emission than the coal with the carbon intensity of biochar and coal are 0.11 kg CO_2/kWh and 0.29 kg CO_2/kWh, respectively.

Table I: Carbon intensity of biochar and coal in 3 different boundaries and avoided emission intensity from biochar substitution.

Carbon intensity	Biochar	Coal	Avoided emission intensity
Feedstock production/extraction (kg CO_2/kWh)	537.7	849.7	312.0 (36.7%)
Logistic of feedstock delivery to power plant (kg CO_2/kWh)	0	0.004	0.004 (100%)
Stationary combustion of feedstock (kg CO_2/kWh)	0.11	0.29	0.18 (62.1%)

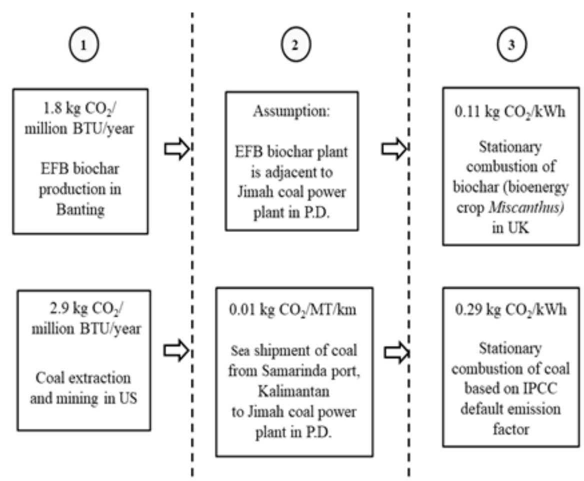

Figure I: Carbon intensity of biochar and coal for three different boundaries with; (1) feedstock production, (2) logistic for feedstock delivery to the power plant and (3) feedstock's stationary combustion

IV. CONCLUSIONS

This study will have a substantial impact to the coal industry as it will support the principle of upgrading the worlds' efficiency of coal power plants. Large capital investment is needed for older power plant refurbishment or sophisticated technologies deployment. The policy may consider applying biochar as the alternative solid fuel such as coal-blend other than utilization of biomass to supplement the coal for power generation. The production capacity of biomass for power is still less than coal's contribution couples with the limitation which is related to the quality of feedstock due to various reasons such as low value heating value (HV), high ash and mineral content.

The LCA particularly on carbon intensity on three boundary conditions have suggested that biochar has big impact on environmental benefits when considering coal substitution with biochar as to minimize the lifecycle carbon footprint in which a noteworthy saving of 62.1% of carbon intensity can be achieved when biochar is replaced with coal as solid fuel in power plants.

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REFERENCES

[1] International Energy Agency, Coal market outlook. *World energy outlook report 2014*, p.171-200., 2014. Available: https://www.iea.org/publications/freepublications/publication/WEO2014.pdf.

[2] R. A. Rohde and R. A. Muller, "Air pollution in china: mapping of concentrations and sources", *PLoS ONE*, 10(8): e0135749, 2015. Available:http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0135749

[3] Sustainable Energy Malaysia, Transitioning the nation towards sustainable energy malaysia, 1, 2, p.1 & p. 56, 2017.

[4] G. Pourhashem. (2014) Coal for power and emerging environmental constraints: biochar to the rescue?, On Forbes Web. Available: https://www.forbes.com/sites/thebakersinstitute/2014/12/22/coal-for-power-and-emerging-environmental-constraints-biochar-to-the-rescue/#5ce5b5961d89. Accessed 27 July 2017.

[5] G. Peters. (2016) Coal mines, power plants still rule. On News Straits Times, November 21, 2016: p. 15.

[6] Sustainable Energy Development Authority Malaysia, Renewable energy (RE). *Annual report 2014*, pp. 34-44, 2014. Available: https://efit.seda.gov.my/?omaneg=00010100000001010101000010000100000001010000100001110&id=2444.

[7] Energy Commission, Primary production by fuel type. *Malaysia Energy Statistics Handbook 2015:* pp. 16-17. 2015. Available: https://www.scribd.com/document/342402804/MALAYSIA-ENERGY-STATISTICS-HANDBOOK-2015-pdf

[8] W.A.W.A.K. Ghani, D. S. Gabriel, and B. A. Azil, "Physico-chemical characterizations of sawdust-derived biochar as potential solid fuels", *The Malaysian Journal of Analytical Sciences*, Vol 18, pp. 724 – 729, 2014.

[9] Clean Coal Centre, Upgrading the efficiency of the world's coal fleet to reduce CO2 emissions. *Cornerstone*, 3, 1, pp. 4-9. 2012. Available:https://www.worldcoal.org/sites/default/files/resources_files/Cornerstone_Volume3_Issue1.pdf

[10] W.A.W.A.K. Ghani, A. B. Alias, R. M. Savory, K. R. Cliffe, "Co-combustion of agricultural residues with coal in a fluidised bed combustor", *Waste Management*, Volume 29, Issue 2, pp. 767-773, 2009.

[11] X. Gao and H. Wu, "Biochar as a fuel: 4. Emission behavior and characteristics of PM1 and PM10 from the combustion of pulverized biochar in a drop-tube furnace", *Energy Fuels*, 25, pp. 2702–2710, 2009.

[12] X. Yang et al., "Thermal properties of biochars derived from waste biomass generated by agricultural and forestry sectors", *Energies*, 10, p. 469, 2017.

[13] Y. Huang et al., "Techno-economic analysis of biochar production and energy generation from poultry litter waste", *Energy Procedia*, 61, pp. 714-717, 2014.

[14] C. Feng and H. Wu, "Bioslurry for stationary applications: particulate matter emission during combustion under air and oxyfuel conditions", *Energy Fuels*, 31, pp. 7241-7246, 2017.

[15] National Innovation Agency of Malaysia (2013) New wealth creation for Malaysia's biomass industry. National Biomass Strategy 2020, Version 2.0.Available: http://www.cmtevents.com/MediaLibrary/BStgy2013RptAIM.pdf

[16] S. Czernik and A. V. Bridgwater, "Overview of applications of biomass fast pyrolysis oil", *Energy & Fuels*, 18, pp. 590-598, 2004.

[17] D. Mohan, C. U. Pittman, and P. H. Steele, "Pyrolysis of wood /biomass for bio-oil: a critical review", *Energy Fuels*, 20, pp. 848-889, 2006.

[18] C. E. Brewer et al., "Characterization of biochar from fast pyrolysis and gasification systems", *Environmental Process Sustainable Energy*, 28, pp. 386-396, 2009.

[19] I. M. Lima, A. A. Boateng, and K. T. Klasson, " Physicochemical and adsorptive properties of fast-pyrolysis bio-chars and their steam activated counterparts", *J. Chem. Techno. Biotechnol*, 85, pp. 1515-1521, 2010.

[20] S. S. Harsono et al., "Energy balances, greenhouse gas emissions and economics of biochar production from palm oil empty fruit bunches," Resources, Conservation and Recycling 77, pp. 108–115, 2013.

[21] M. A. Ariffin et al., "Potential of Oil Palm Empty Fruit Bunch (EFB) Biochar from Gasification Process", *Australian Journal of Basic and Applied Sciences*, 8, pp.149-152, 2014.

[22] N. M. Mokhtar, R. Omar, and A. Idris, "Microwave Pyrolysis for Conversion of Materials to Energy: A Brief Review", *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 34, pp. 2104-2122, 2012.

[23] F. Z., Abas, and F. N. Ani, "Comparing characteristics of oil palm biochar using conventional and microwave heating", *Jurnal Teknologi (Sciences & Engineering)*, 68, pp. 33-37, 2014.

[24] DEFRA (Department for Environment, Food and Rural Affairs), Guidance on How to Measure and Report Your Greenhouse Gas Emissions, *(PB13309)*, 2009. Available: www.defra.gov.uk/publications/files/pb/3309-ghg-guidance-0909011.pdf accessed 31/10/2011).

[25] T. W. P. Smith et al. "Third IMO Greenhouse Gas Study 2014", 2015. Available:http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf.

[26] N. Olmer, Greenhouse Gas Emissions from Global Shipping, 2013–2015, *ICCT Report*, October 2017. Available: https://www.theicct.org/sites/default/files/publications/Global-shipping-GHG-emissions-2013-2015_ICCT-Report_17102017_vF.pdf.

[27] Ministry of Energy, Green Technology and Water (Malaysia), Low carbon cities framework and assessment system's calculator, concept and principles. *Low Carbon Cities Framework and Assessment System (LCCF) report*, 1, pp. 57-58, 2011. Available: http://lccftrack.greentownship.my/files/LCCF-Book.pdf

[28] M. Fripp, "Methane emissions", In: *Life-cycle greenhouse gas emissions from clean coal clean gas and wind generators, NextEra Energy Resources*, Florida, p.7, 2009.

[29] Hamburg Airport, Climate killer aircraft. *Lufthansa Environmental Report*, p.14, 1999. Available: https://www.fluglaerm.de/hamburg/klima.htm. Accessed 27 July 2017.

[30] Jimah Energy Venture Sdn Bhd (August 25, 2016). (Personal Communication).

[31] (2017) Sea-Distance.Org. Available: https://sea-distances.org/.

[32] J. L. Gaunt, and J. Lehmann, "Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy

production", *Environmental Science Technology*, 42, p. 4152–4158, 2008.
[33] US EPA, Appendix A: Default emission factors. In: *Greenhouse Gas Inventory Guidance Direct Emissions from Stationary Combustion Sources*, p.17, 2016.