CARBON DIOXIDE EMISSION FACTOR ESTIMATION FROM INDONESIAN COAL

PRAKIRAAN FAKTOR EMISI KARBON DIOKSIDA DARI BATUBARA INDONESIA

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ABSTRACT

Climate change will become the priority for the air quality management. It focuses more on carbon dioxide emission. Indonesia which has power generation dominated by coal combustion is expected to develop the national CO_2 emission factor. Due to the high variation in Indonesia coal rank and its growing magnitude in CO_2 emission caused by the future coal-fired power plant development, the characteristic emission value becomes an important concern. The method used in this study is developed from the IPCC Guidelines for Energy. The conversion unit plays an important role in the calculation method. The result shows that the higher in C content, the lower in its CO_2 emission factor. It means that coal classified as high C content or high heating value will produce low carbon dioxide emission factor. The average CO_2 emission factor obtained in Indonesian coal is 99,718 kg CO_2/TJ with an average value of carbon content 27.2 kg C/GJ, and NCV equal to 19.8 TJ/Gg. Coal rank is categorized as lignite to subbituminous or bituminous.

Keywords: coal classification, climate change, emission factor, gross calorific value, net calorific value

ABSTRAK

Perubahan iklim merupakan prioritas dalam pengelolaan kualitas udara. Ini lebih terfokus pada emisi karbon dioksida. Indonesia dengan pembangkit listrik yang didominasi oleh pembakaran batubara, diharapkan dapat mengembangkan faktor emisi CO_2 nasional. Karena tingginya variasi batubara di Indonesia dan besarnya kenaikan emisi CO_2 yang disebabkan oleh pengembangan pembangkit listrik tenaga batubara di masa depan, nilai emisi karakteristik menjadi perhatian penting. Metode yang digunakan dalam penelitian ini dikembangkan dari Pedoman IPCC untuk Energi. Unit konversi memegang peranan penting dalam metode perhitungan. Hasil penelitian menunjukkan bahwa semakin tinggi kadar C, semakin rendah faktor emisi CO_2nya. Ini berarti bahwa batubara yang diklasifikasikan dengan kandungan C tinggi atau nilai pemanasan tinggi akan menghasilkan faktor emisi CO_2 rendah. Faktor emisi CO_2 rata-rata yang diperoleh dari batubara Indonesia adalah 99.718 kg CO_2 / TJ dengan nilai rata-rata kandungan karbon 27,2 kg C / GJ, dan NCV sebesar 19,8 TJ / Gg. Peringkat batubara dikategorikan sebagai lignit sampai subbituminous atau bituminous.

Kata kunci: klasifikasi batubara, perubahan iklim, faktor emisi, nilai kalor gros, nilai kalor neto

INTRODUCTION

Indonesia government states that climate change would be the priority for air quality management. It could be viewed by the action on climate change that had been held parallel to the country's objectives on economic and poverty reduction. Indonesia was one of the first countries which ratify the United Nations Framework Convention on Climate Change (UNFCCC) and adopt the Kyoto Protocol, followed by the release of Green Paper Report in 2009 by the Ministry of Finance which outlined both economic and fiscal policies to mitigate the impact of climate change in Indonesia. Then, the government adopted a National Action Plan (NAP) for Greenhouse Gases (GHG) in 2011 that aims

to reduce CO_2 as stated in Presidential Regulation No. 61/2011. Indonesia's commitment to reducing the greenhouse gas (GHG) emissions launched at the 21st meeting of the COPs (Conference of the Parties) in Paris. By 2030, the GHG emission reduction is about 29% under a business as usual conditions, and 41% in the same year if there is international cooperation. On the other hand the Presidential Regulation no. 71 Year 2011 about the Implementation of GHG Inventories was published after Indonesia had previously committed to the 15th COPs meeting. Both regulations are the guidelines for planning, implementing, monitoring, and evaluating the reduction of National Greenhouse Gas emissions and guidelines for Ministries or Agencies in conducting GHG inventory.

The government's NAP has been set up based on the Ministry's responsibilities related to GHG issues. For example, the Ministry of Energy and Mineral Resources (MEMR) has responsibilities for monitoring energy utilization in Indonesia and also prepared a draft of calculation and updating emission factors on the electricity grid system. The plan includes emission reductions in 5 (five) areas such as forestry and peatland, agriculture, energy and transportation, industry, and waste management. National GHG inventory aims to provide periodic information on the level, status and trends of emission change at National, Provincial and District/City levels In the GHG inventory activities. The plan includes also the emission factor values and one of them is CO_2 emission factor of coal.

Although the 2006 IPCC (Intergovernmental Panel on Climate Change) Guidelines is available on the calculation of emission factor value by Tier 1 method, it is recommended that in estimating national greenhouse emissions, Tier 2 (Tier 2) emission factors are better to be used.

The National Greenhouse Accounts (NGA) Factors or Emission Factors (EA) has been prepared by the Ministry of the Energy and Mineral Resources and is designed to be used by industries to estimate greenhouse gas emissions coming from coal utilization. Some countries like USA and Australia, the used methods that described in the US EPA, apply for the 2016 calculation of National Greenhouse and Energy Determination. This method has a general application to the estimation of a broader range of greenhouse emissions inventories.

As one of important fossil energy resources, with oil and gas, Indonesia coal acts as an important commodity which mainly supports Indonesia's energy demand and the government's reliance on this fossil fuel for electricity generation is growing. It is proved by most of Indonesia electric generation are generated from coal-fired power plants, instead of oil and natural gas. In the future or by 2050, the government plans to develop the 35 GW coal-fired power plants. Fossil energy, especially coal, is generally the main source of CO_2 emission which accounts for the most of the greenhouse gases or global warming effects. The greenhouse warming potential tends to be raised significantly due to the emission of CO_2 during coal combustion (Kreith, 2005). As the combustion of coal, however, adds a significant amount of carbon dioxide to the atmosphere per unit of heat energy, more than does the combustion of other fossil fuels.

By considering over the possible consequences of global warming, which may be caused partly by the increase in atmospheric CO_2 (as a major greenhouse gas contributor), and also by requiring of accurate estimates of CO_2 emissions, the MEMR has developed 2 step development emission factors for estimating the amount of CO_2 emitted as a result of Indonesian coal consumption. The MEMR's emission factors are derived from the base of coal analysis, and it will need a large database of coal sample analyses. In the future, it is important for Indonesia to have its own emission factors. This may vary significantly by its coal rank and should be confirmed by updating and verifying statistically. The default emission factors listed have been estimated by the MEMR using the Intergovernmental Panel on Climate Change (IPCC) method. The calculation is generally determined based on coal quality data from coal mine industries because it will ensure that consistency is maintained between inventories at industry or facility level and the emission estimates presented in the National Greenhouse Accounts Reports.

CO_2 emission factors for Indonesia coals have previously been adopted from IPCC sources. However, those emission factors

have shortcomings because they are not based on analyses of real Indonesian coal samples. Most are a single factor applied to all coals, regardless of rank (i.e., whether anthracite, bituminous, sub-bituminous, or lignite) or geographic origin. Because single factor does not account for differences among coals, it fails to reflect the changing "mix" of coal in Indonesian coal consumption that has occurred in the past and will occur in the future. The MEMR's emission factors hopefully will improve the accuracy of estimating of CO_2 emissions, especially for each regional levels, because they reflect the difference in the ratio of carbon to heat content by the rank of coal and its origin.

In the beginning, MEMR's will develop basic CO_2 emission factors covering the various coal ranks by its origin. These basic emission factors are considered as "fixed" for the foreseeable future until better data become available. Then, MEMR will develop emission factors for use in estimating CO_2 emissions from coal consumption by industries, with consuming-sector detail. These emission factors are based on the mix of coal consumed and the basic emission factors by coal rank and its origin. In this case, the value of the emission factors is subject to change over time, reflecting changes in the mix of coal consumed.

The emission factors will not only enable coal-generated CO_2 emissions to be estimated more accurately than before, but they will also provide consistency for an analyst to estimate energy and environment. The emission factors are also useful for analyzing and monitoring CO_2 emissions from coal combustion, whether they are estimated by the origin of the coal or the consuming sector.

Although the IPCC classifies coal as anthracite, bituminous coal, and sub-bituminous coal (Garg, Kazunari and Pulles, 2006), Indonesia distinguishes coal for the power plant just base on its gross calorific value. Indonesia has bituminous coal and sub-bituminous coal which is considered as bituminous coal and also lignite. As a result, Indonesia conducted research on the CO_2 emission factors at this moment, based on coal classification which is used as coal feeder energy, and ignored common classification of coal. The national greenhouse gas emissions were calculated by applying national statistics such as the energy statistical yearbook. Differences may be displayed in the greenhouse emissions and emission estimations due to the different statistical methods used for coal by Indonesia and the IPCC. The purpose of this research is to develop a CO_2 emission factor of Indonesian coal by classifying coal resources collected between 2015 and 2016.

Coal Emission Factor (CEF) determination activity is a biennial update report in order to support the inventory and mitigation activities of GHG in Indonesia from the energy sector. The calculation of CO_2 emissions in the energy sector in this activity only calculates CO_2 emissions from fuel combustion activities, excluding CO_2 emissions resulting from fugitive emissions in coal exploration and exploitation activities. In 2015, the Research and Development Centre for Mineral and Coal Technology (RDCMCT) had conducted coal CEF calculation. The results of net calorific value (NCV) was 21.9 MJ/kg, carbon emission factor was 26.6 kg C/GJ and CEF was 97.665 kg CO_2/TJ. This study focused on updating the baseline data on specific country/local emission factors. For that purpose, the RDCMCT has an assignment to obtain the value of Indonesia's specific CEF which can be used as a reference in calculation of National inventory and mitigation to fulfill the target of reducing CO_2 emission.

COAL MINING IN INDONESIA

Coal reserves in Indonesia are mostly located near the surface till the depth of about hundred meters. The surface mines or open pits are the dominant existing coal mine. The open-pit mine operations generally start with land clearing, excavate the overburden and then extract the coals. In Indonesia, coal resources are mostly deposited in Sumatera and Kalimantan. The 2016 data of resources, published by the Agency of Geological Survey, MEMR, are shown in Table 1 (BCRC-SEA and SCRCI, 2017).

Table 1. The 2016 Indonesia's coal resources in million tons (BCRC-SEA and SCRCI, 2017)

No.	Island	Province	Resources (Miliion Tons)					Reserves (Million Tons)		
			Hipothetic	Inferred	Designated	Measurable	Total	Estimated	Proven	Total
1		Banten	5.47	38.98	28.45	25.1	98	0	0	0
2	Java	Central Java	0	0.82	0	0	0.82	0	0	0
3		East Java	0	0.08	0	0	0.08	0	0	0
4		Aceh	0	423.65	163.69	662.93	1250.27	95.3	321.38	416.68
5		North Sumatera	0	7	1.84	25.75	34.59	0	0	0
6		Riau	3.86	209.85	587.82	689.28	1490.81	85.57	523.32	608.88
7	Sumatera	West Sumatera	19.9	304.25	278.78	347.38	950.3	1.67	196.17	197.84
8		Jambi	129.16	1216.54	896.04	1038.02	3279.77	314.09	351.62	665.71
9		Bengkulu	0	117.33	171.74	126.48	415.54	16.2	62.92	79.12
10		South Sumatera	3290.98	10859.38	14826.24	12020.27	40996.88	5557.53	5509.45	11066.98
11		Lampung	0	122.96	8.21	4.47	135.63	11.74	0	11.74
12		West Kalimantan	2.26	477.69	6.85	4.7	491.5	0	0	0
13		Central Kalimantan	22.54	11299.92	3806.64	2849.22	17977.32	910.76	1090.57	2001.33
14	Kalimantan	South Kalimantan	0	4739.1	4402.79	5893.65	15035.53	1308.49	3961.76	5270.25
15		East Kalimantan	909.95	13680.45	13049.18	15401.1	43040.68	2760.01	4434.93	7194.94
16		North Kalimantan	25.79	795.83	595.37	1041.2	2458.19	423.34	520.36	943.7
17		West Sulawesi	8.13	15.13	0.78	0.16	24.2	0	0	0
18	Sulawesi	South Sulawesi	5.16	48.81	128.9	53.09	235.96	0.06	0.06	0.12
19		Central Sulawesi	0.52	1.98	0	0	2.5	0	0	0
20	Maluku	North Maluku	8.22	0	0	0	8.22	0	0	0
21	Papua	West Papua	93.66	32.82	0	0	126.48	0	0	0
22		Papua	7.2	2.16	0	0	9.36	0	0	0
Total Indonesia			4532.79	44394.72	38952.31	40182.81	128062.64	11484.76	16972.53	28.457.29

The different type and quality of Indonesia coal depend on its location, sedimentation period and geological condition. The coal quality varies from very low to very high calorific value. Land clearing will cause the decrease (to nearly zero) the capacity of the area to absorb CO_2. It means that deforestation by mining activities will increase the CO_2 emission. The increase in coal production, either for export or domestic use, the increase in CO_2 production. Other CO_2 emissions from mining activities come from hauling or transporting materials and operating mine equipment.

Coal acts as an important commodity in Indonesia which mainly supports energy demand. The increasing of Indonesian coal demand is due to its environmentally friendly characterization such as low ash and low sulfur contents (Belkin *et al.*, 2009). Coal contribution for power generation in the future is about 44%, so the calculation of CO_2 emission will indeed be an important matter.

COAL COMBUSTION AND CO_2 EMISSION

Coal Combustion

Coal combustion will produce such amount of heat, and its heat value depends on the content of carbon, hydrogen, and oxygen of the coal. The heat value is also influenced by the sulfur content but its contribution is lesser than carbon, hydrogen, and oxygen. From those 3 elements, carbon acts as the main source of heat which can generate about 14.500 BTU/lb or 8.060 cal/g. Lignite's carbon content is lower than anthracite. The ratio of carbon to heat content depends on the heat producing components of coal, and these components vary with the coal rank.

CO_2 Emission

CO_2 comes from the oxidation of carbon in fuels during the combustion process. The perfect combustion conditions will convert the total carbon content of fuels to CO_2. However, in the real condition, the combustion processes are not generally perfect and those will result in small amounts of partially oxidized and unoxidized carbon. The incomplete oxidation occurs due to low inefficiencies in the combustion. The carbon flow for a typical combustion process can be described as follows:

- Most carbon is emitted as CO_2 immediately
- A small fraction of the fuel carbon escapes as non-CO_2 gases such as CH_4, CO etc. The carbon in these gases, though, is assumed to ultimately oxidize to CO_2 in the atmosphere and is therefore integrated into the overall calculation of CO_2 emissions (i.e. the carbon content value). Therefore, the carbon in these non-CO_2 molecules is intentionally "double-counted" because it is eventually transformed into a CO_2 molecule
- The remaining part of the fuel carbon is unburned, unoxidized, and remains as soot and ash. In general, this fraction of the fuel carbon is assumed to remain stored indefinitely or not emitted in the gaseous form

To account for the unburned fraction of fuel carbon, the 2006 IPCC Guidelines or revised version of 1996 IPCC Guidelines suggested the use of the oxidation factors for coal, the amount of unoxidized carbon, primarily in the form of ash, has been found to be higher and can vary considerably with different combustion technologies and efficiencies (e.g. ranges from 0.6 to 6.6 percent). The IPCC default oxidation factor is 98 percent.

The fuel carbon content is an inherent chemical property (i.e. the mass of carbon atoms relative to total mass of the fuel). A summary of default carbon content factors from the 2006 IPCC Guidelines is given in Table 2.

Table 2. The IPCC default carbon content factors for major and secondary fossil fuels (Garg, Kazunari and Pulles, 2006)

No	Solid Fuel	Emission Factors
	Primary Fuels	
	Anthracite	26.8
	Coking Coal	25.8
	Other Bituminous coal	25.8
	Sub-bituminous coal	26.2
	Lignite	27.6
	Oil shale	29.1
	Peat	28.9
	Secondary Fuels	
	BKB and patent fuel	25.8
	Coke oven/Gas coke	29.5

Note: BKB: Brown Coal Briquette

The energy content (i.e. calorific value or heating value) of fuels is also an inherent chemical property. However, calorific values vary more widely between and within fuel types, as they are dependent upon the composition of chemical bonds in the fuel. Given these variations and the relationship between carbon content and calorific values, carbon content values for estimating CO_2 emissions from fossil fuel combustion are expressed in terms of carbon per energy unit. This form generally provides more accurate emission estimates than if carbon content factors were expressed in terms of mass or volume, assuming reasonably accurate calorific values are available to convert fuel statistics into energy units.

NCV measures the quantity of heat liberated by the complete combustion of a unit volume or mass of fuel, assuming that the water resulting from combustion remains as a vapor, and the heat of the vapor is not recovered. Gross calorific value (GCV), in contrast, are estimated by assuming that this water vapor is completely condensed, the heat is recovered, and therefore are slightly larger. Default data in the 2006 IPCC Guidelines are based on NCV.

CO_2 Prediction Emission

The five major fuel consuming sectors contributing to CO_2 emissions from fossil fuel combustion are electricity generation, transportation, industrial, residential, and commercial. The CO_2 emissions are produced by the electricity generation sector as they consume fossil fuel to provide electricity to one of the other four sectors, or "end-use sector (US EPA, 2018).

Basically, the emission estimation coming from coal combustion requires at least three input parameters, such as CO_2 emission factor, GCV NCV, and carbon stored/unoxidized during its utilization. For preparing the national inventory, the energy conversion factor is required to convert the consumption data by weight to heat units. The CEF value provides the amount of CO_2 emission from different coal types. The CEF can also be expressed as the amount of CO_2 emission per unit weight of the fuel combusted or as the amount of emission per unit heat value of the fuel. The heat value of coal could be either as GCV/higher heat value (HHV) or NCV/lower heat value (LHV).

For the comparative evaluation of some various ranks of coals, the former heat value does not provide a reliable basis. This is primarily caused by variation in the elemental composition in coal like carbon, hydrogen, sulphur, oxygen, and its mineral matter. Because the heat value, either in GCV or NCV, acts predominantly as a function of the carbon content, the latter definition with NCV has been accepted as the international norm.

By reviewing the different types and nature of coal extracted from varying depth of different mines in Indonesia, there is such a wide variation of ash, moisture etc., The preliminary study has been carried out in the RDCMCT for preparation of the IPCC default values for Indonesian coals and the estimation of NCV and CEF for each calorific value category of coal and analyzing a large volume of authenticated data on Indonesian coals. The refined values were used for the subsequent national inventory estimation. During estimation of the Indonesia specific figures for NCV and CEF, the production pattern of different grades of coals under the broad category of some low-rank coals was considered.

Based on several literatures of CEF estimation of coals, from easily measurable quality parameters, some predictive equations, have been developed. The purpose is to get the CEF from VM, FC, GCV, NCV, and other ultimate analysis data. The measurement of such coal parameter was conducted on a different basis, for example as received (ar), dry basis (db), air dried (ad), dry mineral matter free (dmmf) or dry ash free (daf). For Indian coals, the equations developed so far did not work well. However, for Indonesian coals, CEF estimation from different categories of coals is still in progress.

Moreover, better estimation of CO_2 emissions from fuel combustion needs data like the amount of fuel burned, the carbon content of the fuel, a fraction of carbon oxidized. In this case, the CO_2 emission estimation is determined from carbon content which is measured from the coal sampling from mine area which had classified by its calorific value. Hence in this study, attempts have been made to develop predictive CEF on the unit mass basis, net

energy basis and gross energy basis for the Indonesian coals separately from the easily measurable quality parameters, such as volatile matter (VM), fixed carbon (FC), GCV and NCV.

The applications in estimating the emissions from the utilities in a straightforward way after combining the fuel consumption data in mass units or in energy unit and percent of carbon oxidized in the process did not include in this study because power plant and another industrial sector also develop the calculation for predicting the CEF values. Those CEF predictive equations may help in reducing the uncertainties in emission estimates from the key sources like power, cement industries, etc., where a single numerical value of CEF is being used covering a wide range of coals within the same coal type. Next, the exercises will be linked to a study in an efficient super thermal power station, where CO_2 emission was estimated both from stack measurement and input-output carbon balance.

In general, emissions of each greenhouse gas from stationary sources are calculated by multiplying fuel consumption by the corresponding emission factor. In the Sectoral Approach, "Fuel Consumption" is estimated from energy use statistics and is measured in "TeraJoules". Fuel consumption data in mass or volume units must first be converted into the energy content of these fuels. There is 3 tiers method and these all tiers use the amount of fuel combusted as the activity data. Different tiers can be applied for different fuels and gases, consistent with the requirements of

key category analysis and avoidance of double counting (Gómez *et al.*, 2006).

In the past, the Indonesian National Inventory was using the values from IPCC 1996 default in Table 1. The IPCC 1996 indicated a single default value of 19.98 TJ/kt for NCV and 25.8 t of C/TJ for CEF for entire coking and other bituminous coals (Roy *et al.*, 2009).

METHODOLOGY

The study was begun with the preparation of sampling activity, coal testing, and its evaluation. The RDCMCT has planned the CEF development as shown in Figure 1.

Material

Coal samples used for the CEF study come from coal industries either coal mine or stockpile area at South Sumatera (1), South Kalimantan (9), East Kalimantan (5) and Central Kalimantan (2). Coal samples were collected during 2015-2016, with a total number of 469 samples.

Coal Characterization

Coal characterization consists of proximate and ultimate analyses and calorific value. All parameter calculates as received basis. For the CEF calculation, calorific value calculates from GCV into NCV. The coal analysis methods are presented in Table 3. The RDCMCT generally uses ASTM methods for analysis the proximate, ultimate parameter and GCV.
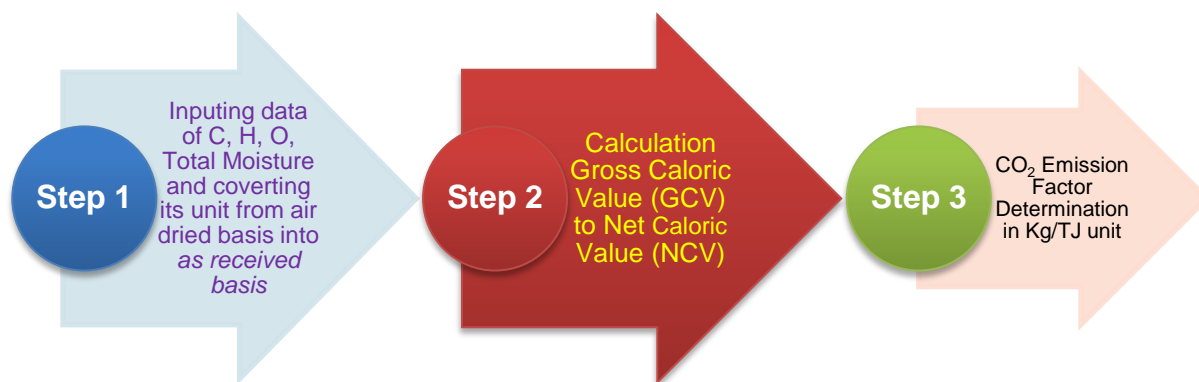

Figure 1. Flowchart of coal CO_2 emission factor determination

CO$_2$ Emission Factor Determination

For the CEF calculation, the estimation approach which is based on 1996 IPCC Guidelines, uses the Tier 2 method. This is the recommended one for energy, especially for emissions from fossil fuel combustion which are estimated from similar fuel statistics, as used in the Tier 1 method. The coal parameter units must be converted in as received basis and the calorific value must be in NCV. The results are used for replacement the Tier 1 defaults country-specific emission factors (Garg, Kazunari and Pulles, 2006).

The emission amount of GHG generated by adherent combustion is calculated by multiplying the amount of coal consumption by an emission factor. This study used fuel analysis method (Quick and Brill 2002) suggested by IPCC that consists of a five-step worksheet to calculate CO$_2$ emission factor of bituminous coal, such as (Lee *et al.*, 2013):

- Examining the amount of carbon and water, which have the biggest influence on the emission amount of CO$_2$. The amount of carbon is changed into the 'asr basis' amount at this stage.
- Examining the production amount depending on the fuel consumption and standardizing the energy unit. A unit of calorific value TJ is standardized into net caloric value.
- Calculating the actual amount of carbon emission by applying the values produced in steps 1 and 2, as well as the oxidation quotient.
- Calculating CO$_2$ emission factor depending on activity (amount of energy and fuel use) by multiplying carbon emission amount by 44/12.
- Calculating carbon emission by analyzing CO$_2$ emission factor depending on the activity produced in the previous step.

Mathematical Equation for Emission Estimation

The 'As Received Basis' change in the calculation of C amount is as follows:

$$X, ar = X,ad \times \left[\frac{(100 - TM, ar)}{(100 - M, ad)} \right] \quad \text{...........................(1)}$$

With:

X,ar : coal parameters such as C, H, N, S, ash and volatile matter, in the 'as received basis'

X,ad : coal parameters such as C, H, N, S, ash and volatile matter, in the 'air dry basis'

TM,ar : total moisture in the 'as received basis'

M,ad : moisture/inherent moisture in the 'air dry basis'

The conversion unit calculation for calorific value from cal/gr unit into TJ or GJ/ kg are as follows:

$$NCV, \frac{TJ}{kg} = NCV, \frac{Cal}{gr} \times \frac{4.1868 \, J}{Cal} \times \frac{1000 \, gr}{kg} \times \frac{10^{-12} TJ}{J}$$
$$\text{..(2)}$$
or
$$NCV, \frac{TJ}{kg} = NCV, \frac{Cal}{gr} \times \frac{4.1868 \, J}{Cal} \times \frac{1000 \, gr}{kg} \times \frac{10^{-9} GJ}{J}$$
$$\text{..(3)}$$

With:
NCV : Net Calorific Value

The calculation of emission factor is as follows:

$$EF, C \left[\frac{kg \, C}{GJ} \right] = \frac{C, ar \, (\%) \times 1 \, kg \, coal}{NCV, \left(\frac{GJ}{kg} \right)} \quad \text{................(4)}$$

Table 3. Coal analysis method

Coal Preparation	Proximate Analysis	Ultimate Analysis	Net Caloric Value (NCV)
ISO 1988 or ASTM D.2013	Air Dried Moisture ISO 331 ASTM D.3173 Ash: ISO 1171 ASTM D.3174 Volatile Matter: ISO 562 ASTM D.3175 Proximate basis conversion (ar, db, daf)	Total Carbon: ISO 625, ASTM D.3178 Total Hydrogen: ISO 625, ASTM D.3178 Nitrogen: ISO 332, ASTM D.3179 Total Sulphur: ISO 351, ASTM D.3177 and ISO 334, ASTM D.4239	ASTM D.5865

Or the general equation for emission estimation is as follows:

$$EF, CO_2 \left[\frac{kg\,CO_2}{TJ}\right] = \frac{C, ar\,(\%) \times 1\,kg\,coal}{NCV, \left(TJ/kg\right)} \quad ....(5)$$

With:

E : Emission
A : Activity Rate
EF, C : Emission Factor Carbon
EF, CO_2 : Emission Factor Carbon Dioxide

RESULTS AND DISCUSSION

The study examines data for 463 Indonesian coal samples from South Sumatera, South, Central, and East Kalimantan coming from 19 coal mining which consists of 4 South Sumatera coal samples, 215 South Kalimantan coal samples, 226 East Kalimantan coal samples and 18 Central Kalimantan coal samples.

Based on coal classification in the chemical handbook, Indonesian coal classification is modified (Podolski *et al.*, 2008). Table 4 showed the result of gross calorific value which used for Indonesia coal classification. The Indonesia coal is classified into four categories. The low calorific value is dominated by low-rank coal from the class of lignite. The medium to very high calorific value composes normally of sub-bituminous to bituminous coal.

Table 4.   Indonesian coal classification by GCV

No.	GCV (Cal/gr, adb)	Number of Samples
	Low (< 5,000)	33
	Medium (5,100 – 6,100)	328
	High (6,100 – 7,100)	84
	Very High (> 7,100)	18
	Total coal samples	469

There were 33 coal samples having low GCV (< 5100 cal/gr, adb), 328 samples with medium GCV (5100 – 6100 cal/gr, adb), 84 samples showed high GCV (6100 – 7100 cal/gr, adb) and 18 samples were in very high GCV (>7100 cal/gr, adb). By determining the gross calorific value of some coal samples, most samples were characterized as sub-bituminous to bituminous coal. But some sub-bituminous coal had lower calorific value (< 6000 cal/gr)

and other have had higher one (>7000 cal/gr).

Most of the Indonesia data originate from analyses of samples collected from active coal mines or stockpile. The selected data records do not mention values for maceral, sulfur forms, ash composition, carbonate CO_2, crucible swelling and vitrinite reflectance. There is proximate data analysis available such as moisture, ash, volatile matter, elemental composition (C, H, N, O, and S) and calorific value. For the calculation of 'as received' basis, it has considered the moisture content.

Any bias could be happened in this calculation due to the difference in analytical methods. Moisture contents were predicted to give an effect on the carbon emission factor calculated above.

Carbon emissions are influenced by coal mineral content especially its carbonate minerals. The endothermic decomposition of those minerals during coal combustion will produce carbon dioxide, so it will increase the CO_2 emissions (Quick and Brill, 2002). However, the US condition above is different with what happened in Australia. For Indonesia condition, it is assumed that the condition will look alike in Australia based on its geological coal deposits.

The result of coal proximate and ultimate analyses is presented in Table 5. The percentage unit is based on as received (ar) basis (Equation 1). The ash content, C, H, N and S total concentrations were respectively 3.44-6.53%; 42.91-73.77%; 5.53-7.02%; 0.60-1.67% and 0.17-0.62%. Based on coal ultimate data analysis, Indonesian coal samples used in this study were characterized as lignite, sub-bituminous or other bituminous.

These results mean that coal qualities so vary. Due to the above condition, using a uniform IPCC default value as an emission factor for all coal sources would not be recommended (Zhou *et al.*, 2009). Indonesia should develop its own National Emission Factor, either from coal resources based calculation or power plant coal feeder based calculation.

From the carbon concentration point of view, Indonesian coal samples characterized as

low-rank coal, that is mostly lignite to sub-bituminous coal. These are due to the subsequent geochemical stage and also the different time-temperature histories which finally lead to the formation of coals in widely differing properties (Radovic, 1998).

For the CEF calculation, the calorific value units are needed to be converted into energy units, such as Joule. In addition, carbon, hydrogen, nitrogen, and sulfur, which are the main components of fuel, as well as moisture (adherent moisture or inherent moisture), ash, volatile matter components, and fixed carbon, all have such a great influence on the combustion process. From all coal samples, the emission factor calculation, it used the calculation formula 4 or 5 for determining the Carbon or CEF (Quick, 2010). The principal combustible elements in coal primarily are carbon and hydrogen. carbon, in particular, is the major concerns in the production of CO_2 during the combustion process (Kim *et al.*, 2014; Lee *et al.*, 2015). Carbon generally constitutes about 60% to about 95% of the total, but oxygen concentration is, in general, inversely related to carbon concentration. Nitrogen in almost coals is in the range of 0.60-1.67%. So, the emission amount of GHG and emission factor calculation becomes very important (Roy *et al.*, 2009). Sulfur concentration in coal seems so vary and related to the environmental consequences of burning coal, it will be also an important constituent, but here, it will not be discussed in detail.

This study mostly used ASTM (American Society for Testing Materials) for coal analysis. Air-dry analysis and dry analysis were used in analyzing the calorific value and elements, respectively. Air dried basis analysis means that the coal has naturally dried in the open air until it cannot dry or dissipate any more moisture. Dry basis analysis means that an analysis expressed on the basis of a coal sample from which the total moisture has been removed. Coal in dry basis includes all contents but moisture. This paper converted calorific values based on 'As Received Basis' to compare CO_2 emission factors because IPCC suggests calorific value based on the 'As Received Basis'.

Based on coal ultimate data (Table 5), the calculation of NCV was obtained using equation 2 or equation 3. The condition of RDCMCT Laboratory can only obtain the GCV, which its value is measured using a bomb calorimeter. In this condition, the calorific value of coal will be higher because of the influence of other parameters such as hydrogen, water vapor, sulfur, and oxygen. For prediction, the CEF, calorific value should be calculated in NCV. The obtained NCV (as the result of corrected GCV with parameters such as water vapor, hydrogen, and oxygen) was in the range of 3537-6767 kcal/kg or it was about 14.8 - 28.5 MJ/kg for Indonesian low to high-rank sub-bituminous coal (Quick, 2014). The average result shown in Table 6 had considered the lower and upper limits of 95% confidence intervals.

Coal-quality characteristics differ from the mining to the other mining region (Juhrich, 2016). In Indonesian cases, different open-pit mines within the same region will yield different grades of coal, but for Indonesian hard coal (high-rank coal) generally has very similar quality compared to low rank.

Tables 7 and 8 illustrate the value of Carbon Content and Carbon Dioxide Emission Factors. The results show a great variation on CO_2 emission factors within GCV coal classification which means that the variation is really influenced by the coal rank.

The calculation of carbon content showed that Indonesian coal samples were in the range of 25.8-29.0 kg C/GJ. The low to medium GCV coal had the high carbon content compared to medium to high GCV coal. These correspond to the CEF value indicating that the high carbon content coals had the high CEF (100,575-106,476 kg CO_2/TJ) and low carbon content coals showed low CEF (94,715-95,062 kgCO_2/TJ). The carbon content and CEF from Indonesian coals were lower than the IPCC default value in Table 9. The comparation was observed against the default values for lignite and sub-bituminous or other bituminous coal.

Table 5. Coal ultimate analysis

Coal Classification by GCV (adb)	TM %, ar	Moisture, %, adb	NCV kcal/kg, ar	Ash %, ar	C %, ar	H %, ar	O %, ar	N %, ar	S Total %, ar
Low	35.79	22.37	3537	3.44	42.91	7.02	45.86	0.60	0.17
Medium	26.08	14.13	4461	4.30	53.08	6.33	34.31	1.04	0.93
High	13.12	7.16	5761	5.34	62.87	6.01	23.74	1.41	0.63
Very High	8.20	2.22	6797	6.53	73.77	5.53	11.88	1.67	0.62
Average			5139	4.42	53.39	6.75	28.95	0.78	0.25

Table 6. Results of NCV calculation and its lower-upper limits of 95% confidence intervals

Coal Classification by GCV (adb)	NCV MJ/Kg = TJ/Gg		
	Calculation	Lower	Upper
Low	14.8	14.3	15.4
Medium	18.7	18.4	18.9
High	24.1	23.8	24.4
Very High	28.5	28.2	28.7
Average	19.8	19.4	20.1

Table 7. Results of carbon content calculation and its lower-upper limits of 95% confidence Intervals

Coal Classification by GCV (adb)	Carbon Content Kg C/GJ		
	Calculation	Lower	Upper
Low	29.0	28.8	29.3
Medium	27.4	27.3	27.5
High	25.8	25.8	25.9
Very High	25.9	25.7	26.1
Average	27.2	27.1	27.3

Table 8. Results of CO_2 emission factor calculation and its lower-upper limits of 95% confidence intervals

Coal Classification by GCV (adb)	CO_2 Emission Factors Kg CO_2/TJ		
	Calculation	Lower	Upper
Low	106,476	105,579	107,374
Medium	100,575	100,229	100,921
High	94,715	94,461	94,969
Very High	95,062	94,408	95,716
Average	99,718	99,340	100,096

Table 9. IPCC default value and lower-upper limits of 95% confidence intervals for carbon content, net calorific value and CO_2 emission factor (Garg, Kazunari and Pulles, 2006)

Coal Classification	Carbon Content Kg C/GJ			NCV MJ/Kg = TJ/Gg			CO_2 Emission Factors Kg CO_2/TJ		
	Default	Lower	Upper	Default	Lower	Upper	Default	Lower	Upper
Lignite	27.6	24.8	31.3	11.9	5.50	21.6	101,000	90,900	115,000
Subbituminous	26.2	25.3	27.3	18.9	11.5	26.0	96,100	92,800	100,000
Other Bituminous	25.8	24.4	27.2	25.8	19.9	30.5	94,600	89,500	99,700
Coking Coal	25.8	23.8	27.6	28.2	24.0	31.0	94,600	87,300	101,000
Anthracite	26.8	25.8	27.5	26.7	21.6	32.2	98,300	94,600	101,000

Due to the Indonesian country-specific emission factors were derived, either from detailed data on carbon concentrations in different batches of coals used or from more detailed information on the combustion technologies applied in Indonesia, so the uncertainties of the CO_2 emission factor estimation should be predicted to decrease the error, and the trends over time can be better estimated. Consequently, for CO_2 emission factors estimation coming from coal-fired power plants cannot be assured using the CO_2 emission factors above which specified by rank.

In the future, the carbon content and CEF value from the Indonesian coals coming from some mining region could be used as

the national emission factor or country-specific emission factor.

CONCLUSIONS AND SUGGESTION

Fossil fuels still dominate the power generation industries in Indonesia. It will produce a huge amount of carbon emission if there is no proper calculation between oxygen and fossil fuels that will be burnt. The right fuel chosen will be an important factor for industries or power generation application.

The studies that have been conducted since 2015, calculated the CO_2 emission factors coming from Indonesian coal. Mostly Indonesian coal samples could be classified as lignite, sub-bituminous, and other bituminous. The low to medium GCV Indonesian coal samples were estimated as lignite or sub-bituminous one, and high to very high GCV coal samples were categorized as other bituminous.

For the calculation of CO_2 emission factors, GCV parameter should be in the NCV one, and the average NCV of Indonesian coal samples is 19.8 in MJ/Kg unit or TJ/Gg with a lower limit value of NCV of 19.4 MJ/Kg and upper limit value of 20.1 MJ/Kg. The average of carbon content for Indonesian coal is 27.2 kg C/GJ with a lower limit value of carbon content 27.1 kg C/GJ and upper limit value of 27.3 kg C/GJ. The average of CO_2 emission factor for Indonesian coal is 99,718 kg CO_2/TJ with a lower limit value of carbon content 99,340 kg CO_2/TJ and upper limit value of 100,096 kg CO_2/TJ.

All the CEF calculations were below the IPCC default value. They can be used as Indonesia specific emission factor from a certain type of coal. Since Indonesia has different coals from low to high-rank categories, the calculated country-specific emission factors might differ for such different specific coals, combustion technologies or even individual plants. For that purpose in the next studies, the activity data must be further disaggregated to reflect properly such disaggregated coal sources.

The updating emission factors must be conducted further by updating technologies of its power plants. Calculation with higher tiers could be considered in the future including its detailed uncertainty.

Therefore, for having the credible calculation of Indonesian coal emission factor, the government should continue to carry out this type of research. It must be considered due to the coals variety in the calorific value and the amounts of carbon, hydrogen, and inherent moisture of such Indonesian lignite, sub-bituminous or bituminous coals and they are always changeable.

A series of measurements and then followed by the standard deviation calculation for those CEF results show that the smaller the standard deviation the better understanding in the precision, whereas conversely, the more spread out the results, the larger the standard deviation and hence the poorer the precision. In summary, the accuracy measurements show that the mean value is close to the true value because precision measures the closeness of the individual results.

ACKNOWLEDGEMENTS

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