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# An Evaluation Methodology with Applied Life-Cycle Assessment of Coal-Biomass Cofiring in Philippine Context

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The study assesses the net environmental impact of deploying biomass cofiring in terms of GHG emissions in the province of Bataan, a potential region for cofiring in Central Luzon Region in the Philippines. It presents a methodology framework that involves the resources and logistics mapping stage and the environmental life-cycle assessment stage. The first stage includes biomass resource assessment to specify the biomass material and potential biomass share for cofiring, the logistics planning to select the optimal and realistic logistical choices, and the technology review to look at the actual technological capabilities for cofiring. Biomass resource assessment selects the most dependable biomass feedstock for cofiring from different locally available biomass: forest residues, agricultural residues, and energy crop. It also quantifies the realistic and sustainable cofiring share of the different biomass feedstock that can be effectively taken. The second stage sets up the base case scenario which consider combustion of pure coal only and two cofiring scenarios with the most dependable biomass type at different biomass shares as drawn from the previous stage. The second stage follows the standard four-phased LCA using emission factors available in literature for the comparative and contribution analysis of the reference scenarios and drawn up cofiring scenarios in the selected region. Results reveal important insights with potential energy planning and policy implications.

## 1. Introduction

In the Philippines, coal-fired power generation has the most apparent development. From the present 6.2 GW capacity, 9.7 GW additional capacity is expected by just around 2020 when all power stations under construction and under development are combined. The Philippine government defended that in order to ensure energy security and cheap power supply, coal must stay in the electricity mix (CoalSwarm, 2015).

Different countries agreed to set the target of cutting energy-related CO2 emissions by more than half by 2050 compared with 2009 and ensuring that they continue to fall thereafter (IEA, 2012). The Philippine government in 2015 pledged to cut down the country's $CO_2$ emissions to as high as 70 %. In achieving this target, coal firing technology holds the greatest potential in seriously cutting down $CO_2$ emissions. The Philippines with its growing economy has to equally attend energy security by keeping coal in the power generation mix and the need for sustainability by reducing emissions in a technically and economically viable way.

Biomass energy as renewable energy resource promises good potential for the Philippines' need both for energy security and environmental sustainability. The country holds wide supply of agricultural products and agro-industrial wastes that can be applied as feedstock for biomass power generation. The Department of Energy reported that the Philippines being 30 % agricultural has a potential of harnessing energy from biomass resources of up to 4,450 MW or 40 % of the country's energy demand (De Guzman, 2014).

Aside from the burning of pure biomass for power generation, biomass may be combined and cofired with coal that may only require minimal retrofitting of existing plants. Over 150 power plants worldwide have employed varying forms of biomass cofiring for power generation (Livingston, 2016). Cofiring with coal at optimal blend of 5 % to 10 % tends to increase the efficiency of the power plant due to improved devolatilization and to decrease the emissions of greenhouse gases (GHG) through chemical absorption. More than the technical and environmental benefits, biomass cofiring presents economic values through the utilization of forest products and agricultural residues which are commonly wasted and burned. The Philippines which primarily imports 90 % of its coal supply will have favourable shift in trade balance (Cremers, 2009).

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The evaluation of the potential environmental benefits and burdens of coal-biomass cofiring is usually conducted through life-cycle assessment (LCA). LCA has gained increasing use in the analysis of electricity generation systems in the past few years including the combined combustion of coal and different types of biomass in power plants. Table 1 lists important LCA studies on cofiring considering different biomass types and scenarios.

*Table 1: Important LCA studies on different biomass cofiring scenarios*

| Authors and year | Cofiring scenarios considered | Important concluding result |
|---|---|---|
| Dzikuć and Piwowar (2016) | Based on existing and simulated biomass shares<br>Woody biomass at 4 %, 5 %, 6 %; 1.3 %, 3 %, 4 % | Increasing the biomass share limits the negative environmental impact |
| Arteaga-Pérez et al. (2015) | Based on biomass thermal pre-treatment<br>Woody biomass (untreated and torrefied pine pellets) at 20 % (energy basis) | Cofiring with raw or torrefied wood pellets may lead to important reductions in impact categories |
| Tsalidis et al. (2014) | Based on biomass pre-processing or pre-treatment:<br>Woody biomass at 20 % (energy basis) | Torrefied biomass cofiring can be the best option when domestic biomass supply is utilized |
| Schakel et al. (2014) | Based on advanced combustion technologies with and without CCS<br>Wood and straw pellets at 30 % (energy basis) | Decrease in $CO_2$ emissions more than offsets the increase in the other categories |
| Shafie et al. (2013) | Based on pure coal and coal-biomass cofiring<br>Rice straws at 5 % (weight basis) | Biomass hauling process considered the biggest GHG contributor factor |
| Kabir and Kumar (2012) | Nine pathways based on biomass materials, cofiring methods, pre-treatment processes<br>Agricultural residue, forest residue, and whole trees at 7.53 – 20.45 % (energy basis) | Biomass densification may generate significant energy and environmental advantage |
| Tabata et al. (2011) | Based on single-firing of coal and coal-biomass cofiring<br>Woody biomass at 0.3 % (weight basis) | Reduction of annual GHG emissions in the area; the cofiring scenario is a net reducer of GHG emissions |

Overall, previous LCA studies built their cofiring scenarios based on selected biomass types, pre-processing options, combustion technologies and hypothetical values of biomass shares. The types of biomass available for cofiring and the value of biomass share which is crucial in the deployment of coal-biomass cofiring were mostly assumed. The present study considers locally sourced biomass feedstock available in the Philippines and also accounts for the realistic availability of these materials expressed as the theoretical and technical potential. The assessment of the resource potential of each biomass then serves as strong basis for drawing cofiring scenarios in the present primarily based on locally available and dependable biomass resource and on realistically deployable biomass shares in cofiring.

Although there are studies suggesting the potential of biomass as energy resource in the Philippines, the full extent of biomass utilization for energy production has not been widely applied. The Philippines has no recorded experience of coal-biomass cofiring technology like many other developing countries which can benefit the most from cofiring. The country's tropical rainforests and agricultural production could provide sustainable sources of biomass for cofiring. There is no country-specific study and thorough environmental evaluation of cofiring technology dedicated for the case of the Philippines or any of its regions exist in literatures. The present study fills in such gap by developing and evaluation methodology fitted for the case of the Philippines.

## 2. Methodology

The evaluation methodology includes the evaluation of the actual availability of biomass resources, planning the logistical choices for cofiring, and reviewing the technological capabilities for cofiring. Previous studies involved the environmental, technological, and economic assessment of different cofiring scenarios that were built mainly on hypothetical assumptions of important cofiring options. The methodology framework of the present study is illustrated in Figure 1. The province of Bataan is the geographical area chosen for case study for the evaluation methodology. Bataan is a peninsular province in Central Luzon with a total land area of 1,373 km$^2$. Two vast elevated forest systems cover the province: the Bataan National Park and the Mariveles Mountains. The remaining lowlands are primarily utilized as agricultural lands where rice is the primary crop (PMO–Bataan, 2006). The forested and agricultural land features of the province provide good potential for sourcing biomass and biomass-based materials.

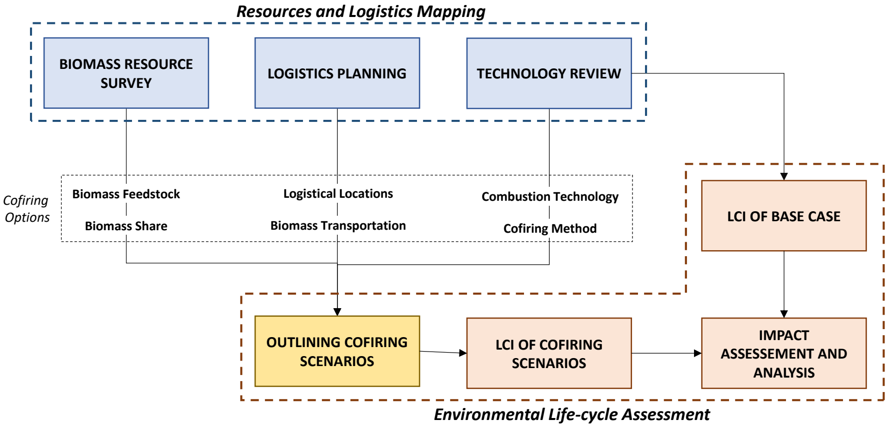

*Figure 1: Methodology framework of the present study*

Two grid-connected coal-fired power plants both at 600 MW capacity have been recently made operational in the province: Mariveles Power Plant of GN Power and Limay Thermal Power Plant of SMC Global Power. The two power plants presently combust pure coal only, but has the potential to engage in coal-biomass cofiring.

## 2.1 Resources and logistics mapping stage

The first stage quantifies the resource availability of different biomass types and identifies the maximum possible ratio for biomass cofiring. This is to select the most dependable biomass feedstock for cofiring based on actual resource availability and to draw relevant cofiring scenarios for the assessment of net GHG emissions impact. Biomass types considered as potential feedstock for cofiring are listed in Table 2.

*Table 2: Potential biomass feedstock for cofiring*

| Biomass Type | Specific Biomass Material | Description |
|---|---|---|
| Agricultural residue (primary) | Rice stalks | Organic refuse generated from harvesting in rice paddies |
| Agricultural residue (secondary) | Rice hulls | Organic refuse from the milling of harvested rice grains |
| Forest biomass | Stemwood | Wood from dead/damaged trees in forests and timberlands |
| Energy crop | Napier Grass | Perennial plant intended for cultivation in idle farmlands |

The theoretical and technical potential of each biomass type in mass units are calculated based on assessment methods endorsed by Biomass Energy Europe. Eq(1) and Eq(2) are used for the calculation of the potential of rice stalks, Eq(3) and Eq(4) for rice hulls, Eq(5) and Eq(6) for forest stemwood and Eq(7) for Napier grass. Terms and factors used in the equations are derived from actual data taken from literatures, field surveys and local data sources. The calculated theoretical potential in mass units are converted into energy units through the estimated higher heating value of each biomass type. The maximum biomass share for cofiring based on actual availability of the most dependable biomass feedstock, and on the actual coal consumption in power plants is estimated by Eq(8).

$$\text{Theoretical potential (rice straw)} = \text{rice production} \times \text{grains to straw ratio} \times \text{harvesting efficiency} \tag{1}$$

$$\text{Technical potential (rice straw)} = \text{theoretical potential (rice straw)} \times \text{sustainable extraction rate} \times \text{use factor} \tag{2}$$

$$\text{Theoretical potential (rice hulls)} = \text{production quantity of rice} \times \text{grains to hulls ratio} \tag{3}$$

$$\text{Technical potential (rice hull)} = \text{theoretical potential (rice hull)} \times \text{availability factor} \times \text{use factor} \tag{4}$$

$$\text{Theoretical potential (stemwood)} = \text{annual allowable collection} \times (1 - \text{harvest losses}) - \text{removals} \tag{5}$$

$$\text{Technical potential (stemwood)} = \text{theoretical potential (stemwood)} - \text{unavailable stemwood due to contraints} \tag{6}$$

$$\text{Technical potential (Napier grass)} = \text{area surplus of farmlands} \times \text{crop yield} \times (1 - \text{logistical losses}) \tag{7}$$

$$\text{Maximum biomass share} = \frac{\text{Biomass technical potential in energy units}}{\text{Total energy input with coal}} \tag{8}$$

The calculated biomass share must be higher than 5 % to qualify as potential biomass feedstock for cofiring. Values of biomass share less than 5 % pose insignificant effects in the reduction of GHG emissions. Three scenarios are drawn on the present study: the base case scenario or combustion of pure coal only, and the two cofiring scenarios. The cofiring scenarios are based on the combined combustion of coal and the selected biomass type at two cofiring shares: 5 % and the calculated maximum biomass share. Two cofiring shares are selected for the assessment in order to look at the effect of varying the biomass share in deploying cofiring.

### 2.2 Environmental life-cycle assessment

Life-cycle assessment is applied to measure the net environmental impact of deploying cofiring which starts from the point of sourcing biomass up to the combined combustion of both fuels. The system boundary of the base case scenario considers the overall coal combustion system in the existing power plant. The system boundaries of the cofiring scenarios include the collection, preparation and transportation of biomass and the combined combustion of coal and biomass. The assessment accounts for the net GHG emissions (i.e. $CO_2$, $CH_4$, and $N_2O$) of each scenario in the system outflows. The mass units of $CH_4$ and $NO_x$ emissions are expressed as kg of $CO_2$ equivalent through characterization factors. Emissions are calculated based on 1 TJ of fuel consumption per unit process, and emission factors derived from the Intergovernmental Panel on Climate Change (IPCC, 2006) using Eq(9). The net environmental impact of the base case scenario in kg of CO2 equivalent is estimated using Eq(10).

$$\text{GHG emissions} = \text{Fuel consumption } \times \text{emission factor based on fuel and process} \tag{9}$$

$$\text{Net emissions (base case)} = \text{emissions from coal combustion} + \text{emissions from agricultural/forestry practices} \tag{10}$$

The net GHG emissions of the base case scenario is the sum of the total emissions generated from the coal combustion system and the emissions generated from traditional agricultural or forestry practices. Emissions from agriculture/forestry practices pertain to the burning and decomposition of organic refuse and forest wood. Farmers usually burn these types of waste in the field. These emissions are included in the base case scenario since these emissions may be avoided if the organic refuse or forest wood are utilized in cofiring instead. Emissions related to the marine transport of coal from source country are excluded since they are occurring outside the geographical boundary of the assessment. The net environmental impact of each of the two cofiring scenarios is estimated using Eq(11).

$$\begin{aligned}\text{Net emissions (cofiring)} &= \text{emissions from coal combustion} + \text{emissions from biomass combustion} \\ &\quad + \text{emissions from biomass logistics}\end{aligned} \tag{11}$$

The calculation of the net GHG emissions of the two cofiring scenarios include the total emissions generated from the coal combustion system and the emissions generated from biomass logistics (i.e. collection, pre-processing and transport of the biomass materials). Emissions from biomass logistics are important since they have the potential to offset emission reduction benefits through cofiring. Emissions reduction from cofiring, as indicated in earlier literature, are deducted from the net GHG emissions of coal. The emissions from agricultural and forestry practices now appear as emissions from biomass combustion, since they are now burned in lieu of power generation, and not in the field.

## 3. Results and discussion

The evaluated potential of each of the biomass feedstock considered for cofiring is presented in Table 3. Primary agricultural residue or rice stalk provides the highest technical potential. The potential of forest residue is zero since legislation on biodiversity protection is a constraining factor that prohibits the collection of stemwood. The energy crop yields lower potential supply due small percentage of available and idle farmlands that can be used as energy crop plantation. Rice stalk may then be regarded as the most dependable biomass feedstock in terms of actual availability for cofiring and may then be used for drawing the two cofiring scenarios. The circulating fluidized bed coal-fired power plant located in the geographical area of case study has 4 units with 150 MW capacity each. Each unit consumes 1.512 Mt of sub-bituminous coal per year or equivalent to 30,240 TJ per year. Apparently, only one unit at 150 MW of the coal-fired power plant can handle cofiring based on the availability of the selected biomass material. The calculated maximum biomass share of rice stalks based on actual availability for combined combustion with coal in one 150 MW unit is 7.03 %. This value is between the recommended cofiring range from literature of 5 % to 10 % (Sahu, 2014). The calculated maximum biomass share may then be reduced to 7 % to allow margins for the supply of biomass. With this, the two cofiring scenarios for cofiring coal with rice stalks are at 5 % and at 7 % biomass share based on total input energy.

*Table 3: Theoretical and technical potential of each considered biomass*

| Biomass | Theoretical Potential (t/y) | Technical Potential (t/y) | Technical Potential, energy units (TJ/y) |
|---|---|---|---|
| Agricultural residue (primary) | 143,405.61 | 136,235.33 | 2,125.27 |
| Agricultural residue (secondary) | 36,964.32 | 11,097.20 | 166.23 |
| Forest biomass | 13,404.86 | 0 | 0 |
| Energy crop | --- | 7,165.7 | 129.77 |

Figure 2 shows the net GHG emissions of the two cofiring scenarios in comparison with the base case scenario. The base case scenario has a total of 3.138 Mt of $CO_2$ eq. emissions, comprised of 2.920 Mt $CO_2$ eq. from the combustion of pure coal in the power plant and 0.217 Mt $CO_2$ eq. from the field burning of agricultural residue. The cofiring scenario at 5 % biomass share has a net emission of 3.644 Mt of $CO_2$ eq. comprised of 2.775 Mt $CO_2$ eq. from the combined combustion of both fuels and 0.662 Mt $CO_2$ eq. from biomass logistics. Meanwhile, the cofiring at 7 % biomass share gives off a net emission of 3.846 Mt of $CO_2$ eq. with 2.717 Mt $CO_2$ eq. from the combined combustion of coal and biomass and 0.927 Mt $CO_2$ eq. from biomass logistics. Assessment of emissions from biomass logistics considered the manual collection and baling of rice stalks and without further material drying or pre-processing since rice stalks are commonly left in the field and dried by extreme sunlight.

The net GHG emissions is higher in the two cofiring scenarios as compared with pure coal combustion. Though the combined combustion of coal and biomass yields significant reduction in GHG emissions, biomass transportation contributes a large share in GHG emissions. As the cofiring share increases, the emission from combined combustion decreases whereas the emission from biomass logistics increases.

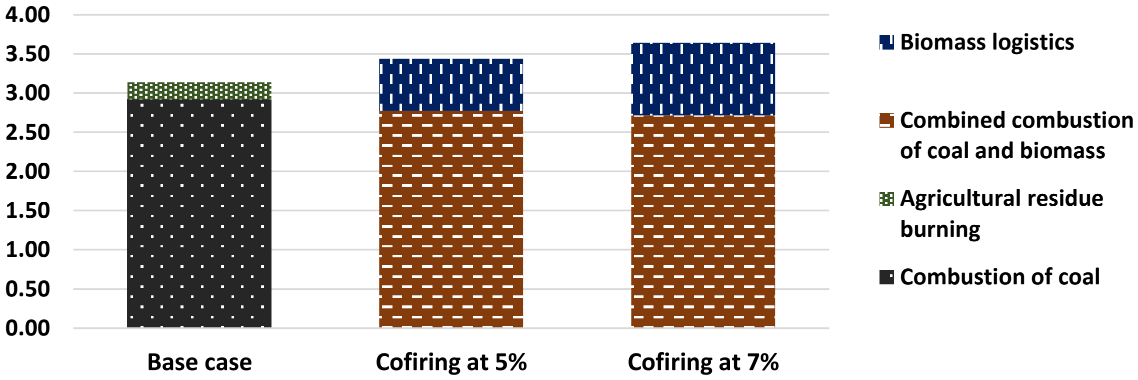

*Figure 2: Net GHG emissions (Mt of $CO_2$ equivalent) from the base case and cofiring scenarios*

It must be noted that the study limits the accounting of net emissions within the geographical area in consideration. The potential emission reduction from the marine transportation of imported coal was not taken into account in the study due to system boundary restrictions.

## 4. Conclusions

The study presented an evaluation methodology for coal-biomass cofiring in the Philippines in which three biomass types are considered. The theoretical and technical potential of each biomass type in the selected geographical area for case study were evaluated. Only the primary agricultural residue or rice stalk qualifies as the dependable source of biomass feedstock which may take a maximum biomass share of 7.04 % in cofiring.

The study assesses the net environmental impact of locally deploying coal-biomass cofiring with net GHG emissions as the criteria. Through LCA databases and simulation studies on cofiring and biomass logistics, the net emissions of $CO_2$, $CH_4$ and $N_2O$ were accounted for the base case scenario of pure coal combustion and the for two cofiring scenarios of 5 % and 7 % biomass share. Results show that the net GHG emissions will potentially increase in the geographical area under study with the deployment of cofiring, particularly cofiring at higher biomass share, due largely to the additional emissions from the transportation of biomass from the field to the power plant site. However, the potential avoided emissions from the reduced marine transportation of imported of coal due to potential displacement from biomass was not yet considered in the study. This factor may pose significant reductions in the net GHG emission within and outside the geographical area under study through coal-biomass cofiring.

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