

Spatial Biomass Resource Planning Framework for Co-firing under Carbon Policy Scheme

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Effective spatial planning is crucial for the cost-effectiveness and sustainable development of biomass energy resources due to the diffuse nature of biomass and high transportation cost. To leverage the existing capitals of the fossil fuels energy systems, portions of biomass can be integrated as fuel within the existing energy facilities through co-firing technology. Although biomass co-firing operates at a low retrofitting cost environment, this does not eliminate all the associated cost required in supplying the biomass to the power generation facilities. This paper presented the development of a spatial biomass resource planning framework which integrates several modelling tools such as Geographical Information System (GIS), Analytic Hierarchy Process (AHP) and Mixed-Integer Linear Programming (MILP) to investigate the level of carbon prices needed to support co-firing implementation in Malaysia in 2020. The results have been showing that carbon price range of 3 - 12 USD/t can be imposed by Malaysia in order to achieve the future national renewable and environmental targets while reducing the coal-based industrial emissions of up to 19.75 %.

1. Introduction

Rising concerns over the future energy security and global climate issues have escalated the efforts to develop renewable energy (RE). With many countries already having renewable targets, energy policies around the world are moving towards encouraging a larger proportion of RE in the global energy mix. Malaysia, having the abundant sources of biomass especially oil palm, is projected to produce an increase of 110,000,000 t of biomass by 2020 as compared to 83,000,000 t in 2012 (AIM, 2013). The introduction of Feed-in-Tariff (FiT) mechanism in the country helps to incentivised bioenergy industries to utilise biomass for energy uses. Despite the introduction of FiT in the country, bioenergy infrastructure developments are still far from achieving the targets, requiring the needs of the other cost-efficient technologies. Biomass co-firing with coal offers a promising approach to solve this issue due to its cost-attractiveness and unique carbon neutrality of biomass. Biomass is a spatially distributed resource with low energy density and low flowability, meaning that transporting biomass to demands will burden the supply chain economic structure with more cost. It is important for the transportation to be minimised in order to reduce the associated cost and environmental problems. This can be realised through pre-treatment technology which increases the energy density of biomass while improving its bulk density so that more biomass can be transported. Although biomass co-firing operates at a low retrofitting cost environment, this does not eliminate the costs needed to build and operate pre-treatment facilities. Previous studies have been carried out on assessing the potential of biomass co-firing technology to be implemented in Malaysia. Shafie et al. (2013) investigated the economic feasibility of utilising rice straw for co-firing through life cycle assessment approach, Lam et al. (2013) developed a supply chain optimisation model to investigate the allocation cost needed to supply waste and oil palm biomass for co-firing application, Griffin et al. (2014) utilised GIS and MILP techniques to quantify the availabilities of different types of biomass in Peninsular Malaysia for biomass co-firing purpose, Nurariffudin et al. (2017) performed a techno-economic assessment of adopting co-firing and microalgae-based CO₂ utilisation technologies in an existing coal-fired power plant in Malaysia, and Mohd Idris et al. (2018) developed a spatial optimisation model to determine the locations of pre-treatment facility needed to enhanced the quality of oil palm biomass for co-firing in Johor, Malaysia. This paper extends the work by Mohd Idris et al. (2018) to include different modelling

tools such as GIS, AHP and MILP in a spatial modelling framework to improve the sensitivity of facility siting of pre-treatment facilities. The developed framework was then applied to Peninsular Malaysia case study to investigate the level of carbon pricing needed to achieve the national emission and renewable target in 2020.

2. Methodology

A conceptual spatial biomass resource planning framework with resource availability assessment, site suitability analysis, network analysis and supply chain optimisation is shown in Figure 1. ArcMap 10.3 and GAMS 24.6.1 were utilised as the platforms to conduct GIS analysis and optimisation works. Several assumptions were made to address the boundaries of this study. Those are described as follows; i) biomass combustion is considered to be having a zero net greenhouse effect, ii) emissions are accounted from several sources such as biomass and coal transportations, biomass cultivation and harvesting, pre-treatment process and coal combustion in power plant, iii) coal is assumed to be transported directly from coal terminals located in Javanese and Sumatra islands of Indonesia to the power plant terminals, iv) capacity of pre-treatment plants is specified at 500,000 t/y production rate, and v) all the coal-fired power plants have the same capacity factor, thermal efficiency and operating days.

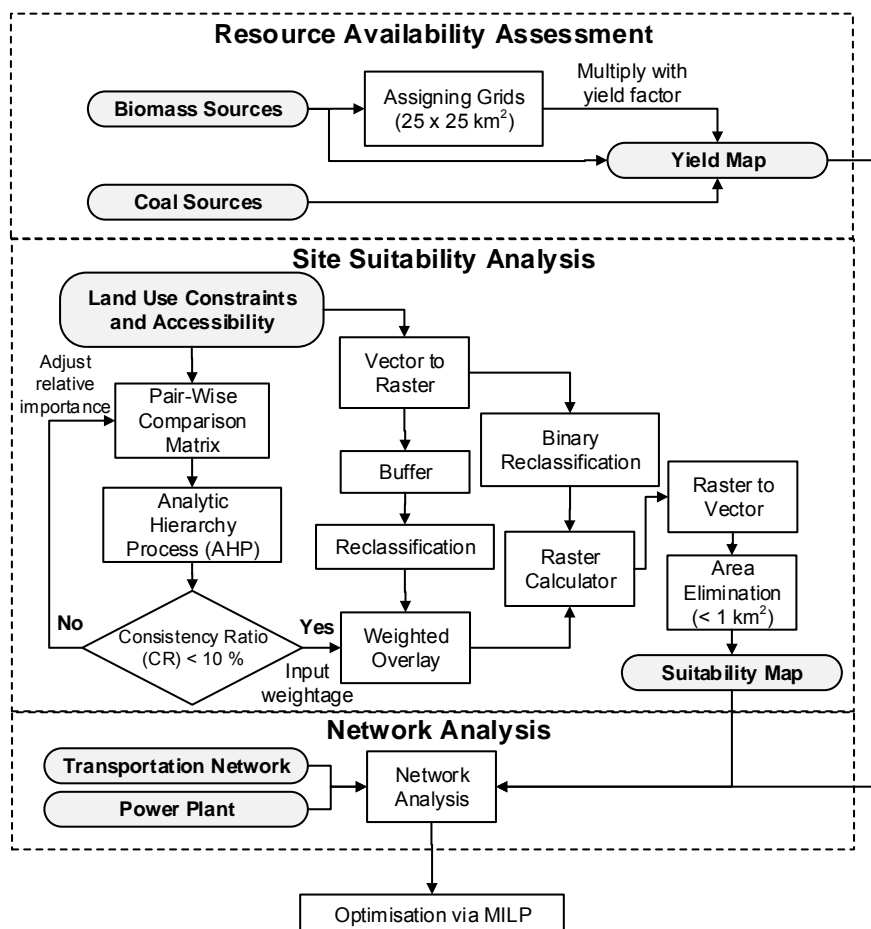


Figure 1: Spatial biomass resource planning framework for biomass co-firing energy system

2.1 Resource availability assessment

Oil palm plantation-based biomass which are oil palm trunk (OPT) and oil palm frond (OPF) were considered as the biomass feedstock in this study. To estimate these biomass, oil palm plantation layer from land use map of Peninsular Malaysia for the year 2013 (MaCGDI, 2013) was divided into 25 km × 25 km grid square to identify the biomass yield per grid of plantation area. OPT and OPF can be collected in oil palm plantations at yields of 186.2 t/km².y and 36.2 t/km².y respectively through replantation activities whereas pruned OPF can be retrieved at 390 t/km².y (Loh et al., 2017). Figure 2 illustrated the spatial distributions of OPT and OPF availabilities in Peninsular Malaysia.

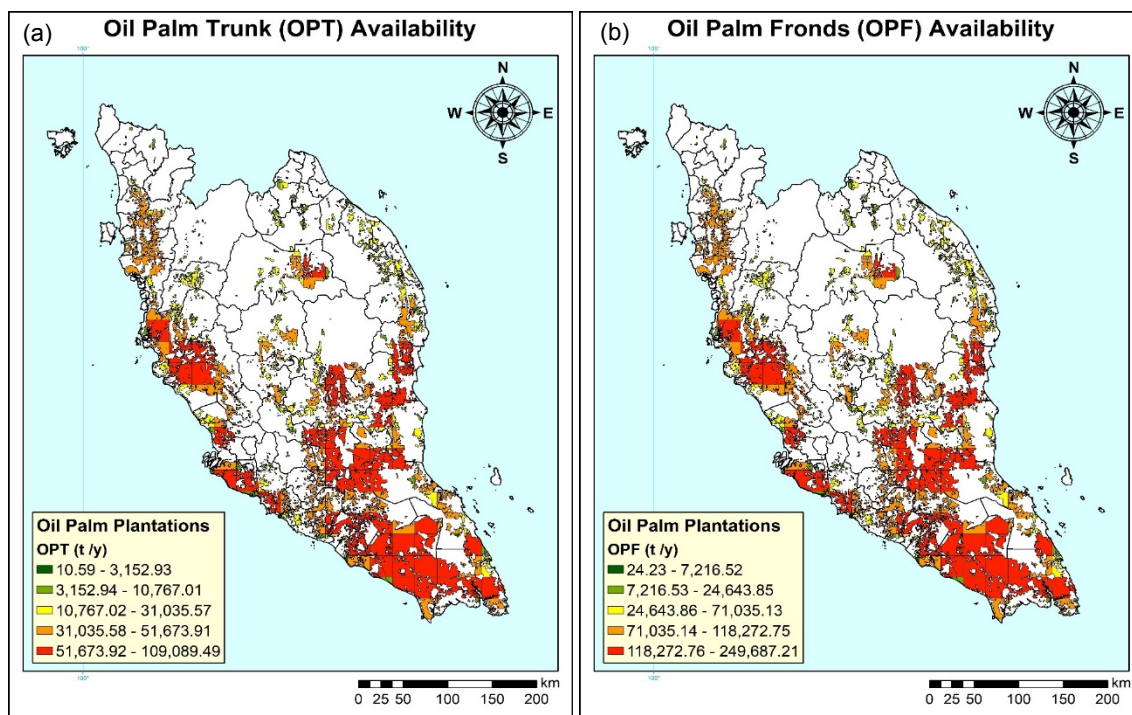


Figure 2: Spatial distributions of (a) OPT and (b) OPF availabilities in Peninsular Malaysia

2.2 Site suitability analysis

Site suitability analysis was performed to identify the potential pre-treatment sites through the utilisations of both GIS and AHP techniques. This analysis involved the screening of the land use map by utilising the land use accessibility and constraints (Table 1) in order to identify the optimal sites to build facilities. Before the exclusion analysis of the land use map was conducted, land use map was converted to a raster format of 30 x 30 m spatial resolution. The analysis was initiated by reclassifying several of the protected areas such as forest and reserves, wetlands, water bodies and urban areas to generate a binary map. Binary reclassification generates a map which has the layers of suitable ('1') and unsuitable ('0') cells. In this case, the protected areas were having a score of '0' whereas the remaining available areas were having a score of '1'. Then, each of the buffers listed in Table 1 for the constraints of biomass supply, slope, road, water and electricity were reclassified into a common suitability scale of '0' (unsuitable), '1' (suitable but avoided), '2' (least suitable), '3' (less suitable), '4' (moderately suitable) and '5' (most suitable) for the standardisation of scores.

Table 1: Land use accessibilities and constraints

Criteria	Unit	Buffer	Purpose	Reference
Biomass supply	m	0 - 80,000	Biomass accessibility	Bain et al. (2003)
Road	m	30 - 1,500	Minimise transportation	Sharma et al. (2017)
Slope	°	0 - 15	Minimise construction cost	Lovett et al. (2014)
Water	m	30 - 1,000	Water accessibility	Sharma et al. (2017)
Electricity	m	30 - 1,000	Electricity transmission and accessibility	-
Forest and reserves	-	Exclusion	Protected areas	-
Wetlands	-	Exclusion	Protected areas	-
Water bodies	-	Exclusion	Protected areas	-
Urban areas	-	Exclusion	Protected areas	-

AHP technique was used to define the preference weightage for each of the associated buffer constraints. This preference weightage was identified by developing a pair-wise comparison matrix that shows the relative importance between each of the constraints. The relative importance scores are from 1 to 9 with a higher value indicates a greater importance. Noted that the consistency of the scores is evaluated by the consistency ratio (CR) which must be below than 10 % for the solution to be acceptable. These relative importance scores were inputted in AHP to quantify the preference weightage for each of the buffers. Using weighted overlay tool

in GIS, the preference weightage was exerted to each of the buffer zones that have been reclassified in the previous step to obtain the preference map. To determine the final suitability map, the preference map and the binary map were multiplied by using raster calculator. The '0' of the binary map erases the multiplied area of the preference map, leaving the final suitability map with suitability scale of 1 - 5. The area which has the highest score in the final suitability map were selected as the potential pre-treatment sites. The final suitability map was converted into vector format and any areas below than 1 km² were eliminated. 263 potential locations were identified after the employments of all related spatial modelling steps. Among these identified potential locations, several pre-treatment facilities are to be built with the consideration of technical, economic and environmental criteria through optimisation.

Table 2: Pair-wise comparison matrix (Sultana and Kumar, 2012)

	Biomass supply	Road	Slope	Electricity	Water	Weightage
Biomass supply	1	3	9	7	9	0.558
Road	1/3	1	6	3	4	0.239
Slope	1/9	1/6	1	1/3	1	0.048
Electricity	1/7	1/3	3	1	2	0.101
Water	1/9	1/4	1	1/2	1	0.054
					Total	1.000

2.3 Network analysis

Network analysis were performed by considering detailed road transportation networks to define the optimal transportation routes from each location to the respective destinations. Distances from biomass supply to pre-treatment facilities and from pre-treatment facilities to coal-fired power plants were identified and inputted into the optimisation model for the calculation of transportation cost.

2.4 Supply chain optimisation

A supply chain optimisation model consisting of various decision variables and parameters related to the technical, economic and environment was based on the model by Mohd Idris et al. (2018). Carbon penalty scheme is introduced in the model through carbon pricing approach that will be exerted whenever CO₂ is emitted to the atmosphere during any of the process in the supply chain network (Figure 3). The optimisation model was formulated based on MILP modelling approach to assist the selections of facility locations through binary variables. The objective function of the model is to minimise the overall supply chain cost of the system while determining the most optimal locations to build facilities, the optimal co-firing rates in coal-fired power plant and the optimal CO₂ reduction scheme through carbon penalty. Figure 3 illustrates the supply chain planning network for biomass co-firing energy system.

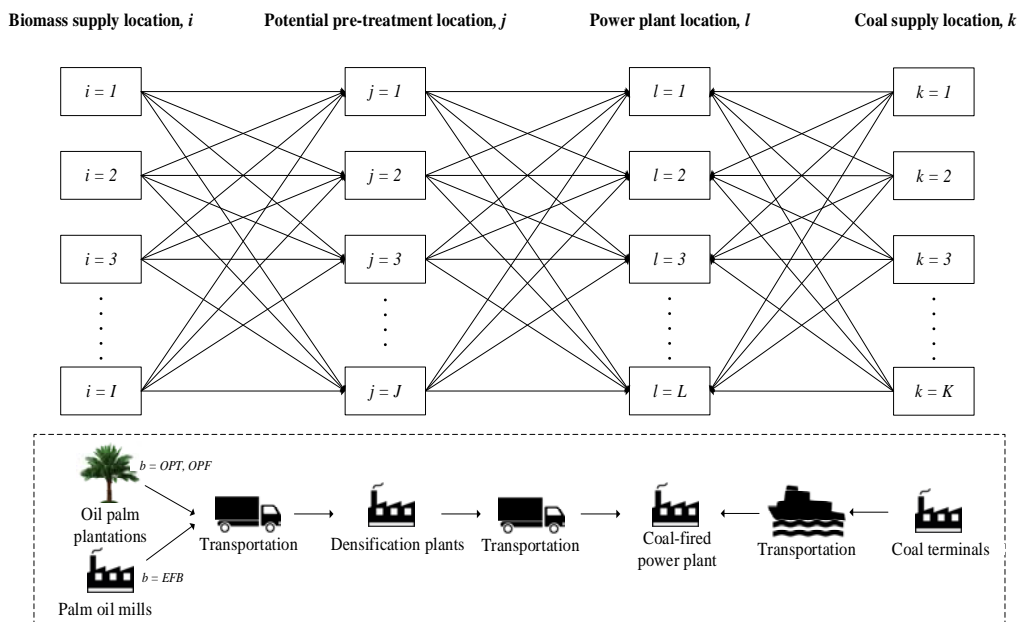


Figure 3: Supply chain planning network of biomass co-firing energy system (Mohd Idris et al., 2018)

3. Results and Discussions

The developed framework was applied to Peninsular Malaysia case study for the investigation of carbon tax required to support co-firing activities in existing coal-fired power plants. Four scenarios were outlined as shown in Figure 4 which consisted of different carbon price variations in order to achieve future emissions reduction and renewable targets.

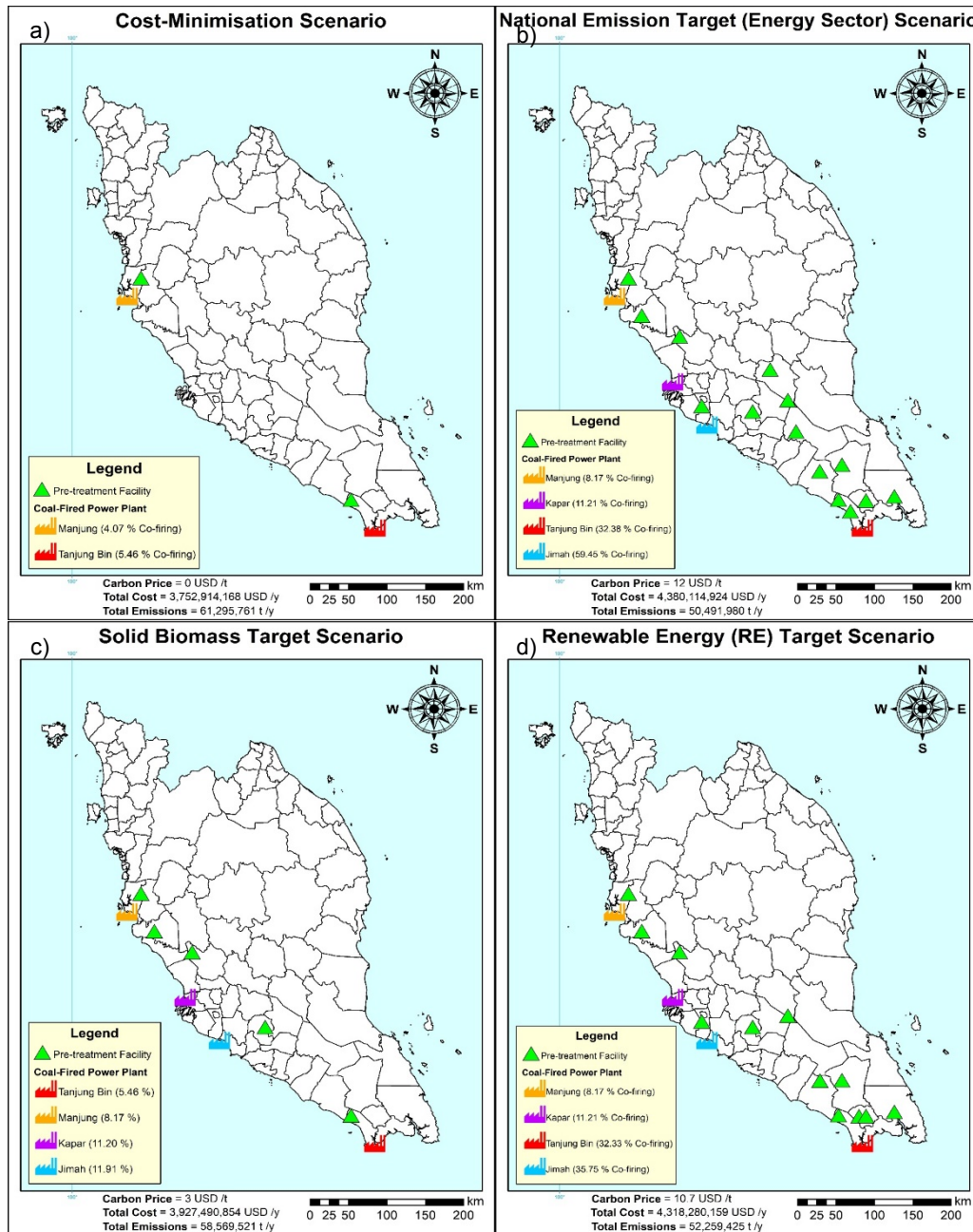


Figure 4: Spatial distributions of pre-treatment sites in Peninsular Malaysia a) cost-minimisation scenario b) emissions reduction target (13,000,000 t CO₂/y) c) solid biomass target (800 MW) d) RE target (2,080 MW)

The first scenario was conducted without the inclusion of carbon price to examine the level of co-firing which could be achieved by existing power plants. It can be observed that without carbon tax, emissions reduction equivalent to 1,844,929 t CO₂/y can be achieved through co-firing practices in their facilities. This means that co-firing technology can already be implemented without any incentives or policy support from government as proved by the reduction of about 10,000,000 USD/t in the total supply chain cost. This can be compared with

the previous model by Mohd Idris et al. (2018) where only small amount of biomass can substitute coal as fuel without any carbon tax exerted. The improvement on the sensitivity of pre-treatment facility siting through the combinations of GIS, AHP and MILP can be seen to be important as this affects the quality of the result. As the current environmental targets set by government are still far to be achieved, financial support is still needed for an energy industry to adopt environmentally friendlier technology.

The next three scenarios were based on achieving the RE and emission targets set by Malaysian government. The targets to be accomplished by 2020 are the national emission reduction target by energy sector (Figure 4b), the national solid biomass energy target (Figure 4c) and the national RE target (Figure 4d). Emissions were reduced at rates of 19.75 %, 7.24 % and 17.23 % for all the scenarios at 12, 3 and 10.7 USD/t of carbon prices. It can be shown that the carbon prices were increasing with the rising magnitudes of emissions reduction. Although having an excellent performance in reducing the emissions, these high co-firing rates implemented in each of the power plants have caused an increase of up to 16.4 % for each of the scenarios.

4. Conclusions

The spatial biomass resource planning framework has been successfully developed for the investigation of co-firing implementations in existing energy facilities in Malaysia. It can be concluded that spatial modelling approach can help to improve the existing supply chain planning method in order to obtain more accurate representation of economic and environmental portfolios, resource availability assessments and optimal siting of facility locations. With the carbon policy scheme provided by government to existing energy industry at a competitive cost, the future environmental targets can be potentially met through this technology alone. The effectiveness of this framework can be further assessed through sensitivity analysis in the future study.

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