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Optimization of Biomass Usage for Electricity Generation with Carbon Dioxide Reduction in Malaysia

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Abstract: Electricity and energy sector are identified as the major carbon dioxide emitter. Coal, natural gas, diesel, oil and hydro are the sources to generate electricity in Malaysia. In the 9th Malaysia Plan, government of Malaysia encourage power producer shift from heavy reliance on natural gas and enhance use of biomass. Agriculture residue; palm oil residue, rice processing residue and wood processing residue were considered as fuel sources to generate electricity in this study. An MILP model has been developed to optimize fuel mix and meet CO_2 emission target. The model was developed and implemented in General Algebraic Modeling System (GAMS) for the fleet of electricity generation in Peninsular Malaysia only. In order to reduce the CO_2 emissions by 35% from current CO_2 emission level, the optimizer has specified to switch from coal to natural gas and biomass from palm oil residues as a fuel. Therefore, agriculture residue is a promising fuel sources for electricity generation at the same time reduce CO_2 emissions.

Key words: Electricity generation, MILP, GAMS, CO_2 emission, biomass

INTRODUCTION

Carbon dioxide is a main greenhouse gas (GHG) that is responsible for climate change. The usage of fossil fuel in energy use is the primary source that increases the concentration of carbon dioxide (CO_2) in the atmosphere. Energy use is largely driven by economic growth, as well as changes in the fuel used in electricity generation. Back in 1998, the United Nations Framework Convention on Climate Change, has already developed the Kyoto Protocol to stabilize the GHG emissions in the atmosphere by having industrialized countries commit to reduce their GHG emissions. The legal binding accord was signed by 165 countries to reduce GHG emissions. Carbon dioxide emissions in Malaysia have increased by 221% since year 1990 to 2004. Fossil fuels itself contribute more than half of the total CO_2 increment. Figure 1 shows an increment of 153% of fossil fuel burning since 1990 to 2004 (EIA, 2005). It was identified that five major sectors in Malaysia emit CO_2. Transportation sector contributes the highest percentage of CO_2 emission which is 27 % from total CO_2 emission, followed by electricity and energy sectors 25.7% (EIA, 2005) as indicated in Fig. 2.

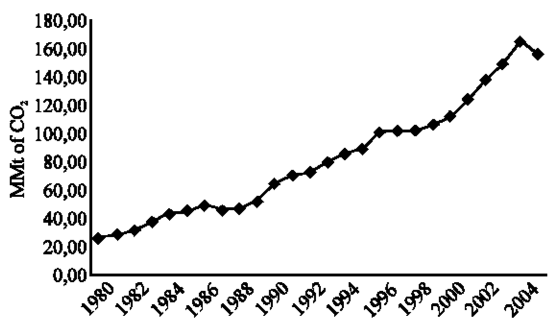

Fig. 1: Carbon dioxide emissions in Malaysia from fossil fuel (EIA, 2005)

A number of studies examined the prospects of incorporating new Pulverized Coal (PC), Integrated Gasification Combined Cycle (IGCC) and Natural Gas Combined Cycle (NGCC) in the electricity generation sector. Narula *et al.* (2002) considered replacing existing coal plants with new plants such as NGCC, IGCC and PC and studied the impact of the incremental cost of CO_2 reduction on the Cost of Electricity (COE) by implementing different technology options and compares COE.

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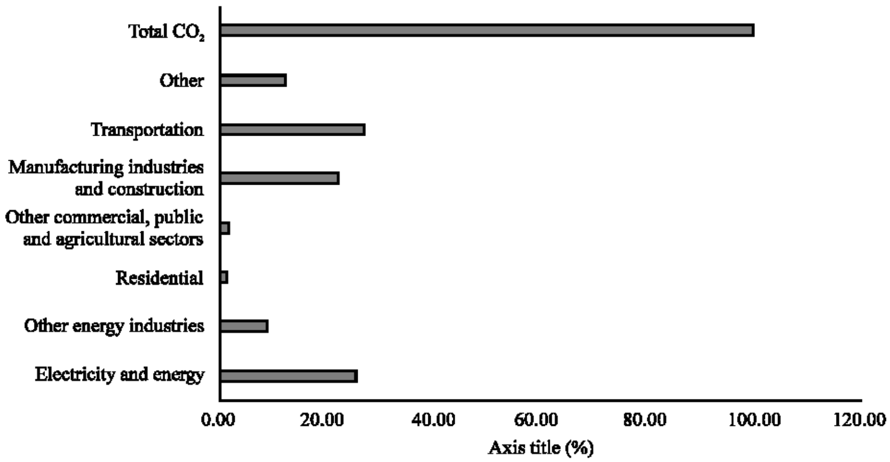

Fig. 2: CO_2 emissions by sectors in Malaysia (EIA, 2005)

Table 1: Biomass resources potential in Malaysia (Hashim, 2005)

Sector	Quantity (kton/year)	Potential annual generation (Gwh)	Potential capacity (MW)
Rice mills	424	263	30
Wood industries	2177	598	68
Palm oil mills	17980	3197	365
Bagasse	300	218	25
POME	31500	1587	177
Total	72962	5863	665

Utilization of biomass especially palm oil has been investigated through several research (Sumathi *et al*., 2008; Wicke *et al*., 2008). Palm oil for example, not only can be used as source of edible oil but also it can be enhanced into excellent renewable energy. Biomass can be converted to electricity through several processes which are direct-fired, gasification, anaerobic digestion, pyrolysis and small modular systems (Sumathi *et al*., 2008). Malaysia has abundant of agriculture residue from rice mills, wood industries, palm oil mills, bagasse and Palm Oil Mill Effluent (POME). Table 1 shows the detail of residue produce from those sectors and its energy potential in GWh.

In view of the rapid growth in power generation capacity and the corresponding rise in CO_2 emission in Malaysia, there is a need for authority to better plan the electricity generation capacity expansion to meet electricity demand as well as to achieve an overall reduction in CO_2 emission. Hence, this study aims to develop an optimization model to minimize cost of electricity generation to simultaneously fulfill the forecast electricity demand and a specified CO_2 emission reduction targets. Aside from conventional electricity generation such as pulverized coal, natural gas and hydroelectric and current technologies such as Pulverized Coal (PC), Natural Gas Combined Cycle (NGCC) and biomass from palm oil residues, wood processing residues and rice processing residues were also considered in the model.

MATERIALS AND METHODS

The project methodologies include three key phases, namely data gathering, superstructure development and model development and implementation.

Phase 1. Data gathering: Phase 1 focuses on gathering the necessary information of:

- Existing plant data, i.e., plant capacities, operational cost and CO_2 emission
- Capital and operational cost of biomass power plant
- Other data such as current electricity demand and fuel price

Phase 2. Superstructure development: Superstructure representing all possible alternatives of fuel mix will be very complex. A simple superstructure is presented to illustrate the concepts. C_i, NG_i, D_i, O_i and H_i represents existing coal, natural gas, diesel, oil and hydroelectric power plants respectively. Hypothetical new power plants are represented by B_i^{new} for biomass power station.

Three CO_2 mitigations strategies will be implemented, which include employing fuel balancing, fuel switching and enhanced use of biomass.

Fuel balancing is to adjust the operation of two generation stations to reduce CO_2 emissions. This strategy involves increasing electricity generation by non-fossil fuel plants. Therefore, fossil fuel plants will generate less electricity, hence less emission of CO_2.

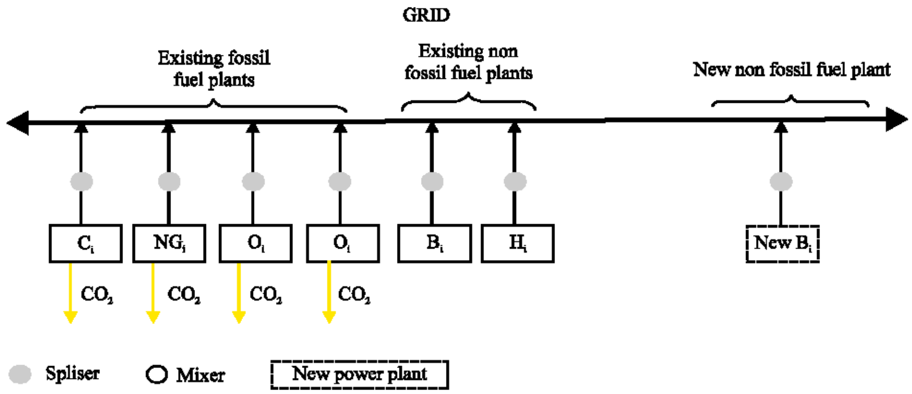

Fig. 3: Superstructure for existing and new technologies

Fuel switching is to switch from carbon-intensive fuels (e.g., coal) to less carbon-intensive fuels (e.g., natural gas). Existing generation stations must be retrofitted in order to use another fuel. Energy produced by alternative fuel (agriculture waste) emits no CO_2 and hence will reduce CO_2 emission.

Third mitigation strategy is increasing use of biomass energy. In this case, superstructure will represents current and new technologies as illustrated in Fig. 3. Existing technologies is represents by fossil fuel plants, such as gas turbine and conventional thermal consume coal, natural gas, diesel and fuel oil.

Phase 3. Model development and model implementation: Optimization model consist of objective function and constraints. The model is formulated using an objective function that minimizes the net present value of the cost of electricity. The objective function consist of annualized cost for existing fossil and non-fossil fuel power plant, retrofit cost, capital cost for new power plant and annualized cost for new fossil and non-fossil fuel power plant.

Objective function:

$$\min f(i,j) = \underbrace{\textstyle\sum_{i\in F} V_{ij}E_{ij} + \sum_{i\in NF} F_i^{NF} E_i}_{\text{Operating and maintenance cost for new power plants}} + \underbrace{\textstyle\sum_{i\in F^c} \sum_j R_{ij} X_{ij}}_{\text{Retrofit cost due to fuel switching}}$$

$$\underbrace{\textstyle\sum_{i\in p^{new}} S_i^{new}\, K_i^{max}\, n_i^{new} + \sum_{i\in p^{new}} M_i^{new}\, E_i^{new}\, y_i^{new}}_{\text{Capital and operating and maintenance cost for new power plants}}$$

Constraints:

- CO_2 emission limit
- Optimal power generation must be less than current electricity generation
- Logical constraint
  - Lower bound of existing coal plant
  - Upper bound for PC, IGCC and NGCC
  - Non negativity constraint

The indices, sets, variables and parameters used in the model are:

Indices:

i = Power stations
j = Fuels

Sets:

F = Fossil fueled power plants
NF = Non-fossil fueled power plants
new = New power plants

Binary variable:

$$X_{ij} \begin{cases} = 1 \text{ if coal-fired boiler i is operational using fuel j} \\ = 0 \text{ otherwise} \end{cases}$$

$$y_i \begin{cases} = 1 \text{ if power plant i is operational} \\ = 0 \text{ otherwise} \end{cases}$$

$$n_{inew} \begin{cases} = 1 \text{ if new power plant i is operational} \\ = 0 \text{ otherwise} \end{cases}$$

Variables:

E_{ij} = Actual electricity generation from ith fossil fuel using jth fuel type for existing power plant (MWh)

E_j = Actual electricity generation from non fossil fuel (MWh)

E_j^{new} = Electricity generation for new power plant (MWh)

Table 2: Actual electricity generation for existing power plant in Peninsular Malaysia (Mirzaesmaeeli, 2007)

Power plant	Generation MWh per year		Operating and Maintenance cost (RM per Mwh) Coal	Natural gas
Coal	Pelabuhan Klang	639 918	5.51-8.03	5.63-15
	Janamanjung	1 254 870		
	Tanjung Bin	1 254 870		
	Pasir Gudang	646 926		
	Prai	1 073 100		
	Jimah	745 000		
Natural gas	Glugor	1 734 480	5.63	
	Pelabuhan Klang	1 734 480		
	Connaught Bridge	6 559 488		
	Serdang	3 740 520		
	Pasir Gudang	3 066 876		
	Paka	8 979 876		
	I-Genting	5 548 000		
	I-Segari	6 012 000		
	I-Powertek	79 000		
	I-PD	175 000		
	I-TTPC	5 372 000		
	I-Nur	619 000		
	I-Pahlawan	2 124 000		
	I-Prai	2 426 000		
	I-GB3	4 237 000		
	I-Panglima	5 318 000		
	I-Kapar	3 185 000		
	I-PgudangYTL	2 477 000		
	I-PakaYTL	4 955 000		
	Kenyir	1 686 100		
Hydro electric	Temenggor	845 900	1.67	
	Bersia	231 000		
	Kenering	427 000		
	Chenderoh	154 700		
	Jor	280 700		
	Pergau	457 800		
	Woh	429 800		
	Piah and Odak	315 000		
	Kenerong	112 000		

Parameters:

V_{ij} = Operating and maintenance (O and M) cost for existing power stations (RM/MWh)

R_{ij} = Retrofit cost (RM/MW)

S_i^{new} = Capital cost for new power plant (RM/MW)

M_i^{new} = Operating and Maintenance (O and M) cost for new power stations (RM/MWh)

K_i^{max} = Maximum capacity for new power plant i (MW)

Case study: The case study is electricity generation in Peninsular Malaysia. All data was tabulated in Table 2. Data base on year 2007. It is assume that electricity growth rate is 10% annually.

RESULTS AND DISCUSSION

Result for optimal generation mix was tabulated in Fig. 4 for CO_2 emission reduction target for base case scenario 0, 20 and 35%. Base case is defined as current scenario in Malaysia. Currently, 0% or no CO_2 emission reduction target for base case. 20 and 35% CO_2 emission reduction target was set up for second and third case. Base case scenario indicated that coal power plant will maintain consume coal as fuel while maintaining other natural gas and hydroelectric power station.

In order to reduce cost and carbon dioxide emission, for Case 2 (20% CO_2 emission reduction target) the optimizer chose to maintain existing hydroelectric and natural gas power station while switch fuel from coal to natural gas and adapt biomass power station. Pelabuhan Klang, Jimah power station and one boiler of Tanjung Bin power station will switch to natural gas. According to the optimizer, two additional new NGCC power stations will be built to fulfill the electricity growth demand. The rest of coal power plant will remain the same.

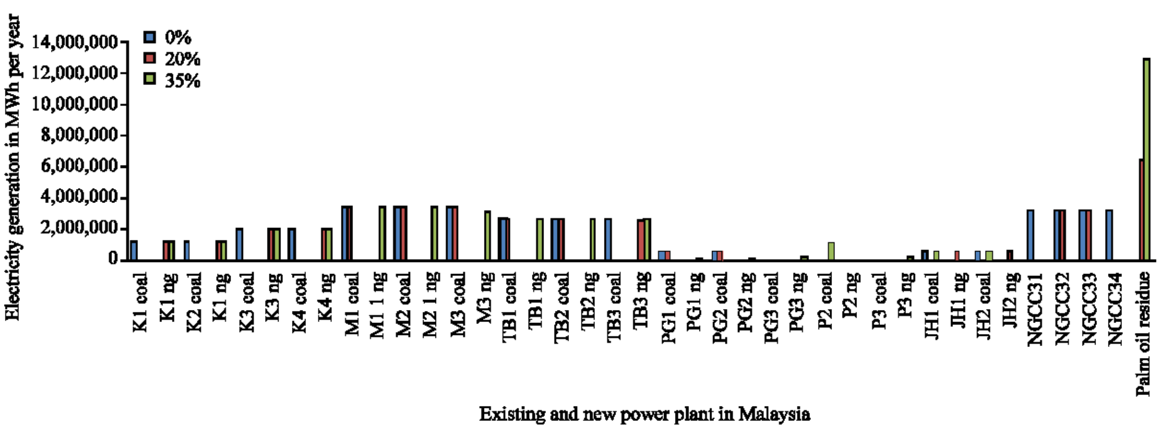

Fig. 4: Optimal electricity generation for base case, 20 and 35% CO_2 reduction

The third scenario is 35% CO_2 emission reduction target. From the result, 4 coal plant will switch to natural gas; Pelabuhan Klang, Janamanjung, Tanjung Bin and Pasir Gudang. No new PC, IGCC and NGCC power plant. Electricity generation from biomass power plant almost double compare to case 2.

CONCLUSION

Malaysia has a huge agriculture waste especially from palm oil and rice processing mill. The waste can be converted to fuel for electricity generation. Instead of using conventional fuel, agriculture residue is a promising fuel sources for electricity generation and at the same time reduce CO_2 emissions.

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