DESIGN OF PALM OIL BIOMASS PROCESSING NETWORK FOR ELECTRICITY GENERATION USING MINLP MODEL: A CASE STUDY ON ISKANDAR MALAYSIA

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Abstract: This paper presents a general decentralized energy generation (DEG) optimization model for developing countries. A mixed integer nonlinear programming (MINLP) model has been formulated and implemented, representing decisions regarding (1) the optimal number, locations, and sizes of various types of processing plants, (2) the amounts of biomass transported, and electricity to be transmitted between the selected locations over a selected period, and minimizes the objective function of overall generation cost. The model has been applied first for designing a DEG system using palm oil biomass for Iskandar Malaysia region of the state of Johor, Malaysia and then extended to entire state. We investigated the benefits of more distributed types of processing networks, in terms of the overall economics and the robustness to demand variations. No change in designed DEG system and distribution network was observed when the demand was lowered to 90%, 75% and 60% of original demand.

Keywords: Palm oil biomass; bio-power; decentralized electricity generation; optimization; supply chain network

INTRODUCTION

Rising concern about the effect of greenhouse gas (GHG) emissions on climate change is pushing national governments and the international community to achieve sustainable development in an economy that is less dependent on carbon emitting activities is a vision that is usually termed a "low-carbon society" (LCS). Electricity is conceivably the most multipurpose energy carrier in modern global economy, and therefore primarily linked to human and economic development as well as the environment. Energy sector reform is critical to sustainable energy development. Global dependence on fossil fuels has led to the release of over 1100 $GtCO_2$ into the atmosphere since the mid-19th century. Currently, energy-related GHG emissions, mainly from fossil fuel combustion for heat supply, electricity generation and transport, account for around 70% of total emissions including carbon dioxide, methane and some traces of nitrous oxide. This multitude of aspects play a role in societal debate in comparing electricity generating and supply options, such as cost, GHG emissions, radiological and toxicological exposure, occupational health and safety, employment, domestic energy security, and social impressions [1]. Through the different stages of development, humankind has experimented with various sources of energy ranging from wood, coal, oil and petroleum to nuclear power. In recent years, public and political sensitivities to environmental issues and energy security have led to the promotion of renewable energy (RE) resources.

Better access to modern energy sources and electricity is an obligatory for improving living standards and reducing poverty in rural areas of developing countries. Currently over 1.6 billion people (85% of the world population) living in rural areas have no access to electricity [2]. Electrification rates in rural areas of developing countries are substantially low. Even when electricity supply is available, the service is unreliable and expensive. The electricity issue in rural areas cannot be solved as a simple problem of demand and supply, or as a mere logistic problem to provide electricity services. There is significant debate over the best means to carry out the electrification process. Most developed countries rely on a centralized electricity generation and distribution system. Electricity is generated at scale in large central plants and then distributed to end users through a transmission network. These networks can be expensive and in most cases take many years or decades to fully develop. Also these centralized energy supply systems are losing its attractiveness due to a number of further annoying factors including the depletion of fossil fuels and their climate change impact, the insecurities affecting energy transportation infrastructure, and the desire of investors to minimize risks through the deployment of smaller-scale, modular generation and transmission systems [3]. An alternative for electrification of rural and remote areas is the introduction of decentralized conversion technologies using resources locally available. Decentralized electrification can provide a more reliable supply and generate income derived from the use of local resources [4].

Decentralized electrification using local resources can reduce regional disparity in rural and remote areas in terms of supply reliability and cost, as well as promote income generation. This study focuses on the decentralized electricity generation (DEG) from biomass and the distribution network. One of the most important and challenging aspects of DEG is the design and operation of biomass and biopower supply chain networks. Supply chain modeling and supply chain system (SCS) optimization have received a lot of attention among companies and academic research groups alike in recent years [1]. Several models and solutions that can be used as decision support tools for strategic analysis as well as tactical planning of the energy systems have been proposed. But no remarkable work has been done for decentralized bio-power systems. This paper presents a general decentralized energy optimization model for developing countries that enables the selection of biomass conversion technologies, capacities, biomass conversion plant locations, and the logistics of transportation from the biomass sites to the conversion sites and then to deliver electricity to specific demand locations.

BACKGROUND

Access to electricity is an important component of rural development. Better access to electricity has been correlated to the improvement of living conditions in several aspects, such as education and income generation. Electrification in rural areas of developing countries, and in particular in the case of remote areas, is difficult due to low population densities, highly dispersed location of populated centers, low energy consumption levels per capita and poor road infrastructure which constrains transportation. This makes conventional rural electrification programs based on extension of the electricity grid and decentralized schemes with foreign fuels expensive or even economically not feasible. Rural electrification programs often require direct governmental support in the form of subsidies. In rural areas where energy resources are widely available in the form of agricultural wastes and forest biomass, DEG using local resources is more suitable as an alternative for electrification. DEG avoids the necessity of extending transmission lines to dispersed populated centers, reduces the dependence on foreign fuels within these areas, and promotes local development through the introduction of the production chain of biomass energy [4]. Biomass is one such resource that could play a substantial role in a more diverse and sustainable energy mix [5]. Biomass, a major source of energy in the world until before industrialization when fossil fuels become dominant, appears an important renewable source of energy and researches have proven from time to time its viability for large-scale production [3]. DEG utilizing biomass is gaining increasing interest for electrification for rural areas in developing countries. A lot of studies have been made in last two decades to assess and implement decentralized power systems including the literature dealing with energy planning supported by mathematical models [3]. Most models applied for designing decentralized energy systems describe the optimal mix of energy resources and technologies under a certain objective function and set of constraints. The analytical approach generally used in these models is single-period optimization [6, 7]. In addition to optimization, there are studies deploying simulation and geographic information systems (GIS) methodologies that give more emphasis to supply stability and optimal allocation of resources [8-10]. Decentralized energy systems have also been designed by means of multi-criteria and multi-objective methodologies [11-16]. A more comprehensive review of model applications for designing rural energy systems is provided by Nakata et al. [17]. Recently, [4] designed decentralized energy systems for rural electrification in developing countries using LP optimization model. In this only available research on decentralized energy system for biomass utilization, authors focused on the regional disparity incorporated by disaggregating electricity demand into urban, rural and remote areas. It is worth noting that among these studies complete assessment of DEG encompassing from source RE fuel, technology selection, optimal site selection, market assessment and distribution network for final product; electricity is not yet explored. This paper suggests a complete DEG system for biopower with SCS. The model is formulated as MINLP optimization problem. The MINLP represents decisions regarding (1) the optimal number, locations, and sizes of various types of processing plants, (2) the amounts of biomass transported, and electricity to be transmitted between the selected locations over a selected period, and minimizes the objective function of overall generation cost.

METHODOLOGY

This study focuses on the DEG from biomass and the distribution network. One of the most important and challenging aspects DEG is the design and operation of biomass and biopower supply chain networks. The performance of the energy system is evaluated according to the net costs of the system. The design of the energy system provides the most suitable conversion technology (or combination of technologies), suitable locations to install conversion plant of selected technology to meet a certain quantity of electricity demand under a set of goals and constraints. Being widely available in target area, Palm oil biomass is considered as RE source. Energy conversion technologies included in the system are combustion, gasification and pyrolysis. The demand-side of the energy system only considers the total amount of electricity demanded in the residential, industrial, and commercial sectors at specifics demand locations. The possible routes for production of electricity from biomass through these selected technologies are illustrated in Fig. 1.

Superstructure representation of proposed DEG system

The proposed model enables the selection of biomass conversion technologies, capacities, biomass locations, and the logistics of transportation from the locations of palm oil mils to the conversion sites and then to deliver electricity to specific demand locations. The conceptual layout of the proposed model is illustrated in Fig. 2, while the proposed superstructure is shown in Fig. 3. The superstructure consists of: (a) A set of biomass types "s (s_1, s_2, s_3)" available at biomass sites "r (r_1, r_2, r_3,….., r_n)" to be used as a feedstock to three conversion technologies "j (j_1, j_2, j_3)" i.e. combustion, gasification and pyrolysis. (b) A set of candidate sites "l (l_1, l_2, l_3, ……., ln)" for conversion plants of various capacity options "c (c_1, c_2, c_3)", i.e. small, medium and large, for each technology where biomass is converted to electricity. (c) A set of market locations "m (m_1, m_2, m_3,……….., m_n)" where specific demand has to be satisfied.

Formulation of the optimization model

An MINLP model has been formulated. The MINLP represents decisions regarding (1) the optimal number, locations, and sizes of various types of processing plants, (2) the amounts of palm oil biomass transported, and electricity to be transmitted between the selected locations over a selected period, and minimizes the objective function of overall generation cost. The prosed model has been solved for a case study on IM region of state of Johor, Malaysia; however, the model has versatile applications for biomass rich countries to design DEG bio-power supply chain networks.

Problem statement

The objective is to determine the number, location, and size of the three types of processing facilities and the amount of biomass to be transported between the various nodes of the designed network so that the overall cost is minimized while respecting the constraints associated with electricity demand. The input parameters for the problem are listed in Table 1. The decision variables are listed in Table 2. The subscript indices used in the model are listed in Table 3.

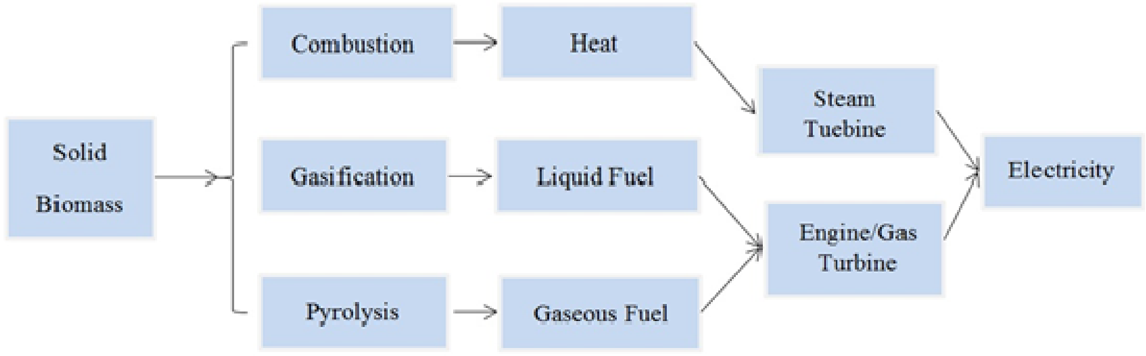

Figure 1: Routes for production of electricity from solid biomass

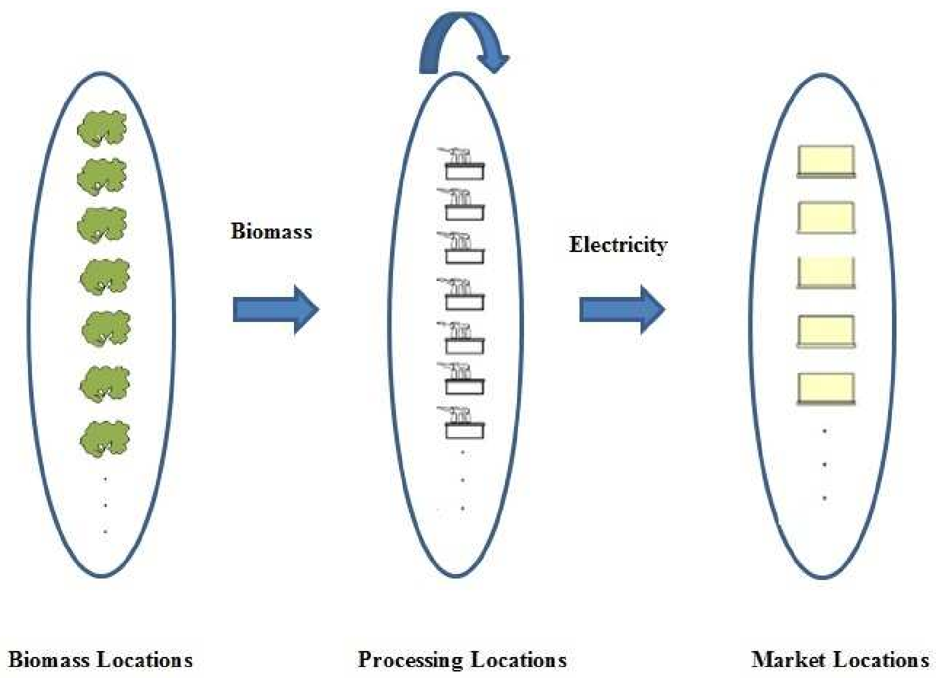

Figure 2: The overall structure of supply chain network system

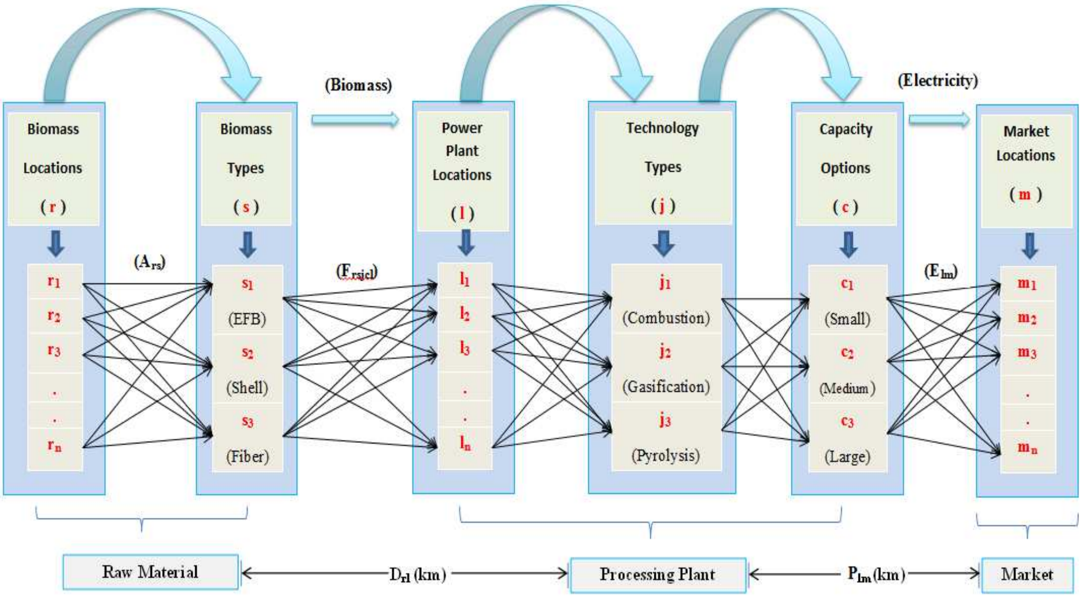

Figure 3: Superstructure representation of Decentralized Bio-Power Generation & Distribution

Objective function

The objective function to be minimized is the overall cost and is shown in equation (1).

$$Cost = TAAC_l + TOPC_l + TTRC_s + TTRNC + TAQC_{rs} \quad (1)$$

Where;

$$TAAC_l = \sum_j \sum_c AAC_{jc} \ X_{jlc} \qquad \forall \ l \quad (2)$$

$$TOPC_l = \sum_j \sum_c OPC_{jc} \ X_{jcl} \qquad \forall \ l \quad (3)$$

$$TTRC_s = \sum_j \sum_c \sum_r \sum_l TRC_{rl} \ X \ F_{rsjcl} \ X \ HYP \qquad \forall \ s \quad (4)$$

$$TTRNC = \sum_l \sum_m TRNC_{lm} \ X \ \mathrm{E_{lm}} \ X \ DPY \quad (5)$$

$$TAQC_{rs} = \sum_c \sum_j \sum_l \mathrm{F_{rsjcl}} \ X \ AQC_{rs} \ X \ HPY \qquad \forall \ r, s \quad (6)$$

Where;

$$TRC_{rl} = D_{rl} \ X \ TRE$$

$$TRNC_{lm} = P_{lm} \ X \ TRNE$$

Table 1: Input parameters for the problem

Symbol	Description	Unit
D_{rl}	Travel distance between biomass site "r" and conversion plant location "l"	Km
P_{lm}	Distance between conversion plant location "l" and final market location "m"	Km
A_{rs}	Available biomass for each type "s" at each biomass site "r"	ton/day
d_m	Toatl demand for "electricity" at each market location "m"	MW
$d_{m(max)}$	Maximum demand for "electricity" at each market location "m"	MW
$d_{m(min)}$	Minimum demand for "electricity" at each market location "m"	MW
CAPcj	Capacity for each plant size option "c" of processing type "j" of conversion plant	MW
AQC_{rs}	Acquisition cost for each biomass type "s" at each biomass site "r"	$/ton
OPC_{jc}	Operating cost for processing type "j" of conversion plant of Capacity size "c" at location "l" on biomass type "s" as feed in DCEG system	$/yr
AAC_{jc}	Annualized capital cost of conversion plant of processing type "j" with capacity size "c"	$/yr
TRE	Transportation expense for transporting biomass "s" from biomass site "r" to conversion plant location "l"	$/Km
TRNE	Transmission expense for electricity transmission from plant location "l" to grid at market location "m"	MW/Km/yr
EFF_j	Processing efficiency of processing type	Dimensionless
CONVE	Conversion factor of biomass to electricity for technology "j" of capacity "c"	MWh/ton
HPD	Conversion factor for days to hours	h/day
DPY	Conversion factor for year to days	day/yr
HPY	Conversion factor for year to hours	h/yr

Table 2: Decision Variables for the problem

Symbol	Description	Unit	Type
Xjcl	Binary variable indicating whether to place a conversion plant of processing type "j" and capacity "c" at location "l"	Dimensionless	Binary
F_{rsjcl}	Amount biomass material type "s" from biomass site "r" to conversion plant of processing type "j" and capacity "c" at location "l"	ton/day	Continuous
E_{lm}	Amount of electricity transmitted from the conversion site at location "l" to the final market location "m"	MW	Continuous

Table 3: Subscripts indices used in Model

Symbol	Description
r	Biomass location
s	Biomass type
l	Possible location of Biomass Conversion Plant
j	Conversion plant processing type (Conversion technology)
c	Processing capacity of conversion plant
m	Market location for final products

Cost components

The Cost has five main components: (a) First is the annualized capital cost. Equations (2) shows the total annualized fixed cost of the chosen capacity options for processing types "j" at locations "l". (b) Second is the operating cost. Equations (3) shows the operating costs for processing types "J" at locations "l" (c) The third component is the transportation cost. Equations (4) describes transportation cost element related to the flows from all biomass raw material sites "r" to the conversion sites "l" for each feed types "s". (d) The fourth component is the transmission/distribution cost. Equation (5) describes transmission cost element related to the flows of electricity from conversion sites "l" to final market locations "m". (e) The fifth component is the total biomass acquisition cost. Equation (6) shows the total biomass acquisition cost for biomass types "s" at biomass sites "r".

These cost components are listed in Table 4.

Mass balance constraints

The mass balance must be satisfied at node of the SCS. Equation (7) is the flow balances at the nodes of locations l and states that at each selected conversion1 plant location l, the sum of the inward flows of all biomass types (indexed by s must be equal to the sum of all the outward flows of electricity from power plant at location l to market location m. Here j is the index for processing type. Also, r is the index for the biomass locations.

$$\sum_{j}\sum_{c}\sum_{r}\sum_{s} F_{rsjcl} \;\; X \;\; CONVE \; X \; HPD \; X \; EFF_j = \sum_{m} E_{lm} \quad \forall \; l \qquad (7)$$

Availability/capacity constraints

The sum of the flows of each biomass type "s" from each biomass site "r" to all the conversion plants cannot exceed the total amount of s^{th} type of biomass that can be availed from the site "r". This biomass availability constraint is expressed as equation (8).

$$\sum_{j}\sum_{c}\sum_{l} \mathrm{F_{rsjcl}} \; X \, HPD \; \leq \; \mathrm{A_{rs}} \quad \forall \; \mathrm{r, s} \qquad (8)$$

The sum of the all biomass types coming from the different sources to each conversion plant location does not exceed the chosen processing capacity at that location. This constraint is expressed as equation (9).

$$\sum_{s}\sum_{r} \mathrm{F_{rsjcl}} \; X \, EFF_j \; X \, CONVE \leq \; CAP_{cj} \;\; X \;\; X_{jcl} \quad \forall \; \mathrm{j, c, l} \qquad (9)$$

There could exist both lower and upper bounds on the demand (the minimum demand level that must be satisfied and the maximum supply level that can be sold). These are expressed as constraints on the production quantity of each final product at each sink location. Both constraints are expressed as equations (10) and (11).

$$\sum_{l} E_{lm} \geq \; d_m(min) \;\; X \; \mathrm{HPD} \quad \forall \; \mathrm{m} \qquad (10)$$

$$\sum_{l} E_{lm} \leq \; d_m \; (max) \; \mathrm{X} \;\; \mathrm{HPD} \quad \forall \; \mathrm{m} \qquad (11)$$

We assume that only a single plant of each processing type is allowed to build at each location, although one can choose from multiple capacity options. This constraint is expressed as equation (12).

$$\sum_{j}\sum_{c} \mathrm{X_{jcl}} \; \leq 1 \quad \forall \; \mathrm{l} \qquad (12)$$

Table 4: Cost Components

Symbol	Description
$TACC_l$	Total annualized fixed cost of the chosen capacity options for processing types "j" at locations "l"
$TOPC_l$	Total operating cost for processing types "j" at locations "l"
$TTRC_s$	Total Transportation Cost for all flows from all raw material sites "r" to the conversion sites for each feed type "s"
TTRNC	Total Transmission/Distribution costs for electricity from conversion plant at location "l" to market location "m"
$TAQC_{rs}$	Total biomass acquisition cost for biomass type "s" at biomass site "r":

Table 5: Projection of Power Supply Demand in IM (2000 - 2025) [19]

Flagship	Power Supply Demand Projection (MW)				
	2005	**2010**	**2015**	**2020**	**2025**
A	443.39	473.54	569.67	700.70	877.27
B	308.35	372.17	490.15	643.57	805.75
C	***1,334.74***	***1,479.34***	***1,800.37***	***2,253.82***	***2,819.97***
D	372.42	405.19	469.61	575.75	719.68
E	114.26	123.63	149.47	184.90	231.12
Total	2,573.16	2,853.87	3,479.27	4,358.74	5,453.79

Figure 4: Iskandar Malaysia [18]

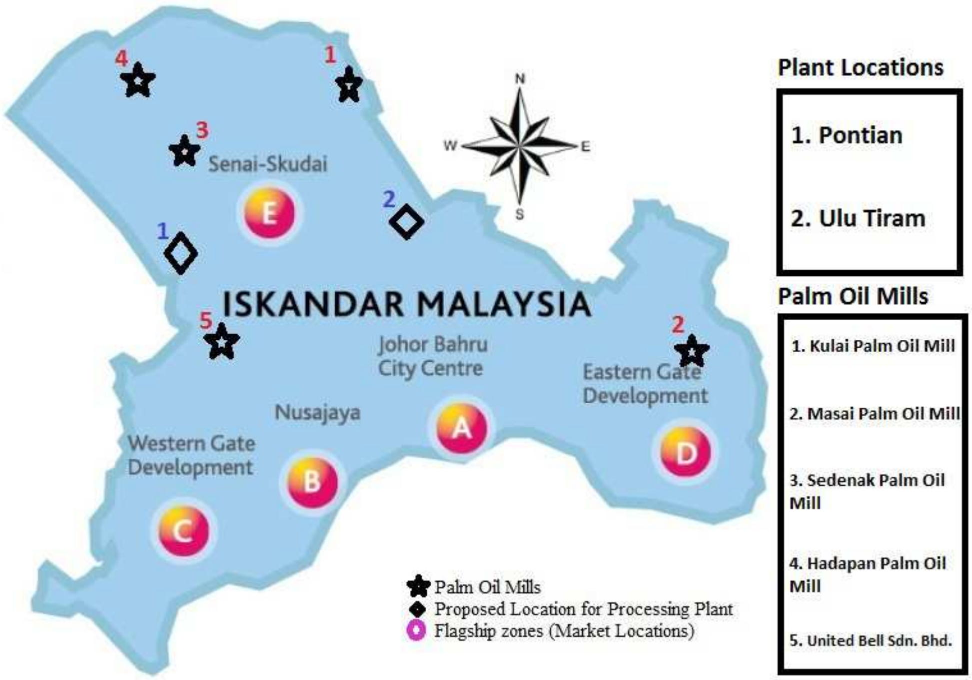

Figure 5: Strategic Flagship Zones of Iskandar Malaysia; adopted from [19]

CASE STUDY FOR MINLP MODEL APPLICATION

Target area

In this case study, we examined a fairly large SCS network design problem for conversion of biomass into electricity within the Iskandar Malaysia (IM) an emerging economic region set-out to be developed as a sustainable city in state of Johor, Malaysia. IM is targeted to have a share of 120 MW (6%) from RE in the energy mix by 2015. Located on the southern-most tip of Peninsular Malaysia, IM is strategically located in the region. Covering an area of 2,217 km^2, approximately three times the size of Singapore, it is easily accessible by land, air and sea (Fig. 4). It has been designated by the Malaysian government to be a prime hub for the 9 economic clusters which will be given special focus and offer excellent investment opportunities.

Being an integrated development, IM has been strategically planned with five Flagship Zones as shown in Fig. 5. Agriculture is still an active and important economic sector in IM. Being the world's second largest producer of palm oil, Malaysia generates huge amount of biomass. Being widely available, Palm oil biomass is considered as RE source in this study. There are a good number of Palm Oil Mills (POMs) that process fresh palm oil and refine crude oil in state of Johor, of which five are within the boundary of IM (Fig. 5) [19]. These five POMs generate considerable amount of palm oil biomass annually. Total Projection of Power Supply Demand IM (2000 - 2025) is shown in Table 5.

In this study palm oil biomass at five POMs in IM (Fig. 5) is considered as biomass source to generate electricity through available and developed technologies; combustion, gasification and pyrolysis, to satisfy the specific electricity demand at four Flagship zones (A, B, D & E) of IM (Fig. 5). Flagship zone C is not considered being its extremely high electricity demand and its larger distances from rural areas where biomass sources are located and to be processed.

Data sources and assumptions

Several up-to-date data used in the study were collected to increase the validity of the model. Data were collected from online database of Iskandar Regional Development Authority, Malaysia and Malaysian Palm Oil Board as well as individually from POMs. We examine biomass processing options; combustion, gasification and pyrolysis to generate electricity. There are six major types of bio-power systems: direct-firing, co-firing, gasification, pyrolysis, anaerobic digestion/fermentation and small, modular systems. Most of the bio-power plants use direct-fired systems. Through gasification, solid biomass can be converted into a gaseous form, known as syngas. The syngas can run through "combined-cycle" gas turbine or other power conversion technology. In addition, gas and liquid fuels can be produced from biomass through pyrolysis. In pyrolysis biomass is heated in the absence of oxygen. The biomass then turns into a liquid called pyrolysis oil, which burns like petroleum to generate electricity. Several bio-power technologies can be installed in small, modular systems which can generates electricity at a capacity of 5 MW or less. Fast pyrolysis system has great potential to generate electricity at a profit in the long term, and at a lower cost than any other biomass to electricity system at small scale. The downdraft gasifier design, being well developed and demonstrated, is the most feasible technology for biomass to energy conversion [3]. A few gasifiers have already been in operation for thirty years and a number of gasification processes are under industrial development at pilot and demonstration scale. Gasifiers are available from Foster Wheeler and Bioneer in Finland, Lurgi in Germany, Vølund in Denmark, TPS in Sweden, PRM Energy in the USA and Repotec in Austria. In addition there is extensive research and development at universities, research institutes and companies around the world. Different technologies are more suitable for different scales of operation as shown in Fig. 6 [20]. Biomass integrated gasification combined cycles (BIGCC) based on pressurized biomass gasification, coupled with economical acceptable hot gas clean-up systems, are one of the most promising options with a high overall conversion efficiency up to 40-50% [21-23]. The first BIGCC running on 100% biomass (straw) has been successfully operated in Sweden. BIGCC offers the opportunity for both performance and environmental advantages, providing a flexible alternative to conventional technologies [24].

In this study, direct combustion (with steam turbine), gasification (pressurized gasification with circulating fluidized bed and gas turbine configuration) and pyrolysis (fast pyrolysis with dual fuel diesel engine configuration) technologies are considered for bio-power generation and BIGCC (in 10-100MW range) is considered as gasification technology. The entire range of systems is shown in Fig. 7 and a comparison of three technologies in term of efficiency, sizes and capital cost is given in Table 6.

Decentralized or distributed network system

The biomass source points of interest in this case study are five POMs in the IM region of state of Johor, Malaysia. Three biomass types; EFBs, fiber and shell are collected from these five biomass source locations.

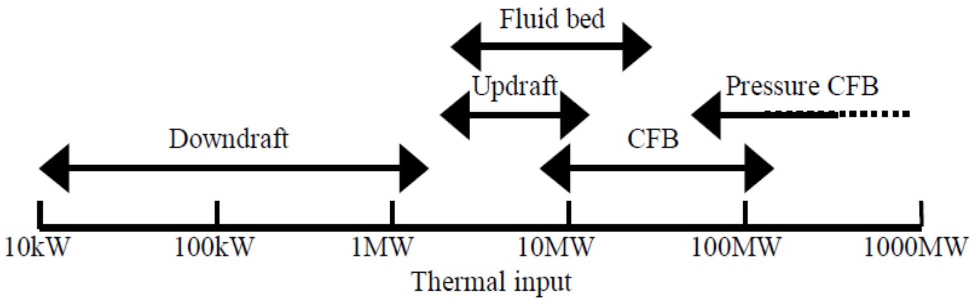

Figure 6: Gasifier Concepts [20]

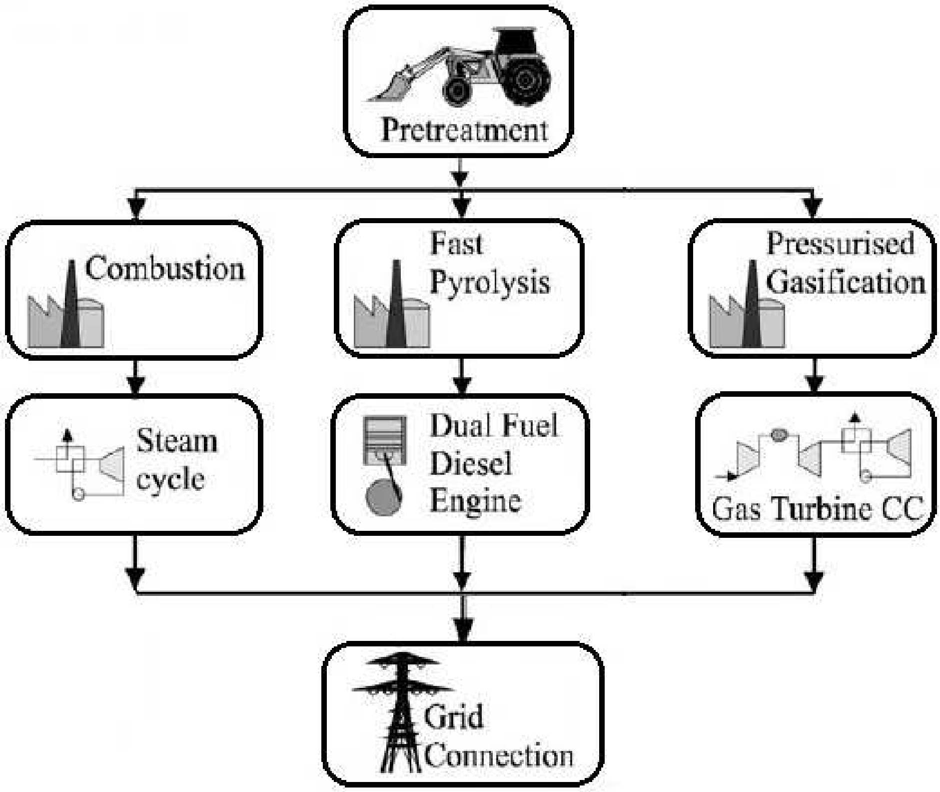

Figure 7: Overall system configuration of technology options

Table 6: Comparison in term of sizes and costs among combustion, gasification and pyrolysis

Data adopted from [25-27]									Calculated data					
Technologies	**Efficiency (EFF) %(LHV)**	**Typical Size MW**	**Selected Sizes (CAP) MW**			**Average Capital Cost (2007, USA) (C_{2007}) $/kW**			**Calculated Average Capital Cost (2012, Malaysia)* Million $** $C_{2012} = 1.3\ X \left(C_{2007} X 1000\ X\ Cap\ X\ \frac{PPI}{100}\right) X\ 10^{-6} = 1.8551\ X\ 10^{-3}\ X\ C_{2007}\ X\ Cap$			**Calculated Annualized Capital Cost Million $/Year** † $ACC = \frac{R_i\ X\ C_{2012}}{1 - \frac{1}{(1+R_i)^n}} = 0.9427\ X\ C_{2012}$		
			Small (S)	**Medium (M)**	**Large (L)**	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
Combustion	35	10-240	10	40	80	5000	3700	3000	1069	317	129	114	34	14
Gasification (BIGCC)	45	10-100	10	30	50	5500	4000	2500	1411	151	47	150	16	5
Pyrolysis	25	5-10	5	-	10	7000	-	5000	599	-	214	64		23

* Inflation was calculated using 2011 PPI= 142.7 (Series Id: PCU221110221110P) [28] andan excess of 30% is assumed for technology transfer to Malaysia.

† R_i = Annual Interest Rate (kept at 10%), and
n = Number of years over which the plant is expected to be financed (assumed 30 years).

These biomass materials can be converted into electricity at two possible locations for either of combustion, gasification or pyrolysis conversion plants of small, medium or large capacity. The produced electricity is then transmitted to four final markets; Flagship A, B, D and E. Latitude and longitude of each location are converted into distance matrices. Key parameter values are summarized in Table 7-15. Capital is amortized over a period of 30 years, assuming all of the capital is loaned, with a nominal interest rate of 10%. Operating costs were calculated for continuous operation including processing costs, maintenance cost and the plant overheads, no start-up costs were included. The plant maintenance costs account for 2.5% of total capital requirement (TCR) and the plant overheads are 2% of TCR. Processing expense for combustion accounts for 3.5% of TCR, for IGCC it is 7% of TCR and for pyrolysis it accounts for 10% of TCR [29]. The default values used for calculating all costs are summarized as: 30 years project life, 10% interest rate, 85% capacity/load factor (6200 h/yr or 310 day/yr) and biomass cost 19.70 $/ton.

The size and execution time of the problem are summarized in Table 16. The machine details are Intel®-Core™- i5 2410M CPU 2.30 GHz and 4.00 GB RAM

OUTCOMES OF MINLP MODEL APPLICATION

After compiling and running the mathematical model in GAMS (version WEX-VS8 23.7.3), using the CONOPT 3 solver (version 3.15A), 23.7.3 WIN 27723.27726 VS8 x86/MS Windows, the following optimized results (selected sites, technology, and capacity options) are obtained and are presented in Table 17-23 and Fig. 8.

Table 7: Biomass material volume at biomass locations; (A_{rs}) [30]

Biomass Location	Amount of biomass available (ton/day)		
	EFB	**Shell**	**Fiber**
POM-1	100	58	23
POM-2	190	109	59
POM-3	295	166	90
POM-4	140	80	43
POM-5	184	104	56

Table 8: Maximum & Minimum final electricity demand at final market locations; (d_m) [19]

Market Location	Demand*; d_m (MW)	Maximum demand; d_m(max) (MW)	Minimum demand; d_m(min) (MW)
Flagship A	22.78	30	23
Flagship B	19.61	30	20
Flagship D	18.78	25	19
Flagship E	5.79	10	6

*4% of demand forecasted for 2015 is taken as targeted demand from Table 5

Table 9: Acquisition cost of biomass types “s” at conversion sites “r”; (AQC_{rs}) [$/ton] [31, 32]

Location / Capacity	POM-1	POM-2	POM-3	POM-4	POM-5
EFB	19.70	19.70	19.70	19.70	19.70
Shell	19.70	19.70	19.70	19.70	19.70
Fibre	19.70	19.70	19.70	19.70	19.70

Table 10: Annualized capital cost of conversion plant of processing type "j" with capacity size "c"; (ACC_{jc}) [$/yr]; Calculated in Table 6

Technology / Capacity	Direct Combustion	Gasification	Pyrolysis
Small	114,000,000	150,000,000	64,000,000
Medium	34,000,000	16,000,000	-
Large	14,000,000	5,000,000	23,000,000

Table 11: Operating cost for processing type "j" of conversion plant of capacity size "c"; (OPC_{jc}) [$/ yr]

Technology / Capacity	Direct Combustion	Gasification	Pyrolysis
Small	9,120,000	17,250,000	9280,000
Medium	2,720,000	1,840,000	
Large	1,120,000	575,000	3335,000

Table 12: Capacity options; (CAP_{cj}) [(ton/day)]

Capacity parameter		Direct Combustion	Gasification	Pyrolysis
*CAP_{cj}	Small	10	10	5
	Medium	40	30	
	Large	80	50	10

*Table 6

Table 13: Distance matrix from biomass to processing plant location"1"; (D_{rl}) [Km]

Location	L1	L2
(POM-1)	61	37
(POM-2)	72	27
(POM-3)	47	51
(POM-4)	54	77
(POM-5)	30	54

Table 14: Distance matrix from processing plant location "1"to market location "m"; (P_{lm})* [Km]

Location	L1	L2
Flagship A	69	26
Flagship B	52	21
Flagship D	45	56
Flagship E	49	35

* As there is no need to develop new transmission lines, so 20Km new transmission line is assumed to build for each location

Table15: Other scalars/parameters used in model

Scalar/Parameter	Value	Unit	Remarks
TRE	10.55	$/km-ton	[32]
TRNE*	0.0098	$/km-MWh	[33]
HPD	20	h/day	@ 85% load factor
DPY	310	day/yr	@ 85% load factor
HPY	6200	h/yr	HPD X DPY
EFF_j			
Direct Combustion	35	% (LHV)	Table 6
Gasification	45	% (LHV)	
Pyrolysis	25	% (LHV)	

*TRNE value 104.3 $/kW-yr for 750 miles transmission line from [33] converted to $/km-MWh

Table 16: The size of the problem and the execution time to solve

100 % demand case	
Blocks of equations	12
Blocks of variables	9
Number of single equations	69
Number of single variables	302
Number of non-zero elements	1477
Number of discrete variables	18
Execution time	0.016 sec

Table 17: The selected conversion processing sites and technology and capacity for distributed network system

Demand case	**Technology**	**Plant location**	**Capacity**		
			Small	**Medium**	**Large**
100%	Combustion	Location 1	X	x	x
		Location 2	X	x	x
	Gasification	Location 1	X	x	✓
		Location 2	X	x	✓
	Pyrolysis	Location 1	X	x	x
		Location 2	X	x	x
90%	Combustion	Location 1	X	x	x
		Location 2	X	x	
	Gasification	Location 1	X	x	✓
		Location 2	X	x	✓
	Pyrolysis	Location 1	X	x	x
		Location 2	X	x	x
75%	Combustion	Location 1	X	x	x
		Location 2	X	x	x
	Gasification	Location 1	X	x	✓
		Location 2	X	x	✓
	Pyrolysis	Location 1	X	x	x
		Location 2	X	x	x
60%	Combustion	Location 1	X	x	x
		Location 2	X	x	x
	Gasification	Location 1	X	x	✓
		Location 2	X	x	✓
	Pyrolysis	Location 1	X	x	x
		Location 2	X	x	x

Table 18: Selected plant locations for electricity supply to satisfy market location demand

Demand case	Biomass Site	Biomass Type	Plant Location	
			Location 1	Location 2
100%	POM-1	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-2	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-3	EFB	✓	✓
		Shell	✓	✓
		Fibre	✓	✓
	POM-4	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x
	POM-5	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x
90%	POM-1	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-2	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-3	EFB	✓	✓
		Shell	✓	✓
		Fibre	✓	✓
	POM-4	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x
	POM-5	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x
75%	POM-1	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-2	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-3	EFB	✓	✓

		Shell	✓	✓
		Fibre	✓	✓
	POM-4	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x
	POM-5	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x
60%	POM-1	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-2	EFB	x	✓
		Shell	x	✓
		Fibre	x	✓
	POM-3	EFB	✓	✓
		Shell	✓	✓
		Fibre	✓	✓
	POM-4	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x
	POM-5	EFB	✓	x
		Shell	✓	x
		Fibre	✓	x

Table 19: Selected plant locations for electricity supply to satisfy market location demand

Demand case	Plant location	Flagship A	Flagship B	Flagship D	Flagship E
100%	Location 1	x	✓	✓	x
	Location 2	✓	✓	x	✓
90%	Location 1	x	✓	✓	x
	Location 2	✓	✓	x	✓
75%	Location 1	x	✓	✓	x
	Location 2	✓	✓	x	✓
60%	Location 1	x	✓	✓	x
	Location 2	✓	✓	x	✓

Table 20: Amount of biomass to be supplied to conversion plants; (ton/day); (on 100% demand)

Biomass Site	Biomass Type	Amount of Biomass to be transported to		Total
		Location 1	**Location 2**	
POM-1	EFB	x	4.512	13.536
	Shell	x	4.512	
	Fibre	x	4.512	
POM-2	EFB	x	4.512	13.536
	Shell	x	4.512	
	Fibre	x	4.512	
POM-3	EFB	2.256	2.256	13.536
	Shell	2.256	2.256	
	Fibre	2.256	2.256	
POM-4	EFB	4.512	x	13.536
	Shell	4.512	x	
	Fibre	4.512	x	
POM-5	EFB	4.512	x	13.536
	Shell	4.512	x	
	Fibre	4.512	x	
Total		**33.84**	**33.84**	
Grand Total				**67.68**

Table 21: Amount of electricity to be transmitted to market location; (MW); (on 100% demand)

Market Location	Amount of electricity to be transmitted from		Total
	Location 1	Location 2	
Flagship A	x	23	23
Flagship B	15	5	20
Flagship D	19	x	19
Flagship E	x	6	6
Total	34	34	
Grand Total			**68**

Table 22: Summary of optimized costs; (M$/yr)

No.	Cost component	Optimized cost
1.	Total annualized fixed capital cost	3.400000000
2.	Total processing cost	0.391000000
3.	Total transportation cost	2.416693378
4. e	Total transmission cost	0.082633600
5.	Total acquisition cost	0.022907046
6.	**Total cost**	**6.313234024**

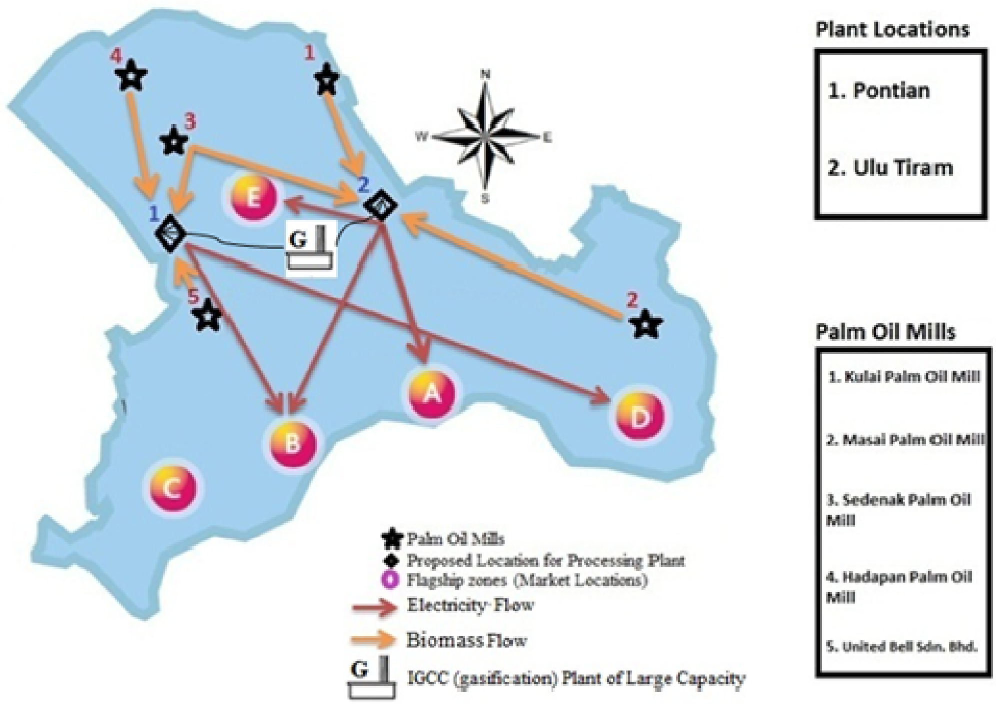

Figure 8: Optimal DEG system for IM

RESULTS AND DISCUSSION

The proposed optimization MINLP model is tested for designing distributed biomass processing network systems to generate electricity for IM region in State of Johor, Malaysia. In the optimal distributed processing network designed with maximum demands at an optimized total annual cost of **6.313234024** M$/yr, biomass resources selected from the five biomass sites are transferred to two selected conversion plant locations. For both selected conversion sites, gasification technology based power plant of 50 MW capacities each are selected to satisfy a total electricity demand of 68 MW (4% of total demand to be satisfied by palm oil biomass as RE source as per government policy) at four market locations. 33.84 ton/day of biomass is required to be transported to each location from all five biomass sites. POM-1 & 2 will satisfy the biomass demand at location 1, POM 4 & 5 for location 2, while POM 3 will partially serve for both locations. The demand at market locations Flagship A & E will entirely be satisfied by plant at location 2, Flagship D entirely by plant at location1, while the demand at Flagship B will be satisfied partially by plants at both locations. A total amount of 1697 ton/day of palm oil biomass is currently available in IM out of which 3.99% is required to satisfy 4% of total electricity demand (until 2015) of the region. We lowered the demands from 100% (of the values given in Table 10) to 90%, 75% and 60% to reflect possible market demand fluctuations, and designed optimal processing networks for each demand scenario.

Optimal DEG system design

Results show that the minimum production cost for electricity from palm oil biomass is 6.313234024 M$ per annum. Electricity is produced to satisfy a total annual electricity demand of 68 MW for IM region, and to satisfy the government policy of 5 percent country's electricity consumption to be produced from biomass (assuming 4 percent from palm oil biomass while 1 percent from other sources of biomass is assumed). T he cost of production is obtained by the optimizer in order to meet the electricity demand of 4 percent from the annual electricity usage (100% demand case) of the region. No change in distribution network was observed when the demand was lowered to 90% , 75% and 60% except the optimized cost reduced to 5.681910622 M$ per annum for 90% , 4.734925518 M$ per annum for 75%, and 3.787940415 M$ per annum for 60% demand case. While, amount of biomass require to be processed at each location reduced to 30.384 ton/day for 90%, 25.344 ton/day for 75%, and 20.304 ton/day for 60% demand case. Biomass sites to plant locations flows and plant locations to market locations flows remain unchanged. For the capacities of each technology selected for this study, the model gave optimal results for a demand increase up to 135% and infeasible for a demand of 140%. This means that the current DEG system can serve for demand of next 10-15 year without adding any infrastructure investment and it can be predicted that addition of additional units at the same selected locations can serve the demand for next 30-40 years. Biomass based power generating technologies are still not fully matured enough to cater the high amounts of feedstock and to satisfy the higher electricity demands. Research and development work in the area is progressing on a reasonable pace and more effective plants with improved efficiency and higher capacities are expected to be developed at commercial scale in near future. It is envisaged that DEG biopower systems will contribute major share in RE mix.

As, IM have a palm oil biomass potential of 1697 ton/day but limitations over capacity of processing technologies restrict the biopower generation for higher demands. Future systems for biomass power will be able to handle the large amount of biomass and the model will serve a bottom up model for energy planners for IM.

Based on the costs, capacity and efficiency of three technologies considered in this study, the model selected BIGCC for optimal DEG network. The more established systems present a lower risk to potential developers of biomass to electricity systems. Risk is often a very important factor is system selection and would tend to favor the combustion option being more developed. In future systems, as, fast pyrolysis has only a slight advantage over the gasification and combustion options, especially at small scales, due to decoupling options that are not available in combustion or gasification based-systems. De-coupled fast pyrolysis systems may be more cost-effective than the alternative technologies in particular circumstances. Thus in future systems the fast pyrolysis option can be expected to face stiff competition from alternative systems.

MINLP Model Application For State Of Johor As Target Area

The formulated MINLP Model was first tested for a small region of Johor State, Malaysia. After having satisfactory results it was also tested for larger data sets in order to validate the reliability of model. For whole State, there are sixty six POMs and eight demand locations which makes problem more complex. Three biomass types; EFBs, fiber and shell are collected from these sixty six biomass source locations (POMs situated in State of Johor, Malaysia). These biomass materials can be converted into electricity at eight possible locations for either of combustion, gasification or pyrolysis conversion plants of small, medium or large capacity. The produced electricity is then transmitted to eight final market locations. In optimal DEG system, a combination of combustion and gasification technology was selected by optimizer at all proposed location to satisfy the demand at all market locations and the scenario was remained unaffected by demand fluctuation when demand was lowered to 90%, 75% and 60% of original demand. This proved that the formulated model is capable to handle complex and larger problems and can be used for designing DEG systems for regions having biomass resources especially in developing countries where rural areas still need electrification.

Conclusions

Optimization model has been formulated and tested to design optimal DEG networks by considering acquisition costs of the biomass, operating costs, capital costs, transportation costs, and electricity transmission costs. We compared DEG system in terms of generation cost and robustness, as measured by the sensitivity of the cost per year, to demand variations. The model can be applied to all types of biomass like agriculture wastes, forest wastes or combination of different types available at particular locations. Especially, in rural areas where energy resources are widely available, DEG using local resources is more suitable as an alternative for electrification.

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