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ORIGINAL ARTICLE

Optimal Biomass Transportation Model

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ABSTRACT – The transportation represents a key proportion of the operational cost for the biomass industries worldwide. As biomasses are mainly carried by trucks for parts of the transportation, the focus of this paper is on the transport of treated and untreated biomass (rice husk, empty fruit bunch, and woody biomass) by large, medium and small trucks. The objectives were to formulate biomass transportation model for transporting treated and untreated biomass resources and to obtain optimal result for selecting the best transportation mode. By screening of biomass types, locations for treated and untreated biomass resources and screening of suitable transportation mode used, the important model parameters were obtained and linear programming for minimizing overall transportation costs was formulated. General Algebraic Modelling System (GAMS) software was used to solve the optimization formulations. From the optimization result obtained by using GAMS, large truck was selected to be the best transportation mode for treated, untreated and hybrid biomass since it showed minimal overall transportation cost.

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Transportation Mode
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GAMS

INTRODUCTION

Biomass is one of the most vital renewables in Malaysia together with solar, small hydro power and biogas resources [1]. Biomass could produce energy in the form of biofuels which have huge potentials to solve the challenges of energy crisis faced by the world nowadays [2]. It differs from fossil resources in many ways, including organic, inorganic, energy contents and physical properties [3]. Malaysia as a major agriculture commodity producer is well-positioned against the ASEAN countries to encourage the utilization of biomass as a renewable energy source in the national energy mix [1,4]. One of the biggest challenges for expanding the bioenergy industry is a sustainable and economical procurement system for biomass feedstock supplies. Transportation is a key factor that often accounts for significant portion of the delivered cost [5]. In the context of biomass, transportation efficiency is a challenge by considering the whole supply chain.

Transportation from forestry harvest areas to mills costs the forestry industry millions of dollars annually, accounting for up to half of the operational costs in forestry supply chains [6]. Given the level of spending on transportation costs, even small increases in efficiency can reduce costs substantially [7]. Biomass transportation cost will dictate feedstock receiving cost and the overall biomass market competitiveness. There are several modes of transportation are used in forestry: truck, train, ship and water [2]. As biomass are mainly delivered by trucks as the transportation mode, the focus is on the transport of treated and untreated biomass by different types of trucks, i.e small, medium and large sizes of trucks. Issues are related to transportation cost minimization target.

Previous biomass transportation models were studied by [8] for biomass collection, storage and plant sizing for ethanol production, and the new integrated biomass logistical centre (IBLC) by [9]. There was another work which studied about the solution of multi-echelon biomass supply chain synthesis problem by proposed an improved mathematical model. The problems which take in consideration by the researchers are processing hub selection, biomass allocation design and transportation mode selection, with the consideration of vehicle capacity constraints [10].

The previous works that were mentioned have not focus on the type of trucks that will be used in hauling the biomass as well as the conditions of the resources. Hence, the objectives of this paper are to formulate optimization model for biomass transportation using treated and untreated biomass resources (rice husk, empty fruit bunch and woody biomass) and to obtain optimal result for selecting the best transportation mode. The important model parameters are obtained to formulate linear programming for minimizing overall transportation cost by selection of suitable biomass resources, identify locations for treated and untreated biomass resources, and screen for suitable transportation modes. The GAMS software is used to solve the optimization formulation and to obtain the best transportation mode to transport treated, untreated and hybrid biomass resources.

METHODOLOGY

There were three scenarios were studied in this paper; (1) Optimization model for biomass transportation using treated biomass resources, (2) Optimization model for biomass transportation using untreated biomass resources and (3) Optimization model for biomass transportation using hybrid biomass resources (treated and untreated). The overall

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transportation costs considered in both cases are the raw material cost, transportation cost and carbon dioxide (CO_2) emission cost. Parameters that used in the modelling were obtained from sources include Google Maps for distance determinations, from [3], and [11]. It is need to mentione that, there will be a significant difference on the raw material cost between treated and untreated ones since is the former is expensive compared to the latter. Figure 1 shows the flow chart of the whole research process for all scenarios. . First, three suitable and commonly used biomass resources available in Malaysia were chosen according to their availabilities The locations for treated and untreated biomass resources were identified based on surveys and communications Then, suitable modes of transportation that include all categories of trucks were screened. Next, model parameters which are crucial obtained are used to formulate linear programming for minimizing overall transport cost.

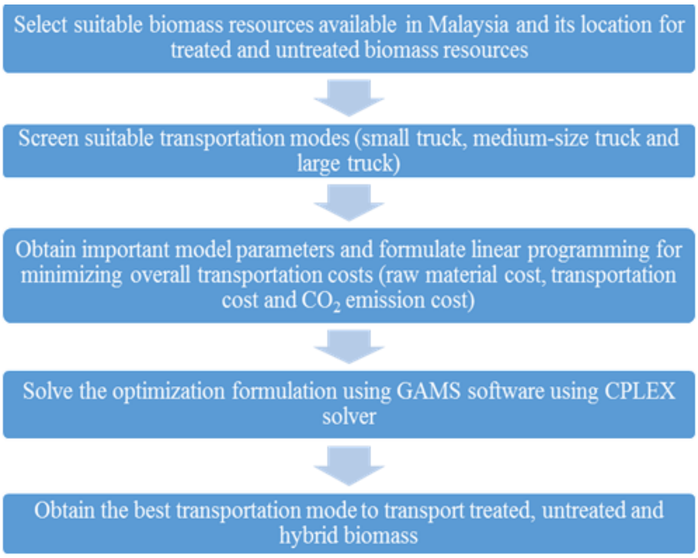

Figure 1. Flow chart of methodology

The formulation for the optimal selection was based on the overall transportation costs of treated and untreated biomass in month basis. The raw material cost, transportation cost and CO_2 emission cost of each truck type had been considered, while the other associated costs were neglected. Three scenarios are simulated: Optimization model for biomass transportation using (1) all treated biomass resources, (2) all untreated biomass resources and (3) hybrid - random mixed of treated and untreated biomass resources. For the formulation each scenario, details as shown below;

Scenario 1: Optimization model for biomass transportation using all treated biomass resources

In the model's formulation for Scenario 1, overall transportation cost minimization for treated biomass resources was the objective function. It was indicated by considering raw material cost of treated biomass resources, transportation cost for treated biomass resources and carbon dioxide gas emission cost of truck. Mathematical model that contain the objective function's details are shown by Eq. (1) till Eq. (4). Meanwhile, Eq. (5) till Eq. (7) represent the model's constraints. Explanations for each formulation for Scenario 1 were tabulated in Table 1. Following the table, each term in all of those formulations was explained in Table 2.

$$OTC_x = RMC_x + TC_x + CO2EC_x \qquad \text{Eq. (1)}$$

$$RMC_x = [(x1 + x2 + x3) * CTRHT] + [(x4 + x5 + x6) * CTEFBT] + [(x7 + x8 + x9) * CTWBT] \qquad \text{Eq. (2)}$$

$$TC_x = \{[(FREQS * x1 + FREQM * x2 + FREQL * x3) * DISTTRH] + [(FREQS * x4 + FREQM * x5 + FREQL * x6) * DISTTEFB] + [(FREQS * x7 + FREQM * x8 + FREQL * x9) * DISTTWB]\} * TCTK \qquad \text{Eq. (3)}$$

$$CO2EC_x = \{[(DISTTRH * x1 + DISTTEFB * x4 + DISTTWB * x7) * LCS * FREQS] + [(DISTTRH * x2 + DISTTEFB * x5 + DISTTWB * x8) * LCM * FREQM] + [(DISTTRH * x3 + DISTTEFB * x6 + DISTTWB * x9) * LCL * FREQL]\} * CO2TK * CCO2T \qquad \text{Eq. (4)}$$

$$x1 + x2 + x3 = e = SATRH \qquad \text{Eq. (5)}$$

$$x4 + x5 + x6 = e = SATEFB \qquad \text{Eq. (6)}$$

$$x7 + x8 + x9 = e = SATWB \qquad \text{Eq. (7)}$$

Table 1. Description of mathematical formulations in Scenario 1

Formulation	Description
Eq. (1)	Objective function and overall transportation cost equation for treated biomass in RM/month
Eq. (2)	Raw material cost for treated biomass in RM/month
Eq. (3)	Transportation cost for treated biomass in RM/month
Eq. (4)	Carbon dioxide gas emission cost for delivering treated biomass in RM/month
Eq. (5)	Constraint to ensure the supply ability of supplier for treated rice husk can cover the amount of raw material needed in plant
Eq. (6)	Constraint to ensure the supply ability of supplier for treated empty fruit bunch can cover the amount of raw material needed in plant
Eq. (7)	Constraint to ensure the supply ability of supplier for treated woody biomass can cover the amount of raw material needed in plant

Table 2. Description of terms used in Eq. (1) till Eq. (7)

Term	Category	Description
OTC_x	Parameter	Overall transportation cost of treated biomass in RM/month
RMC_x	Parameter	Overall transportation cost factor for raw material cost of treated biomass in RM/month
TC_x	Parameter	Overall transportation cost factor for transportation cost of treated biomass in RM/month
$CO2EC_x$	Parameter	Overall transportation cost factor for carbon dioxide gas emission cost of treated biomass in RM/month
$CTRHT$	Parameter	Cost of treated rice husk per tonne in RM/tons
$CTEFBT$	Parameter	Cost of treated empty fruit bunch per tonne in RM/tons
$CTWBT$	Parameter	Cost of treated woody biomass per tonne in RM/tons
$FREQS$	Parameter	Frequency of small truck for deliver biomass from supplier to plant
$FREQM$	Parameter	Frequency of medium truck for deliver biomass from supplier to plant
$FREQL$	Parameter	Frequency of large truck for deliver biomass from supplier to plant
$DISTTRH$	Parameter	Distance to deliver treated rice husk from the supplier to plant per trip in m
$DISTTEFB$	Parameter	Distance to deliver treated empty fruit bunch from the supplier to plant per trip in m
$DISTTWB$	Parameter	Distance to deliver treated woody biomass from the supplier to plant per trip in m
$TCTK$	Parameter	Average transportation cost of truck per tonne per kilometre in RM/tons.km
LCS	Parameter	Loading capacity of small truck in tons
LCM	Parameter	Loading capacity of medium truck in tons
LCL	Parameter	Loading capacity of large truck in tons
$CO2TK$	Parameter	Carbon dioxide gas emitted by truck per tonne per kilometre
$CCO2T$	Parameter	Emission cost of carbon dioxide per tonne in RM/ tons
SATRH	Parameter	Supply ability of supplier for treated rice husk
SATEFB	Parameter	Supply ability of supplier for treated empty fruit bunch
SATWB	Parameter	Supply ability of supplier for treated woody biomass
$x1$	Decision Variable	Amount of treated rice husk transported by small truck a month in tons/month
$x2$	Decision Variable	Amount of treated rice husk transported by medium truck a month in tons/month
$x3$	Decision Variable	Amount of treated rice husk transported by large truck a month in tons/month
$x4$	Decision Variable	Amount of treated empty fruit bunch transported by small truck a month in tons/month
$x5$	Decision Variable	Amount of treated empty fruit bunch transported by medium truck a month in tons/month
$x6$	Decision Variable	Amount of treated empty fruit bunch transported by large truck a month in tons/month
$x7$	Decision Variable	Amount of treated woody biomass transported by small truck a month in tons/month
$x8$	Decision Variable	Amount of treated woody biomass transported by medium truck a month in tons/month
$x9$	Decision Variable	Amount of treated woody biomass transported by large truck a month in tons/month

Scenario 2: Optimization model for biomass transportation using all untreated biomass resources

In the model's formulation for Scenario 2, overall transportation cost minimization for untreated biomass resources was the objective function. It was indicated by considering raw material cost of untreated biomass resources, transportation cost for untreated biomass resources and carbon dioxide gas emission cost of truck. Linear programming that contain the objective function's details are shown by Eq. (8) till Eq. (11). Meanwhile, Eq. (12) till Eq. (15) represent the model's constraints. Explanations for each formulation for Scenario 2 were tabulated in Table 3. Following the table, each term in all of those formulations was explained in Table 4.

$$OTC_y = RMC_y + TC_y + CO2EC_y \quad \text{Eq. (8)}$$

$$RMC_y = [(y1 + y2 + y3) * CURHT] + [(y4 + y5 + y6) * CUEFBT] + [(y7 + y8 + y9) * CUWBT] \quad \text{Eq. (9)}$$

$$TC_y = \{[(FREQS * y1 + FREQM * y2 + FREQL * y3) * DISTURH] + [(FREQS * y4 + FREQM * y5 + FREQL * y6) * DISTUEFB] + [(FREQS * y7 + FREQM * y8 + FREQL * y9) * DISTUWB]\} * TCTK \quad \text{Eq. (10)}$$

$$CO2EC_y = \{[(DISTURH * y1 + DISTUEFB * y4 + DISTUWB * y7) * LCS * FREQS] + [(DISTURH * y2 + DISTUEFB * y5 + DISTUWB * y8) * LCM * FREQM] + [(DISTURH * y3 + DISTUEFB * y6 + DISTUWB * y9) * LCL * FREQL]\} * CO2TK * CCO2T \quad \text{Eq. (11)}$$

$$y1 + y2 + y3 = e = SAURH \quad \text{Eq. (12)}$$

$$y4 + y5 + y6 = e = SAUEFB \quad \text{Eq. (13)}$$

$$y7 + y8 + y9 = e = SAUWB \quad \text{Eq. (14)}$$

Table 3. Description of mathematical formulations in Scenario 2

Formulation	Description
Eq. (8)	Objective function and overall transportation cost equation for untreated biomass in RM/month
Eq. (9)	Raw material cost for untreated biomass in RM/month
Eq. (10)	Transportation cost for untreated biomass in RM/month
Eq. (11)	Carbon dioxide gas emission cost for deliver untreated biomass in RM/month
Eq. (12)	Constraint to ensure the supply ability of supplier for untreated rice husk can cover the amount of raw material needed in plant
Eq. (13)	Constraint to ensure the supply ability of supplier for untreated empty fruit bunch can cover the amount of raw material needed in plant
Eq. (14)	Constraint to ensure the supply ability of supplier for untreated woody biomass can cover the amount of raw material needed in plant

Table 4. Description of terms used in Eq. (8) till Eq. (14)

Term	Category	Description
OTC_y	Parameter	Overall transportation cost of untreated biomass in RM/month
RMC_y	Parameter	Overall transportation cost factor for raw material cost of untreated biomass in RM/month
TC_y	Parameter	Overall transportation cost factor for transportation cost of untreated biomass in RM/month
$CO2EC_y$	Parameter	Overall transportation cost factor for carbon dioxide gas emission cost of untreated biomass in RM/month
$CURHT$	Parameter	Cost of untreated rice husk per tonne in RM/tons
$CUEFBT$	Parameter	Cost of untreated empty fruit bunch per tonne in RM/tons
$CUWBT$	Parameter	Cost of untreated woody biomass per tonne in RM/tons
$FREQS$	Parameter	Frequency of small truck for deliver biomass from supplier to plant
$FREQM$	Parameter	Frequency of medium truck for deliver biomass from supplier to plant
$FREQL$	Parameter	Frequency of large truck for deliver biomass from supplier to plant
$DISTURH$	Parameter	Distance to deliver untreated rice husk from the supplier to plant per trip in m
$DISTUEFB$	Parameter	Distance to deliver untreated empty fruit bunch from the supplier to plant per trip in m
$DISTUWB$	Parameter	Distance to deliver untreated woody biomass from the supplier to plant per trip in m
$TCTK$	Parameter	Average transportation cost of truck per tonne per kilometre in RM/tons.km
LCS	Parameter	Loading capacity of small truck in tons
LCM	Parameter	Loading capacity of medium truck in tons
LCL	Parameter	Loading capacity of large truck in tons

$CO2TK$	Parameter	Carbon dioxide gas emitted by truck per tonne per kilometre
$CCO2T$	Parameter	Emission cost of carbon dioxide per tonne in RM/ tons
SAURH	Parameter	Supply ability of supplier for untreated rice husk
SAUEFB	Parameter	Supply ability of supplier for untreated empty fruit bunch
SAUWB	Parameter	Supply ability of supplier for untreated woody biomass
$y1$	Decision Variable	Amount of untreated rice husk transported by small truck a month in tons/month
$y2$	Decision Variable	Amount of untreated rice husk transported by medium truck a month in tons/month
$y3$	Decision Variable	Amount of untreated rice husk transported by large truck a month in tons/month
$y4$	Decision Variable	Amount of untreated empty fruit bunch transported by small truck a month in tons/month
$y5$	Decision Variable	Amount of untreated empty fruit bunch transported by medium truck a month in tons/month
$y6$	Decision Variable	Amount of untreated empty fruit bunch transported by large truck a month in tons/month
$y7$	Decision Variable	Amount of untreated woody biomass transported by small truck a month in tons/month
$y8$	Decision Variable	Amount of untreated woody biomass transported by medium truck a month in tons/month
$y9$	Decision Variable	Amount of untreated woody biomass transported by large truck a month in tons/month

Scenario 3: Optimization model for biomass transportation using hybrid- random mixed of treated and untreated biomass resources

Scenario 3 is a scenario when biomass transported is neither all treated biomass nor untreated biomass. In other word, it is the scenario when some of the biomass delivered is treated while some are untreated. In this scenario, we had made an assumption that rice husk and empty fruit bunch used is treated while the woody biomass used is untreated. In the model's formulation for Scenario 3, overall transportation cost minimization for hybrid biomass resources was the objective function. It was indicated by considering raw material cost of hybrid biomass resources, transportation cost for treated biomass resources and carbon dioxide gas emission cost of truck. Modelling that contain the objective function's details are shown by Eq. (15) till Eq. (18). Meanwhile, Eq. (19) till Eq. (21) represent the model's constraints. Explanations for each formulation for Scenario 3 were tabulated in Table 5**.** Following the table, each term in all of those formulations was explained in Table 6.

$$OTC_z = RMC_z + TC_z + CO2EC_z \qquad \text{Eq. (15)}$$

$$RMC_z = [(z1 + z2 + z3) * CTRHT] + [(z4 + z5 + z6) * CTEFBT] + [(z7 + z8 + z9) * CUWBT] \qquad \text{Eq. (16)}$$

$$TC_z = \{[(FREQS * z1 + FREQM * z2 + FREQL * z3) * DISTTRH] + [(FREQS * z4 + FREQM * z5 + FREQL * z6) * DISTTEFB] + [(FREQS * z7 + FREQM * z8 + FREQL * z9) * DISTUWB]\} * TCTK \qquad \text{Eq. (17)}$$

$$CO2EC_z = \{[(DISTTRH * z1 + DISTTEFB * z4 + DISTUWB * z7) * LCS * FREQS] + [(DISTTRH * z2 + DISTTEFB * z5 + DISTUWB * z8) * LCM * FREQM] + [(DISTTRH * z3 + DISTTEFB * z6 + DISTUWB * z9) * LCL * FREQL]\} * CO2TK * CCO2T \qquad \text{Eq. (18)}$$

$$z1 + z2 + z3 = e = SATRH \qquad \text{Eq. (19)}$$

$$z4 + z5 + z6 = e = SATEFB \qquad \text{Eq. (20)}$$

$$z7 + z8 + z9 = e = SAUWB \qquad \text{Eq. (21)}$$

Table 5. Description of mathematical formulations in Scenario 3

Formulation	Description
Eq. (15)	Objective function and overall transportation cost equation for hybrid biomass in RM/month
Eq. (16)	Raw material cost for hybrid biomass in RM/month
Eq.(17)	Transportation cost for hybrid biomass in RM/month
Eq. (18)	Carbon dioxide gas emission cost for deliver hybrid biomass in RM/month
Eq. (19)	Constraint to ensure the supply ability of supplier for hybrid-treated rice husk can cover the amount of raw material needed in plant
Eq. (20)	Constraint to ensure the supply ability of supplier for hybrid-treated empty fruit bunch can cover the amount of raw material needed in plant
Eq. (21)	Constraint to ensure the supply ability of supplier for hybrid-untreated woody biomass can cover the amount of raw material needed in plant

Table 6. Description of terms used in Eq. (15) till Eq. (21)

Term	Category	Description
OTC_z	Parameter	Overall transportation cost of hybrid biomass in RM/month
RMC_z	Parameter	Overall transportation cost factor for raw material cost of hybrid biomass in RM/month
TC_z	Parameter	Overall transportation cost factor for transportation cost of hybrid biomass in RM/month
$CO2EC_z$	Parameter	Overall transportation cost factor for carbon dioxide gas emission cost of hybrid biomass in RM/month
$CTRHT$	Parameter	Cost of treated rice husk per tonne in RM/tons
$CTEFBT$	Parameter	Cost of treated empty fruit bunch per tonne in RM/tons
$CUWBT$	Parameter	Cost of untreated woody biomass per tonne in RM/tons
$FREQS$	Parameter	Frequency of small truck for deliver biomass from supplier to plant
$FREQM$	Parameter	Frequency of medium truck for deliver biomass from supplier to plant
$FREQL$	Parameter	Frequency of large truck for deliver biomass from supplier to plant
$DISTTRH$	Parameter	Distance to deliver treated rice husk from the supplier to plant per trip in m
$DISTTEFB$	Parameter	Distance to deliver treated empty fruit bunch from the supplier to plant per trip in m
$DISTUWB$	Parameter	Distance to deliver untreated woody biomass from the supplier to plant per trip in m
$TCTK$	Parameter	Average transportation cost of truck per tonne per kilometre in RM/tons.km
LCS	Parameter	Loading capacity of small truck in tons
LCM	Parameter	Loading capacity of medium truck in tons
LCL	Parameter	Loading capacity of large truck in tons
$CO2TK$	Parameter	Carbon dioxide gas emitted by truck per tonne per kilometre
$CCO2T$	Parameter	Emission cost of carbon dioxide per tonne in RM/ tons
SATRH	Parameter	Supply ability of supplier for treated rice husk
SATEFB	Parameter	Supply ability of supplier for treated empty fruit bunch
SAUWB	Parameter	Supply ability of supplier for untreated woody biomass
$z1$	Decision Variable	Amount of treated rice husk transported by small truck a month in tons/month
$z2$	Decision Variable	Amount of treated rice husk transported by medium truck a month in tons/month
$z3$	Decision Variable	Amount of treated rice husk transported by large truck a month in tons/month
$z4$	Decision Variable	Amount of treated empty fruit bunch transported by small truck a month in tons/month
$z5$	Decision Variable	Amount of treated empty fruit bunch transported by medium truck a month in tons/month
$z6$	Decision Variable	Amount of treated empty fruit bunch transported by large truck a month in tons/month
$z7$	Decision Variable	Amount of untreated woody biomass transported by small truck a month in tons/month
$z8$	Decision Variable	Amount of untreated woody biomass transported by medium truck a month in tons/month
$z9$	Decision Variable	Amount of untreated woody biomass transported by large truck a month in tons/month

RESULTS AND DISCUSSION

Figure 2 shows the modelling and formulation for optimal feedstock and transportation selection for (a) all treated biomass, (b) all untreated biomass and (c) hybrid – random mixed of treated and untreated biomass. Meanwhile, Table 7, Table 8 and Table 9 shows the result for GAMS for optimal feedstock and transportation selection for all treated biomass, all untreated biomass and hybrid – random mixed of treated and untreated biomass respectively.

```
variable
f;

positive variable
x1, x2, x3, x4, x5, x6, x7, x8, x9;

equation
obj, c1, c2, c3;

obj..(418*x1 + 418*x2 + 418*x3 + 395*x4 + 395*x5 + 395*x6 + 516*x7 + 516*x
8 + 516*x9) + (29484*x1 + 5896.80*x2 + 2948.4*x3 + 18408*x4 + 3681.6*x5 +
1840.8*x6 + 12636*x7 + 2527.2*x8 + 1263.6*x9) + (3161.03*x1 + 3161.03*x2 +
 3161.03*x3 + 2199.34*x4 + 2199.34*x5 + 2199.34*x6 + 1354.73*x7 + 1354.73*
x8 + 1354.73*x9) =e= f;
c1..x1+ x2 + x3 =e= 600;
c2..x4 + x5 + x6 =e= 3000;
c3..x7 + x8 + x9 =e= 10000;

model treated /all/;
solve treated using mip minimize f;
```

(a)

```
variable
f;

positive variable
y1, y2, y3, y4, y5, y6, y7, y8, y9;

equation
obj, c4, c5, c6;

obj..(481.39*y1 + 418.39*y2 + 418.39*y3 + 370.95*y4 + 370.95*y5 + 370.95*y
6 + 187.56*y7 + 187.56*y8 + 187.56*y9) + (6325.8*y1 + 1265.16*y2 + 632.58*
y3 + 12636*y4 + 2527.20*y5 + 1263.6*y6 + 31200*y7 + 6240*y8 + 3120*y9) + (
678.20*y1 + 678.20*y2 + 678.20*y3 + 1354.73*y4 + 1354.73*y5 + 1354.73*y6 +
 3345*y7 + 3345*y8 + 3345*y9) =e= f;
c4..y1+ y2 + y3 =e= 5000;
c5..y4 + y5 + y6 =e= 20000;
c6..y7 + y8 + y9 =e= 300;

model untreated /all/;
solve untreated using mip minimize f;
```

(b)

```
variable
f;

positive variable
z1, z2, z3, z4, z5, z6, z7, z8, z9;

equation
obj, c7, c8, c9;

obj..(418*z1 + 418*z2 + 418*z3 + 395*z4 + 395*z5 + 395*z6 + 187.56*z7 + 18
7.56*z8 + 187.56*z9) + (29484*z1 + 5896.80*z2 + 2948.4*z3 + 18408*z4 + 368
1.6*z5 + 1840.8*z6 + 31200*z7 + 6240*z8 + 3120*z9) + (3161.03*z1 + 3161.03
*z2 + 3161.03*z3 + 2199.34*z4 + 2199.34*z5 + 2199.34*z6 + 3345*z7 + 3345*z
8 + 3345*z9) =e= f;
c7..z1+ z2 + z3 =e= 600;
c8..z4 + z5 + z6 =e= 3000;
c9..z7 + z8 + z9 =e= 300;
```

(c)

Figure 2. Modelling and formulation for optimal feedstock and transportation selection for (a) All treated biomass, (b) All untreated biomass and (c) Hybrid – random mixed of treated and untreated biomass.

Table 7. Result of GAMS for optimal feedstock and transportation selection for all treated biomass

Decision Variable	Value
VAR f	4.8565E+7
VAR x1	.
VAR x2	.
VAR x3	600.000
VAR x4	.
VAR x5	.
VAR x6	3000.000
VAR x7	.
VAR x8	.
VAR x9	10000.000

Table 8. Result of GAMS for optimal feedstock and transportation selection for all untreated biomass

Decision Variable	Value
VAR f	7.0427E+7
VAR y1	.
VAR y2	.
VAR y3	5000.000
VAR y4	.
VAR y5	.
VAR y6	20000.000
VAR y7	.
VAR y8	.
VAR y9	300.000

Table 9. Result of GAMS for optimal feedstock and transportation selection for hybrid-random mixed of treated and untreated biomass

Decision Variable	Value
VAR f	1.9218E+7
VAR z1	.
VAR z2	.
VAR z3	600.000
VAR z4	.
VAR z5	.
VAR z6	3000.000
VAR z7	.
VAR z8	.
VAR z9	300.000

From the GAMS optimization results and by using CPLEX solver, decision variables and optimal mode of transportation that minimize the objective function were obtained. . From Table 7, Table 8 and Table 9, large truck was the optimal mode of transportation to transport biomass resources for all scenarios (treated, untreated and hybrid). These can be seen based on the values shown by GAMS i.e x3, x6, x9, y3, y6, y9z3, z6 and z9. These values would minimize the overall transportation costs for each scenario of *f* values, shown in Table 7 to Table 9.

Based on a study about transport and supply logistics of biomass fuels, these results can be explained from fundamental principle based on economy of scale. Generally, the larger the vehicle size, the larger the quantity of biomass being carried, thus the lower the cost per tonne of moving a load. Larger truck has much bigger carting capacities compared to the small truck. In three scenarios above, large truck can carry up to 20 tonnes of biomass resources for one trip compared with the small truck and medium truck which can carry 2 tonnes and 10 tonnes per trip. When the unit costs of transport are considered, the larger truck have lower terminal and trip costs per tonne transported [12].

However, the application of large truck is limited due to physical constraints such as road surface quality. Hence, further study should be continued with a more detailed consideration.

CONCLUSION

In conclusion, the best simulation model should be selected by the simulation that has the minimal overall transportation cost and the model which fulfil the constraints associated. An optimization model had been formulated for biomass transportation in this research. By using General Algebraic Modelling System (GAMS), the best transportation mode can be selected by using optimal result obtained. From the optimization result with GAMS, it showed that large truck is the transportation mode which can give minimal cost consumption in the perspectives of raw material cost, transportation cost and carbon dioxide emission cost for treated, untreated and hybrid biomass. This optimization model can be possibly implemented in any projects to select the best transportation mode used to deliver biomass.

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