Contribution of Green Garbage to Energy Production in Municipal Solid Waste Management

Bussarakam Thitanuwat and Chongchin Polprasert

Abstract— *Green garbage is a potentially renewable resource which can be increased, following the greenery space expansion plan. Accordingly, it could be the alternative energy source for the Bangkok Metropolitan Administration (BMA) consumption. The aims of this paper are to quantify the renewable energy potentially produced from trimmings (yard wastes, fallen leaves, and cut branches) and to evaluate the efficiency of energy transfer per unit area from the primary producer to the electricity generation. The total potential renewable energy produced annually from green garbage was determined to be 4.85x10^8 MJ. The quantity could be used to generate electricity of about 5.73x10^8 kWh per year, earning 1.34 billion Bahts annually. The overall energy transfer efficiency was estimated 0.05%. Based on the results of this study, The BMA's trimmings, at present, could contribute to energy for electricity generation, which is equivalent to the amount of money spent on all the cost of fuel used to operate BMA's solid waste collection and transportation plus 35% of other operating expenses.*

Keywords— **Energy production, green garbage, municipal solid waste, solar radiation.**

1. INTRODUCTION

Bangkok Metropolis, the capital city of Thailand, requires a lot of resources -particularly, food and energy- to serve currently 5.7 million registered and 2.3 million non-registered population. The activities of these people consequently result in a variety of environmental problems such as air pollution, poor quality of public waters, and insufficient solid waste management. One of the popular policies to solve such the above mentioned problems is to establish more public parks, grow big trees along the streets, and convert unattended spaces into recreational sites as well as to improve city landscape and promote energy conservation.

On the other hand, large amount of green residuals, which has been increasing with the expansion of urban and green space areas, needs to be disposed of properly; otherwise, more environmental problems would be caused from it. Presently, management of these green residuals in BMA employs composting process to treat just only 9% of collected green waste and the remainder goes to landfill [1].

The contribution of wastes recycling to energy production has been widely accepted, especially as an energy material like "wood and leave debris" contains the calorific valve of 19-20 mega joules per kilogram (MJ/kg) [2]. Moreover, it has been suggested that the conversion of green waste into renewable energy is not only environmentally beneficial but also financial rewarding [3]. To link the greenery expansion policy to improve the city aesthetics with the energy derived from green waste, therefore, this study was conducted to quantify (1) the renewable energy potentially produced from green residuals (wood, leave and yard wastes) and (2) efficiency of energy transfer from the primary producer to electricity generation. BMA solid waste management operation was taken as a case study to address the above-mentioned objectives.

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2. METHODOLOGY

Field survey and data collection

Data collection includes quantification of greenery areas, total amounts of green residual waste, and resources used such as diesel consumption and the numbers of vehicles in waste collection and transportation. They were gathered, using questionnaires and interviews with the officers in-charge from 50 district's offices, the department of environment and the office of public park in BMA.

Additional data (i.e. calorific values of green residual and diesel, the unit conversion and the condition of electric plant) were sought from the literature. In this paper, the monthly amounts of green garbage collected as yard waste from household and trimmings from public parks and street curbs were quantified and used to determine whether they are sufficient to be potential source of renewable energy supplied to BMA's electricity consumption and to what extent.

Conversion of energy production from green garbage

Data values on energy production were interpreted and reported in the functional units of "mega joules per ton of waste collected" and "mega watts per area".

The first functional unit is to express the amount of energy that can be produced per unit mass of waste collected, while the latter is to signify the energy flux transfer from solar radiation that touches the Earth's mantle until the waste discarded from human consumption in the city, using Equations (1-A) and (1-B). The carbon-balanced model was used to simulate the energy transfer which includes a major process to convert light energy from the average of photosynthetic 168 W/m^2 into chemically-stored energy compound in the form of "organic matter" [4],[5]. The photosynthetic reaction coupled with thermodynamic computation is shown as follows:

$$CO_2\,(g) + H_2O\,(l) \longleftrightarrow CH_2O\,(s) + O_2\,(g)$$

$$\Delta H_0^f\ ; \quad -393.5 \quad -285.8 \quad -211.3 \quad 0 \quad ;kJ/mol$$

ΔH° = (-211.3+0)-(-393.5-285.8)
ΔH° = +468 kJ/mol

As the reaction enthalpy value is found positive, energy content is adsorbed within the organics at a thermodynamic proportion of 39 kJ/g C. Energy transfer efficiency is computed, using Equation (2).

The energy transfer efficiency from the basic operation of steam electric plant is taken from the average of 40-45% [6]. The transfer efficiency of each stage can be calculated by dividing the energy flux of output-stage with the input-stage as demonstrated in Equation (3).

The overall efficiency of energy transfer from solar radiation to electricity generation can be determined by dividing the energy flux produced from green waste with the solar radiation flux as shown in Equation (4).

E_w = [(Calorific value) x (Total amount of waste per year)] / (Total areas of BMA) (1-A)

E_{elec} = (Gross Electrical Output per year) / (Total areas of BMA) (1-B)

where E_w is energy flux from green wastes (MJ/m^2-y); E_{elec} is energy flux from electricity production (MJ/m^2-y); the units of calorific value, total wastes, gross electrical output, and area are MJ/kg, ton/y, MJ/y and m^2, respectively.

$\eta_{steam\text{-}boiler} = (E_{out}/E_{in}) \times 100\%$ (2)

where η is the overall efficiency of electric plant (unitless); E_{in} is the amount of heat added to steam (MJ/y); E_{out} is the gross electrical energy output (MJ/y).

$\eta_{transfer\text{-}stage\ (n)\ to\ (n+1)} = (E_{(n+1)\text{-}stage}/E_{(n)\text{-}stage}) \times 100\%$ (3)

where $\eta_{transfer\text{-}stage\ (n)\ to\ (n+1)}$ is the efficiency of energy transfer in each stage (%); $E_{(n)\text{-}stage}$ is energy flux from the beginning stage (MJ/m^2-y); $E_{(n+1)\text{-}stage}$ is energy flux next from the beginning stage (MJ/m^2-y).

$\eta_{transfer\text{-}overall} = (E_{elec}/E_{solar}) \times 100\%$ (4)

Where $\eta_{transfer\text{-}overall}$ is the overall efficiency of energy transfer (%); E_{solar} is energy flux from solar radiation (168 W/m^2 or 2,612.74 MJ/m^2-y).

3. RESULTS AND DISCUSSION

BMA's green garbage generation and management.

From the BMA greenery area, large quantities of green residuals; for examples, wood, fallen leaves, and cut branches; from the process of garden and tree trimming operations are produced as shown in Table 1.

In this study, the amount of collected green wastes are obtained from three sources- public parks, roadsides and households. Firstly, wastes collected from public parks consisting of yard waste and fallen leaves are carried out by two responsible groups; the office of public park and the BMA's district offices. The second source comes from roadsides or street park taken care by the BMA's district offices. In this portion, waste components are different from the first, mainly consisting of cut branches, wood and some of fallen leaves. The last source is from household's gardening, handled by the Solid Waste Management Division. The composition of green residual from this source is similar to the previous one; however, they are combined with other household refuse without any preliminary segregation for the purpose of reuse or recycling.

Prior to being landfilled outside BMA, the collected wastes are transported to the transfer centers at On Nut, Nongkhaem, or Sai Mai, depending on the closer distance to the center. The overall processes of green garbage sources and management are illustrated in Fig. 1.

Total amount of green waste produced annually in BMA is found to average 248,886 ton of which 2%, 7% and 91% come from public parks, roadsides and households, respectively. These indicate that the major portion of green residuals (226,554 ton/y) is collected from domestic households, which is found to be just only 6.6% of total SW generated in BMA [1].

Potential energy from renewable green garbage.

The energy potential of the BMA's green garbage from three sources- public parks, roadsides, and households- are estimated to be about 9.07x10^7, 3.45x10^8, and 4.42x10^9 MJ/y, respectively. Result shows that households can be the potential source of these renewable energy derived from the quantity of green garbage generated in BMA area. However, these energy quantities, based on area of concern (see Table 1), are computed to be 0.0065, 0.0036, and 0.00091 MW/ha, indicating that biomass generated from public parks could be the most potential source of renewable energy for electricity generation

From the average diesel consumption of 5.72 liters per ton of collected wastes found in this study, the total diesel fuel used in the BMA's solid waste collection and transportation can be determined to be 1.81x10^7 L/y, accounting to 544 million baht per year [10]. Meanwhile the diesel consumption only for green wastes collection was found to be 1.42x10^6 L/y, accounting to 43 million baht per year.

Therefore, to evaluate the capability of green waste utilization in BMA, the energy transformation to electricity generation was determined, based on steam boiler generator with the transfer efficiency in the range of 40-45% [6]. Using the average of 42.5%, the electricity generated from green waste is computed to be about 2.06x10^9 MJ/y (or 5.73x10^{8}kWh/y).

Cost estimation from electricity sold to outside grid, which is an interconnected network for transmitting electricity from suppliers to consumers, is found to be 1,432 million baht per year [11], of which 3% can be spent on buying the diesel fuel to cover 100% the collection of total green garbage and approximately 35% can cover all of the total diesel fuel used in the BMA's solid waste collection; while the rest of money (62% or 888 million baht) can cover 33.5% of the cost in the BMA's solid waste collection which accounting to 3,195 million baht per year [12].

From the results above, the net annual value of money from using green garbage for electricity generation is summarized in Table 2.

Energy transfer efficiency.

The mobilization of energy starts with approximate 49 percent of the total incoming solar radiation (342 W/m^2) directly absorbed by the earth's surface. Conversion of CO_2 and H_2O by plants into "green organic matter" then occurs from the energy flux of 2,612.74 MJ/m^2-y.

The energy fluxes of collected green wastes in the BMA's area of 1,569 km^2 is found to be 3.09 MJ/m^2-y. In the meantime, the energy flux calculated from the process of electricity generation is estimated 1.31 MJ/m^2-y which are about 50% of the energy flux from un-processed green wastes.

The transfer efficiency can be divided into two stages. Firstly, from solar radiation (stage1) to the collected green wastes, the transfer efficiency is found to be 0.12%. Secondly, from the previous one (stage2) to electricity generation, it is taken from [6] to be 42.5%.

Overall, energy transfer efficiency, from solar radiation through electricity generation, is found to be 0.05%. The mobilization of energy flux from the beginning (solar radiation) in this case study is depicted in Fig. 2.

Table 1. Average amount of green garbage and its potential energy in Bangkok Metropolis.

Sources		Green garbage (Ton/month)	Potential of energy produced[(2)] (MJ/y)	(MW/ha)[(3)]
(1) Public park (31 public parks)[(1)]		387.76 ± 178.28		
Subtotal (1)		387.76	9.07×10^7	0.0065
(2) Roadsides and public green spaces	Central BKK	326.50 ± 59.52		
	Southern BKK	231.66 ± 66.70		
	Northern BKK	358.59 ± 127.69		
	Eastern BKK	130.22 ± 50.86		
	Northern Thonburi	240.84 ± 97.48		
	Southern Thonburi	185.44 ± 38.69		
Subtotal (2)		1,473.25	3.45×10^8	0.0036
(3) Households	Central BKK	3,180.09 ± 106.02		
	Southern BKK	4,355.73 ± 189.54		
	Northern BKK	2,936.30 ± 125.75		
	Eastern BKK	3,482.08 ± 189.01		
	Northern Thonburi	2,269.07 ± 87.34		
	Southern Thonburi	2,656.23 ± 124.73		
Subtotal (3)		18,879.50	4.42×10^9	0.0009
Total		**20,740.51**	$\mathbf{4.85 \times 10^9}$	**0.001** [(4)]

(1) The data of green waste quantities are derived from 31 public parks [7] where the office of Public Park is directly responsible for waste handling. Meanwhile the district offices are taking care of other public parks where waste are collected and mixed with trimmings from street curb or roadsides.

(2) Calculated from the average calorific value of 19.5 MJ/kg.

(3) Calculated from the total area in each source including publicpark [8], roadsides with other green spaces [9], and household area are estimated at 446, 3,094, and 156,870 hectare, respectively.

(4) Calculated based on the total amounts of green garbage and total area of BMA (Not the summation of values calculated above).

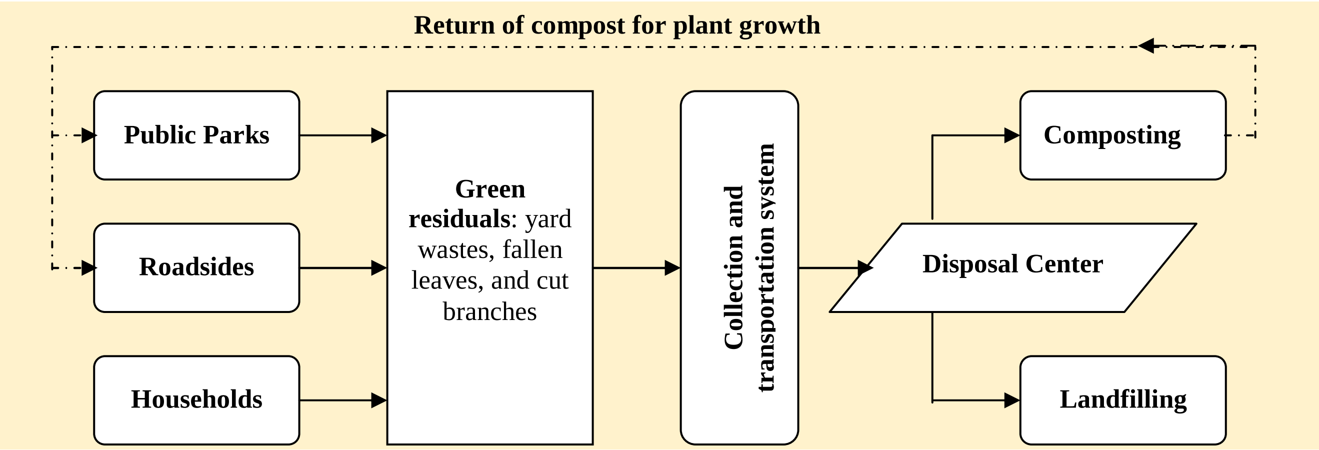
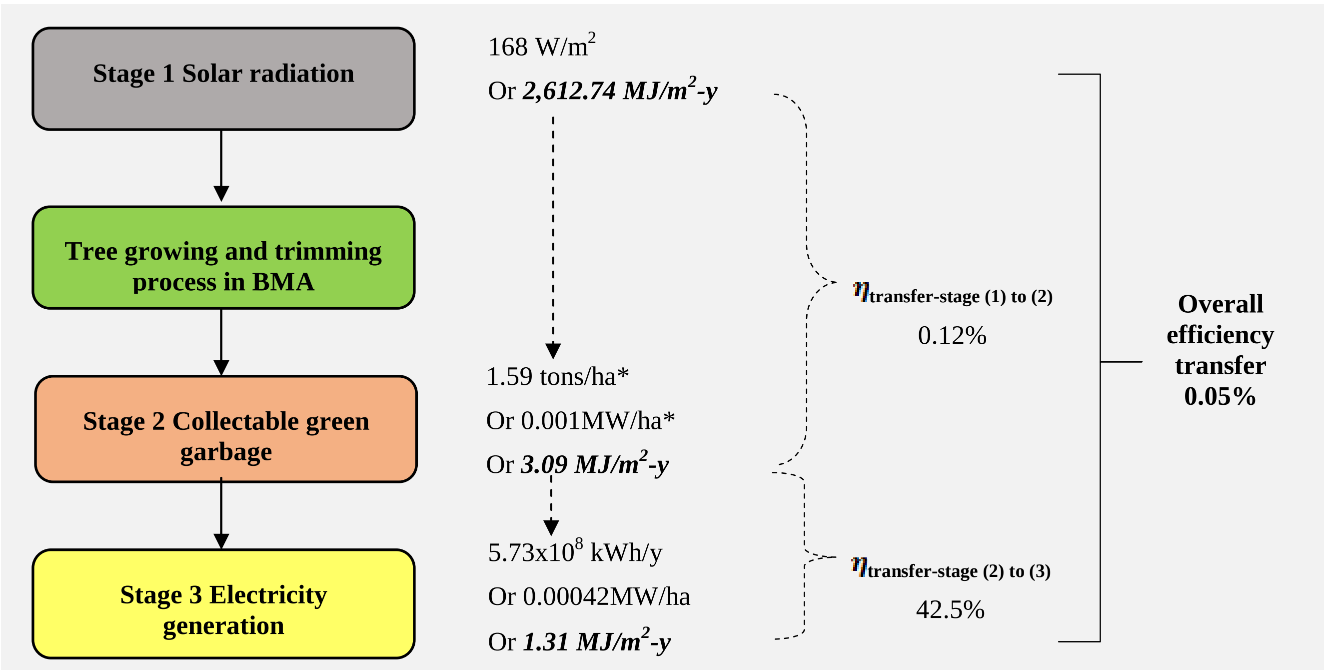


Fig. 1 Material flow of green garbage management in BMA.

Table 2. Net annual value of money from using green garbage to electricity generation.

	(A) Expenses	(B) Income
	BMA's SW collection cost: 3,195 million baht.	1. Collected green garbage: 248,886.12 tons
	1.Operation cost: 2,651 million baht.	2. Potential of renewable energy: 4.85×10^9MJ
	2.Fuel consumption and cost: 1.81×10^7 L, accounting to 544 million baht.	3. Electricity generation: 5.73×10^8 kWh
	2.1 For MSW (except green garbage): 1.67×10^7 L, accounting to 501 million baht.	4. Electricity sold: 1,432 million baht
	2.2 For green garbage: 1.42×10^7 L, accounting to 43 million baht.	
Net value:	3% of earned money covered 100% of fuel cost for green garbage collection. 35% of earned money covered 100% of fuel cost for other MSW collection. The rest 62% of earned money (888 million baht) covered 33.5% of the BMA's SW collection cost.	



* Calculated based on the total amounts of green garbage and total area of BMA

Fig. 2 Energy mobilization for green garbage in BMA.

4. CONCLUSION

The potential energy produced from green waste biomass in BMA was found to be 4.85×10^9 MJ/y. Using 42.5% energy transfer efficiency for a steam-boiler power plant, the total electricity generated was found to be 5.73×10^8 kWh/y, earning about 1,432 million baht annually. This amount of money can be used to cover all of green waste collection cost and also all of total fuel used for all BMA's solid waste collection. Thus, contribution of green garbage to energy production should be considered seriously to implement in BMA solid waste management as it is not only environmental friendly, but also decreasing the greenhouse gas emissions and definitely saving the cost of operation and maintenance. Moreover, the results obtained from this study suggest that greater green area in urban be implemented with more trees so as to increase more aesthetical green environment as well as the amount of energy harvested from green garbage.

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