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Estimation of an Eucalyptus Hybrid *(E.grandis x E.urophylla)* Fuel Wood as a Biomass Source for the 10 MW Malaysia Dendro Power Generation Plant

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Abstract

This research presents the potential of *Eucalyptus hybrid* tree species as commercial energy crops to support the operation of Dendro power plants in Malaysia. Fuelwood is used in dendro-power plants to generate electricity. With the improvement of modern technology in electricity generation from natural sources and renewable energy sources, the use of wood in Dendro power plants is more effective, durable, environmentally friendly, and sustainable. A sample of *Eucalyptus hybrid* fuelwood was analyzed to determine if it could be used as a commercial energy crop in Malaysia. The moisture content and calorific value of *Eucalyptus hybrids* were also tested and calculated. The moisture content of the *Eucalyptus hybrid* wood samples averaged 11%. The calorific value of the *Eucalyptus hybrid* wood samples averages 17.06 MJ/kg. In this study, the *Eucalyptus hybrid* yield per unit energy crop area was estimated specifically for the operation of a 10 MW Dendro power plant. The development of a 10 MW Dendro power plant is expected to generate 50 GWh of electricity per year. This study uses a quantitative approach to estimate the fuelwood resource requirements to operate a Dendro power plant, which has never been done before. Calculations have shown that up to 32,482 tons of *Eucalyptus hybrid* fuelwood will be needed per year to generate electricity. An estimated 768,834 *Eucalyptus hybrid* trees will need to be planted and prepared for felling to generate electricity at the Dendro power plant. Finally, it is expected that an area of 706 hectares of land will be required to plant *Eucalyptus hybrid* trees to be used as commercial energy crops to generate electricity at the Dendro power plant.

1. Introduction

With the deficiency of fossil fuel reserves dwindling and the effects of global climate change increasing, researchers and energy providers are now turning their attention to exploring methods of generating renewable energy from various bio-sources. The purpose of cultivating energy crops is to obtain bioenergy from them, which is then used to generate heat or electricity [1]. This is because by cultivating these energy crops, the bioresource can be provided in a planned and continuous manner, and its sustainability can be ensured. The mentioned energy crops are grown specifically to produce a large yield of wood, which is then processed into biofuel and burned to generate electricity. Energy crops fall into the category of herbaceous or woody plants. [2] stated that willow and poplar are the two most commonly used woody species in Europe. Apart from these, the calorific value of each tree species is one of the most important factors in selecting tree species for energy crops.

The use of wood fuels is one of the fastest-growing sustainable energy production technologies. The great potential to reduce the negative impact of using trees as fuel is very large when it comes to the environmentally friendly processing and conversion of energy-efficient plants and agricultural waste. The forms of wood that can be purchased to be used as fuel include logs, sawdust, wood pallets, and briquettes, as explained by [3]. The mass burned to produce a given amount of energy is one of the most important characteristics of a fuel. Firewood is certainly no exception. The calorific value of firewood, which is used to determine how much energy is released as heat during combustion, is determined when the wood burns entirely with oxygen. The amount is often expressed in units of kJ per kilogram. The relationship between the moisture content of a fuel and its heating value is easy to understand. When moist fuelwood is burned, more energy is required to heat and evaporate any moisture that may be present before combustion can be continued. [4] said that the lower the moisture content, the higher the heating value of the fuelwood. [5] also stated that the moisture content of biomass fuel is usually between 10 and 20% to maximize the heating value of the fuel.

The potential for renewable energy production from fuelwood is very large due to the availability of suitable plant species, appropriate soil conditions, and systematic planting and harvesting methods. It is also to promote carbon emission neutrality from bioenergy production. The theory of carbon emission neutrality needs to be seen critically, because from the cultivation of energy crops, transport it and conversion from the crops to energy, carbon is emitted into the atmosphere [6]. In Europe, commercial cultivation of energy crops has greatly increased, with the tree species being willows and poplars. In Malaysia, this type of energy production has not yet started, and there is no commercial opportunity to grow energy crops. [7] noted that dendro-power generation using Gliricidia sepium fuelwood has long been practiced in Sri Lanka, but only in small power plants and more for domestic use, such as manufacturing, agriculture, or small home-based businesses. Experience in Sri Lanka has shown that poor management of fuelwood resources leads to disruptions in power generation and is not sustainable. In addition, material resource management must also be ensured to ensure the sustainability of energy production from fuelwood with the need for additional wood so that energy production is not interrupted due to a lack of fuelwood resources.

[8] mentioned that dendro-electricity is a method of generating electricity by burning wood. The wood comes from trees grown specifically for power generation. Firewood is easily available in tropical countries like Malaysia, so it is very suitable in countries like Malaysia. If wood develops as a fuel for renewable power generation, it can be a substitute for power generation from fossil fuels, whose share in power generation is decreasing worldwide. Any biomass production for energy purposes contributes to reducing the net carbon emission when compared to fossil fuel based energy generation [9]. In Malaysia, there are several woody plant species that can be used for renewable bioenergy generation. The selected tree species must have a fast growth rate. According to [10] and [11], Eucalyptus hybrid trees, also known as "white wood" in Malaysia, are among the fastest-growing plants. Leucaena leucocephala, Gliricidia sepium, Calliandra calothyrsus, Jatropha curcas, and Acacia mangium are examples of other types of trees that grow rapidly and can be considered bioenergy sources for power generation.

This attempt to plant energy crops is a good one because the soil conditions in Malaysia make the tree species in question grow very quickly. With the coppice method, wood resources from energy crop trees become larger and can be collected regularly to be used as a storage resource when needed. The process of generating electricity from biomass resources begins with the transportation of biomass resources, which are burned in a conventional steam turbine. The generator produces steam, which drives the turbine, and electricity is produced [12]. An alternative method to economically increase the sustainability and efficiency of renewable energy is wood gasification, also known as dendro-thermal systems. Facilities generating electricity from these fuelwood sources can be connected to the electric grid to create a large grid-based system or to a mini-grid for sites not connected to the grid.

In Sri Lanka, wood and biomass are the most common fuel sources and can be easily procured at reasonable prices [13]. The lack of a large hydroelectric infrastructure forces the country to invest most of its precious foreign exchange in the purchase of fossil fuels. Energy farms are established on one-third of all degraded or underutilized land, and 150,000 rural families, or one-quarter of the population, gain employment [14]. In Malaysia, energy generation from this biosource can be used as an alternative, especially in remote areas that are far from the electricity grid. In addition to providing energy sources, the cultivation and production of energy also create jobs for local people.

This paper presents the results of a study on either Eucalyptus hybrid trees can be used as one of the commercial energy crops for power generation in Malaysia. In this study, an estimate is made for Eucalyptus hybrid wood fuel to meet the demand if a 10 MW Dendro power plant is developed. In addition, this study estimates the amount of energy per unit weight of fuelwood using gasification generators and turbines, along with the best system efficiency. As far as this study has been conducted, no qualitative study of this type has been conducted in Malaysia to obtain an estimate of the fuelwood requirement for the operating needs of the power plant to be developed. The lack of quantitative studies on the type of wood from trees that can be used as an energy source, the amount of wood products needed to generate dendro-electricity, the area needed to meet the demand of a power generation plant, and the number of tree trunks that need to be planted in the available area are some important findings of this study.

2. Methodology

Fig. 1 shows the methodology flowchart. This research is to study whether Eucalyptus hybrid trees can be used as energy crops to support the operation of the Dendro power plant in Malaysia. It starts with the evaluation of the Eucalyptus hybrid tree based on a list of criteria developed to check either this plant species is suitable as an energy crop for the Dendro power plant. Second, the samples were collected and prepared for the testing and analysis. Then, the sample needs to check its moisture content and the calorific value. The result of calorific value will be used for the estimation of the energy per unit mass and the estimation of yield per unit land for the Dendro power plant is needed.

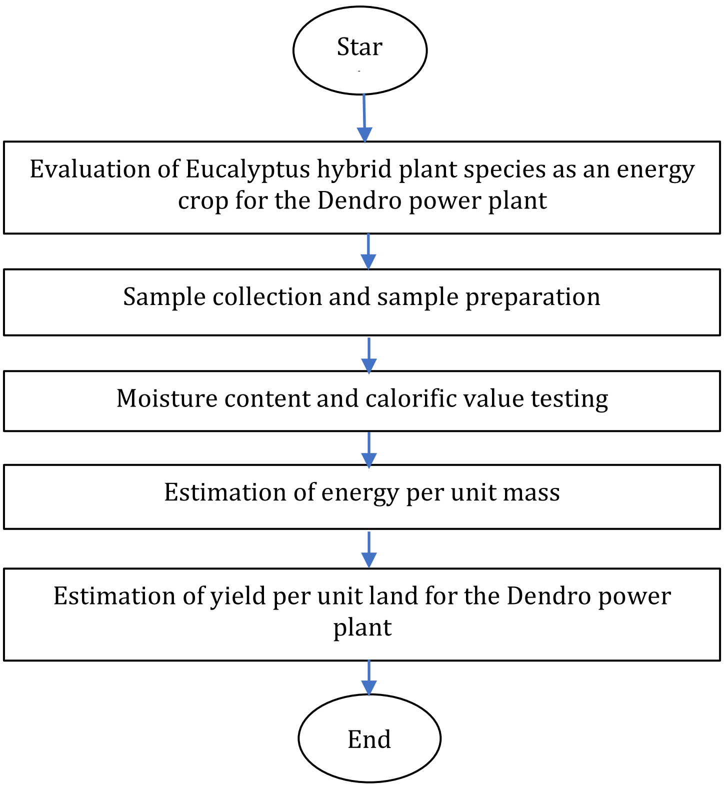


Fig. 1 *This is a figure of methodology flowchart*

2.1 Materials

The tree species *Eucalyptus hybrid*, also referred to as "*Pokok Kayu Putih*" in Malaysia, was the subject of this investigation. Fig. 2 shows the pictures of tree species of *Eucalyptus hybrid.* Selection is based on the characteristics of the tree species and either it is suitable as a commercial energy crop for the dendro power plant.

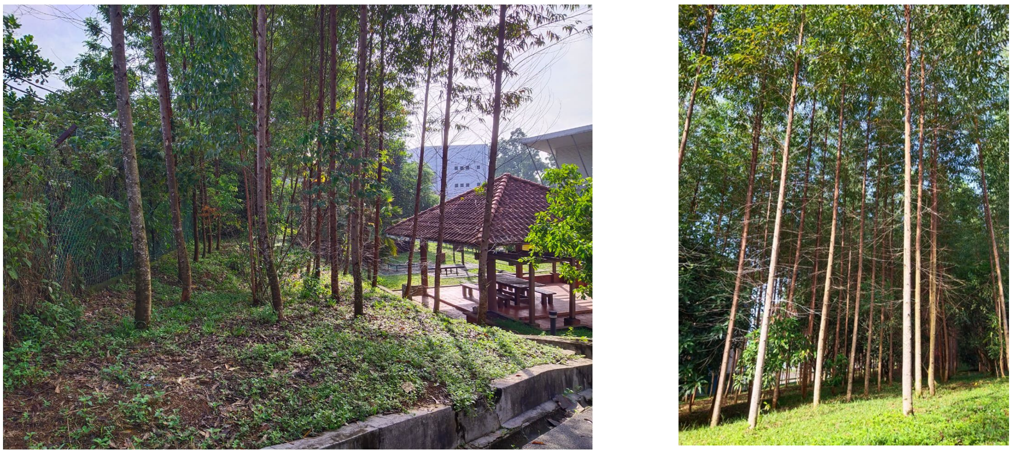


Fig. 2 *Pictures of tree species Eucalyptus hybrid*

2.2 Evaluation the Plant Species as an Energy Crop for the Dendro Power Plant

The following criteria have been assessed to evaluate whether this tree species is suitable for an energy crop plantation:

- rapid-growth plants
- species of plants
- ability to coppice
- high rate of growth
- accepting soils of poorer quality
- nitrogen fixation
- several uses plants
- propagation is simple
- tolerant of fire and drought
- less vulnerable to infections and pests

2.3 Sample Collection and Preparation

The *Eucalyptus hybrid* fuelwood samples were harvested from available plants at Tan Sri Aishah Ghani College, Universiti Putra Malaysia, Serdang, Selangor, Malaysia. The trees were planted with a 3 x 3 m spacing. The wood samples taken are from three parts of the tree, namely the bottom, middle, and top of the tree trunk. Each part of the sample was made up of as many as three samples to get a more accurate reading of the average test result. Each wood sample was cut into block of 5 cm by 5 cm. Fig. 3(a) shows the fuelwood sample after drying it in the oven.

The sample was prepared for further analysis through a number of processes. The obtained wood samples were dried directly under the sun for 1 week, processed into sawdust with the aid of grinding machinery, and stored in a container for further testing. Each part of the sample was made with as many as three replicate samples to get a more accurate reading of the average test result. Fig. 3(b) shows the fuelwood sample ready for calorific value testing.

(a) **(b)**

Fig. 3 *(a) Picture of fuelwood sample after drying it in the oven; (b) Picture of fuelwood sample ready for calorific value testing*

2.4 Moisture Content

The ASTM D4442 standard method for wood and wood-based materials determined the sample's moisture content [15]. The weighted sample is dried in an oven at 103°C for 24 hours. Fig. 4 shows the picture of the oven being used for the drying process. The moisture content of the sample was calculated as the difference between the initial weight of the wet sample and the final weight of the dry sample. That value will be times with the final weight of the dry sample and divided by 100, to get the percentage of moisture content of the sample.

Fig. 4 *Picture of the oven being used for the drying process*

2.5 Calorific Value

The heating value is one of the most crucial calorific value properties to be identified. Many methods for calorific value determination have been developed over the past decades. One of the calorimetric techniques is sample combustion. The bomb calorimeter is the equipment used to determine the gross calorific value of solid fuels [16]. The approach involved utilizing a bomb calorimeter to calculate a sample's calorific value according to the ASTM standard test method [17]. Once it was verified that the combustion chamber was dry, the oxygen gas valve was opened. The sample was weighed before being put into the holding crucible. Above the crucible, the ignition wire was wrapped in a U-shape and joined at both ends. After the bomb vessel's lid was tightly screwed on and fitted into the machine, the oxygen gas was then released into the container. After 20 minutes of analysis, the fuel sample's calorific value was calculated. Figure 6 shows the time - temperature curve with three characteristic temperature points during the combustion process in the bomb calorimeter. It is divided into 3 phases which are preliminary experiment, main experiment and post experiment [18]. The measurement of calorific value is using adiabatic calorimeter method in which the temperature in the outer vessel (Tov)is equal to the temperature of the inner vessel (Tiv) throughout the experiment. The calorific value will be in Joule/gram and convert it to

MJoule/Kilogram (MJ/kg). The result of calorific value will be used for the estimation of the energy per unit mass and the estimation of yield per unit land for the Dendro power plant is needed. Fig. 5 shows the pictures of the bomb calorimeter being used for testing.

(a) (b) (c)

Fig. 5 *(a) Picture of Bomb calorimeter that was used for calorific value testing; (b) Picture of fuelwood sample ready for calorific value testing; (c) Picture of Bomb calorimeter panel that shows the result*

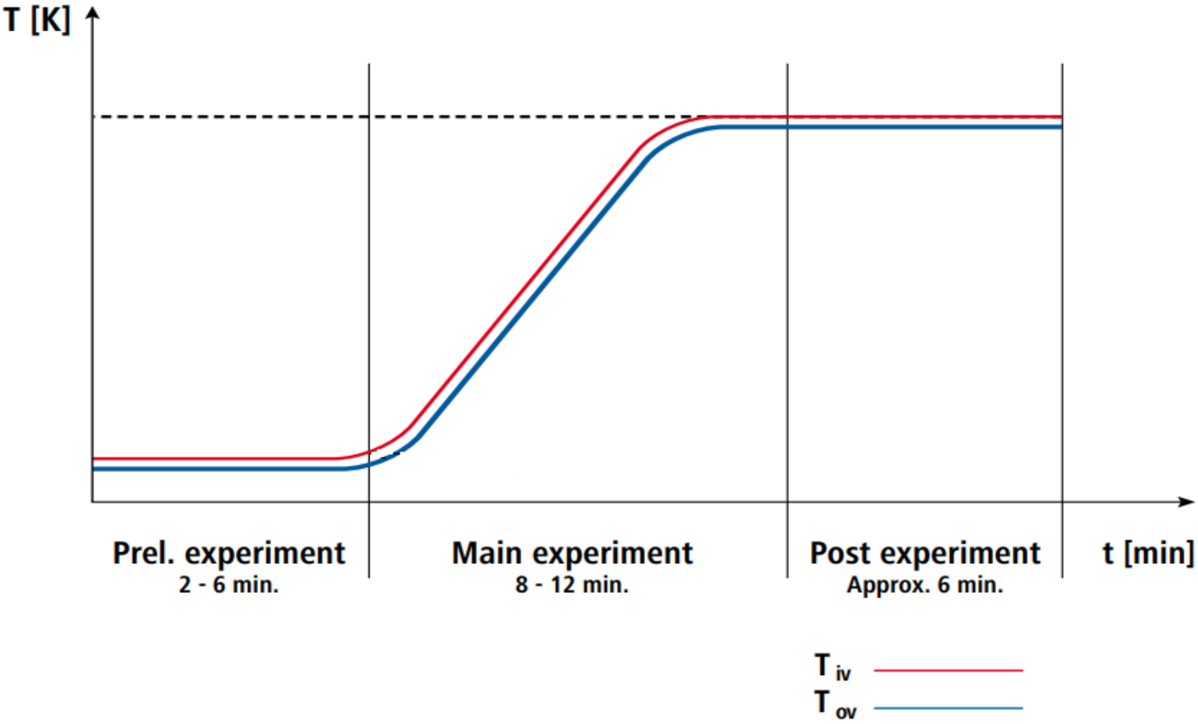


Fig. 6 *Time-temperature curve of the combustion process in Bomb Calorimeter*

3. Results and Discussion

Eucalyptus hybrid yield per area estimation through targeted planting in support of the operation of a 10 MW Dendro power generation plant.

3.1 Evaluation the Plant Species as an Energy Crop for the Dendro Power Plant

The selection was made considering the characteristics that would make this particular tree species suitable as a commercial energy crop for a dendro-power plant. The following criteria were evaluated to assess whether this tree species is suitable for an energy plantation:

- Rapid-growth plants: *Eucalyptus* trees are generally considered fast-growing trees, and the hybrid *Eucalyptus grandis* and *Eucalyptus urophylla* is no exception. In fact, it is one of the fastest-growing *Eucalyptus hybrids*. Among the different species of commercially planted *Eucalyptus hybrids* (*Eucalyptus* *grandis X Eucalyptus urophylla*) stand out in Brazilian forestry for their rapid growth and harvest cycles of 6 to 7 years [17].

- Species of plants: *Eucalyptus grandis* is a species of *Eucalyptus* tree native to Australia. *Eucalyptus urophylla* is a species of *Eucalyptus* tree native to New Guinea and Indonesia. *Eucalyptus grandis × Eucalyptus urophylla*, also known as *Eucalyptus hybrids*, is a hybrid of these two *Eucalyptus* species. All of these species are known for their rapid growth and are commonly used for pulp, French fries, and lumber [10].
- Ability to coppice: *Eucalyptus* trees are generally considered good candidates for coppicing because of their rapid growth rate and ability to regenerate from stumps or root systems. Some studies have shown that eucalyptus trees can be successfully coppiced, with coppiced trees forming new shoots and regenerating quickly [10].
- High rate of growth: In some studies, it has been shown that *Eucalyptus hybrids* can grow up to 15 meters tall and 15 cm in diameter in just 7 years [19]. It has also been shown to have high biomass productivity per hectare per year.
- Accepting soils of poorer quality: *Eucalyptus hybrid*, is generally considered a hardy tree species that tolerates a wide range of soil conditions. Eucalyptus trees grow in a variety of soil types, including sand, clay, loam, and rocky soils. They are also grown in other parts of the world, including Asia, Australia, Europe and the United States, where they have been shown to be adaptable to a wide range of soil conditions [20].
- Nitrogen fixation: *Eucalyptus* trees are able to fix nitrogen through a symbiotic relationship with nitrogen-fixing bacteria. These bacteria, which are present in the roots of Eucalyptus trees, are able to transform atmospheric nitrogen into a form that the trees can use. *Eucalyptus* trees are also able to absorb nitrogen from the soil, and they are generally considered good nitrogen stores. Mixed *Eucalyptus* plantings with a nitrogen-fixing species have the potential to increase productivity while maintaining soil fertility compared to *Eucalyptus* monocultures [21].
- Several uses plants: *Eucalyptus hybrids* have the potential to be used for a variety of purposes, including pulp and paper industry [22], wood French fries, lumber, energy production, erosion control, windbreaks, reforestation, and ornamental uses.
- Propagation is simple: *Eucalyptus hybrids* are generally considered easy to propagate. There are a number of methods for propagating *Eucalyptus* trees, including seed propagation [10], vegetative propagation, and tissue culture.
- Tolerant of fire and drought: *Eucalyptus hybrid*s are generally adapted to areas with low rainfall and are known for their ability to tolerate drought. It also has a number of adaptations that allow it to survive in dry environments. For example, they have a deep root system that allows them to access water from deeper soil layers. Due to their ability to tolerate drought, *Eucalyptus* trees are also fire-tolerant [10].
- Less vulnerable to infections and pests: *Eucalyptus* trees are generally considered to be relatively resistant to pests and diseases. However, they are not immune to these issues and, in some cases, are vulnerable to attacks from a variety of pests and diseases. Very few pest and disease problems have been reported in the nursery stage of *Eucalyptus* [10].

3.2 Moisture Content

Table 1 displays the typical moisture content of the *Eucalyptus hybrid* wood samples. The top part of the samples had the highest moisture content at 11.3%, followed by the middle and lower sections at 11.1% and 11.0% respectively. Wood samples eventually reach a water content where there is no difference in evaporative pressure between the wood and the surrounding atmosphere in an environment with constant temperature and relative humidity [23].

Table 1 *Moisture content of Eucalyptus hybrid fuelwood samples*

Name of sample	Moisture content (%)
A, bottom part of tree	11.0
B, middle part of tree	11.1
C, top part of tree	11.3

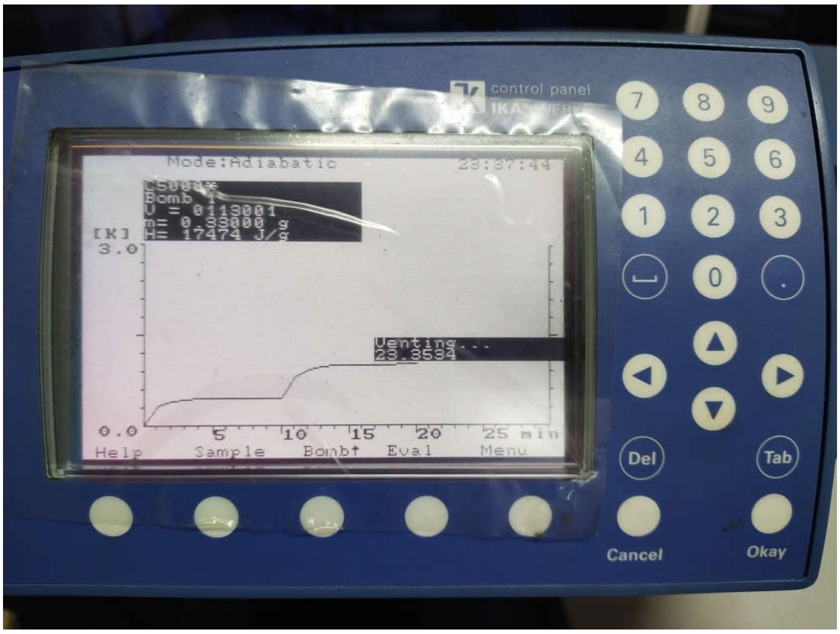
Additionally, it was discovered that the moisture content of the tree samples increased from the base to the top. Although the samples' moisture content complied with the standards for wood fuels, a higher moisture level made the fuel's weight ineffective. The effective bulk density, usable energy content, heating quality, and efficiency of wood are all decreased by moisture. High fuel moisture content lengthens the drying process and requires a bigger chamber, claims [24]. In actuality, trees with low moisture content burn more cleanly and produce less carbon monoxide (CO) [25].

3.3 Calorific Value

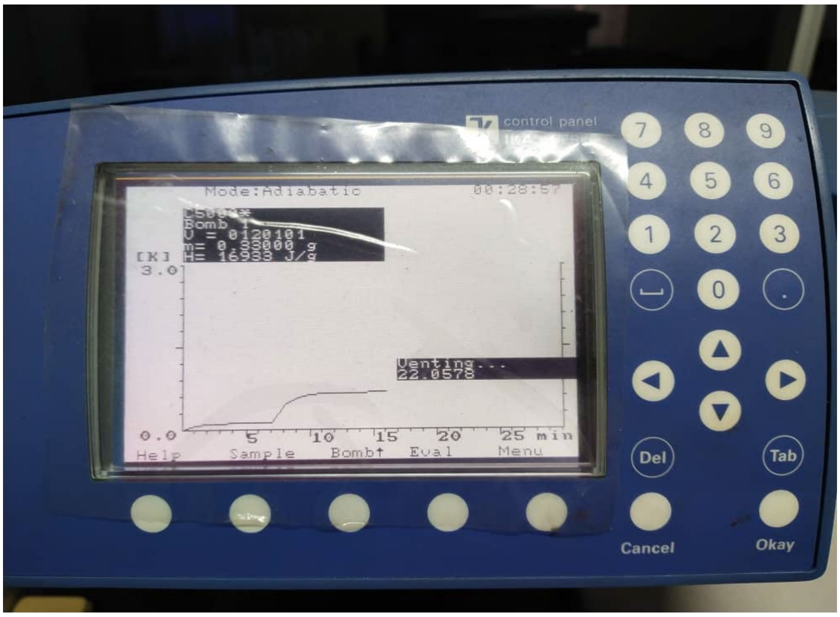
The calorific value of the *Eucalyptus hybrid* wood samples is displayed in Table 2. Figure 7, shows the results of calorific value measured for each part of the tree that displayed on the bomb calorimeter panel. The most crucial element is energy content, commonly referred to as calorific value, which determines how much heat is produced per unit mass (MJ/kg), proving the efficacy and efficiency of any fuel. According to the tabulated figures, the lowest portion of the tree has the highest calorific value, which is 17.47 MJ/kg. The topmost part of the tree has a heating value of 16.77 MJ/kg. 17.06 MJ/kg is the average calorific value. According to [17], the usual calorific value of preheated wood fuel is 19 MJ/kg. From the tree's trunk to its top, the calorific content of the *Eucalyptus hybrid* falls [26].

Table 2 *Calorific value of Eucalyptus hybrid fuelwood samples*

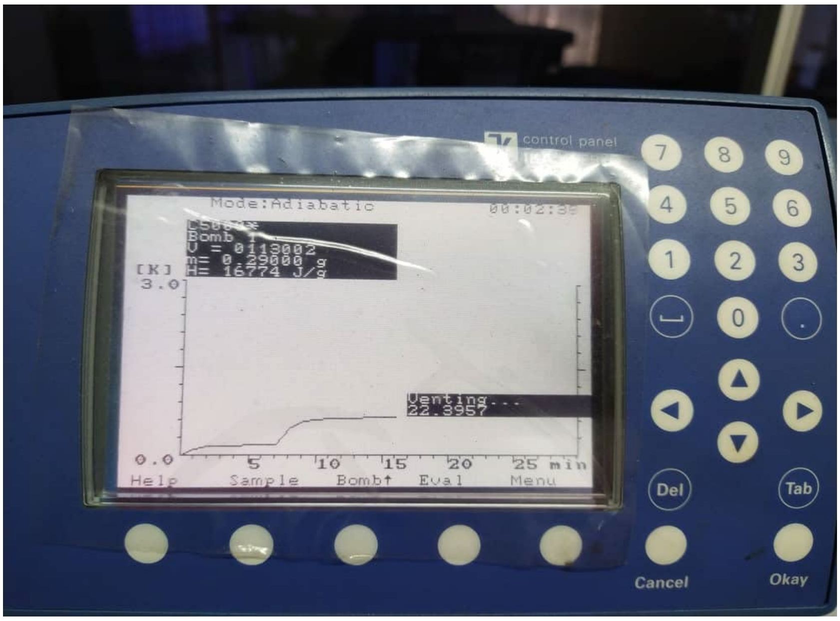
Name of sample	Calorific value (MJ/kg)
A, bottom part of tree	17.47
B, middle part of tree	16.93
C, top part of tree	16.77



(a)



(b)



(c)

Fig. 7 *Pictures of Bomb calorimeter panel that shows the calorific value in J/g ; (a) sample for bottom part of tree; (b) sample for middle part of tree; (c) sample for top part of tree*

3.4 Estimation of Energy Per Unit Mass

The development of a 10 MW dendro power plant is expected to generate up to 50 GWh of electricity in one year, which can be used by the company itself or sold to the utility company.

Energy output of the electricity-producing turbine

= power plant capacity x 24 hours x 365 days x load factor of the power plant

= 10MW x 24 hours x 365 days x 0.6

= 52,560 MWh

= 52.6 GWh

(The load factor of the power plant is 60%, the power plant operates for 12 hours per day, 7 a.m to 9 p.m)

The input power of power plant
= power plant capacity / (turbine efficiency x gasifier efficiency)
= 10,000 kW / (0.92 x 0.62)
= 17,532 kW
(consider the electrical turbine efficiency of 0.92 and the gasifier efficiency of 0.62)

Output power of power plant
=10,000kW
=10MW

Mass flow rate
= Input power of power plant / calorific value of biomass source
= 17,532kW / 17,060kJ/kg
= 1.03kg/s
(The tested calorific value for a *Eucalyptus hybrid* is 17,060 kJ/kg.)

Fuel flow rate to the gasifier
= mass flow rate x 60 seconds x 60 minutes
= 1.03kg/s x 60 seconds x 60 minutes
= 3,708kg/h

Fuel flow rate to the gasifier on a daily basis
= fuel flow rate to the gasifier / 24 hours
= 3,708kg/h x 24 hrs
= 88,992kg/day
≅ 89 tonnes/day

The yearly fuel consumption of the power plant
= (88,992kg/day x 365days) / 1000
= 32,482 tonnes/year

3.5 Estimation Yield Per Unit of Land for the 10 MW Dendro Power Plant

Based on calorific value testing results, the estimation of yield per unit area was carried out by the special planting of *Eucalyptus hybrids*. The *Eucalyptus hybrid* tree's basic density ranges from 0.487 to 0.495 g/cm3 [23]. Each *Eucalyptus hybrid* tree produces 0.084 m3/tree or 58.54 m3/hectare of wood [27].

Minimum yield of fuelwood
= (minimum basic density of *Eucalyptus hybrid)* x (yield of wood produce per tree) x 1000
= 0.487 x 0.084 x 1000
= 40.9kg

Maximum yield of fuelwood
= (maximum basic density of *Eucalyptus hybrid)* x (yield of wood produce per tree) x 1000
= 0.495 x0.084 x 1000
= 42.0kg

Fuelwood estimation per tree per year
= (40.9+42.0) / 2
= 41.45kg
≅ 42kg

One *Eucalyptus hybrid* tree may yield about 42 kg of wood per year if it is grown sustainably. With a planting spacing of 3 × 3 meters, 1089 trees can be planted on a hectare of land [23]. From 1 hectare of land, 1089 trees x 42 kg = 45,738 kg of *Eucalyptus hybrid* fuelwood can be produced. A production capacity of 1 hectare is 45,738 kg, or roughly 46 tonnes.

The yearly fuel usage of the power plant is 32,482 tonnes.

Therefore, the total area needed to grow the hybrid eucalyptus energy crop
= The yearly fuel consumption of the power plant / The production of fuelwood capacity per hectare
= 32,482 tonnes / 46 tonnes per hectare
= 706 hectares.

To meet the Dendro power plant's yearly fuel requirements
= trees can be planted per hectare x land area requirement
= 1,089 trees per hectare x 706 hectares land area required
= 768,834 trees are needed yearly.

4. Conclusions

The purpose of this study is to determine the potential of *Eucalyptus hybrid* trees to be used as commercial energy crops to support the operation of the Dendro power plant in Malaysia. The yield of *Eucalyptus hybrid*s per unit area for the development of a 10 MW Dendro power plant was estimated. It was also projected that the 10 MW Dendro power plant will generate 50 GWh of electrical energy annually. The calculations show that the Dendro power plant requires 32,482 tons of fuelwood per year for its operation. The *Eucalyptus hybrid* power plant will then need to be planted on a total of 706 hectares of land. The annual fuelwood requirement for the Dendro power plant is 768,834 *Eucalyptus hybrid* trees. It is expected that the results of this study will contribute to the advancement of renewable energy generation technology. This study is significant because it is the first to quantitatively assess how much wood is needed to generate dendro-electricity.

Acknowledgement

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception:*** *Chandima Gomes, Hashim Hizam;* ***sample collection:*** *Mohd Izhwan Muhamad, Arifin Abdu;* ***testing, analysis and results:*** *Mohd Izhwan Muhamad;* ***draft manuscript preparation:*** *Mohd Izhwan Muhamad, Hashim Hizam, Mohd Amran Mohd Radzi, Mohammad Lutfi Othman. All authors reviewed the results and approved the final version of the manuscript.*

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