An experimental study of generating electricity from urban tropical forest plants

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Abstract. Coal is a fossil energy source that is still dominant in the generation of world electricity. The use of this energy source causes environmental damages and pollutions. Coal mining causes irreparable damage to land, water, and natural resources around the mine. Exhaust gas emissions from energy generation with coal fuel contribute 44% of total global emissions. Alternative energy sources that can be renewable, sustainable, and environmentally friendly (green) need to be developed to reduce and stop environmental pollution. This research was conducted to explore alternative energy sources that are green, namely the source of electrical energy from living plants. Research on the generation of electrical energy from living plants has been widely carried out and gives satisfying results. In this study, the living plants studied were urban tropical forest plants so that the electricity generated could be used for lighting or sources of charging batteries for electronic devices or electric vehicles. The generation of electrical energy is carried out on each tree by using different electrodes combinations that work according to the principle of the Voltaic cell. The results showed that the combination of the gold-zinc electrode (Au-Zn) produced the highest voltage of 750mV in the sengon tree. The electric voltage generated in each tree species varies according to the combination of the electrodes used and the distance between the two electrodes. Experiments carried out on seven tree species and three combinations of electrodes produced an average electric voltage of 325.6mV. This voltage can be used to charge a 5V battery by connecting 20 cells serially.

1. Introduction
The severe problem facing the world today is the energy crisis caused by the depletion of fossil energy reserves [1,2]. Electricity generation uses fossil energy sources, which are non-renewable energy sources. Almost all regions that contain fossil energy have been discovered and exploited, while the need for electrical energy continues to increase so that the world's fossil energy reserves are running low [3,4]. Consumption of fossil energy sources will gradually reduce the ability of countries in the world to generate electricity with this fossil energy source [5]. This massive use of fossil sources has become a polemic in itself for the sustainability of nature and the surrounding environment. Alternative solutions to overcome problems due to long-term use of fossil energy are the use of renewable and environmentally friendly energy sources [5,6].

Energy has been developed from various renewable sources, including sunlight, wind, chemical reactions, bioenergy, and others [7,8]. Bioenergy is an energy source that comes from living things in
both animals and plants. Bioenergy sources that have been utilized today are biomass and biogas [9,10]. Alternative sources of bioenergy that can be developed as sources of electricity are living plants [11]. The need for electricity in remote areas rich in vegetation can be met through energy generation from living plants. Placement of electronic devices for monitoring and data logging in remote areas such as forests can be implemented by taking energy sourced from this living plant [11].

The source of electrical energy from living plants comes from plants' interaction with soil microbes [12]. Plants process solar energy through photosynthesis. The process produces a variety of materials needed to support plant development. The resulting material is partly used by plants and partly excreted through the roots. Microorganisms around the plant root zone process these wastes. The process is a series of biochemical reactions that produce electron release. The electrons released during the reaction can be captured with electrodes placed around tree roots to harvest electrical energy. The generation of electrical energy continues for as long as plants live. The process of harvesting electricity does not produce pollution that interferes with plants' living processes [13].

Several studies have been conducted to determine the amount of electrical potential generated by living plants. Research conducted by researchers from the University of Wageningen in the Netherlands managed to measure the output power of 0.4W at a radius of one meter from the plant [14]. MIT researchers managed to measure several trees' potential and get the average electric potential of the tree obtained at 200mV [11]. At the same time, research from Indonesia was conducted by the Unlam Physics Department and found that mango trees were able to emit 1.2V electrical potential, 400mV jackfruit trees, 345mV acid trees, and 90mV banana trees.

Based on these results, Indonesia's trees are very potential as an alternative source of electrical energy with a high voltage compared to tree species in Europe and America. Indonesia's biological wealth in the form of wood plants is enormous and varied. Wood plants are often found in wild forests and urban forests as green zones or urban forest parks. Electricity needs in these forests will be met from the results of electricity generation from living plants. Electronic devices that may be operated in wild forests are forest environmental conditions (temperature and humidity) monitoring devices or forest fire prevention devices. Electricity needs in urban forest parks come from lighting lamps, monitoring devices for environmental conditions (temperature, air quality), or charging smartphone park visitors.

Based on the problems and considered the ideas, it is necessary to study the potential of electrical energy from living plants in Indonesian forests, specifically in urban forest parks. This study will use variations in the electrode material and the distance between the electrodes in measuring electrical potential and the potential of electric energy generated. This study's results can provide knowledge related to the development of innovations in the field of renewable energy by utilizing living plants as a source of electrical energy to reduce dependence on fossil energy.

1.1 Harvesting Electric Energy from Living Plants

Like humans who cook food to get energy, plants also "cook" their food to carry on life and grow. Every plant that has chlorophyll or green leaf substances does a cooking process called photosynthesis. Photosynthesis is the process of converting solar energy into chemical energy. Plants use sunlight, water, and nutrients from the soil, and carbon dioxide from the air, then process it to become glucose or sugar and produce oxygen as a byproduct [14,15].

Research to utilize the organic material left over from photosynthesis from the plant has been carried out by a group of Dutch scientists who are members of the Plant-e company. They managed to harvest electricity from living plants, without damaging or killing it. This breakthrough nicknamed Plant-Microbial Fuel Cell (Plant-MFC) utilizes the natural bacteria of plants to produce electricity. Glucose (C\(_6\)H\(_{12}\)O\(_6\)) produced from photosynthesis is not all utilized by plants, as much as 70 percent of photosynthesis is not used by plants and thrown away through its roots [16]. Organic matter which is discharged into the soil will be decomposed by microorganisms naturally into carbon dioxide (CO\(_2\)), protons (H\(^+\)), and electrons (e\(^-\)). Harvesting electrical energy is done by capturing these electrons by using electrodes. Electrons released will be wasted if they are not accommodated, so the electron capture
process does not interfere with plant development. Energy harvesting can continue, and plants can grow naturally so that this energy source is renewable and environmentally friendly.

The experiment was carried out by placing two carbon pieces, which separated the bulkhead and functioned as an anode and cathode. The anode is placed by bacteria to attract electrons (e-) and flow it towards the cathode to become a source of electrical energy in the same direction. Electrical energy is used by the cathode to attract protons (H+) and combine them with oxygen (O2). This cycle continues all the time, both at night and during the day, while plants are still alive. This experiment can produce a power of 0.4W per square meter within a plant radius. The types of plants used in this study were grasses, including rice [14,15].

![Figure 1. Principles for Harvesting Electric Energy from Plants](image_url)

1.2 Electrochemistry

The electrons produced by plants involve electrochemical processes, which are chemical reactions that produce potential electrical energy. Electrons move from the cathode to the anode mounted as a different pole in the electric energy potential. Electrode material selection is based on the electrochemical series or Volta series. Electrodes often used are Zn, Ni, Sn, Ca, Li, Ba, Na, K, Mg, Fe, Mn, Pb, Al (H), Hg, Au, Cu, Ag, Pt. The metal element with the more negative electrode potential is placed on the left side, while the more positive electrode potential is placed on the right [17].

2. Research Methods

The study was conducted using experimental methods in several places where there are many plants and various plant species. The chosen locations are the Malabar city forest, Bukit Buring, and Raden Soerjo Cangar Forest Park. The determination of the measurement point is done after the survey first. The electrodes used are copper (Cu) with iron (Fe), gold (Au) with zinc (Zn), and silver (Ag) with aluminum (Al). The electrode's shape is a slab with a length of 7 cm, a width of 2 cm, and a thickness of 3 mm.

In the selection of plants, the aspects considered in selecting plants are included in the easy insertion of electrodes. The seven selected plant species are sengon, mahogany, mango, rambutan, jackfruit, cananga, and waru. The trees were chosen because they are abundant in city forest parks, and their trunk structure allows easy insertion of electrodes.
The measurement procedure consists of three stages. First, determining the measurement point on the tree trunk, namely at the height of 50cm from the ground and the negative electrode (cathode), is inserted 2cm deep. Second, determining the measurement point at ground level for the insertion of the positive electrode (anode), namely at a distance of 0.5 m, 1 m, and 1.5 m from the tree trunk. Third, the two electrodes are connected to the digital multimeter probe, the red probe is connected to the electrode on the tree trunk, and the black probe is connected to the electrode on the ground. This voltage measurement is carried out for 10 minutes by recording the voltage value every 2 minutes. The electrodes are cleaned with water to remove the adhered sap before being used for the next measurement.

3. Results And Discussion

3.1 Electrode Material Variation Effects

The average value of the measured voltage on several plants stems using several electrode pairs within 0.5m is shown in Figure 2. The measurement results shown are the average measurements every two minutes for 10 minutes. The Au-Zn electrode pair produces a higher voltage than the Cu-Fe and Ag-Al pairs. The Au-Zn electrode pair produces almost the same voltage in all trees except jackfruit trees. The average potential difference is quite significant in each tree type shown by the Cu-Fe and Ag-Al electrode pairs. These results indicate that the Au-Zn electrode pair can produce the highest voltage, followed by the Ag-Al pair, but these two metals are classified as expensive noble metals. The result of this measurement is similar to the result of the voltage measurement on the pulai tree which produces a voltage between 0.38V-0.8V using various electrode pairs [18].

![Figure 2. Effect of electrode combination on the measurement of electrical voltage](image)

3.2 Tree Species Effects

The highest voltage is obtained in the sengon tree for the three pairs of electrodes, as shown in Figure 3. Mahogany, rambutan, and waru trees produce almost the same voltage, while mango, jackfruit, and rambutan trees produce very variable voltage. These results indicate that the sengon tree is stable enough to produce the highest voltage; mahogany, rambutan, and waru trees produce a stable medium voltage and mango, jackfruit, and rambutan trees produce an unstable medium-low voltage. Therefore sengon, mahogany, rambutan and waru trees are plants that can be used as a potential source of electrical energy. The voltage measurement results were higher than [11] for jackfruit and lower for mango trees. These differences can be caused by different species, geographic conditions (soil, weather etc.), time of measurement, type and purity of the electrode material, method of measurement, etc.
3.3 Electrode Distance Effect

The electrode distance effect was investigated by placing the electrodes at a distance of 0.5, 1.0, and 1.5 meters from the tree trunk. The differences in measurement results on each tree using electrode pairs is expressed in terms of the standard deviation shown in Table 1. It showed that the standard deviation of measurements is less than 20mV for all electrode pairs and all trees except of rambutan and waru trees. This value is quite low compared to the voltage produced so that the electrode laying distance has a profound effect on the voltage produced.

| Std Dev. | Cu-Fe | Au-Zn | Ag-Al |
|----------|-------|-------|-------|
| Sengon   | 16.59 | 13.20 | 29.25 |
| Mahogany | 12.49 | 19.10 | 11.12 |
| Mango    | 16.26 | 16.75 | 13.72 |
| Jackfruit| 19.16 | 3.11  | 13.05 |
| Rambutan | 4.41  | 11.13 | 7.02  |
| Cananga  | 20.50 | 23.09 | 32.13 |
| Waru     | 4.79  | 84.50 | 29.26 |

3.4 Stability

Measurements were made for 10 minutes by taking data every two minutes and the electrode distance of 1.0 meters. The stability of voltage measurements every two minutes in the sengon tree are shown in Figure 4. The Cu-Fe electrode pair produces the most stable voltage even though the value is the smallest, while the Au-Zn and Ag-Al electrode pairs produce a reasonably stable voltage with fluctuations in the 5th minute. In general, the three-electrode pairs can produce a stable voltage for 10 minutes of measurement.
4. Conclusion
Harvesting electrical energy in living plants can be done using several electrode pairs indicated by the voltage obtained through a measuring instrument. Gold and zinc electrode pairs produce the highest voltage, while copper and iron electrode pairs produce the lowest. Meanwhile, sengon tree species can produce the highest voltage compared to other trees. The distance between the electrodes measured from the rod to the electrodes on the ground does not significantly influence the voltage measurements' results. The electrode pairs tested in this study produce a stable voltage for the duration of the measurement to continuously produce electrical energy. All electrode pairs are suitable for use with comparable results and costs. This research needs to be further developed by studying the effects of soil chemistry and loading tests.

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