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Analysis and Evaluation of Electrical Signals in a Variety of Living Trees in Palestine's Environment

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تحليل وتقييم الإشارات الكهربائية في مجموعة متنوعة من الأشجار الحية في بيئة فلسطين

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Abstract:

Trees have electrical activity; a continuous electrical power can be produced between electrodes inserted in the tree's trunk and its contiguous soil, which allows for flowing ions thus producing electricity. This paper presents the analysis and evaluation of electrical signals in a variety of living trees in Palestine's environment. Several tests have been conducted outside of laboratories under the natural situations of trees, focusing on the analysis of open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) produced from eleven kinds of trees using fifteen types of electrodes pairs. The results show that the optimal pair of electrodes that allow producing the highest levels of V_{OC} in the trees is Zn-Cu, as the Zinc electrode is the trunk's electrode while the copper electrode is the ground's electrode. The generated voltage levels using the Zn-Cu pair of electrodes were in the range between 995 mV to 1090 mV based on the type of tree. Date Palm and Eucalyptus trees generated the highest electrical power 0.7mW and 0.6mW, respectively. Although the electrical power generated from trees is low, it is possible by using electrical power booster and harvesting circuits to power up low-power devices such as LED lights, scientific calculator, charging mobile phone, fire sensors, or biosensors for detection of environmental conditions.

Keywords: renewable energy, tree energy, Palestine's environment, short-circuit current, open-circuit voltage, low-power sensors.

الملخص:

تمتاز الأشجار بنشاط كهربائي، حيث يمكن إنتاج طاقة كهربائية مستمرة بين الأقطاب الكهربائية الموضوعة في جذع الشجرة والتربة المجاورة لها، مما يسمح بتدفق الأيونات وبالتالي إنتاج الكهرباء. تعرض هذه الورقة تحليل وتقييم الإشارات الكهربائية في مجموعة متنوعة من الأشجار الحية في بيئة فلسطين. تم إجراء العديد من التجارب خارج المختبرات في ظل الظروف الطبيعية للأشجار، مع التركيز على تحليل جهد الدائرة المفتوحة (Voc) وتيار الدائرة القصيرة (I_{SC}) الناتج عن أحد عشر نوعًا من الأشجار باستخدام خمسة عشر نوعًا من أزواج الأقطاب الكهربائية. أظهرت النتائج أن الزوج الأمثل من الأقطاب الكهربائية الذي يسمح بإنتاج أعلى مستويات Voc في الأشجار هو Zn-Cu، حيث أن قطب الزنك هو قطب الجذع بينما قطب النحاس هو قطب الأرض. كانت مستويات الجهد المتولدة باستخدام زوج أقطاب Zn-Cu في حدود 995 مللي فولت إلى 1090 مللي فولت بناءً على نوع الشجرة. أنتجت أشجار النخيل والكينيا أعلى قدرة كهربائية 0.7 مللي واط و 0.6 مللي واط على التوالي. على الرغم من أن الطاقة الكهربائية المتولدة من الأشجار منخفضة، إلا أنه من الممكن استخدام دوائر تقوية الطاقة الكهربائية ودوائر حصاد الطاقة لتشغيل الأجهزة منخفضة الطاقة مثل مصابيح LED، والآلة الحاسبة العلمية، وشحن الهاتف المحمول، وأجهزة استشعار الحرائق، أو أجهزة الاستشعار الحيوية لاكتشاف الظروف البيئية.

كلمات مفتاحية: الطاقة المتجددة، طاقة الأشجار، بيئة فلسطين، تيار الدائرة القصيرة، جهد الدائرة المفتوحة، أجهزة استشعار منخفضة القدرة.

Introduction

Nowadays, the globe is shifting toward the use of renewable energy sources rather than non-renewable energy sources, which will be depleted one day. In nature, there are several energy sources that can be classified as non-renewable or renewable. Non-renewable energy, such as coal, petroleum, and natural gas, contributes to pollution and damage to the environment and cannot be re-grown at a scale commensurate to its usage. On the other hand, renewable energy such as solar, wind, geothermal, hydropower, and electrical energy from trees, is a clean energy that can be renewed naturally and indefinitely, and hence will not run out (Aqel, et al., 2018, p. 63) .

Trees can generate a continuous low power electricity between the electrodes inserted in the living tree's trunk or phloem and its contiguous soil. To create the physical models that underpin the potential of the presence of a continuous electrical voltage between the tree and its surrounding soil, experiments are required to be carried out in a laboratory under controlled settings in terms of light, humidity, temperature, and others. All of these requirements of settings make research and studies on different types of trees outside of laboratories challenging, which may explain the low number of available related publications. As a result, there is a lacking in the literature of a good analysis of electrical signals related to different types of trees in Palestine ecosystems.

Consequently, the current work intends to bridge this knowledge gap. Discovering and evaluating the behavior of electrical signals produced in a variety of different types of living trees in Gaza, Palestine using different material types of electrode pairs, focusing on the analysis and characterization of two components of electric signals short-circuit current (I_{SC}), and open-circuit voltage (V_{OC}) in these trees outside of laboratories under their natural situations. Moreover, an optimization technique is proposed in order to boost up the low electrical power output generated from the living trees and harvest this electrical power to be capable to operate low-power devices.

The following Section II presents several related works from the literature. The proposed work methodology is elaborated on in Section III. The obtained results are presented and discussed in Section IV. Section V provides a conclusion of this research work.

Related Works

Trees have electrical activity; it was identified the presence of a continuous electrical potential difference between the electrodes inserted in the tree's trunk or phloem and its contiguous soil (Zapata, et al., 2020, and Wright & Fisher, 1981, p. 845-848). There is research at University of Portland and University of Washington, which proven that sustained electrical voltages from tens to hundreds of millivolts could be produced between the tissues of living trees and the surrounding soil (Himes, et al., 2010). By designing and fabricating a micro-scale energy harvesting circuit, the researchers at these universities could optimize and boost the millivolt-level output of living tree electricity to 1 volt (Himes, et al., 2010, and Carlson, et al., 2010, p. 741-750).

The origin of this electrical voltage measured in the trees is returned to the fact that an imbalance of potential hydrogen (pH) is produced between the tree and its surrounding soil because the trees continuously suck water into the xylem by transpiration, which contains nutrients and charged particles causing the creation of an electric current circulating between parts of the trees (Fromm &

Lautner, 2007, p. 249-257, and Love, et al., 2008). However, another fact approves that the generated electrical current is because of the electro-kinetic phenomenon, which is initiated by the movement of water and liquids in an absorbent medium (Horwitz, 1939, p.519, and Gibert, et al., 2006, p.572-584).

According to the literature review, the strength of electrical signal generated from the living trees is dependent on the stimulation intensity, which could be linked to changes in tension of water or ion concentrations, resulting in a transitory electrochemical imbalance (Fromm & Lautner, 2007, Oyarce & Gurovich, 2010, Gelli, et al., 1997, Stankovic, et al., 1997, and Mwesigwa, et al., 2000). In this instance, different studies have reported the effect of various stimuli, such as light conditions (Datta & Palit, 2004, p. 680-683, and Gurovich & Hermosilla, 2009, p. 290-300), temperature variations (Volkov, et al., 2007, Pyatygin, et al., 2008, and Zimmermann, et al., 2009), and mechanical wounds (Oyarce & Gurovich, 2010, p. 34-41) .

The technique of generating electricity using living PKL trees and soil of its pot based on Zn/Cu electrodes-based electrochemical cells is presented in (Rasel, et al., 2021, p.527-536). It founds that the performance in generating electricity was improved when placing Cu plate in the soil of the pot and Zn plate onto the living PKL tree instead of placing Zn plate in the soil of the pot and Cu plate onto the living tree, which allows for the illumination of a LED bulb.

In (Pechsiri & Puengsungwan, 2023, p. 47-56) a bioelectric generator approach based on the Plant-Microbial Fuel Cell (PMFC) principle is proposed as a sustainable energy source for smart farming. The EH is presented as a sensor node supply for WSNs as well as a sensing module for keeping track of soil conditions. The experiments are carried out on avocado trees, which are used as fuel cells because they contain plant-microbial organisms at their roots. The harvestable voltage was in ranges from 0.37 to 0.65 Volts, and the output voltage could be boosted up to 3.12 Volts using a BQ25504 boost converter, which was appropriate to supply a sensor node in WSN applications.

A comprehensive taxonomic survey on recent energy harvesting techniques and algorithms was presented in (Singh, et al., 2021, p.18-140), which were proposed by various authors and examined the work done by the various researchers in the field of Energy Harvesting in Wireless Sensor Networks (EH-WSNs) and the energy-scarcity problem of WSNs. The finding was that the outdoor photo-voltaic systems provided a maximum power density of about 100 mW/cm^3, and the piezoelectric harvesters provided a low power density in microwatt of about 330μW/cm^3. The bioenergy harvester from the living tree provided hundreds of microwatt power with a maximum voltage of around 3.3V. The thermoelectric, rectenna, and hybrid energy harvesters (EHs) have been given high efficiency of more than 80%. However, hybrid energy harvesting (HEH) is the most highly recommended technique since it has characteristics that are independent of location and time that harnessed power from multiple energy sources concurrently, which may become increasingly popular for the next cutting-edge autonomous or self-driving device technologies resulting in battery-less operated systems and wireless sensors.

In (Leoni, et al., 2022, Singh & Kumar, 2021, and Leoni, et al., 2022, p. 01-04), the authors presented a study on the characterization of living plants as an energy source for autonomous sensors and low-power devices, which are the main components of Internet of Things (IoT) systems. They presented a plant-based energy harvesting system that can continually extract up to hundreds of microwatts of electrical energy from living plants. The obtained results open the door for further research and studies into the creation of electronic devices that can supply embedded systems for plant monitoring with electricity derived from living plants.

Experiments could be carried out in a laboratory under controlled settings in order to create the physical models that underpin the potential of the presence of a continuous electrical voltage between the tree and its surrounding soil. In this context, various studies involving different agricultural species have been conducted in the laboratory (Oyarce & Gurovich, 2010, Gil, et al., 2008, Gil, et al., 2009, and Ríos-Rojas, et al., 2015). It is difficult to conduct research and studies on many types of trees outside of laboratories due to all of these setting requirements, which may account for the paucity of related publications. As a result, there is a dearth of research that provides a thorough investigation of electrical signals associated with various tree species in Palestine ecosystems. Therefore, the aim of the current work is to bridge this knowledge gap. Investigating the behavior of electrical signals generated in a variety of trees in Gaza, Palestine, with a particular emphasis on the analysis and characterization of two electrical signal components—short-circuit current (I_{SC}) and open-circuit voltage (V_{OC})—in these trees outside of labs and in their natural settings.

The next section presents the proposed methodology implemented for this work.

The Proposed Methodology

This section describes the proposed methodology of this research work and the procedures in detail of several experiments that have been carried out in order to achieve the main aim of this work, which is the analysis, and evaluation of electrical signals in a variety of trees in Palestine's environment. The experimental work has to be conducted outside of laboratories under the natural situations of eleven types of trees, which are Olive, Date Palm, Lime, Orange, Mulberry, Fig, Pomegranate, Guava, Eucalyptus, Dodonaea viscosa, and Melia azedarach trees located in Gaza, Palestine.

Stages of The Experimental Work

1. Investigation and selection of the optimal electrode pairs based on the highest output of open-circuit voltage (V_{OC}): This stage of experimental work focuses on measuring the electrical voltage produced from various types of trees represented by open-circuit voltage measurements as a function of electrode types, in order to determine the optimal pair of electrodes that allows for producing the highest electrical voltage from different types of trees.
2. Measurement of the short-circuit current (I_{SC}) and the open-circuit voltage (V_{OC}) generated by the eleven types of living trees using the optimal pairs of electrodes determined in the first stage: The goal of this stage of the experimental work is to use the optimal electrode pairs identified in the first stage to measure the electrical voltage (V_{OC}) and current (I_{SC}) generated from various species of trees. The generated electrical power then can be calculated using the measured electrical voltage (V_{OC}) and current (I_{SC}). After completing this stage of the study, it could be able to identify the optimal tree from the

eleven types of tested trees that produce the highest short-circuit current (Isc) and thus the highest produced electrical power.

3. Optimization and boosting of power output and investigating on some potential applications that can run some low-power devices: The electrical power generated from the living trees is expected to be low and this stage is required in order to optimize and boosting up the generated output of electrical power and investigate some potential applications that can operate some low-power devices and sensors such as LED lights, scientific calculator, and charging mobile phone. For this stage of optimizing and boosting the weak electrical power generated between the living tree trunk and its surrounding soil, and based on the level of the generated electrical power an appropriate passive and self-powered booster and harvesting module are to be proposed that can be powered from the low-power tree electricity for harvesting and storage of this generated electricity.

Samples of Living Trees

Eleven different kinds of trees, available in abundance locally and their structure of trunk allow easily for electrode insertion in, were selected in this research work, which are Olive, Date Palm, Lime, Orange, Mulberry, Fig, Pomegranate, Guava, Eucalyptus, Dodonaea viscosa, and Melia azedarach trees.

For this study, tree samples with age of (7-9 years old) were selected from each type of the eleven different kinds of trees. The selected trees were with good health and without a noticeable disease or damage found on the trunk. All of the sample trees were located in the same location of the chosen farm in Gaza, Palestine, with the same geographical coordinates (latitude: 31°23'19.4"N, longitude: 34°20'07.8"E), ensuring that they have the same insolation regime as well as edaphological conditions, orientation, and water availability.

Specifications of Electrodes

The type of electrode pairs inserted in the tree's trunk or phloem and its contiguous soil affects the level of electrical activity and the generated continuous electrical potential difference between these electrodes (Choo & Dayou, 2013, and Choo, et al., 2014). Therefore, several tests are to be conducted in order to measure and evaluate the characteristics of electrical signals produced from a variety of trees using five types of electrode materials that are iron, aluminum, steel, zinc, and copper.

Because there are so many different types of electrodes, the optimal pair that generates the highest power output must be identified before any further optimization can be implemented. In this present work, five different electrode materials were chosen for this study where most of them are available in the local market and easy to obtain which are iron (Fe), aluminum (Al), steel (mixture of at iron (Fe) and carbon (C)), Zinc (Zn), and copper (Cu) in the shape of nails and rods. The electrodes that are to be embedded into the tree's trunks were chosen to be in form of nails, as they can easily be inserted into trees without causing a big injury for trees. The trunk's electrodes were nails of aluminum, iron, steel, zinc, and copper having the same dimensions (diameter= 2.5mm, length = 5cm), with a good hardness, in order to create better contact with tree tissues. Furthermore, the electrodes firmed in the soil were a rod of aluminum, copper, and iron having the same dimensions (diameter= 14mm, length = 50cm). Using these electrodes, fifteen combinations of distinct electrode pairs are to be implemented in this test, one to be embedded into the tree trunk and the second into the surrounding soil of the tree (trunk electrode- soil electrode) as follows: Steel-Al, Fe-Al, Cu-Al, Al-Al, Zn-Al, Steel-Fe, Fe-Fe, Cu-Fe, Al-Fe, Zn-Fe, Steel-Cu, Fe-Cu, Cu-Cu, Al-Cu, and Zn-Cu electrode pairs.

Equipment and Setup of Experiments

To measure the parameters of the produced electrical signals, the primary measurement equipment UT61D UNI-T multi-meter was used. It has an input impedance of 3000 MΩ, an accuracy of ±(0.8% + 3 dig.) millivolts (mV) and ± (1% + 3 dig.) microampere (μA), and a resolution of 0.1mV (DC) and 1 μA (DC). 1 mm copper cables insulated with a flexible plastic coating were used for connecting the electrodes with the multi-meter.

Figure 1 shows the equipment and materials used for conducting the experiments, which include UT61D UNI-T multi-meter, crocodile insulated wires, trunk's electrodes as nails (steel, iron, aluminum, zinc, and copper), and ground's electrodes as rods (iron, aluminum, and copper).

According to the authors in (Oyarce & Gurovich, 2010, p. 34-41), compared to the other tissues of the plant, phloem has a significant role in the electrical response of the trees since the living cells that compose these areas have a lower resistance to the current flow. Therefore, to measure the produced open-circuit voltage of the sample trees, the electrodes are to be inserted to be in direct contact with the phloem tissue of the tree's trunk at depth of around 4cm on the east orientation of the trunk. The trunk electrodes were positioned at 50cm height from the ground while the ground's electrodes that are used as reference electrodes, were inserted 30cm into the surrounding soil of the tree away around 50cm from the trunk of the tested tree. The setup used for the electrodes inserted into the trunk and the surrounding soil of the trees to measure the electrical voltage was the same for all sample trees. The next section presents and discusses the analysis of the results of the conducted experiments.

Figure 1: Equipment and materials used for conducting the experiments of this study.

Results and Discussion

This section presents and discusses the results of the three stages of the experimental work described in Section III.

Stage 1: Identification of optimal electrode pairs that allow producing the highest levels of V_{OC}:

The preliminary stage of this study requires performing continuous measurements of the open-circuit voltage for eleven types of trees with changing the type of electrode pairs. The open-circuit voltage (Voc) is the maximum voltage available between the tree trunks and its surrounding soil, and this occurs at zero current (with no load). In this phase of measurement, it is only intended to determine which pairs of electrodes are the best in terms of the produced electrical voltage, which allows producing the highest output of open-circuit voltage (Voc) in the living trees. Therefore, the data were collected from eleven kinds of trees through measurements by implementing fifteen types of electrode pairs, one inserted into the tree's trunk and the second into the surrounding soil of the tree.

As presented in (Ríos-Rojas, et al., 2015, and Le Mouël, et al., 2010, p. 95-99), the change in the environmental conditions affects the activities of the living trees thus making changes in the electrical potential of trees. Therefore, to ensure that the data collection and observations will not be affected by the external uncontrollable environmental factors, the fieldwork measurements were performed on bright days with a clear sky without clouds, with similar temperature and air humidity. All of the data were collected in September 2022, in the daytime between 1:00 pm and 3:00 pm based on Jerusalem time, since at this time the solar presence is the highest with the lowest presence of clouds and the highest stability of weather. The average temperature was around 30^{o}C with relative humidity around 51%.

For all the tested trees, the setup implemented for the trunk's electrode was to insert it to be in direct contact with the phloem tissue of the tree's trunk at depth of around 4cm on the east orientation of the trunk and a vertical height of 50cm from the ground. While the ground's

Figure 2: Connection of multi-meter probes to the electrodes (cathode and anode probes are connected to the trunk and ground electrodes, respectively)

Table 1: Average of open-circuit voltages (mV) measured on variety of trees using different types of electrode pairs

Electrodes / Tree	Steel-Al	Fe-Al	Cu-Al	Al_Al	Zn-Al	Steel-Fe	Fe-Fe	Cu-Fe	Al-Fe	Zn-Fe	Steel-Cu	Fe-Cu	Cu-Cu	Al-Cu	Zn-Cu
Melia azedarach	-70.7	-68.3	-535.3	52.7	427.2	285.8	306.0	-168.5	340.2	814.5	511.5	521.8	50.2	627.0	1001.0
Date Palm	-181.0	-43.2	-505.2	48.8	364.8	235.7	323.7	233.5	329.8	728.5	468.2	565.7	467.5	555.0	1043.7
Olive	-243.8	-204.8	-701.5	48.2	260.2	211.5	292.7	-196.3	294.3	715.3	452.2	535.5	37.8	604.7	1016.3
Fig	-308.7	-202.8	-613.3	46.2	209.2	159.8	251.8	-140.8	265.0	676.7	450.3	535.3	140.8	571.5	1073.2
Lime	-350.8	-186.8	-573.8	49.2	286.7	27.2	183.8	-190.3	261.5	682.5	334.8	478.2	85.2	477.7	1027.8
Guava	-306.3	-136.8	-686.3	83.0	314.5	111.8	287.2	-266.2	377.8	733.3	441.3	603.3	51.2	642.8	1041.2
Orange	-216.8	-122.0	-556.5	58.3	285.7	129.7	234.0	-185.5	317.8	660.8	390.2	506.2	90.7	535.2	1023.8
Mulberry	-192.8	-21.2	-479.5	39.8	427.2	102.7	268.8	-184.7	325.3	723.3	341.7	489.0	34.3	461.0	1031.8
Dodonaea	-299.7	-99.7	-637.5	44.2	284.8	116.2	295.7	-260.5	367.7	674.0	392.8	568.8	11.2	574.7	1013.2
Pomegranate	-85.2	-1.8	-254.7	31.0	432.7	283.5	373.8	100.3	259.3	814.2	479.3	577.5	289.2	596.8	1058.0
Eucalyptus	-136.3	-66.7	-512.5	53.5	380.2	70.2	141.7	-305.8	338.3	686.7	394.0	495.2	64.2	650.0	1015.8

electrodes were buried into the surrounding soil of the tested tree at depth of 30cm and a horizontal distance of 50cm from the tree's trunk. There were some early-stage measurements conducted on trees using different pairs of electrodes that showed that the trunk's electrode is at negative potential while the ground's electrode is positive in most measurements. Therefore, all measurements conducted in this study are referenced to the ground where the trunk's electrode is considered the negative electrode, while the ground's electrode was used as the positive electrode. The cathode probe of the digital multi-meter was connected to the trunk's electrodes, while the anode probe was connected to the ground's electrode that is buried in the soil as shown in Figure 2. Figure 2 shows the experimental setup where Zn-Cu pair of electrodes were embedded into a Guava tree, the trunk's electrode (Zn) is connected with the multi-meter as the negative electrode, while the positive one is the ground's electrode (Cu). Table 1 presents the average values of open-circuit voltages (mV) measured on different kinds of trees using different types of electrode pairs. Figures 3 to 4 show the data of the continuous measurements of open-circuit voltage which were conducted for the eleven types of trees (Olive, Date Palm, Lime, Orange, Mulberry, Fig, Pomegranate, Guava, Eucalyptus, Dodonaea viscosa, and Melia azedarach), with sampling data reading every one minutes. To determine which pairs of electrodes are the best in terms of the produced electrical voltage, fifteen combinations of electrode pairs were tested which are Steel-Al, Fe-Al, Cu-Al, Al-Al, Zn-Al, Steel-Fe, Fe-Fe, Cu-Fe, Al-Fe, Zn-Fe, Steel-Cu, Fe-Cu, Cu-Cu, Al-Cu, and Zn-Cu.

Compared with the other pairs of electrodes, it is clear that the optimal pair of electrodes that allows for generating the highest levels of open-circuit voltages is Zn-Cu pair (Zn is the trunk's electrode and the Cu is the ground's electrode). In all sample trees, the average value of the measured Voc was above 1000mV as presented in Table 1.

As shown in Figures 3 to 4, the second-optimal pair of electrodes is Zn-Fe which allow for generating an open-circuit voltage in ranges between (660.8mV to 814.5mV) based on the type of tree. The

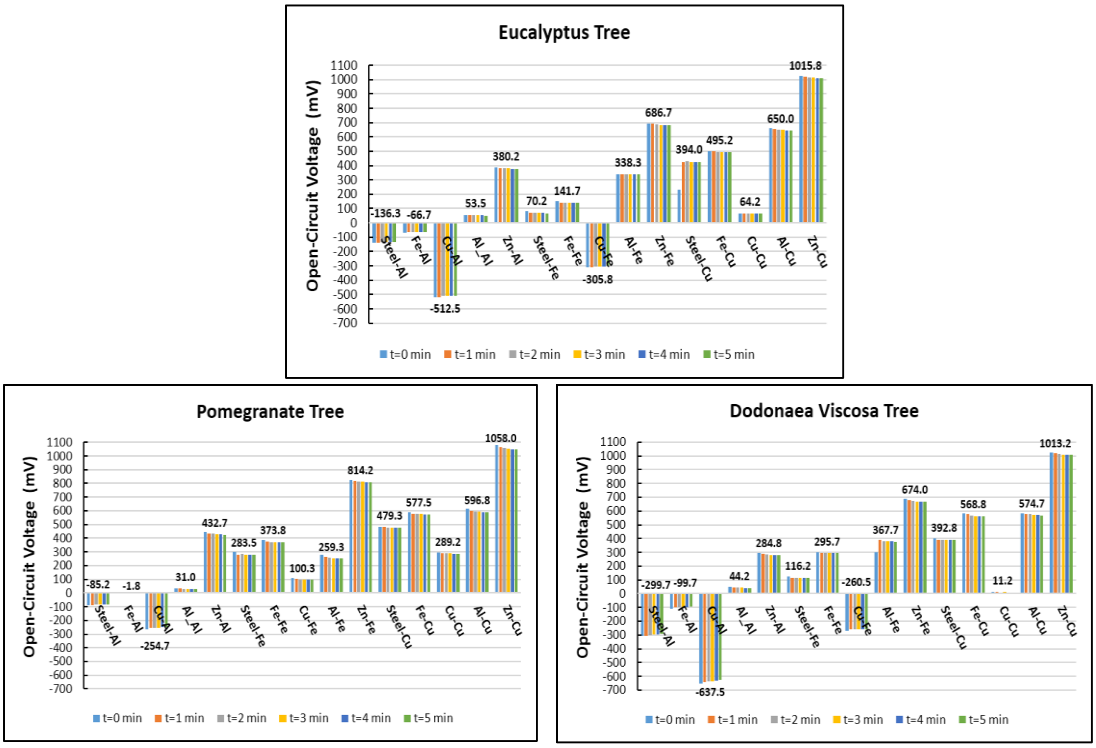

Figure 3: Open-circuit voltage measurements using fifteen electrode pairs for the Eucalyptus , Pomegranate and Dodonaea viscosa trees.

third optimal electrode pair in terms of generating the highest Voc, as presented in Table 1, is Fe-Cu, which generated an open-circuit voltage based on the type of tree in ranges between (478.2 mV to 603.3 mV), followed in descending order by: Al-Cu (461 mV to 650 mV), Steel-Cu (334.8 mV to 511.5 mV), Al-Fe (259.3 mV to 377.8 mV), Cu-Al (-254.7 mV to -701.5 mV), Zn-Al (209.2 mV to 432.7 mV), Fe-Fe (141.7 mV to 373.8 mV), Cu-Fe (-100.3 mV to -305.8 mV), Steel-Al (-70.7 mV to -350.8 mV), Al-Al (31 mV to 83 mV), Steel-Fe (27.2 mV to 285.8 mV), Cu-Cu (11.2 mV to 467.5 mV), and Fe-Al (-1.8 mV to -204.8 mV).

The justification of that the Zn-Cu pair of electrodes allows for generating the highest levels of open-circuit voltages is that copper has the highest electric conductivity level compared to the other types of electrodes, which allows for more electrons to move about with minimum resistance. Moreover, the level of chemical change (oxidation) in the zinc nail inserted in the tree's trunk is higher than the oxidation level in the other electrode types, allowing for exchanging high level of its electrons in order to reach a lower energy state, thus releasing a higher level of energy, which generates the electrical power.

The zinc nail inserted into the tree's trunk acts as the negative electrode, creating electrons, and the copper rod buried in the soil around the tree acts as the positive electrode, triggering an electrochemical reaction that results in a minor potential difference. As zinc (Zn) atoms attract electrons less than copper (Cu) atoms, if you place a piece of zinc and a piece of copper in contact with each other, electrons will move from the zinc to the copper. The concentration of the electrons on the copper will cause them to repel each, halting the flow of electrons from zinc to copper. Thus, an electric current can flow from the zinc to the copper electrodes during the chemical reaction if the zinc and copper electrodes are connected by a wire.

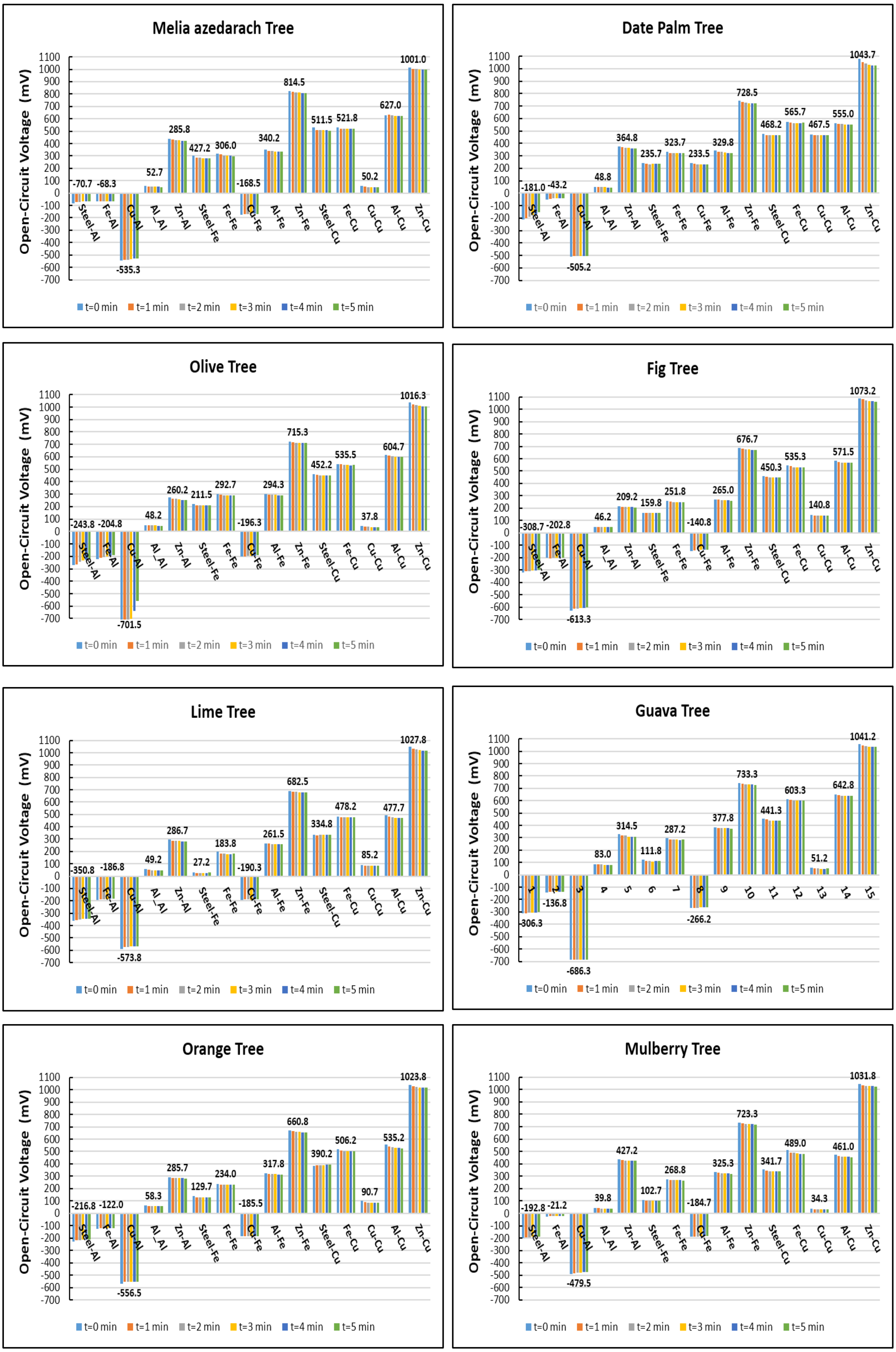

Figure 4: Open-circuit voltage measurements using fifteen electrode pairs for the trees (Olive, Date Palm, Lime, Orange, Mulberry, Fig, Guava, and Melia azedarach)

The data presented in Table 1 and Figures 3 to 4 were collected when the trunk's electrode was considered the negative electrode, connected to the cathode probe of the multi-meter, while the ground's electrode used as the positive electrode, connected to the anode probe of the multi-meter. If the polarity connections of electrodes and connections to the multi-meter are reversed, the polarity of the measurement readings will be reversed and some of them become in negative values.

In (Choo & Dayou, 2013), four combinations of electrode pairs were investigated on pulai , banana , and aloe vera trees and concluded copper-zinc electrodes produced the highest voltage (0.8V) followed by Cu-Fe (0.5V), Cu-Al (0.4V) and Al-Zn (0.38V) is the lowest.

The results in (Choo & Dayou, 2013) are similar to the results of this study in terms of the optimal pair of electrodes that allows for generating the highest levels of open-circuit voltages although the method of connecting the electrodes and the measurements setup in (Leoni, et al., 2022, p. 01-04) was (a bipolar setup: the two electrodes are inserted into the tree trunk) and is different than the method was used in this study which is (referenced to the ground: one inserted into the tree's trunk and the other is buried into the surrounded soil of the tree).

The conclusion of the first phase of this study is that the optimal pair of electrodes that could generate the highest values of Voc in all eleven types of trees is the Zn-Cu pair. Therefore, this type of electrode pair Zn-Cu will be used in the measurements of the second phase of the study which investigates the optimal tree that provides the highest short-circuit current (Isc) thus the highest produced electrical power.

Stage 2: Investigating and identifying the types of living trees producing the highest level of electrical powers based on measurement of I_{SC} and V_{OC} generated by trees:

Based on the results presented in Stage 1, it is clear that the optimal pairs of electrodes that allow producing the highest open-circuit voltages in the trees is Zn-Cu as the zinc electrode is the trunk's electrode while the copper electrode is the ground's electrode buried into the surrounding soil of the tree as a reference electrode. After completing the first stage of this study and analyzing its results, the second stage of this study has been conducted by focusing on the measurement of the short-circuit current (Isc) in the eleven types of trees using the Zn-Cu pair of electrodes which is considered the optimal pair that permitting to generate the highest electrical voltage. The short-circuit current (Isc) is the current through the trunk's electrode and the ground's electrode when the voltage across them is zero (the two electrodes are short-circuited).

In this second phase of the study, the measurements have been focused on collecting the data of Isc and Voc in the eleven types of trees using only Zn-Cu electrode pair. Continuous measurements of short-circuit current and open-circuit voltage were conducted for the eleven types of trees (three sampled trees of each type), with sampling data reading every five minutes. After recording the values of Isc and Voc for each type of tree within a period of thirty minutes, the generated electrical power in each of the eleven types of trees was calculated as presented in Table 2.

As shown in Figure 5, the short-circuit currents measured between the trunk's electrodes and the electrodes buried into

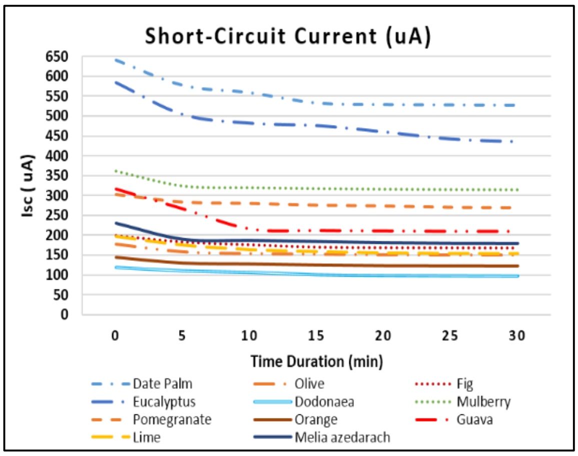

Figure 5: Continuous measurements of short-circuit current on twelve types of trees using Zn-Cu.

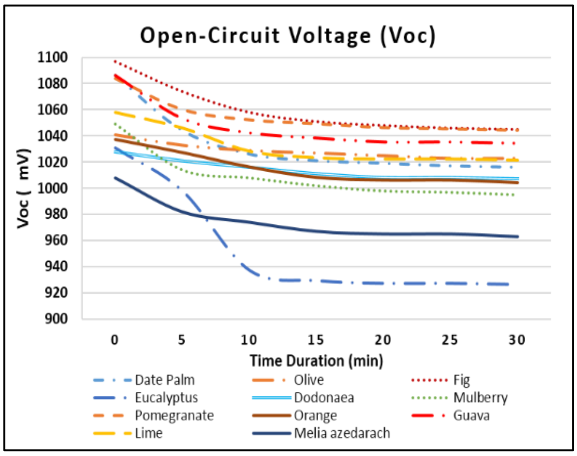

Figure 6: Continuous measurements of open-circuit voltage on twelve types of trees using Zn-Cu.

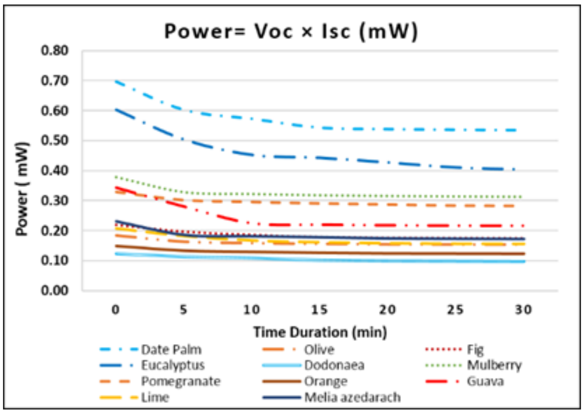

Figure 7: Calculated power generated on twelve types of trees using Zn-Cu electrodes**.**

the surrounding soil of the sampled trees are in the range of 97.1µA to 641.2µA. The highest short-circuit current was produced in the Date Palm tree with a maximum value reaches to 641.2µA and an average value reaches to 556.36 µA. The lowest short-circuit current was produced in the Dodonaea tree with a maximum value reaches to 118.5µA.

In this second stage of the study, the measurement values of the generated voltage levels using the Zn-Cu pair of electrodes were in ranges between 926 mV to 1097 mV based on the type of tree as shown in Figure 6. The highest open-circuit voltage was produced in the Fig tree with a maximum value reaches to 1097 mV while the maximum value of the short-circuit current in this tree was 199.3 µA. That means, the tree that produces the highest Voc, may not be the tree that produces the highest Isc. Therefore, the produced power has been calculated for all eleven types of trees as presented in Table 2. Based on the comparison of generation performance of electrical power between the type of trees that were tested, the results show that the Dates tree produces the highest electrical power more than any other type of trees, followed by the Eucalyptus tree with a maximum power of around 0.70mW (1086mV, 641.2µA) and 0.60mW (1031mV, 584.2µA), respectively (Figure 7).

According to the magnitude of the generated electrical power, the other types of trees were sorted in descending order as follows: Mulberry tree with a maximum power of 0.38 mW, Guava tree (0.34 mW maximum power), Pomegranate tree (0.33 mW maximum power), Melia azedarach Tree (0.23 mW maximum power), Fig tree (0.22 mW maximum power), Lime tree (0.2 mW maximum power), Olive tree (0.18 mW maximum power), Orange tree (0.15 mW maximum power), and finally the Dodonaea tree which generate the lowest electrical power (0.12 mW maximum power) comparing to the other types of the tested trees. As shown in Figure 7, it was noticed that the power becomes stable in most of the tested trees after 15 minutes of duration.

The level of chemical change (oxidation) in the zinc nail inserted in the trunk of the Dates tree is higher than the oxidation level in the other tested trees, allowing for exchanging high level of its electrons, thus releasing a higher level of energy, which generates the highest electrical power compared to the other tested trees.

Eight types of tree samples tested in this study were fruitful trees and their fruits are edible by humans (Olive, Date Palm, Lime, Orange, Mulberry, Fig, Pomegranate, Guava). While the other three types of tested trees were not fruitful trees and may their fruits be edible by animals and not by humans (Eucalyptus, Dodonaea viscosa, and Melia azedarach). It was clear from Table 2, that there is no relationship between whether the tree is fruitful or not fruitful and the electrical power generated from this tree.

Stage 3: Optimization and boosting of power output and investigating on some potential applications that can run some low-power devices:

Without boosting the power signals produced from the trees, normal electronic devices are not be able to run on mili-volt level of voltages that have been got out of a tree. In order to produce a useful energy from trees, a step-up low voltage boost converter should be used to be capable to picking up a low voltage in millivolts and storing it in batteries thus producing a higher voltage output which is enough to run and activate low-power sensors. A

Table 2: Measurements of Voc and Isc measured on different kinds of trees using Al-Cu pair of electrodes.

Tree	Open-Circuit Voltage, Voc (mV)			Short- Circuit Current, Isc (uA)			Power = Voc × Isc (mW)			
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Std. Dev.
Melia azedarach	1008	963	974.86	229.7	179.7	190.36	0.23	0.17	0.19	0.019
Date Palm	1086	1016	1032.71	641.2	527.4	556.36	0.70	0.54	0.57	0.054
Olive	1041	1023	1028.71	177.4	150.7	156.53	0.18	0.15	0.16	0.010
Fig	1097	1045	1059.86	199.3	167.4	175.87	0.22	0.17	0.19	0.015
Lime	1058	1021	1031.43	196.4	152.9	164.56	0.21	0.16	0.17	0.018
Guava	1086	1034	1046.14	316.6	209.6	234.39	0.34	0.22	0.25	0.045
Orange	1037	1004	1014.86	144.2	121.8	127.27	0.15	0.12	0.13	0.009
Mulberry	1049	995	1009.00	361.4	314.2	323.79	0.38	0.31	0.33	0.022
Dodonaea	1028	1007	1014.14	118.5	97.1	104.07	0.12	0.10	0.11	0.008
Pomegranate	1084	1044	1054.29	303.1	270.2	280.04	0.33	0.28	0.30	0.015
Eucalyptus	1031	926	953.57	584.2	435.8	483.59	0.60	0.40	0.46	0.065

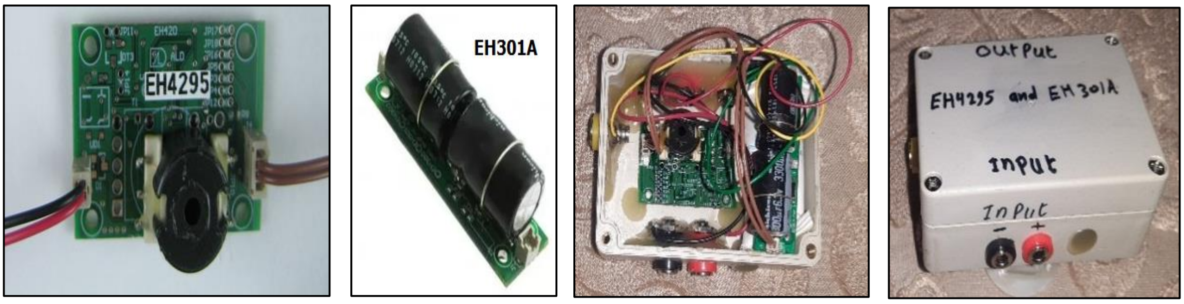

Figure 8: EH4295 booster and EH301A harvesting module.

research team from the University of Washington developed a boost converter that receives a low input voltage and stores it to produce a larger output (Carlson, et al., 2010, p. 741-750). This boost converter can work with input voltages of as tiny as 20 millivolts and can boost it to produce 1.1 volts output voltage.

There are many commercial micro-scale boost converters and energy harvesting (EH) booster modules available in the international markets such as EH4200 series modules (Le Mouël, et al., 2010, p. 95-99). It is a micropower step-up low-voltage booster module can operate with levels of input power as low as 2µW and 60mV suitable for use with a wide variety of ultra-low energy generating sources.

EH4295 booster module is a self-powered voltage-booster module, which derives its power directly from a low-input voltage source. EH4295 (Figure 8), has operating specifications as follows: minimum operating input voltage of 60mV, min operating input power of 2µW, maximum input voltage of +4V, maximum input current of 50mA, maximum input power of 250mW, and maximum output voltage of + 12V. EH301A energy harvesting module (Figure 8) can accept energy from many types of electrical energy sources and store this energy to power conventional 5V electrical devices. EH301A is completely self-powered and always in the active mode which can accept instantaneous input voltages ranging from 0V to +/-500V AC or DC, and input currents from 200nA to 400mA from energy harvesting sources that produce electrical energy in either a steady or an intermittent and irregular manner with varying source impedances (Advanced Linear Devices, Inc., 2022, https://www.aldinc.com/energy-harvesting.php). Therefore, the EH4295 booster module has been used with

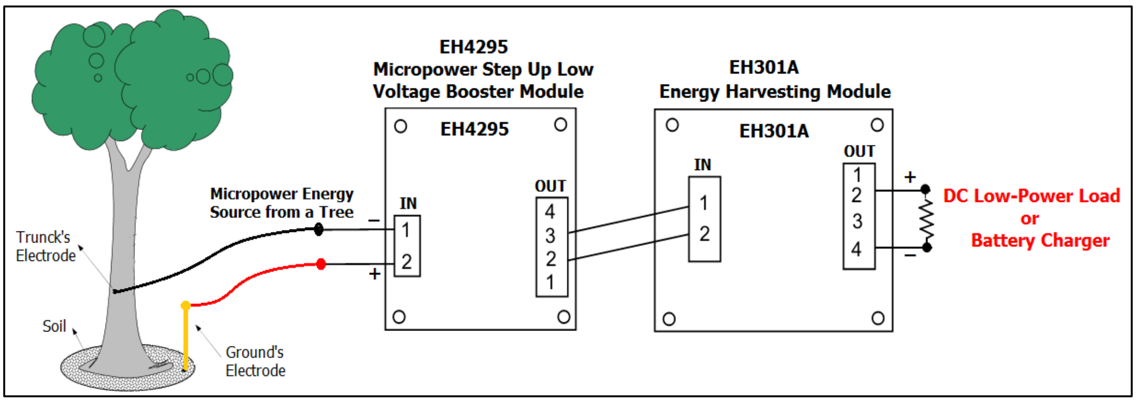

Figure 9: Using EH4295 and EH301A modules to boost and harvest the low power energy produced by trees.

EH301A harvesting module in order to boost and harvest the low electrical power energy from the living trees as shown in Figures 8 and 9.

Figure 10 shows the level of boosted and harvested electrical voltage produced from an Eucalyptus tree using EH4295 and EH301A modules, which reaches greater than 5V. This harvested electrical energy can be used to run and power conventional low-power devices work at voltage level less than 5.2V.

Figures 11,12, and 13 shows some low power device could be powered by the harvested electrical energy from the living trees such as scientific calculator, LED, and charging mobile phone. Practically, the power from trees is not large as solar energy. However, the electrical power from trees could be a low-cost option that can be used for powering low-power devices and sensors such as fire sensors to detect forest fires, biosensors for detection of some environmental conditions, or sensors for tracking the tree's health.

Figure 10: Boosting and harvesting the low voltage energy produced from a Eucalyptus tree to greater than 5V using EH4295 and EH301A modules**.**

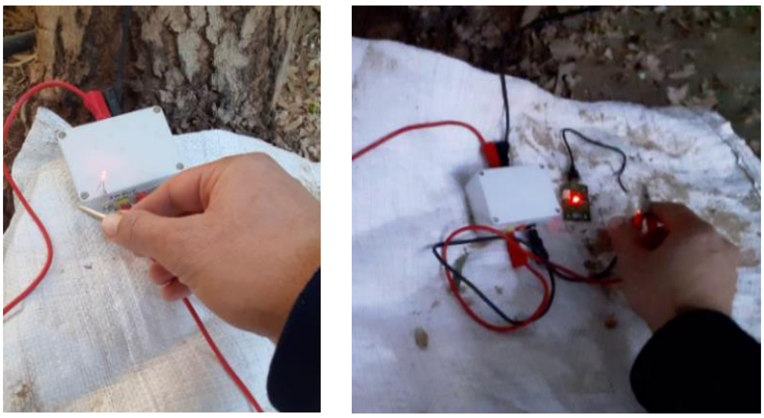

Figure 11: Turning On a LED by the electrical energy harvested from a tree.

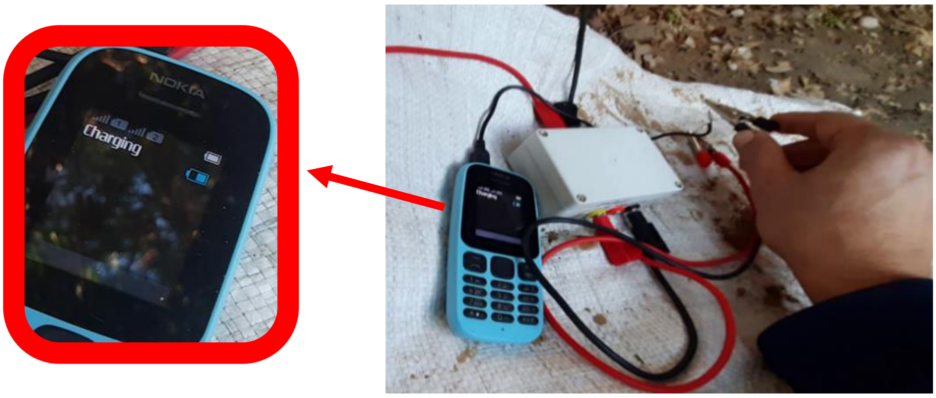

Figure 12: Charging mobile phone by the electrical energy harvested from a tree.

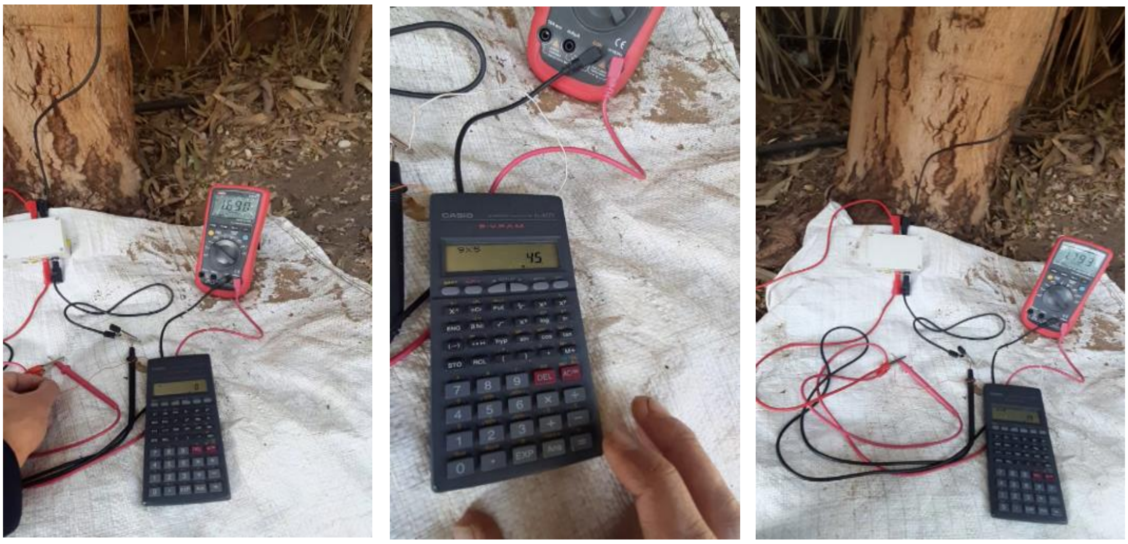

Figure 13: Operating a scientific calculator by the electrical energy harvested from a tree

Conclusion

In this paper, the analysis and evaluation of electrical signals in a variety of eleven types of living trees in Palestine's environment have been presented. Several experiments have been conducted outside of laboratories under the natural situations of variety of trees, in order to evaluate the characteristics of electrical signals produced from the tested trees using fifteen types of electrode pairs. It was found that there is a continuous electrical potential difference between the electrodes inserted in the tree's trunk and its contiguous soil. Furthermore, the magnitude of the electrical power generated from the living trees is affected by the type of electrode materials. Moreover, the type of trees also influences the magnitude of the electrical power output. The conducted experiments in this study focused on the analysis and characterization of the short-circuit current (I_{SC}) and the open-circuit voltage (Voc) which are produced from trees. The analysis of results show that the highest levels of open-circuit voltages was generated from the trees when using Zn-Cu pair of electrodes where the zinc electrode inserted in the tree's trunk while the copper electrode is buried into the surrounding soil of the tree. Based on the type of tree, the magnitude of the generated voltage using Zn-Cu pair of electrodes was in the range between 995 mV to 1090 mV. It was found that the tree produces the highest Voc, may not be the tree that produces the highest Isc. The highest electrical power was obtained from Date Palm trees with a maximum value reaches to 0.70mW (1086mV, 641.2µA).

The electrical power generated from living trees is low, but with using a micropower step-up low-voltage booster module, some low-power devices and sensors could be powered up such as LED lights, scientific calculator, and charging mobile phone, fire sensors to detect forest fires, biosensors for detection of some environmental conditions, or sensors for tracking the tree's health. Optimizing and boosting the weak electrical power generated between the living tree trunk and its surrounding soil by implementing a passive and self-powered booster and harvesting module which can be powered from the low-power tree electricity for harvesting and storage of this generated electricity which can be considered as one type of renewable energy.

The future work will concern in examining some static factors that may affect the distribution of electrical signals of voltage and current, such as age of tree, placement of electrodes (height and orientation), multiple anode-cathode connections, and setting of measurements (referenced to ground or bipolar setups). In the next study, it is recommended to use screw electrodes instead of nail electrodes since they can easily be screwed into and extracted from the trunk of trees and can provide a larger contact surface area of the trunk than smooth nail electrodes without causing large injury for the trees.

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