Renewable Energy Potential From Cyperus Rotundus Linn Through Plant-Microbial Fuel Cell (P-MFC) As an Electrification in Indonesia's 3T Area

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Abstract. 4,400 villages in Indonesia's 3T areas still need electricity. Plant-Microbial Fuel Cell (P-MFC) is a cheap and environmentally friendly technology to produce electrical energy. Nut grass is an interesting type of plant to study in the application of P-MFC. This grass is easy to find in various environmental conditions, including 3T areas. So, the purpose this study is to examine the application of nut grass (Cyperus rotundus Linn) as an energy source in P-MFC, its potential for existence in the 3T area of Indonesia, as well as opportunities and challenges in the 3T area of Indonesia. This study was prepared using the narrative review method. The results show that nut grass (and other C4 plant) has potential as an energy source in P-MFC because it produces 120-712.1 mW/m^2 electricity, This is different from C3 plants which can only produce electricity below 100 mW/m^2. Its presence in the 3T area is abundant because this type of grass is widespread in tropical areas on roadsides, fields, and swamps. The challenge is the need for clear regulations regarding using grass plants as an energy source.

Keywords: cyperus rotundus linn, Indonesia's 3T electrification, plant microbial fuel cell

1 Introduction

In today's era, electricity has become a basic need for humanity. Currently, as many as 4,400 villages in the 3T (disadvantaged, frontier, and outermost) areas of Indonesia do not have electricity. The 3T area is an area that classified as a state border and is far from the city, so that access to life's necessities is still limited, especially regarding electrification. This is due to access to areas that are difficult to reach by the PLN electricity network and the difficulty of mobility to 3T areas, making investment costs for building electricity networks expensive [1]. The distribution of 3T areas in Indonesia is based on Presidential Regulation No. 63 of 2020, covering Papua Province at 48%, Nusa Tenggara at 22%, Maluku at 14%, Sumatra at 11%, and Sulawesi at 5%. Every year, the government makes efforts to electrify these areas, but in reality, up to now, there are still many villages that have yet to experience electric energy. Due to the lack of electrification in the 3T area, the people there need to catch up with economic, cultural, educational, and human resource qualities compared to other areas [2]. If the electrification

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problem in the 3T area is not immediately resolved, it will be easier for Indonesia to become a developed country, and its people will not be prosperous. The 3T area has the potential to break away from Indonesia.

Nut grass (Cyperus rotundus Linn) is a type of grass that is widespread in tropical and subtropical areas, found in almost all types of soil, altitude, soil moisture, and various pH levels, but not in soil with high salt levels. This grass can survive the highest temperatures on the farm. In general, nut grass is found in open places or slightly protected from sunlight, such as in agricultural land that is not too dry, fields, gardens, moors, and roadsides, and grows as a weed that is difficult to eradicate [3]. The 3T area in Indonesia has diverse geographical conditions and indeed grows a lot of nut grass, such as in Papua and Maluku, which have very suitable environmental conditions for nut grass to grow. However, so far, nut grass has only been used as animal feed or even just cut down [4].

The abundant nut grass, including in the 3T area, can be utilized as a new, renewable energy source through Plant-Microbial Fuel Cells (P-MFC). P-MFC is a technology that can convert organic matter in soil into electrical energy with the help of microbes [5]. In particular, sedge grass was chosen as the primary source of P-MFC because it has several advantages: easy adaptability to various environmental conditions, a robust fibrous root system, the ability to accumulate high biomass, and more efficient photosynthesis that produces large amounts of biomass. Nut grass performs photosynthesis by converting sunlight, CO_2, and water into oxygen and organic material. Excess organic material will be removed through the plant's root system (rhizosphere). Microorganisms use this organic material for metabolism, which produces electrons, protons, and carbon dioxide. Electricity is generated from the simultaneous flow of electrons through the anode and cathode in the P-MFC system. This technology does not produce dangerous emissions because the by-product produced is water [6]. As long as environmental conditions are maintained, and the sun continues to shine, the P-MFC can continue to produce electricity.

The importance of electrification in the 3T area and the abundance of nut grass, which has yet to be utilized optimally, is the author's basis for conducting this study. This article aims to examine nut grass as a source of electrical energy through P-MFC, its potential for existence in the Indonesian 3T area, and the opportunities and challenges of the Indonesian 3T area. It is hoped that this study can become a reference for academics and industry to advance electrification in Indonesia's 3T area..

2 Methods

This idea was written using a narrative review approach which focused on research articles reporting on (1) distribution and characteristics of sedge grass, (2) environmental conditions in the 3T area of Indonesia, and (3) microbial fuel cell plants as electricity producers. Keywords used in the literature search, include cyperus rotundus linn, Indonesia's 3T electrification, plant microbial fuel cell.

Articles were selected from a database of journals, such as ScienceDirect, ProQuest, Springer, and Garuda Ristekdikti. The journal has been indexed nationally (SINTA) and internationally (SCImago and Scopus), published between 2011 and 2023, so the research results obtained are still relevant. After selecting the title, abstract, and discussion, 17 articles were obtained, which were used as the primary basis for writing this study. After obtaining the data, the discussion is presented in a qualitative descriptive manner supported by tables to present quantitative data. The data is presented in a single table which contains information regarding the type of plant, treatment during the research, and the electricity output produced. Schematic of the literature selection process is shown in **Figure 1.**

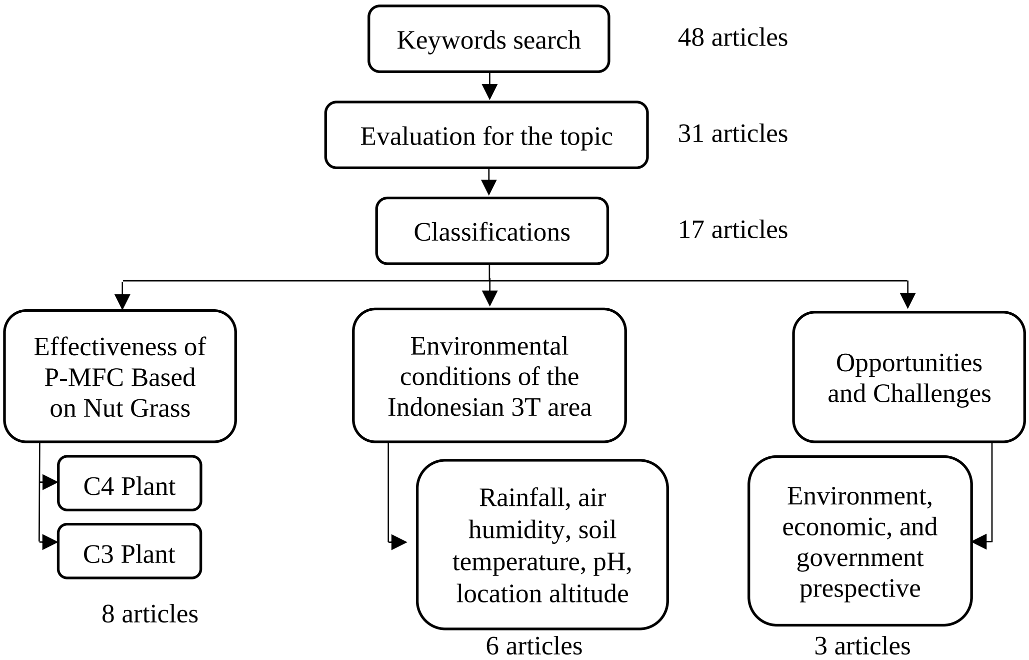

Fig. 1. Literature Selection Scheme

3 Results and Discussion

3.1 Effectiveness of P-MFC Based on Nut Grass in Electricity Production

P-MCF has a working principle that can convert organic material in plant soil (in this study, nut grass) into electrical energy. In general, the process that occurs in P-MFC so that it can produce electricity is as follows [6].

1. Photosynthesis of nut grass produces food reserves in the form of organic materials, such as glucose, carbohydrates, and acetate.
2. Excess organic material will be wasted through the root system so that the area around the roots is rich in organic material.
3. Microorganisms in the soil oxidize organic matter to produce protons, electrons, and carbon dioxide.
4. Electrons are used in the anode, which is connected to a wire, and an external load, which is connected to the cathode.
5. Protons pass through the membrane to the cathode, and oxygen is reduced to water.
6. Electricity is obtained from the rotation of electrons from the anode to the cathode.

The components involved in this process are the anode media, which functions to provide a suitable substrate for the growth of microorganisms and facilitates the oxidation of organic compounds; the cathode electrode, which functions to facilitate the oxygen reduction reaction to water; the anode electrode, which functions to collect electrons produced during the organic compound oxidation process, an external electrical circuit that functions to channel electrons from the anode to the cathode, and of course energy storage media such as batteries [6]. An illustration of the P-MFC working system can be seen in **Figure 2.**

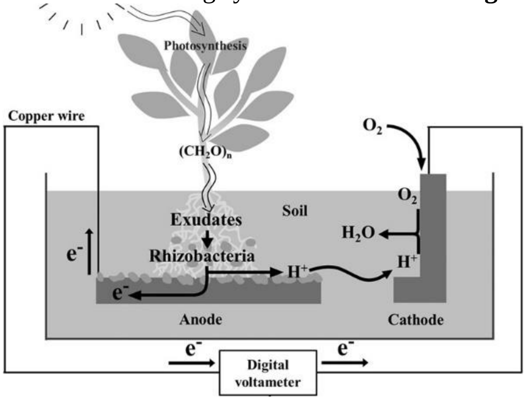

Fig. 2. P-MFC Work Scheme

In more detail, P-MFC works based on the concept of anaerobic decomposition. The process begins with hydrolysis, which converts complex organic materials, such as carbohydrates and proteins, into monomers. Then, these monomers (sugars and amino acids), through degradation by fermentation microorganisms, are converted into alcohol and fatty acids. Furthermore, the fermentation results are degraded by microorganisms, resulting in the decomposition of compounds in the form of carbon dioxide, electrons, and protons, which are then donated to the anode on the P-MFC to produce electricity [5]. This process can continue as long as the soil has sufficient organic content and the sun continues to shine for photosynthesis of nut grass. The electricity obtained can be channeled directly to housing residents in the 3T area or stored in batteries.

P-MFC has various designs, depending on the location of the application. According to Timmers et al. (2013), a design that is suitable for use in significant grassland locations is tubular P-MFC because it can be used directly on soil, both dry and wet, without additional reactors. The components of the tubular P-MFC consist of a silicone hose on the innermost part, a graphite felt cathode that is wrapped around the hose, a membrane that is wound after the cathode, and finally, a graphite felt anode which is wrapped around the outermost part. Then, the anode-cathode circuit is connected to a hose, which functions to supply oxygen to the cathode. The tubular P-MFC is planted in the ground at a depth of 10 cm from the ground surface, with both ends of the hose remaining in contact with the outside air [7]. Other designs, such as flat plates and cylinders, can also be applied if 3T people have cultivated nut grass in their yard, not grass that grows wild in open areas. However, the use of flat plate and cylindrical P-MFC designs is considered less effective. This is because both require special reactors, for example, tall tubes in cylindrical P-MFCs and rice field pipes in flat plate P-MFCs [8]. These design variations also increase investment costs so that the P-MFC that is suitable for the current needs of the 3T community is tubular. The tubular P-MFC design can be seen in **Figure 3.**

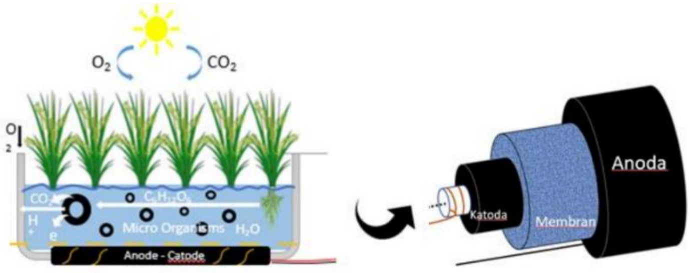

Fig. 3. P-MFC Tubular Design

Factors that influence the performance of P-MFC, including plant type, microbe type, soil condition, substrate type, electrode type, and several different treatments, also influence the electrical output results. Nut grass is a type of plant that photosynthesizes C4, namely a plant that can adapt to hot and dry environments. In the application of P-MCF, C4 plants have better performance compared to C3 because C4 can convert sunlight with better efficiency. Theoretically, the maximum conversion efficiency value for C4 plant types is 6%, and for C3 is 4.6%. This makes nut grass a potential plant for the application of P-MFC [6].

The roots of nut grass have the characteristics of fibrous roots and are about 1-5 cm long in the soil. Fibrous roots have many root strands, so if there is excess nutrition in the grass, more organic content will be transferred to the soil. This allows microbes to metabolize longer, thus producing more electricity [9]. According to Hafsah et al. (2020), around 70% of organic material resulting from photosynthesis ends up in the plant root system. Apart from that, nut grass is a type of weed that is found in clusters. The clustered plant roots make the soil below contain constant nutrients every day, making it suitable for large-scale P-MFC applications.

Microbes in soil play an essential role in the oxidation process of organic material, which produces electricity. Various kinds of bacteria, such as Firmicutes, β-Proteobacteria, Bacteroidetes, and δ-Proteobacteria, show the ability to produce electricity well in P-MFC. These bacteria live in dry and wet soil. Firmicutes are more dominant in dry soil and can even form spores that are resistant to drought. β-Proteobacteria, Bacteroidetes, and δ-Proteobacteria are more dominant in wet soil, such as damp forests and swamps. Nut grass is a plant that can grow in various conditions, both in dry and wet land, so, likely, the types of bacteria that have been tested for effectiveness for P-MFC are also found in the root system of nut grass [10].

Soil characteristics are closely related to the population of microorganisms in it. To form a microbial community, structure, soil surface, pH, and soil nitrogen accessibility are the main driving factors. More electricity is produced in P-MFC when agricultural land is used as inoculum compared to forest land. This is because agricultural soil contains a lower C/N ratio (the weight ratio of organic carbon to total nitrogen in the soil), polyphenol content, and acetate concentration. In contrast, forest soil contains more non-electrogens, which results in reduced energy [10]. Nut grass is a type of plant that grows a lot in rice fields because this plant photosynthesizes via the C4 pathway, which is adapted to hot and dry environments.

The electrical power output produced by P-MFC of nut grass varies. However, currently, there has been no research regarding the effectiveness of electricity produced by P-MFC based on nut grass. Its effectiveness can be estimated from similar grasses that are classified as C4 plants, such as Spartina anglica, Sporobolas arabicus, Cyperus esculentus, and Chrysopogon zizanioides. Literature study data regarding the comparison of electrical power output of P-MFC based on C3 and C4 grasses whose characteristics resemble nut grass are presented in **Table 1.**

Table 1. The Electricity Output Produced by P-MFC Based on Grass

No.	Type of Plants	Treatments	Power Density (mW/m^2)	References
1	*Spartina anglica*	The experimental conditions were carried out in swamp land, the reactor was a P-MCF cylinder type (diameter 9.9 cm), observations were carried out for 26 weeks and maximum power was obtained (222 mW/m^2) in the 17th week.	222	[11]
2	*Gylceria maxima*	Experimental conditions were carried out on dry land, the reactor was a cylindrical P-MCF type (diameter 3.5 cm), observations were carried out for 118 days and maximum power was obtained (67 mW/m^2) between the 66th and 72nd days.	67	[12]
3	*Sporobolas arabicus*	Experimental conditions were carried out in dry land, a single chamber P-MCF reactor, observations were carried out for 8 weeks and maximum power was obtained (120 mW/m^2) in the 4th week using Graphite and Sporobolasarabicus electrodes.	120	[13]
4	*Puccinellia distans*	Experimental conditions were carried out on dry land, a single chamber P-MCF reactor, observations were carried out for 4 weeks and maximum power was obtained (83.7 mW/ m^2) in the 1st week.	83.7	[14]
5	*Cyperus esculentus*	The experimental conditions were carried out on wetland, a cylindrical P-MCF type reactor, observations were made three times and repeated electrical power measurements until an average value was obtained.	712.1	[15]
6	*Chrysopogon zizanioides*	Experimental conditions were carried out in a climate controlled chamber, single chamber P-MCF reactor, observations were carried out for 7 days and maximum power was obtained (132.595 mW/ m^2) on day 1 at 6 and 7 am using carbon and zinc electrodes.	132.595	[16]

Based on this data, it can be seen that C4 plants produce more electrical power than C3 plants. The majority of C3 plants (in this study are Gylceria maxima and Puccinellia distans) only produce a maximum electrical power of less than 100 mW/m^2. This is because photosynthesis in C3 plants experiences a 25% reduction in fixed carbon, which is released as carbon dioxide into the atmosphere so that the organic products produced are reduced. Puzzle grass is thought to have almost the same electrical output as Cyperus esculentus because it comes from the same genus. In this study, Cyperus esculentus produced very high electrical power, namely a maximum of 712.1 mW/m2 in the 17th week of observation. Electric power of 1 mW can provide electricity for 2000-3000 customers with a capacity of 900 kVA. If this plant is applied to P-MFC, there is enormous electrification potential, and it can even provide electricity for thousands of villages in the 3T area.

Other C4 plants, such as Spartina anglica, Sporobolas arabicus, and Chrysopogon zizanioides are also potential plants for the application of P-MFC because they have sizeable electrical power output, respectively 222 mW/m^2, 120 mW/m^2, and 132,595 mW/m^2. This shows that C4 plants, including nut grass, are viable candidates for mass application of P-MFC for electrification in 3T areas. As previously discussed, soil conditions, types of microbes, and organic substrates in the soil greatly influence the electrical output of P-MFC. These factors cause the difference in maximum electrical power output in Table 1 data, so it is essential to know the environmental conditions of the 3T area before implementing nut grass-based P-MFC.

3.2 Distribution of Nut Grass in the 3T Area of Indonesia

Different environmental conditions affect the nutgrass population in an area. Nut grass can thrive in environmental conditions that have rainfall of 500-3000 mm per year (but can also survive in arid conditions, namely rainfall of 100 mm per year), air humidity ranging from 60-85%, soil pH between 4.0-7.5, temperature around 24-32ºC, and location at an altitude of 800-1000 m above sea level (Elfianis, 2020; Socfindo Conservation, 2021). The 3T area reviewed in this study are area based on Presidential Regulation No. 63 of 2020.

Sumatra currently has 7 3T area. The entire area, except North Musi Rawas, is a small archipelago that is in direct contact with sea waters. The type of soil in the area is sandy and has a pH range of 7. According to Putra et al. (2018), the dominant weed in cultivated plants on coastal sand is a type of weed with narrow leaves and is classified as a C4 plant such as Cyperus rotundus L.. Rainfall in Nias is relatively high (300-400 mm), it has a mountainous topography and narrow hills. With varying heights (0-800 m) above sea level (DPL), air humidity in the area ranges from 83-94%, and air temperature 26.7°C. Meanwhile, the North Musi Rawas area has moderate rainfall (100-150 mm), the topography of the area consists of highlands and lowlands (125-250 MDPL), air humidity is 65%, and air temperature is 25-31° C. The conditions in these two areas are potential places for sedge grass to live. Nias has environmental conditions that tend to be humid and wetlands, which are favored by sedge grass, whereas in North Musi Rawas, even though the land is drier, it still supports sequin grass to grow.

Southeast Nusa Tenggara has 14 3T area. The environmental conditions in this area are almost the same as the conditions in the 3T area in Sumatra, namely the coastal areas of the islands. Rainfall in this area is low (0-20 mm), the topography has varying heights (100-500 meters above sea level), the air humidity is around 77%, and the air temperature is 24-34°C. Judging from these parameters, it can be seen that Nusa Tenggara is a lowland and slightly dry area. Based on Kusumawardani's statement (2018), puzzle grass can survive very extreme weather. Even though the only conditions suitable for the survival of sedge grass are humidity and air temperature, it is estimated that sedge grass remains abundant in this area, considering that sedge grass can survive in a variety of environmental conditions.

Sulawesi only has 3 3T areas, namely Donggala, Tojo Una-una, and Sigi. All three are areas included in the province of Central Sulawesi (Central Sulawesi). This area has low (50-100 mm) to medium rainfall (100-150 mm), the majority of the topography is valleys and highlands (100-2000 MDPL), air humidity is 72-85%, and air temperature is 25-34° C. These conditions are classified as usual between dry and humid so that sedge grass grows optimally in these three areas. Moreover, Donggala, Tojo Una-Una, and Sigi have alluvial soil types with a soil pH of around 5.3-5.8, so they also support the survival of sedge grass.

Maluku has 8 3T area. Maluku has rainfall that is classified as low (100-150 mm) to high (400-500 mm), the topography is dominated by hills (200-800 MDPL), air humidity is 73%, air temperature is around 23.5-31°C, and has fertile alluvial sedimentary soil because there are not many cities or factories. The majority of people there work in the plantation sector, which means the land is also fertile for the growth of sedge grass. The 3T area in Maluku is also an archipelago that is directly connected to the coast, so it is predicted to have an abundant population of sedge grass, such as Nias in Sumatra and Nusa Tenggara.

Papua has the most 3T area in Indonesia, namely 30 area. However, nut grass is thought to grow well in this area because it has a variety of rainfall, from low to medium to high. Papua's topography is dominated by swampy lowlands, grasslands, valleys, and highlands filled with tropical rainforest (0-1500 MDPL). This area has air humidity of 79-81% and air temperature of 29°C - 31.8°C. Apart from that, the land conditions in Papua are considered fertile because urban areas have not yet been built, so the growth of sedge grass is maintained. The survival parameters of the jigsaw can be met in Papua, so it is estimated that the population will be abundant in this area.

3.3 Opportunities and Challenges of P-MCF Based Nut Grass in Indonesia's 3T Area

P-MFC based on nut grass is an environmentally friendly technology with several advantages; because P-MCF does not interfere with the metabolic activity of nut grass, which affects the grass population, nut grass can still grow generally during the P-MFC process of generating electricity, and its population can even increase as soil fertility increases. P-MFC does not produce harmful effects on the soil because the by-product is water, which is reabsorbed by the roots to increase the growth of nut grass. CO_2 emissions resulting from the oxidation process of organic material in P-MFC are absorbed by the soil, unlike other power plants, which still emit large amounts of CO_2 into the air. Overall, P-MFC is a candidate for future power generation in the 3T area that is safe for the environment.

Viewed economically, nut grass-based P-MFC is a cheap electricity-producing technology. The electricity produced by P-MFC for one year costs an investment of USD 735/m3 to 36,000/m^3. Compared to other power plants, solar panels. Wind power plants, as well as micro-hydro, P-MFC, are much more affordable, primarily if used for electrification in 3T areas. The costs incurred for mobilization from the factory to the destination location and equipment installation are also more affordable compared to other power plants because the size of the equipment series is small and not sensitive to environmental conditions. Communities in 3T areas can accommodate electricity produced by P-MFC nut grass on batteries. Then, batteries containing electricity can be sold to other areas, thereby improving the economy of the 3T area community while also helping the electrification of other areas.

Land management for nut grass-based P-MFC installations does not require large areas of land and does not interfere with human activities. The issue of land ownership is also not a problem because the majority of locations where nut grass grows are public places owned by the government. Industries that want to install P-MFC only need to apply for permits from the local government without paying rental fees. If the location of the nut grass is on private community land, a revenue-sharing system can be implemented between the government and the landowner.

The challenge in implementing this innovation is government regulations regarding independent electrical installations that need to be connected to the PLN electricity network or what is usually called off-grid. The off-grid system is very suitable to be implemented in the 3T area of Indonesia. Apart from the fact that PLN electrification has yet to reach the area, people can store large amounts of electricity in batteries without having to sell excess electricity to PLN. However, if P-MFC users become more widespread in various area, PLN could suffer losses because the 3T community needs to provide income in the form of electricity or money to PLN. So far, the government regulations contained in Ministerial Regulation (Permen) of Energy and Mineral Resources (ESDM) Number 26 of 2021 are only limited to regulating off-grid systems for PLTS. They have yet to be applied to other power plants. A win-win solution is needed in the future regarding this problem so that the energy economic cycle in Indonesia is maintained.

4 Conclusions and Suggestions

Electricity is a primary need for all humans. As many as 4,400 villages in Indonesia's 3T areas still need electricity. On the other hand, Plant-Microbial Fuel Cell (P-MFC) is a cheap and environmentally friendly technology that utilizes the biochemical activity of plants to produce electrical energy. Therefore, the author conducted a study on the potential for renewable energy from nut grass (Cyperus rotundus Linn) through P-MFC as an electrification in the 3T area of Indonesia. The results show that nut grass (and other C4 plant) has potential as an energy source in P-MFC because it produces 120-712.1 mW/m^2 electricity. This is different from C3 plants which can only produce electricity below 100 mW/m^2. Its presence in the 3T area is abundant because this type of grass is widespread in tropical areas on roadsides, fields, and swamps. The challenge is that regulations are needed that specifically regulate the use of grass plants as an energy source so that they can become a legal source of electricity. The regulations in question include equipment standardization, operating procedures, ownership of electrical resources, and environmental management aspects. The hope, this study can become a reference for academicians or industry to advance electrification in Indonesia's 3T areas.

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