Elektroof: Smart roof as an energy independent solution for Indonesia in the future

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Abstract. The Electric Steam Power Plant is still being one of the most commonly used power plants in Indonesia. The use of coal has so many bad impacts on humans and also environmental health. The existence of coal reserves is decreased each year caused of non-renewable energy. Therefore, an innovation for alternative power plants sourced from renewable energy is needed to reduce pollution and be more environmentally friendly. This study examines the possibility of using solar energy and raindrops as the main energy source for elektroof systems. The method used for this study is by comparing the literature about the utilization of piezoelectric and solar cells as the new source of power generators in typical house buildings in Indonesia. The results of the literature study showed that 1 elektroof can produce electrical energy of 183 wh when the weather is hot and when the weather rains elektroof can produce 156 wh so that the elektroof can be used as a tile on the roof of the house that can simultaneously become a self-contained power plant. Elektroof can generate energy by utilizing renewable energy in the form of sunlight and rainwater. Thus, elektroof is possible for use in Indonesia which is a tropical country.

1. Introduction
The Economic growth in Indonesia has grown significantly over the last few decades. Until now, the Indonesian economy is the largest in Southeast Asia and the 7th largest in the world based on the gross domestic product (GDP) based on purchasing power parity (PPP) [1]. The rapid economic growth has led to an increase in electricity demand in Indonesia. Indonesia is the largest energy consumer in the Association of Southeast Asian Nations (ASEAN), accounting for more than 36% of the region's energy demand [2]. According to World Bank data, Indonesia's electricity consumption in 2019 reached 1084 kWh per capita, which has increased significantly in recent years. To meet this electricity growth, Indonesia is still very dependent on fossil fuel power plants [1]. Data from the world bank said that Indonesia's electricity production in 2015 was contributed by oil, gas, and coal amounting to 89.3% of the total energy mix.

Most of the country's electricity sources, both developed and still under development, still use fossil fuels [3]. The use of fossil fuels is still very popular because of their capability in delivering energy and its price [4]. Moreover, fossil fuels as no renewable energy will be run out in the future. The use of fossil fuels is also one of the causes of various environmental problems such as global warming and air pollution which causes health problems and affects the quality of life of the population [3]. In addition, the increase in population and people's living standards along with the increasing demand for electrical
energy can have an impact on the high rate of growth of CO₂ emissions. From the results of the final energy demand projection, CO₂ emissions produced in 2030 will reach 912 million tons of CO₂ eq (BaU) [5]. Increased CO₂ emissions will have an impact on increasing temperatures on earth so that it can cause climate change. Many impacts caused by the use of fossil fuels have led to the need for the use of new, renewable energy sources that are more environmentally friendly.

We will review and discuss the possibility of using Elektroof as a standalone power plant in every home so that it can become an environmentally friendly clean energy producer. The Elektroof is a development of solar power plants that are limited to utilizing the dry season only, while Indonesia has one more season, namely the rainy season which is also a source of renewable energy. Electrophysical components consist of solar and piezoelectric panels that serve as electricity producers. This source of electricity is sourced from renewable energy that utilizes 2 seasons in Indonesia, namely sunlight and rainwater so that this tool does not produce pollution that negatively impacts people and the environment.

2. Coal: the main fuel for power plant

Data from outlook energy 2019 show that the coal power plant is the largest electricity contributor in Indonesia with a percentage of 56% of all existing power plants [5]. The use of coal is still the dominant and main used as a power plant material compared to other energy sources. Even though Indonesia only has 3% of the world's coal reserves [6]. If coal is used continuously as the main source of electricity generation in Indonesia, it is estimated that coal reserves in Indonesia will be used up in 56 years [7]. In addition, the use of coal as the main ingredient in the operation of electric steam power plants also brings various impacts to humans and nature.

Coal mining causes irreversible damage to land, air, and water sources [6]. The International Energy Agency (IEA) revealed that fossil fuels Coal accounted for 44% of total global CO₂ emissions. Coal burning is the largest source of greenhouse gas (GHG emissions), which trigger climate change. Serious smog in the form of 90% of SO₂ emissions, 70% of dust emissions, and 67% of NOx emissions is produced during the coal combustion process [8]. In addition, coal combustion also produces several pollutants in the form of SOx, NOx, CO, and particles in the form of fly ash which are released through the chimney so that they can be carried by the wind to the surrounding community who live near the power plant [9]. Pollutants produced from coal combustion are one of the contributors to air pollution in Indonesia. Air pollution is a silent killer causing 3 million premature deaths worldwide and can lead to an increased risk of lung cancer, stroke, heart disease, and respiratory disease [6].

The results of the GEOS-Chem atmospheric modeling conducted by the Harvard University – Atmospheric Chemistry Modeling Group (ACMG) research team show that air pollution from the current operation of the Indonesian coal-fired power plant has caused around 6,500 premature deaths per year. The main causes are stroke (2,700), ischemic heart disease (2,300), chronic obstructive pulmonary disease (400), lung cancer (300), and other cardiovascular and respiratory diseases (800). Air pollution caused by coal-fired power plants is not only limited to the area where the power plant is located but also affects other areas in Indonesia [6]. If the use of this coal continues in the future, it can cause more serious impacts on humans and the environment.

3. The possibility of using renewable energy in Indonesia

Indonesia is one of the growing countries due to several factors, namely economic fast growth, increasing urbanization, and stable population growth in Indonesia. Some of these factors resulting in Indonesia are included in the category of countries that have a high level of energy consumption. Indonesia uses 40% of the total energy in ASEAN (Association of Southeast Asian Nations). Between 2000 and 2014, Indonesia's energy consumption increased by around 65% and is predicted to reach 80% by 2030 [10]. With high energy consumption, Indonesia must develop all renewable energy in Indonesia. So that all fossil resources will become energy reserves, and electricity needs in Indonesia in 2050 can be achieved by clean and environmentally friendly renewable domestic energy sources. The maximum share of renewable energy that can be achieved in 2050 is 33% and 80% without technology diffusion
with the least cost optimization resulting in lower generation costs than CO$_2$ emissions. Total CO$_2$ emissions in 2050 are predicted to be five to six times greater than current emissions.

Indonesia is on the equator so it has a lot of potential renewable energy such as solar, water, biomass, geothermal and tidal waves [10]. Geothermal energy is one of the renewable energy that can be found in Indonesia and has a potential of 40%. Around 252 geothermal locations in Indonesia are spread out following volcanic formation pathways that stretch from Sumatra, Java, Nusa Tenggara, Sulawesi, to Maluku. This has a total potential of about 27 GWe. Geothermal energy is renewable and environmentally friendly energy, this huge potential needs to be increased in its contribution to meet domestic energy needs which can reduce Indonesia's dependence on dwindling fossil energy sources. The potential of geothermal energy is expected to meet the target of developing geothermal energy to generate electricity through a Geothermal Power Plant of 6000 MWe by 2020 [11].

On the other side, wind power generation is no longer a new problem in the world. However, in Indonesia, wind energy is not developed optimally, until now the installed capacity of wind power plants is only about 1.6 MW of the total predicted 9.29GW capacity, due to several factors, and one of them is the low level of confidence on the availability of wind in Indonesia [12]. Ocean wave energy also has great potential in Indonesia, it is predicted that located south of the Java Sea has the most promising location for wave power potential, with the highest energy resources available from January to December. The maximum annual average wave power in the Java Sea can reach 22 kW/m [13]. However, the utilization of renewable energy is still hasn’t maximized until now it is only limited to the use of solar energy. This is very unfortunate because if another renewable energy is also implemented optimally, it can make Indonesia independent of clean and environmentally friendly energy.

Solar energy has great potential in Indonesia because it is located at the equator, so it has a relatively high level of solar radiation and rainfall throughout the year. Most areas of Indonesia get enough solar radiation intensity with average daily radiation of about 4 kWh/m$^2$ [14]. Even the intensity of rainfall in Indonesia reaches 2000 – 3000 mm/year. So this can be utilized properly to support the development of new renewable energy in Indonesia by utilizing both seasons simultaneously. Optimally and bring up an idea or ideas, namely Elektroof: Multi-weather Electricity Generating Tile as an Environmentally Friendly Clean Energy Alternative Solution.

4. **Elektroof Details and system**

Elektroof is a multi-weather electric tile that utilizes 2 seasons in Indonesia. Elektroof is capable of generating electrical energy in hot and rainy weather. The design of the elektroof is described using SketchU/p software as shown in figure 1 below. The elektroof consists of Monocrystalline Solar Panel, Piezoelectric PVDF, and Elektroof Connector.

![Figure 1. Elektroof design and component](image-url)
4.1. Monocrystalline Solar Panel
Monocrystalline Solar Panel made from single molded silicone. In the course of making, the crystal is sliced and formed into bars. The excess of this single silicone has more space to stream the electron that generates the electricity. Moreover, this type of solar panel resistance could use in high temperatures and also in shady weather. The resulting efficiency panel reaches 15-20%; vertical solar panel (20.4818%) and flexible solar panel (16.4044%). The flexible reach higher output than the vertical. Depending on the radiation intensity to the panel surface differences are observed between energy productions. The average energy performances of monocrystalline and polycrystalline are 546.82 Wh and 517.52 Wh, respectively. Maximum and minimum energy production from panels were actualized on 19.08.2014 and 24.08.2014, respectively. The results obtained from the measurement show that monocrystalline solar panels performed better compared to polycrystalline on every experiment day [15].

**Figure 2.** Comparison bar of energy output between monocrystalline and polycrystalline daily [16]

The bar in figure 2 shows from the daily experiment for a week that the output energy of the monocrystalline is always more than the polycrystalline. The highest energy output was on Monday and the lowest was on Saturday caused of the different sun exposure times. Besides, the comparison between monocrystalline and polycrystalline is that monocrystalline solar panels produce higher hourly power output performance than polycrystalline.

**Figure 3.** Hourly power output graphics [16]
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4.2. Piezoelectric PVDF
Piezoelectric is a material that produces electricity based on the pressure effect on it. The composition of Polyvinylidene Difluoride (PVDF) is CH2-CF2 or it’s also called 1,1 difluoro-ethylene. The pre-eminence of PVDF is flexible, easy handling, and also undemanding. As its molecular structure, PVDF material has three forms which are; phase α, β, γ. The most usage of the form is the “phase β”. Piezoelectric PVDF is used for producing electricity from rainfall pressure. The research shows that rainfall resulting much more energy than gas pressure and also disc loop. PVDF polymer piezo films have many advantages, mainly due to their mechanical properties: flexibility (adapted to the non-planar surface), high mechanical resistance, dimensional stability, homogeneous piezo activity within the plane of the film, high piezoelectric coefficients without any aging effect for temperatures up to 808°C (PVDF) or 1108°C (copolymer), high dielectric constant, chemically inert material with a low acoustic impedance close to that of water[17].

![Figure 4. PVDF Crystal](image)

The PVDF crystal is easy to be shaped and also flexible cause the PVDF crystal has a high content of yield strain. The Piezoelectric PVDF works by the collision into the crystal and the crystal excrete the electric field that produces electricity. PVDF crystals as shown in figure 4 above.

4.3. Elektroof Connector

![Figure 5. Elektroof Connector Plug](image)

The Elektroof Connector serves as the connector between one to other elekstroof. Furthermore, the connector is used to transfer the energy from one connector to another. The advantage of the connector is to reduce the human error in Solar panel wiring which can give a big impact on energy distribution. installation of solar panels generally using cables plus and minus to cause a human error during installation. therefore, the elekstroof connector will be able to reduce human error at the time of
installation. On the connector elektroof, the plus and minus parts of the cable have been adjusted to facilitate the user in installation. On the installation of the user just need to install the elektroof connector plug in figure 5 with the elektroof connector plug hole in figure 6 that has been adjusted the pluses and minuses. In figure 5 and figure 6 are also shown the plus terminal and minus terminal parts on the elektroof connector. The connector was made from zinc alloy. Clearly, as the nickel content in the electrodeposit increases the protective nature of the coating will change too, the alloy becoming electrochemically nobler and hence being less sacrificial to the substrate steel [19].

5. Measurement energy

5.1. Energy conversion

Elektroof tile is formed from 2 components that produce electricity which have different sources. Because it has 2 electricity generators, the power produced by the elektroof has 2 variations. When the weather is hot, solar panels work to generate electrical energy. Elektroof using monocrystalline solar panels 50 wp size 54×64×3 cm which can provide an output power of 50 watts. The input power received by solar modules from solar radiation does not 100% enter the inverter because it is affected by the loss of components and systems, along with the calculation of power to the energy generated [20].

| Type of losses                  | Value of losses (%) |
|--------------------------------|---------------------|
| Losses manufacture (power tolerance) | 3                   |
| Losses dirt                     | 5                   |
| Losses temperature module       | 5,7                 |
| Losses cable                    | 5                   |

Based on the data loss component and solar panel system in table 1 above then for solar panels 50 wp will produce an output power of 40.65 watts. So if it is known that Indonesia’s solar irradiation 4.5 kWh day/m² [21], it will be obtained energy produced by solar panels as follows:

\[
\frac{40.65 \text{ wp}}{1000 \text{ W/m}^2} \times 4500 \text{ Wh/day/m}^2 = 183 \text{ Wh}
\]

(1)

From the calculation above (1) it is known that one elektroof tile can produce 183 Wh of power. Then when the weather is rainy, the solar panels on the elektroof will automatically stop working and their role is replaced by piezoelectric which converts the boom caused by rain into electrical energy. The power generated by the piezoelectric is as follows:

Piezoelectric PVDF size 1 x 1 cm [22]

(2)

Piezoelectric voltage = 0.15 V [22]

(3)

Panel voltage = 18 V

(4)

Because the panel and piezoelectric voltages are not the same (3) and (4), they must be equalized first. This voltage equalization is important so that the piezo can be in sync with the panel and not become a burden that ends up reducing the power generated by the panel. Voltage equalization is done by increasing the number of piezoelectrics and stringing them together.

\[
\frac{18 \text{ V}}{0.15 \text{ V}} = 120 \text{ piezo}
\]

(5)

To get the same voltage, 120 piezoelectric PVDF pieces are needed in series with a size of 1 x 1 cm. The 120 piezos are divided into two groups, namely group 1 and group 2. Group 1 is a rhombus-shaped
area with a size of 4 x 4 cm, while group 2 is a rhombus-shaped area with a size of 2 x 2 cm. each grub is placed in 6 different points. As figure 6 shows below.

![Figure 7. Piezoelectric group division](image)

For group 1 there are 6 groups each measuring 4 x 4 cm and because for 1 piezo it has a size of 1 x 1 cm then group 1 can accommodate 16 piezos for 1 point. Then the power generated by group 1 is as follows:

$$P = \frac{V^2}{R} = \frac{(16 \times 0.15)^2}{1} = 5.76 \text{ Watt}$$

Because there are 6 groups (6), then:

$$5.76 \times 6 = 34.56 \text{ watt}$$

For group 2 there are 6 groups each measuring 2 x 2 and because 1 piezo has a size of 1 x 1 cm, group 2 can accommodate 4 piezos for 1 point. Then the power produced by group 2 is as follows:

$$P = \frac{V^2}{R} = \frac{(4 \times 0.15)^2}{1} = 0.36 \text{ Watt}$$

Because there are 6 groups (8), then:

$$0.36 \times 6 = 2.16 \text{ watt}$$

So, for a total of 120 piezos, it can produce a power of (7) and (9) 36.72 watt this assuming torrential rain intensity of 50 mm-100 mm for 1 hour. If within 1 day of heavy rain with an intensity of 50 mm-100 mm for 5 hours then the resulting power is 183.6 watts. The power generated from piezoelectric cannot be directly supplied to home devices because it is still in the form of DC. Therefore, the power must first be converted into AC. If the DC is converted to AC then the power must be reduced for the calculation of losses of 15% of its DC power [23]. So that for piezoelectric energy output obtained as follows:

$$183.6 \times 15\% = 27.54 \text{ Watt}$$

$$183.6 - 27.54 = 156.06 \approx 156 \text{ Watt}$$

So, for one elektroof module can be generated electrical energy of 183 wh when the weather is hot and when it is raining then the elektroof can generate electrical energy of 156 wh in one day.

5.2. Energy Distribution
The energy produced by the elektroof goes through several stages as shown in figure 8. Elektroof connector functions as a transfer of the resulting power to flow power from one elektroof to another elektroof. This power supply has a tip, namely the elektroof which is at the lower left end of the roof.
The elektroof which is at the left end of the roof is then in charge of flowing to the charge controller. The charge controller functions to protect, control the process of charging, discharging the battery, and determining the photovoltaic operating point with its voltage level and thereby affecting the yield of photovoltaic energy [24]. Then from the charge controller, the power is stored in the battery. Batteries function to support fluctuating solar resources and provide energy at night and during the day [24]. The battery here also has a very important role in the power generated by the piezoelectric on the elektroof. Because piezoelectric power is inconsistent when directly supplied to home appliances, a battery is needed to overcome this limitation [25] This inconsistency is due to the nature of the rain having fluctuating and erratic intensity. The capacity of the battery used as a place to accommodate power depends on the amount of power needed by a house. Please note, the power stored in the battery is still in DC and must first go through an inverter to be converted into AC before being used for home appliances. This inverter will later play a role in controlling the interaction with the voltage and frequency of the electric utility at home [26].

![Elektroof electricity distribution](image1.png)

Figure 8. Elektroof electricity distribution

![Left end elektroof which is connected to charge controller](image2.png)

Figure 9. Left end elektroof which is connected to charge controller

Power can be supplied to home appliances after the current is converted to AC. From the calculations that have been done previously (1), it is known that the elektroof can produce 183 watts of energy per hour when the solar panel is active or the weather is sunny. If it is calculated, the energy produced by just one panel can be distributed to turn on a 34-watt fan for 2 hours, 65-watt television for 1 hour, and
Led lamps with 10-watts of power for 5 hours. In addition, from previous calculations, it is also known that when the piezoelectric power generated in the active elektroof reaches 156 Watts per hour (11). Although the power produced is less than when the solar panel is active, this power can already be used to power home appliances, such as a 34-watt fan for 2 hours, 65-watt television for 1 hour, and Led lamps with 10-watts of power for 2 hours.

6. Application of elektroof in a building
Elektroof is a tile producing electricity that consists of renewable energy. In its application, elektroof can be applied as a roof cover as well as a power plant in the house. Elektroof is used on part of the roof of the house with an amount tailored to the electricity needs of the house. For example, if used type 36 house with daily electricity consumption of 2876 watts, it will need 30 elektroof modules to meet all the electricity needs. For its application as a tile on the roof of the house can be seen in figure 9 below.

![Figure 10. Type 36 house with elektroof roof](image)

6.1. Cost Analysis of the installation
The unit cost of a 50 wp monocrystalline solar panel is IDR 325,000 [15]. Photovoltaic system power generation has a higher capital cost per unit compared to fossil-based power sources. However, the operating costs of photovoltaic systems are much lower than fossil-based power sources because photovoltaic systems have safe efficiency and can last for 25 years [16]. Piezoelectric PVDF has received wide attention due to its good flexibility, strength, easy processing, low cost, and other advantages [17]. While the cost for a PVDF type piezoelectric unit with dimensions of 1cm × 1 cm is IDR 10,000 [18]. In one PVDF type piezoelectric electrode used as many as 120 pieces so that the overall cost incurred for the use of piezoelectric is IDR 10,000 × 120 = IDR 120,000. So the total cost for 1 unit of elektroof is around IDR 500,000. The use of elektroofs does require a large investment cost, but for the next 25 years, if these costs are accumulated with steam power plants, of course, the use of elektroofs will be cheaper. On the other hand, several years later the development of solar panels and piezoelectric shows a decrease in costs caused by the accelerated market growth and economies of scale. Thus, an annual cost reduction of about 4% can be made in the coming years [27].

6.2. Cost Analysis of the installation
The roof of the house can be used as an independent power plant location because it is a strategic location to get sunlight and rainwater. If every house in Indonesia can supply its own electricity needs, then Indonesia can become an energy-independent country. The use of PLN electricity in each house will be reduced because the community can be energy independent. The reduction in the use of PLN electricity
will naturally stop the operation of coal-fired power plants and later reduce the negative impact on the community and the surrounding environment.

Application elektroof will take place in several stages. The first stage is to conduct further research on the material and the effectiveness of the power generated by the elektroof. In the second year, an experiment will be conducted with elektroof or sampling. Sampling is an experimental stage of a settlement in Indonesia and is evaluated on an ongoing basis. The last stage of the application of elektroofs will be to replace the roof of all houses in Indonesia using elektroofs with the aim that Indonesia can become an energy independent country and can achieve SDGs point 7 of clean and affordable energy. SDGs indicator point 7 targets to substantially increase the share of renewable energy in the global energy mix to take urgent action to combat climate change and its impacts and ensure access to affordable, reliable, sustainable, modern, and clean energy services to increase efficiency [28].

7. Conclusion
As has been explained and clearly stated, sunlight and raindrops can be utilized on a large scale to generate electrical energy. Sunlight is converted into electrical energy by utilizing solar panels and the collision of rainwater can be converted into electrical energy using piezoelectric. Elektroof is a combination of solar panels and piezoelectric which are used to generate electrical energy. Elektroof is a tile that produces multi-weather electricity that can be applied as a tile on the roof of a house and at the same time used as an independent power plant in each house. The power generated by the elektroof can be used to power the entire house, from fans, TVs, refrigerators to lights. So that the use of Elektroof will be able to become an alternative solution for clean, environmentally friendly energy that can reduce pollution in Indonesia and can achieve SDGs point 7, namely clean and affordable energy.

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