Feasibility Analysis of Renewable Energy Alternative Selection in Rural Areas Using Zero Energy Building Concept

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Abstract. This study aims to utilizing renewable energy in rural areas using zero energy building (ZEB) concept and feasibility analysis, related to alternative renewable energy-based electricity generation in the use of energy in rural area. The first step, is to find out the amount of renewable energy in each city or district by looking at the average amount of rainfall, average wind speed, and the electrification ratio in each district or city in each province, the second stage is a literature study related to renewable energy technology, and the final step in this study is to determine the feasibility analysis related to the technology of renewable energy resources used by calculating the payback period and determining the cost of electricity produced. Alternative 1 was chosen because it is the most efficient choice with only 2.56 years of payback period, suitable for use in rural areas and able to meet all the daily electricity needs of the house, by generating electricity of 1.156 kWh / year, with a COE of Rp1.410. This study compares several alternative of renewable energy technologies (i.e. solar panel and wind turbine) that can be used to meet electricity consumption needs in rural areas, combined with using a pico-hydro rainwater harvesting, which uses rainwater as an alternative energy source.

1. Introduction
Energy can be used to meet the most basic human needs such as cooking, lighting, water heating, and water extraction. Water extraction is the process of taking water from sources that are available either temporarily or permanently which is used for flood control, and irrigation. In addition, energy is the basis for most economic activities, both for food production, transportation, and commercialization, or simply producing commodities to elaborate other products or supply services [1]. According to the International Energy Agency (IEA), nearly one billion people do not have access to electricity, most of them in sub-Saharan Africa and developing countries (Asia World Energy Outlook, 2018). Some of those who do not have electricity, live outside the electricity grid who have no other choice in this matter, and must rely on unreliable and unhealthy alternative energy, such as kerosene [2, 3]. The electrification ratio (ER) in Indonesia is 98.30% which can be seen in Figure 1, meaning that the level of comparison of the number of people who enjoy electricity with the total population in a region or country. Nusa Tenggara Timur (NTT) is a province in Indonesia with the smallest electrification ratio in Indonesia with a electrification ratio rate of 62%, followed by Kalimantan Tengah at 84%, and Kalimantan Barat at 87%.

The main cause of the national electricity grid cannot be distributed in isolated areas, is
Figure 1: Electrification ratio in Indonesia in late 2018 (source: DISEMINASI RUPTL 2019-2028 PT PLN (Persero))

Table 1: Renewable power capacity in the reference case for 2030 and the total potential of renewable power

| GW              | Reference Case 2030 | Theoretical potential for renewable power capacity |
|-----------------|---------------------|---------------------------------------------------|
|                 | On-grid power capacity | On-grid renewable power capacity | Solar PV | Large hydropower | Small hydropower | Bioenergy | Geothermal |
| Total Indonesia | 193.5               | 55.8                   | 716.4    | 532.6            | 75.0             | 19.4      | 32.7       | 29.5       |
| Sumatra         | 39.2                | 17.6                   | 196.2    | 137.1            | 15.6             | 5.7       | 15.6       | 12.9       |
| Java-Bali       | 119.8               | 19.1                   | 71.5     | 38.7             | 4.3              | 2.9       | 9.2        | 10.1       |
| Kalimantan      | 10.3                | 5.4                    | 184.2    | 149.0            | 21.6             | 8.1       | 5.1        | 0.2        |
| Sulawesi & Nusa | 20.3                | 11.6                   | 97.6     | 66.8             | 10.8             | 1.8       | 2.6        | 4.8        |
| Tengara         | 3.9                 | 2.1                    | 166.8    | 140.9            | 22.8             | 0.8       | 0.2        | 1.5        |

(Source: Renewable Energy Prospects: Indonesia, 2017)

because the costs charged at the start of the expansion of electricity through the national grid, are very expensive for governments in developing countries [2, 4]. One of the alternatives that can be used for areas that are still isolated by electricity is to use the zero-energy building (ZEB) concept. The zero-energy building concept is one of the alternatives that can be used both in rural areas, or even in developed city. Various different terms have been used to characterize very low-energy buildings, with the target of zero energy or emissions from buildings, where every energy consumed in the building is produced by renewable sources at the building site [5]. According to Renewable Energy Prospects, based on the potential for each region and on the road maps available for several renewable technologies (E.g. solar PV, hydropower, and geothermal), the second column in Table 1 shows what is assumed in renewable power capacity for each region in the reference case for 2030 [6]. Comparing the planned level of deployment with the theoretical potential per renewable resource and the total power demand in each region provides an initial basis for estimation of REmap Options. However, important constraints and other considerations are also taken into account in the derivation.
2. Literature Review
Some literature has discussed much related to renewable energy technologies (E.g. wind turbine, solar PV) in rural areas, include complementary of three types of renewable energy sources (solar, wind, and tidal wave) to increase micro-girds power company in electrically isolated areas [7]. Researchers discuss about the optimization model for the planning of a stand-alone, renewable energy-based electricity system for developing (off-grid) communities [8]. The design of optimizing the use of hybrid solar panels, biomass and diesel to meet the energy needs of villages connected to the electricity network, using hybrid optimization models for electric renewable energy (HOMER) to find the optimal unit configuration to produce power that is needed at minimum cost under different economic conditions [9]. The techno-economic feasibility assessed using HOMER, and discussed the identification, analysis of opportunities and challenges facing the penetration of renewable energy technology (RET) in Cameroon [10, 11]. While the relationship between renewable, non-renewable energy consumption and economic growth in South Asian countries during the period 1990 – 2014 was also discussed [12]. The renew current and emerging renewable energy technology to utilize the abundant renewable energy resources in Nigeria [13]. The last two study use a comparison of the energy consumption to compare with the renewable energy sources produced. More importantly, there are no studies, to our knowledge, that discuss renewable energy in Indonesia by considering available renewable energy resources by looking at the electrification ratio, and the average energy consumption used in rural areas.

Therefore, the main contributions in this study are as follows: (i) this study discusses the economic feasibility analysis of renewable energy technologies used in rural areas. (ii) the location of this study is in Kalimantan Barat, Melawi district, is considered if seen from Table 3 has a large average rainfall compared to the others, and has a fairly strong wind speed compared to others. Electrification ratio in Nusa Tenggara Timur has the smallest electrification ratio in Indonesia, but this study compares several renewable energy sources available in three provinces with the smallest electrification ratio in Indonesia, including Kalimantan Barat, Kalimantan Timur and Nusa Tenggara Timur. Data collection on renewable energy sources (E.g. average wind speed, temperature, rainfall) can be seen in Table 3. (iii) This study compares several alternative of renewable energy technologies that can be used to meet electricity consumption needs in the district of Melawi. (iv) data related to electricity consumption is obtained by estimating electricity demand for 10 remote un-electrified in Sulawesi and Sumatra and our own investigations during field visits, the size of a generic village is estimated to establish a baseline of a typical Indonesian village [14]. (v) using a pico-hydro rainwater harvesting, which uses rainwater as an alternative energy source, as did [15]. The aim of this study is to utilize renewable energy alternative in rural areas using zero energy building concept.

3. Research Methodology
3.1. Method
This case study is based on data obtained every day for the last 10 years, starting from January 2008 to December 2018 (rainfall) and the last 1 year, starting from January 2018 to December 2018 (wind speed, and average temperature) which is accessed through Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) website. The first step is to find out the amount of renewable energy in each city or district by looking at the average amount of rainfall, average wind speed, and the electrification ratio in each district or city in each province, see Table 3. The second step is a literature study that will be used in relation to renewable energy technology. Literature of micro-hydro rainwater harvesting technology referred to [15–18] are used as a reference to determine the number of solar photovoltaic (PV) needed and calculate the electricity capacity that solar PV produces. The final stage in this study is to determine the feasibility analysis related to the technology of renewable energy resources used by calculating the simple payback period and determining the cost of electricity produced, referring to [18].
Table 2: Household energy consumption in rural areas

| Electrical appliance        | Power consumption (W) | Usage duration per day (Hour) | Quantity |
|----------------------------|------------------------|------------------------------|----------|
| Fluorescent Lamp (inside)  | 16                     | 18:00–00:00                  | 2        |
| Fluorescent Lamp (outside) | 16                     | 18:00–06:00                  | 1        |
| Colour TV 19”              | 80                     | 18:00–23:00                  | 1        |
| Speaker (Stereo)           | 20                     | 18:00–23:00                  | 1        |
| Refrigerator               | 100                    | 17:00–09:00                  | 1        |
| DVD/VCD Player             | 25                     | 18:00–20:00                  | 1        |

(Source: Blum, Wakeling, & Schmidt, 2013)

### 3.2. Household Energy Consumption

Data on household energy consumption in rural areas, can be seen in Table 2 [14], from the results of investigations of 10 un-electrified villages in Sulawesi and Sumatra, and investigations during field visits consisting of 1475 people in 350 households, with 4.5 people per household on average. This energy consumption data is important in this study because it will be used as a basis in determining the amount of renewable energy technology to be used.

### 3.3. Pico-Hydro Rainwater Harvesting Energy Generation

While related to rainwater harvesting, this study assumes that the house in this study have a size of 6m x 6m with an area of 36m² referring to [19], with a roof coefficient of 0.7 [20], for every rain that falls, if it rains only as much as 1mm means that in an area of 1m², can accommodate as much as 0.001m³ of rain or equivalent to 1 liter, after knowing the rainfall in each desired location, see Table 3. Next process is to determine the amount of monthly rainfall that occurs at a certain time period that have a chance of reaching 80%. Because this study using a pelton wheel as a turbine, to determining the power generated using a pico-hydro generator can be estimated as shown in Eq. 1 and 2 [17].

$$V = \sqrt{2gh}$$  \hspace{1cm} (1)

$$P = \rho Q \left( \frac{V}{2} \right) \left( \frac{V}{2} - V \right) (1 - \cos \beta)$$  \hspace{1cm} (2)

Where $P$ is power (W), $\rho$ is density of water (kg/m³), $Q$ is flow rate (m³/s), $V$ is velocity exiting the pipe (m/s), $g$ is gravity (m²/s²), $h$ is height of gutter (m), and $\cos \beta$ is an exit angle of the blade (Degrees). In general, the water would exit at a 180 degree angle, this is not physically possible as the exiting water would collide with the entering water, it has been determined that an exit angle of 165 degree is optimal [21].
Table 3: Climatology recapitulation data of Nusa Tenggara Timur, Kalimantan Barat, & Kalimantan Tengah

| Province                        | District / city                  | Electrification Ratio (%) | Average Temperature (°C) | Average humidity (%) | Rainfall (mm) |
|---------------------------------|----------------------------------|---------------------------|--------------------------|----------------------|---------------|
|                                 |                                  |                           |                          |                      |               |
| Nusa Tenggara Timur            | Kabupaten Flores Timur           | -                         | -                        | -                    | 5,693.9       |
|                                 | Kabupaten Kupang                 | -                         | -                        | -                    | 4,261.8       |
|                                 | Kabupaten Manggarai              | -                         | -                        | -                    | 17,649.0      |
|                                 | Kabupaten Rote Ndao              | -                         | -                        | -                    | 6,206.6       |
|                                 | Kabupaten Sikka                  | -                         | -                        | -                    | 4,023.9       |
|                                 | Kabupaten Sumba Timur            | -                         | -                        | -                    | 2,670.0       |
|                                 | Kota Kupang                      | -                         | -                        | -                    | 21,074.9      |
|                                 | Kabupaten Kapuas Hulu            | 65.1                      | 27.1                     | 83.9                 | 351.2         |
|                                 | Kabupaten Ketapang               | 77.6                      | 27.7                     | 82.7                 | 214.0         |
|                                 | Kabupaten Melawi                 | 62.6                      | 27.0                     | 84.1                 | 312.8         |
|                                 | Kabupaten Sambas                 | 88                        | 26.8                     | 87.0                 | 242.7         |
|                                 | Kabupaten Siantang               | 64                        | 26.7                     | 86.0                 | 261.7         |
|                                 | Kota Pontianak                   | 100                       | 26.9                     | 84.6                 | 299.7         |
|                                 | Kabupaten Barito Utara           | 77.11                     | 28.0                     | 82.7                 | 257.0         |
|                                 | Kabupaten Kotawaringin Barat     | 70.84                     | 27.0                     | 84.1                 | 206.7         |
|                                 | Kabupaten Kotawaringin Timur     | 79.13                     | 26.9                     | 85.3                 | 221.1         |

The average annual rainfall in the Province of Nusa Tenggara Timur is smaller than in the Province of Kalimantan. However, the average wind speed in Nusa Tenggara Timur Province is far greater than in Kalimantan Province. Data related to electrification ratios for the province of Kalimantan were obtained through the work visit report from commission VII of the Indonesian Parliament to Kalimantan Tengah. While the authors have not found a reliable source for obtaining electrification ratios in Nusa Tenggara Timur, so the location of this study focuses on Kalimantan Barat, Melawi District. The reason why Melawi District was chosen as the research location because it has the smallest electrification ratio, and has a fairly good rainfall intensity, which is very suitable for the pico-hydro rainwater harvesting system.

3.4. Solar Photovoltaic

To design a solar photovoltaic system in a rural area, are as mentioned in the Eq. 3 [16].

\[
PV(Area) = \frac{E_L}{G_{av} \times \eta_{pv} \times TCF \times \eta_{out}}
\]  

(3)

Where \(E_L\) is average daily load (kWh/day), \(G_{av}\) is average daily irradiation (kWh/m²), \(\eta_{pv}\) is solar panel efficiency (%), temperature correction factor (TCF), \(\eta_{out}\) is overall efficiency included battery and inverter (%), and \(PV\) (Area) is solar panel area (m²), while \(P_{MPP}\) is a...
maximum power output from one solar panel, this formula is used to determine how much solar panel area is needed. In general, the optimal temperature of solar panels when operating is 25°C. If the solar panels work in an environment with temperatures above the optimal temperature, there will be a reduction in the power generated, to find out how much the amount of power lost, the TCF formula is used as in Eq. 4 and 5 [18].

\[
\text{Temperature Correction Factor} = \frac{P_{MPP} \text{ when temperature raise (Celcius)}}{P_{MPP}} \tag{4}
\]

\[
P_{MPP} \text{ when temperature raise} = 0.5\%/(\text{Celcius}) \times P_{MPP} \times \Delta_{\text{increase temp-optimal temp.}} \tag{5}
\]

3.5. Wind Turbine
The equation used to determine the power of wind turbine, is as follows (Eq. 6).

\[
P = 0.5 \times \rho \times A \times C_p \times V^3 \times N_g \times N_b \tag{6}
\]

Where \(P\) is power (W), \(\rho\) is air density in \(\text{kg/m}^3\), \(A\) is rotor swept area, \(C_p\) is Coefficient of performance, \(V\) is wind velocity (m/s), \(N_g\) is generator efficiency, and \(N_b\) is gear box bearing efficiency.

3.6. Feasibility analysis
In determining the feasibility analysis of the renewable technology that used in rural areas, this study using simple payback period and cost of energy (COE) obtained from [18]. Renewable energy systems are economically feasible only if the total revenue exceeds the costs incurred by the system in the period of time up to the system lifetime. The time at which earnings equals cost is called the payback time. A simple payback calculation can provide a preliminary judgment of economic feasibility, the following is the formula for determining a simple payback period:

\[
SP = \frac{IC}{(AKWH \times \frac{Rp}{kWh} - IC - FCR - AOM)} \tag{7}
\]

Where \(SP\) is the simple payback in years, \(IC\) is initial cost of installation (Rp), \(AKWH\) is energy produced annually (kWh/year), \(Rp/kWh\) is price of energy displaced or price obtained for energy generated, \(FCR\) is fixed charge rate per year, and \(AOM\) is annual operation and maintenance cost (Rp/year), \(AOM\) cost is 1% of the total installation cost. The cost of energy (COE) is primarily driven by the installed cost and the annual energy production, is as Eq. 8.

\[
COE = \frac{IC \times FCR + AOM}{AKWH} \tag{8}
\]

4. Result and Discussion
This study has 3 Alternative schemes with 3 types of renewable energy technology used, namely pico-hydro rainwater harvesting, solar photovoltaic, and wind turbine. Utilization using pico-hydro rainwater harvesting gives pretty good results, based on equation (2) the average power produced using this technology is 160.4W for a year, of course there are several influential factors such as gutter height and the most important is the average rainfall in that location. The generator used in pico-hydro rainwater harvesting is the PMA Generator ME1112, which has a maximum capacity up to 4000W of AC current. Solar photovoltaic uses 2 panels of 300WP 24V, because based on using equation (3) the area of solar PV needed is 2.02m², while the dimension of 1 solar panel that used have an area of 2m², with the maximum capacity of using this solar system is 528W of DC current because of total efficiency of this system. Using
wind turbine does not generate much of electricity, because the wind speed is very small in Melawi district, best solution to use wind turbine is in the area that has an average speed of at least 4m/s. Using equation (6) the average electricity produced is 15.5W/year of DC current. Table 4 shows the average electricity produced by each technology.

Table 4: The Energy Production Based on Technology Used

| Months     | Pico-Hydro Rainwater Harvesting (W) | Solar Photovoltaic (W) | Wind Turbine (W) | All RET Combined (W) |
|------------|-------------------------------------|------------------------|------------------|----------------------|
| January    | 130.1                               | 16.368                 | 21.1             | 16.519               |
| February   | 190.4                               | 14.784                 | 20.5             | 14.993               |
| March      | 175.9                               | 16.368                 | 16.6             | 16.560               |
| April      | 184.7                               | 15.840                 | 20.9             | 16.646               |
| May        | 155.6                               | 16.368                 | 11.9             | 16.536               |
| June       | 155.4                               | 15.840                 | 6.1              | 16.001               |
| July       | 79.4                                | 16.368                 | 16.0             | 16.463               |
| August     | 101.8                               | 16.368                 | 19.4             | 16.489               |
| September  | 113.2                               | 15.840                 | 15.5             | 15.969               |
| October    | 196.2                               | 16.368                 | 12.1             | 16.576               |
| November   | 226.7                               | 15.840                 | 11.2             | 16.078               |
| December   | 214.9                               | 16.368                 | 14.1             | 16.597               |

Figure 2: Installation Scheme

wind turbine does not generate much of electricity, because the wind speed is very small in Melawi district, best solution to use wind turbine is in the area that has an average speed of at least 4m/s. Using equation (6) the average electricity produced is 15.5W/year of DC current. Table 4 shows the average electricity produced by each technology. In this case, solar panels generate the most electricity, while wind turbines produce the smallest electricity. Using only solar panels, actually meet the needs of daily electricity consumption. The problem is, the electricity produced by solar photovoltaic systems and pico-hydro rainwater harvesting system is DC current, while the average electrical appliances for household is AC current, an inverter is needed to convert DC current to AC current, a full installation scheme in this study is shown in Figure 2.

The use of a charge controller in this study is a must, because it prevents the battery from overcharge, may protect against over voltage, and regulates the distribution of electricity from the energy source to the battery, which of course is used to maintain battery life. Table 5 shows...
Table 5: List of Renewable Energy Technology Component Used

| Solar Photovoltaic System | Component                          | Quantity | Price (Rp) |
|---------------------------|------------------------------------|----------|------------|
|                           | Greentek 300WP 24V Solar Panel      | 2        | 4,649,00   |
|                           | Mounting Bracket PV - Mid Clamp    | 3        | 58,000     |
|                           | Xantrex Schneider Electric C60 PWM | 1        | 2,600,00   |

| Pico-Hydro Rainwater Harvesting System | Component                          | Quantity | Price (Rp) |
|---------------------------------------|------------------------------------|----------|------------|
|                                       | PMA Generator ME1112               | 2        | 2,380,00   |
|                                       | Pelton Water Wheel Turbine         | 2        | 570,000    |
|                                       | Xantrex Schneider Electric C35 PWM | 1        | 1,000,00   |

| Wind Turbine System | Component                          | Quantity | Price (Rp) |
|---------------------|------------------------------------|----------|------------|
|                     | SV-400W Wind Turbine               | 1        | 3,000,00   |
|                     | Xantrex Schneider Electric C35 PWM | 1        | 1,000,00   |

| Supporting System   | Component                          | Quantity | Price (Rp) |
|---------------------|------------------------------------|----------|------------|
|                     | TBE Inverter Pure Sine Wave 1200w  | 1        | 1,582,50   |
|                     | MT 12V 200Ah Deep cell Battery     | 3        | 3,750,00   |

The first alternative is to use only a solar panel system to meet daily needs, the second alternative is using solar panels and pico-hydro rainwater harvesting combined, and the last alternative, is third alternative using all the technologies, namely pico-hydro rainwater harvesting, solar photovoltaic, and wind turbine. By using equation (8) to calculate cost of energy and equation (7) the payback period can be determined. For Rp/kWh value obtained from which states that “In Indonesia, the purchase price or FIT rate of solar PV power is 0.7dollar/kWh” [22]. Thus, the Rp/kWh value used in this study was 0.7dollar/kWh or
equivalent to Rp9,871 / kWh. The type of solar panel that used is mono crystalline, although this type of panel is very expensive but has a longer lifespan and offer a high level of efficiency compared to polycrystalline. Generators with permanent magnet are used in the pico-hydro rainwater harvesting system, and wind turbine, providing efficiency about 78%, and more durable, provide a lifespan up to 25 years for all renewable energy systems. Deep cycle type batteries are used, because these batteries designed to be regularly deeply discharged using the most of its capacity, because every battery has a cycle charge, the lifetime of this battery is up to 20 years. Table 6 shows the comparison of the payback period and the cost of energy for each alternative.

From all of the three alternatives available, all of the alternative is feasible to use. Because all each alternative reaches a payback period before reaching the system’s service life, which is up to 20 years. But alternative 1 is the most efficient choice, because it has the fastest payback period with only 2.56 year, which produced 1.156 kWh/year of energy, has the smallest annual maintenance costs, and the use of solar panels alone is enough to meet daily needs.

In other word, wind turbine produces about 4 kWh/year, and Pico-hydro rainwater harvesting system produce energy at only 0.962 kWh/year, although not much is used for electricity usage throughout the house and produce the smallest energy among other alternatives. But it can be used for example charging emergency lights, flashlights, cell phones, notebook, or even HTPC. Last but not least, is alternative 3 that has a 4.48 year payback period, with the largest COE cost of Rp 2,230, and generate 1.162 kWh/year of energy.

5. Conclusion
In this case study, the Melawi district in the province of Kalimantan Barat, has good potential in utilizing Pico-hydro rainwater harvesting technology, because it has a fairly large average rainfall of 312.8 mm/year, and generate 160.4 W/year electricity. However, Pico-hydro rainwater harvesting technology is not able to meet the electrical energy needs of the entire house every day, therefore the use of solar photovoltaics in this study is able to meet the daily energy needs of households. Alternative 1 was chosen because it is feasible and suitable for use in rural areas and also able to meet all the daily electricity needs of the house. Calculation of feasibility analysis still use a simple method that is simple payback period, future studies will use more complex analysis feasibility, that the results obtained can be more detailed.

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