Indonesian hydro energy potential map with run-off river system

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Abstract. Indonesia aims to decarbonize the energy sector by accelerating the use of new and renewable energy, expected to reach 31% of total energy supply in 2050. One of important tools to achieve the target is renewable energy potential maps including hydro energy potential maps. Yet, existing hydro energy potential maps have several weaknesses such as sites coordinate not on the river network. This study aims to update and to improve the run-off river system energy hydro maps by using a novel method considering multiple factors that are head values, discharge river, gravity, and the efficiency of the hydro system. In calculating the head value, we use DEM data from SRTM 1 arc second to estimate difference between upstream and downstream elevations. We also did Q90 modeling using WFLOW software as generate the discharge value. In the end, we verified the maps by using field measurement data in 776 sites from previous study. As a result, we estimate the total potential of hydro energy with the run-off river system in Indonesia reaches 94,627 MW distributed in 52,566 sites.

1. Introduction

Electricity demands in Indonesia is increasing at rate 6.9% per year [1]. To meet the electricity demands, Indonesia is accelerating the uses of new and renewable energy that is expected to contribute 31% of total energy supply in 2050 [2]. One important type of renewable energy sources is hydropower because it can produce more reliable power plant compared to other renewable energies [3, 4]. Unsurprisingly, the largest renewable energy productions in the world is from the hydro power [5].

The National Energy General Plan or RUEN states that hydro energy potential data in Indonesia reaches 75 GW [6]. The data was created by State Electricity Company (PLN) by using results from studies by Japan International Cooperation Agency (JICA) 1983. The potential data should be updated since various affecting factors may occur such as landslide, climate change, and land use change. Moreover, the methodology used by the Japan International Cooperation Agency are very limited information, and many location coordinates are not on the river line. Recent studies have introduced more advanced methods such as studies by Garegnani, et al. [7], Cantão, et al. [8], and Tian, et.al [9].
One of common tools for assessing renewable energy potentials is geospatial information system (GIS) [7, 9-13]. Garegnani, et al. [7] assessed the energy potential of ROR hydro power in two Alpine valleys by using a GIS covering legal, technical and financial data. Yizhi Tian, et al. [9] used the methodology only for one watershed, future research should propose many plans for many watersheds for assessing national hydro energy potentials. Tam O and Tam T [10] using virtual hydropower assessment (VHA) method to identifies suitable sites for hydropower production based on digital elevation and specific discharge maps in Estonia, a low-lying country in Europe. Zaidi, et al [11] proposed new approach using open source Advanced Spaceborne Thermal Emission (ASTER)’s digital elevation model (DEM) to estimate the head value. Chelelgo, et al. [14] the calculation of the head value is obtained based on the minimum elevation value around the river location using DEM SRTM 3 arcsecond.

Some GIS advantages are the re-inventory of hydro energy potentials into a better map form, a user-friendly visualization of potential location distribution, and an overlay of potential data with electricity consumption data. Nevertheless, previous GIS-based studies assessing hydro power potentials have weakness that are estimation only for few watersheds, in order to estimates national potential, need many difference scenarios in each watershed.

Therefore, this study aims to update the potential data of run-off river hydro energy system in Indonesia. Compared to the previous studies, the novelty of this study is estimated water discharge based on rainfall hydrological calculations and DEM SRTM 1Arc Second for head estimation.

2. Data Preparation
The estimation of the run-off river system hydro potential from a location on the river can use the following equation [15]

\[ P = Q \times H \times g \times \eta \]  

\( P \) = Power Capacity (kW)
\( Q \) = Dependable Discharge (m³ / sec)
\( H \) = Head (m)
\( g \) = Gravity
\( \eta \) = total efficiency (turbine and electric generator)

2.1 Dependable Discharge
The dependable discharge is the discharge that is available to meet water needs with a calculated risk of failure. The purpose of the dependable discharge calculation is to determine the planning discharge which is expected to always be available in the river. The discharge data used in calculating the dependable discharge must meet the following criteria based on SNI 6738: 2015 [16]. The WFLOW model calculates runoff rainfall that results in this river discharge calibrated with river flow discharge data at the hidrometric station. In each river basin the value of surface water availability is calculated and expressed as the mean monthly flow heights as dependable Q90.

2.2 Head
Head (height of falling water level) is the difference between the elevation values of the upstream and downstream points of the river or the difference in water level at the upstream and downstream points of the sea level. "Head" occurs due to natural river morphology and can also be artificial (weir). With this head value, it allows the potential energy from water to be generated into electrical energy. Head value estimates from SRTM DEM 1 Arc Second data is the highest resolution surface topographic image data that can be accessed by the public.
2.3 Map of Indonesia's Hydro Potential

The energy hydro potential map generated from energy calculations based on the value of head, discharge, gravity and the efficiency of the hydro system. The determination of the potential values listed in this map has the following limitations:

a) The calculated hydro potential is the potential of the run-off river (ROR) system;
b) The minimum elevation calculated in the head calculation is 50 meters, namely the morphology of the land that meets the potential requirements;
c) The minimum river head value is 10 meters and the maximum value is 100 meters;
d) The river line used comes from BIG (2013) which is the result of digitizing images, not software processing;
e) The debit calculation used is Q90 based on SNI 6738: 2015 [16];
f) Classification of potential values based on SNI 8396: 2019 [17];
g) The efficiency of the hydro system used is 0.6 or 60%;
h) Calculation of the potential using the acceleration due to gravity of 9.8 m/s².

2.4 Verification of Potential Location of Hydro Energy

The verification of the results of the mapping is carried out with the aim of measuring the accuracy of sites that are indicative of previous studies, as well as existing sites, both those that already have a hydro power plant or are still in the form of a hydro power plant development plan. The data used as data can be seen in Table 1.

| Type of Data          | Source                                                      |
|----------------------|-------------------------------------------------------------|
| Hydro Inventory Study| Japan International Cooperation Agency – JICA and PLN [18] |
| Existing Hydro Power Plant| Directorate General of Electricity, Ministry of Energy and Mineral Resources [19] |
| RUPTL 2019-2028      | State Electricity Company (PLN) [2]                        |
| Location Pre-FS and FS| State Electricity Company (PLN) [18]                       |
| Location Pre-FS      | Consultant [18]                                            |
| Field Measurement    | P3TEK KEBTKE, Balitbang ESDM [20]                          |

3. Result And Discussion

Based on the calculation results, it was found that the total potential sites in Indonesia were 52,566 sites, with the total potential of Indonesian hydro energy with the run-off river system of 94,627 MW. The distribution of potential sites can be seen in Figure 1.

As results, this study improves the quality of hydro energy potential data by correcting the original potential of 75,000 MW in 1,249 sites into 12,894 MW in 89 sites. The results of this study have been used by the PLN’s General Plan of Electricity Supply 2019 – 2028 [2].

Based on Table 2, the largest amount of hydro energy potential is on the island of Kalimantan, especially in the province of North Kalimantan. North Kalimantan has a hilly plain morphology. So that many river sites have a Head value as a condition for the potential for hydro energy. Kalimantan is dominated by dense forests, so that the catchment area is still able to maintain water availability.

When compared with the islands of Bali, NTB and NTT which are island groups. The plain morphology of the archipelago tends to be flat because it is dominated by coastal areas which tend to be flat. Generally, hydro energy potential is located in the foothills or hills. There are not as many rivers as the island of Kalimantan.

The second largest hydro potential is the island of Papua, a potential gathering point in mountainous areas. Just like Kalimantan, the condition of the water catchment area is still very good because it is located in a dense forest area. The morphology of the southern island of Papua tends to be flat, causing
no head to be detected, and the land area is dominated by swamps where the water flow rate tends to not flow.

Based on the number of verification points in Figure 2, almost all provinces are represented by verification points. Some studies that do not match the modeling results can be caused because the location does not use the run-off river system but uses a reservoir or dam system.

Figure 1. Map of Indonesia's Hydro Energy Potential [21]

There is total 776 sites that "Match" in verification that is 47 Existing Power Plant sites [19], 32 sites of the 2019-2028 RUPTL[2], 484 sites for the 1997 JICA Study[18], 82 PLN Pre-FS sites [18], 97 sites of the PLN FS [18], 21 Pre-FS consultant sites [18], 13 Pre-FS P3TKEBTKE sites [20].

Table 2. Amount and Potential of Indonesian Hydro Energy [21]
4. Conclusion

This study updates and improves the ROR hydro energy potential data in Indonesia by using a methodology that has three advantages. First, the dependable discharge value estimate from runoff – rainfall method which cover all land surface area. Second, the head value estimate from DEM SRTM 1 arcsecond which more precise than DEM SRTM 3 arcsecond that previous used. Last, the potential sites are clearly right on the river network that gives correct location.

Based on this methodology we estimated that the ROR hydro energy potentials in Indonesia reach 94,627 MW scattered in 52,566 sites. Five provinces with largest potentials are West Papua, North Kalimantan, Central Kalimantan, East Kalimantan, West Kalimantan.

We suggested future researches to overlay this hydro energy potential data with electricity generation cost, grid flexibility level, grid networks, and intermittent renewable development plan. Such overlay is crucial for multi-criteria decision analysis to derive feasible potentials of ROR hydro energy system.

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