Assessing the Potential of Solar PV Installation based on Urban Land Cover Analysis

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Abstract. This paper presents a technical assessment of solar photovoltaic (PV) installation potential in urban areas based on its urban land cover type, using a case study of Indonesian cities including Yogyakarta, Kupang and Tomohon. The assessment was performed using a free online application to assess the urban land cover types, i-Tee Canopy. This application can be used to identify and distinguish urban land cover types such as building rooftop, vegetation, grass, soil, road and water, which then can be used to assess the suitable area for Solar PV installation. Additionally, solar photovoltaic power output data from Global Solar Atlas is used to calculate potential energy production from PV installations in each city. The result shows that in an urbanised city such as Yogyakarta, the most suitable PV installation is in building rooftops. Meanwhile, Kupang and Tomohon have higher potential for ground-mounted PV installation in bare ground or grass. The approach and result of this study could be used for planners and policymakers to determine city-scale solar PV installation planning to maximise solar energy production. It can also be used to calculate the solar energy estimation using free online applications, which is easy to use and more accessible for stakeholders.

1. Introduction

Renewable energy should become the concern of many stakeholders at this time for developing the city and regional planning. Coal-fired power generation continues to be the largest source of the world’s electricity production, accounting for about 37% share [1]. Coal still become the most dominant source of electricity in Indonesia for now and in the near future [2] for about 50% with 25,000 MegaWatt (MW). In Indonesia, renewable electricity generation only takes part for around 18%, which mainly uses hydropower. The reliance on coal needs to be cut quickly to reduce the environmental impact due to excessive carbon dioxide emission [3]. In 2017, the Indonesia Ministry of Energy and Mineral Resources (MEMR) set a goal to increase renewable energy up to 23% by 2025. Additionally, the government committed to reducing greenhouse gas emissions to 29%-41% by 2030 [4].

Renewable energy production also supports Sustainable Development Goals (SDGs) number 7, where the investment in renewable energy is very important to give people access to affordable and reliable energy services. Solar energy is one of the renewable energy sources available enormously in tropical countries such as Indonesia. Globally solar PV and wind have become the main source of renewable energy for more than 150 GW [5] and have the potential in reducing energy-related emissions in developing countries [6]. Currently, solar energy harvesting in Indonesia is quite low for only 3% of...
total energy production. Thus, assessing the solar energy potential in Indonesian cities is important to map the potential of the installation system and the estimated solar energy generated.

The assessment of solar energy potential in city-scale is commonly done using GIS [7], 3D city model with energy modelling software [8], PVsyst [9], photogrammetry [10], remote sensing [11], and LiDAR [7]. However, this method requires special skills to use the tools, and some tools are paid software or utilising expensive equipment. Therefore, this study offers a simple way to assess the urban-scale solar energy potential using free online applications that can be used by non-professional users. The goal is that more stakeholders can assess the solar energy potential and use it in the decision-making process.

2. Materials and Methods

This study started with the land cover type assessment, which was performed using a free online application, i-Tree Canopy. This application can be used to identify and distinguish urban land cover types such as building rooftops, vegetation, pavement and water surfaces, which then, in this case, is used to assess the potential of Solar PV installation in urban areas. Moreover, solar photovoltaic power output data from Global Solar Atlas is used to calculate potential energy production from those potential installation sites.

2.1. Land Cover Assessment

The land cover area was estimated using a satellite imagery processing online application, i-Tree Canopy. The application uses random point sampling in identifying land cover and estimating their sizes (see Figure 1). The website is linked with Google Maps and uses its earth surface images as the main input of the process. The application is originally used to identify tree canopy cover based on earth surface images [12]. However, it may also identify other land cover types such as impervious buildings, impervious roads, water bodies, and bare land. In terms of its operation, the operator/user must manually classify land cover types according to land cover images randomly shown on the map box. The study harnesses the application to identify the land cover of case study cities. The land cover is classified into buildings, soil / bare ground, grass / herbaceous, tree / shrub, water, road, and others. The number of point sampling used for each city is 1,000, as recommended by the user manual [13]. The advantage of the application is it may provide a cheap and quick classification of land cover and estimate their sizes, although it cannot provide maps in GIS/shapefile format and is not as accurate as LiDAR [12,14]. The application, however, is beneficial for the identification of land cover as inputs for siting solar panel installations.

![Figure 1. Land Cover Assessment using Random Point Sampling](image)
2.2. Global Horizontal Irradiation Data
The Global Horizontal Irradiation (GHI) data is retrieved from the Global Solar Atlas, which is based on the Solargis resource database and OpenStreetMap as the base map data. For solar energy calculation purposes, the average daily data of GHI is generated in each city area. The map of GHI in the case study cities including Yogyakarta, Kupang and Tomohon is shown in Figure 2, and the city delineation is shown in red dashed line. Kupang has the highest average daily GHI of 5.64 kWh/m$^2$/day, and Tomohon has the lowest one of 4.58 kWh/m$^2$/day.

![Image of GHI map for Yogyakarta, Kupang, and Tomohon](image_url)

**Figure 2.** Map of Cities showing the Global Horizontal Irradiance (GHI) from the Global Solar Atlas.

2.3. Estimation Solar PV output
The estimation of solar energy potential (energy yield) of the PV system is calculated using the following equation (1). Parameters used including G represents the average daily GHI in kWh/m$^2$/day, A represents the available urban areas for PV installation in m$^2$ and Dy represents the number of days in a year. Multiplied by solar efficiency parameter: $\text{eff}$ indicates the efficiency of the PV modules and $\text{PR}$ for performance ratio.

$$E_{pv} = G \times A \times Dy \times eff \times PR$$

Some assumptions are made for the calculation, the efficiency of PV modules is set to 17%, and the PR is set at 80%. The energy generation is calculated to evaluate the potential solar energy generation, which can be compared to the overall city energy demands.

3. Result and Discussion

3.1 Land Cover Classification and Estimation
From seven land cover types identified, the study selects three land cover types that are suitable for PV installations which are Buildings, Grass / Herbaceous, and Soil / Bare Ground. Building land cover is chosen because it may be used for rooftop PV style [15,16]. Moreover, grass and bare ground land cover are chosen because they are potentially used for ground-mounted PV style [17,18].

Three cities used as case studies show different urban land cover patterns. Based on the analysis, the most dominant land cover that is potentially used for PV installation in Yogyakarta is buildings (55.56%), then in Kupang is bare ground (31.08%), lastly in Tomohon is grass (20.83 %). It is important to note that the case study cities have different administrative sizes. The largest city is Kupang with 307.34 km$^2$, followed by Tomohon with 144.57 km$^2$, and the smallest is Yogyakarta with 33.2 km$^2$. 
Table 1. Urban land cover in case study cities

| LAND COVER | COVERAGE | YOGYAKARTA | KUPANG | TOMOHON |
|------------|----------|------------|--------|---------|
| Grass/ Herbaceous | km² | 1.05 | 41.08 | 30.13 |
|             | %      | 3.15 | 13.37 | 20.83 |
| Buildings   | km²    | 18.45 | 42.3  | 7.39   |
|             | %      | 55.56 | 13.76 | 5.11   |
| Soil/ Bare Ground | km² | 1.83 | 95.55 | 20.28 |
|             | %      | 5.52 | 31.08 | 14.03 |
| Total suitable area | km² | 21.33 | 178.93 | 57.8  |
|             | %      | 64.23 | 58.21 | 39.97  |
| Road       | km²    | 3.04  | 12.78 | 4.78   |
|             | %      | 9.16  | 4.16  | 3.31   |
| Tree/ Shrub | km² | 5.85  | 104.98 | 77.07 |
|             | %      | 17.64 | 34.16 | 53.31  |
| Water      | km²  | 0.33  | 0.91  | 4.78   |
|             | %    | 0.99  | 0.3   | 3.31   |
| Other      | km²  | 2.65  | 9.74  | 0.14   |
|             | %    | 7.98  | 3.17  | 0.1    |
| Total      | km²  | 33.2  | 307.34 | 144.57 |
|             | %    | 100   | 100   | 100    |

The comparison of the land cover area in three cities is shown in Figure 3. Yogyakarta has the largest proportion of suitable land cover for PV installation, including soil/ bare ground, buildings rooftop and grass/ herbaceous for about 64.23% of the total area or 21.33km². Meanwhile, Tomohon has the smallest proportion of land cover area suitable for PV installation for 39.97% or 57.8km². The suitable area in Tomohon is larger than Yogyakarta even though the proportion is smaller (58.21%), which happen due to the total size of the city. Tomohon city is almost five times bigger than Yogyakarta. Then, the study estimates the potential PV energy yield (GWh) according to these land cover types (see Table 2).
3.2 Solar Energy Potential Estimation

The overall urban surfaces in Yogyakarta, Kupang and Tomohon could potentially produce PV energy for approximately 5.23 GWh, 50.09 GWh and 13.14 GWh, respectively (as shown in Table 2). Compared to its city size, the potential of PV energy generated per total city area for Yogyakarta and Kupang is similar for approximately 0.16 GWh/year/km². Tomohon has the lowest PV energy potential for only 0.091 GWh/year/km², which happens due to the existence of massive trees or forests covering most of the city area. Our findings also show that the size of the site (in this study is city-wide) influences the total solar energy production potential. The larger the size of the city, the potential solar energy yield is also higher.

| Table 2. PV Energy Potential compared to City Area and Population |
|---------------------------------------------------------------|
| Yogyakarta | Kupang | Tomohon |
| Potential PV Energy (GWh) | 5.23 | 50.09 | 13.14 |
| Total City Area (km²) | 33.2 | 307.34 | 144.57 |
| Potential PV Energy per Total City Area (GWh/km²) | 0.158 | 0.163 | 0.091 |
| Population | 373,589 | 442,758 | 100,587 |
| Shared PV Energy Per Capita (kWh/people) | 14.0 | 113.14 | 130.64 |

Compared to the city population, the PV energy production in Yogyakarta can only provide each person with 14.00 kWh/year. Meanwhile, in Kupang and Tomohon, the amount of PV energy generated could supply each person with 113.14 kWh/year and 130.64 kWh/year, respectively (as illustrated in Figure 4). Although Yogyakarta land cover has a higher potential for PV installation and generating renewable energy, it has lower energy shares for its huge population. Based on Ministry of Energy and Mineral Resources data 2019, the electricity consumption per capita in Indonesia was 1,084 kWh/year [19]. Thus, this amount of estimated PV energy produced by each city is far lower than the electricity consumption in Indonesia.
3.3 Diversification of PV System

Different variations of land cover in cities affect the choice of the most appropriate PV system to be developed in each location. Diversification of PV system development would give opportunities to increase solar energy production in urban areas. This diversification of the PV system aims to optimise the urban surface to be able to capture solar energy. To support a full-scale fusion of photovoltaics in cities, any surface that is suitable for PV installation must be utilised, including urban built-up area [9,20,21] and unbuilt area [22–24]. This diversification could include integrating solar PV on building facades (BIPV), rooftop, pavement or pergola [25,26] for the built-up area and ground-mounted PV system for the unbuilt area [17]. For instance, Yogyakarta city has a higher potential to implement rooftop PV style or building integrated photovoltaic (BIPV) since most of the suitable area in the city is on building surfaces. Moreover, Kupang and Tomohon could develop more on ground-mounted PV style since grass, and bare ground land cover is the most dominant suitable area for PV installation in these cities. The image of the dominant land cover characteristic for each city is presented in Figure 5.

![Figure 5. Sample of PV Installation Potential Sites in each City from the Global Solar Atlas](image)

| Yogyakarta          | Kupang                      | Tomohon                    |
|---------------------|-----------------------------|-----------------------------|
| rooftop PV and BIPV on building surfaces | ground-mounted PV on soil/ bare ground | ground-mounted PV on grass/ herbaceous |

Figure 4. Potential of PV Energy Generation from City and Designated for its People
4. Conclusion
This paper presents a technical assessment of the potential of solar photovoltaic (PV) installation in urban areas based on its urban land cover type. The assessment was performed using a free online application to assess the urban land cover types, i-Tree Canopy. Solar photovoltaic power output data from Global Solar Atlas is used to calculate potential energy production from PV installations in each city. As a result, Yogyakarta has the most suitable PV installation is in building rooftops. Meanwhile, Kupang and Tomohon have higher potential for ground-mounted PV installation in bare ground or grass. The approach and result of this study could be used for planners and policymakers to determine city-scale solar PV installation planning to maximise solar energy production. It can also be used to calculate the solar energy estimation of an area using free online applications, which is easy to use and more accessible for stakeholders.

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