GEOSPATIAL ASSESSMENT FOR PLANNING A SMART ENERGY CITY USING ROOFTOP SOLAR PHOTOVOLTAIC IN BANDUNG CITY, INDONESIA

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ABSTRACT:

Increasing the production of clean and environmentally friendly energy has become one of the world agendas as a strategic effort in dealing with long-term climate change. Seeing the potential of the energy produced, the ease in the installation process, with the small risk of harm generated, solar energy has received significant attention from many countries in the world. The potential for solar energy in Indonesia alone reaches 207 GWp, but only 145.81 MWp has been utilized. Currently, the Indonesian government has set a target to build a Solar Power Plant capacity in 2025 of 6.5 GWh. Urban areas are areas with higher energy demand than rural areas, but the availability of vacant land in urban areas is very minimal for installing solar power plants. Therefore, rooftop solar PV(Photovoltaic) can be a solution in dense areas such as cities. Good planning by looking at the potential resources and energy needs in spatial is needed to manage and utilize energy optimally and sustainably in urban areas. This study aims to develop a geospatial assessment for plan smart energy city that uses rooftop solar PV's potential energy in every building that is effective and efficient. The novelty in the analysis of the distribution of the potential for rooftop solar PV development in urban areas integrates meteorological and spatial aspects and socio-economic aspects. Integration of multi-dynamic spatial data uses in determining the rooftop solar PV construction location, such as meteorological data for solar energy potential, increasing energy needs of each building, and socio-economy data. The data source used comes from statistical data and remote sensing data. The analysis will be carried out temporally (2008, 2013, and 2018) to see the pattern of changes in aspects used in a certain period so that the development plan can be carried out more optimally. This research's output is the formation of a priority analysis of solar PV rooftop construction in urban areas, especially the city of Bandung. The result of energy can also produce by the construction of rooftop solar PV in a potential area. This research is expected to be utilized by policymakers to develop renewable energy in the city of Bandung and increase community participation in switching to renewable energy.

1.INTRODUCTION

Increasing the production of clean and environmentally friendly energy has become one of the world agendas as a strategic effort in dealing with long-term climate change. The increase in population and economic activity has made energy demand continue to increase. In 2019, world energy consumption reached 583.9 Exajoules, or the equivalent of 162194.4 TWh, with fossil energy's contribution coming 84.3% (BP, 2020). In 2018 carbon dioxide (CO_2) emissions produced by the energy sector rose 1.7% to 33.1 Giga Tons (IEA, 2019). Gas emissions cause an increase in temperature. This century, the temperature increase has reached 4°C (New, M., Et al., 2010). Fossil energy needs to be replaced with renewable energy to reduce emissions and their impact on the environment.

Seeing the potential of the energy produced, the ease in the installation process, with the small risk of harm generated, solar energy has received significant attention from many countries in the world. Indonesia's potential for solar energy reaches 207 GWh, but only 145.81 MW has been utilized (ESDM, 2020). Currently, the Indonesian government has set a target for a Solar Power Plant capacity in 2025 up to 6.5 GW (ESDM, 2020, planned).

The urban area is an area characterized by the combination of population density, social and economic organization, and the transformation of the environment into a built environment (Weeks JR, 2010). Urban areas have a higher energy demand than rural areas, but the availability of vacant land in urban areas is very minimal for the installation of solar power plants (ESDM, 2020). Therefore, rooftop solar PV (Photovoltaic) can be a solution in dense areas such as cities. Good planning by looking at the potential resources and energy needs in spatial is needed in the process of managing and utilizing energy optimally and sustainably in urban areas.

There are several studies on urban planning for renewable energy. In the research of Yu, L. et al., 2018, he made a plan about a mixed energy system in Qingdao city to support the development of renewable energy in the city. In this study, Yu, L showed that government subsidies could be a supporting medium in developing renewable energy in urban areas. In mixed energy planning, Yu L's urban system has not looked at the element of spatial planning, and he only uses available statistical data. In the research of Thelluhsen et al., 2020, he was planning a method for planning a smart energy city with 100% renewable energy. In his research, he can show a renewable energy plan as a fulfillment of all energy needs along with the parameters used for the planning. However, in Thelluhsen's research, it is still in the planning of the entire city that it has not looked at the spatial aspects to the detail of every building that will generate energy and require energy. In smart energy city planning, a detailed review of the spatial aspects of each

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building is required, looking at the potential and energy needs and seeing the socio-economic aspects of developing renewable energy to be effective and efficient.

The novelty in the analysis of the distribution of the potential for rooftop solar PV development in urban areas does integrate not only meteorological and spatial aspects but also socio-economic aspects. The planning that will be carried out will cover which buildings will be a priority in the development of renewable energy in a city. The objective of this study is to develop a multi-scenario spatial model for the distribution of construction rooftop solar PV in building in urban areas that are effective and efficient. Determine the potential energy that can be generated from the scenario created. Integration of multi-dynamic spatial data is used in determining the location of the rooftop solar PV construction, such as meteorological data for solar energy potential, electrification needs of each building, economic data, and social data. The data source used comes from statistical data and remote sensing data. The analysis will be carried out temporally (2008, 2013, and 2018) to see the pattern of changes in aspects used in a certain period so that the development plan can be carried out more optimally. The output of this research is the formation of a priority analysis of solar PV rooftop construction in urban areas, especially the city of Bandung. And also, the result of energy can produce by the construction of rooftop solar PV in a potential area. This research is expected to be utilized by policymakers in the development of renewable energy in the city of Bandung and can increase community participation in switching to renewable energy.

2.DATA AND METHOD

2.1 Data

In this study, some data is used to plan a smart energy city. The data used consists of 3 aspects. The first aspect is to see the suitability based on socio-economics by using data on health facilities, public facilities, places of worship, transportation facilities, roads, schools, and tourism places. The data is chosen, so that smart city energy planning takes into account the infrastructure that supports the activities of a city. The second aspect is to see the suitability based on the increase in energy demand in an area using impervious surface data, energy needs in 2008, 2013, and 2018, population, and building footprint in Bandung City. The data will later be used to see which areas experience a high energy demand so that it can be prioritized in planning a smart energy city. The third aspect is to see the potential for solar PV on each roof of the building using meteorological data in the form of solar radiation data, aerosol optical depth, precipitation, and land surface temperature. The data will be used to determine how much solar energy PV can produce in each region so that when it is built, the energy produced is also appropriate. Complete specifications for each data used can be seen in **Table 1**.

Data	**Unit**	**Source**	**Data Type**
Years Impervious Surface	Year	**Gong et al., 2020**	Annual-Raster – 30m
Building Footprint	-	**BIG, 2015**	Polygon Vector – 1:5000
Shortwave radiation	W/m^2	**Abatzoglou, J. et al., 2018**	Average Monthly-Raster – ~5km
Land Surface Temperature	Kelvin	**Wan, Z et al., 2015**	Average 8 days - Raster – 1 km
Aerosol Optical Depth (AOD)		**Lyapustin, A. et al., 2018**	Daily -Raster – 1 km
Precipitation	Mm/day	**Funk, C et al., 2015**	Daily-Raster – 5,5 km
Annual Electricity Consumption	KWh	**BPS, 2009;BPS 2014; BPS 2020**	Statistical Data
Population	Human	**BPS, 2009;BPS 2014; BPS 2020**	Statistical Data
District Area Administration of Bandung City	-	**BIG, 2020**	Polygon Vector
Health Facilities	-	**BIG, 2020**	Point Vector
Public Facilities	-	**BIG, 2020**	Point Vector
Transportation Facilities	-	**BIG, 2020**	Point Vector
School	-	**BIG, 2020**	Point Vector
Worship Place	-	**BIG, 2020**	Point Vector
Roads	-	**BIG, 2020**	Point Vector
Tourism	-	**OSM,2021**	Point Vector

Table 1 Data used in this research

2.2 Method

In planning a smart energy city, there are several aspects to be considered, namely the potential for energy availability, increasing energy and socio-economy. Furthermore, after obtaining these three aspects, the three aspects are combined to obtain a suitable area for the development of a smart energy city in the city of Bandung. The general research workflow can be seen in Figure 1.

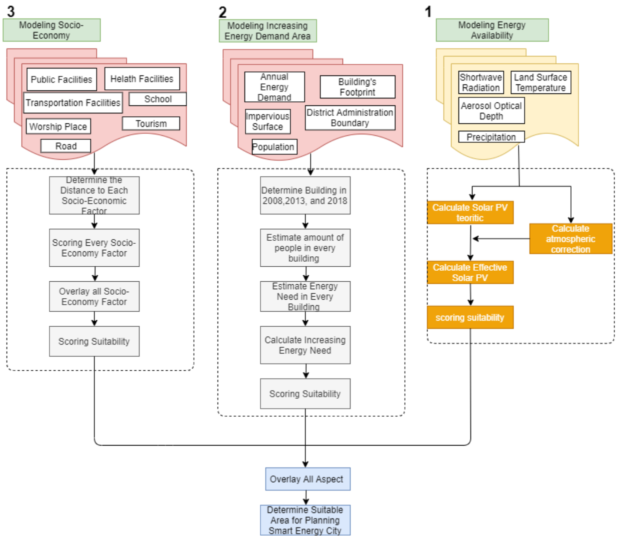


Figure 1 General Method Of Research

2.2.1 Modeling Energy Availability

In determining the energy availability, solar PV is modelled effectively on the roof of the building. In modelling the effective solar pv, it will use solar radiation data which is then corrected with aerosol optical depth, precipitation, and land surface temperature data. The equation used is adopted and modified from the Principe Jeark, et al., 2019 equation which can be seen in equation 1.

$$p'_{pv} = \eta \times R(1 - \Delta\eta_t - \Delta\eta_d) \times peak\ hour \tag{1}$$

Where p'_{pv} = Solar PV Efektif every m^2 (W/m^2)
η = conversion efficiency of the solar cell (15%)
R = solar radiation data (W/m^2)
$\Delta\eta_t$ = Temperature Correction
$\Delta\eta_d$ = AOD and Precipitation Correction
$peak\ hour$ = duration of sun radiation (hour)

Correction of LST, AOD, and Precipitation is carried out using equations 2 and 3.

$$\Delta\eta_t = 0.094\ \left(\frac{\sum_{i=1}^{n} LST - NOCT_{max}}{n}\right) \tag{2}$$

$$\Delta\eta_d = 0.035\ \left(\frac{\sum_{i=1}^{n} x_{a,i} x_{r,i}}{n}\right) \tag{3}$$

Where 0.094 = coefficient of reducing temperature efficiency
LST = Land surface Temperature (Celcius)
$NOCT_{max}$ = maximum temperature for solar PV Work properly
n = number of days
0.035 = coefficient of efficiency reduction against AOD and rain
$x_{a,i}$ = amount of AOD content in n days
$x_{r,i}$ = the number of rainy days in *n* days

After obtaining the effective solar PV for each building, the suitability scoring is divided into 5 classes based on energy availability using the natural break method.

2.2.2 Modeling Increasing energy

In modelling the increase in energy, first, the energy requirements are modelled for several years of research. This study will use 2008, 2013, and 2018. The selection of Bandung city buildings for each research year will use impervious surface data. After obtaining the year for each building, then the number of people for each building is calculated which will then be used to calculate the energy needs of each building. In determining the number of people per building, equation 4.

$$number\ of\ people\ in\ building = \frac{\frac{TP}{nB} + \frac{TP}{TBA} x\ BA}{2} \tag{4}$$

Where TP = Total of Pupulation
nB = Number of buildings
TBA = Total of Building Area (m^2)
BA = Building Area each Building (m^2)

After getting the number of people per building, then the energy consumption per capita is calculated using statistical data. Furthermore, the number of people per building will be multiplied by the energy needs per capita so that the energy needs of each building can be obtained. The equation used in determining the energy requirements of each building is equation 5.

$$EN = \frac{EC}{TP} x\ number\ of\ people\ in\ building \tag{5}$$

Where EC = Energy Consumption in Bandung City (Mwh)
EN = Energy need every building (Mwh)

After obtaining the energy needs of each building, the energy increase in the three years is calculated using equation 6.

$$\text{Incresing Energy} = (EN_{2018} - EN_{2013}) + (EN_{2013} - EN_{2008}) \tag{6}$$

After obtaining the energy increase, then scoring is done by dividing it into 5 classes using natural break.

2.2.3 Modeling socio-Economy

In socio-economic modelling, the distance of a building will be calculated from public facilities, health facilities, transportation facilities, schools, roads and places of worship. In modelling the euclidean distance method, the closest building distance will be obtained with a predetermined factor. In calculating the distance, each factor is calculated separately and then combined to obtain regional suitability based on socio-economic aspects. Each factor will be scored before combining it using equation 7. This equation is used because the distance will greatly affect the suitability of the solar PV installation in terms of effectiveness and efficiency.

$$Skor = 5 - \frac{Distance - Distance_{min}}{Distance_{max} - Distance_{min}} x\ 5 \tag{7}$$

3.RESULT AND DISCUSSION

3.1 Suitability from Energi Availability

Based on the results of energy modeling for building roofs, the value for each roof of the building is obtained as in **Figure 2.** It can be seen that the effective Solar PV in the city center is lower than the suburban part. This is because the surface temperature and dust in the city center are higher than in the periphery of the city so that the correction value will be greater than in the suburban areas.

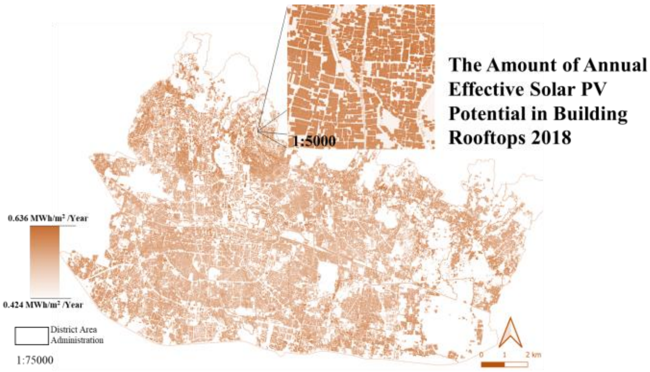


Figure 2 The Amount of Annual Effective Solar PV Potential In Building Rooftops

In seeing the suitability of the development of a smart energy city, the most suitable areas are located in the suburban area, as shown in **Figure 3**. This can be a reference if the government wants high-yield energy, then the selection of suburban areas can be an option.

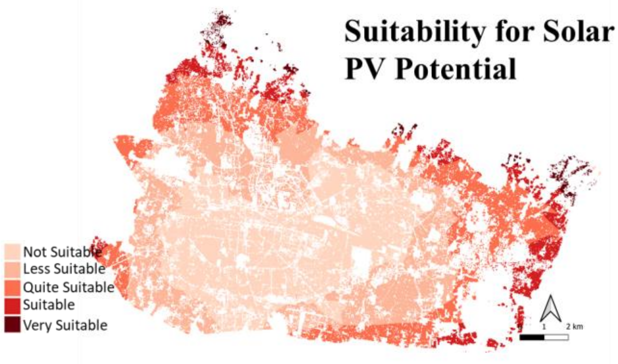


Figure 3 Suitability For Solar PV Potential

3.2 Suitability from Increasing Energi Demand

In determining the increase in energy first. energy requirements are modeled as shown in Figure 4. It can be seen that there is an increase in energy demand every year in each building.

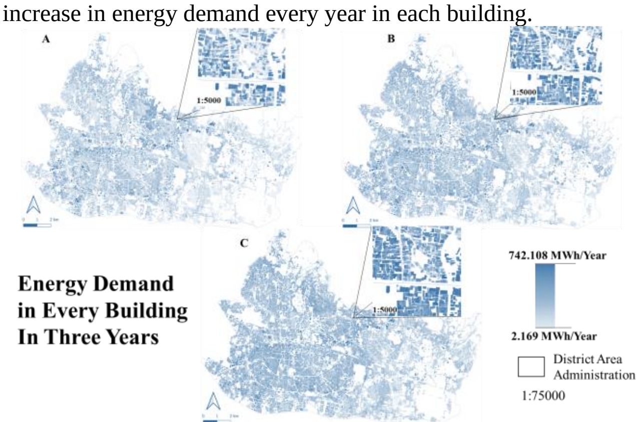
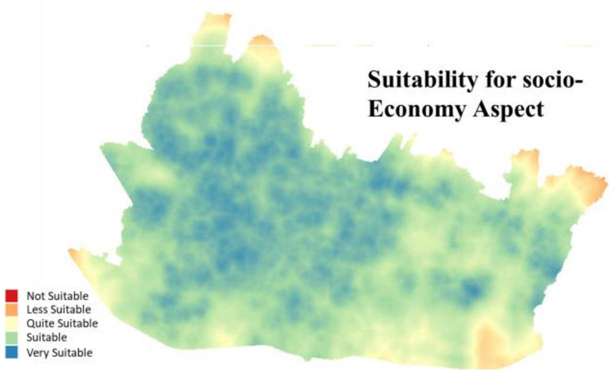


Figure 4 Energy Demand In Every Building In Three Years

After obtaining energy needs, the areas that have a significant increase in energy demand are calculated. It can be seen in Figure 5 an area with a significant increase in energy and suitability for the construction of a solar PV rooftop if the government wants solar PV to meet its excess energy needs.

3.3 Suitablality from from Socio-Economy Aspect

In determining the suitability of the smart energy city planning area based on the socio-economic aspect, the results are based on Figure 6. It was found that all of Bandung's wulayah found that Majority is an area with an area that is very suitable for the construction of solar PV rooftops. This can be used as a reference for building solar PV to support socio-economic activities in the community.



4.CONCLUSION

In this research, it has been found the suitability of the area to be built a smart energy city in the city of Bandung. The centre city is very possible tu built a solar PV rooftop look from energy demand and socio-economy aspect, but the cenre city have low energy potential for solar PV energy compare to surburb area. But from result solar PV potential the different of potential energy in centre city and surburbs is not significant, so it's possible to built solar PV rooftop in centre city area. In this case, it can be a reference for the government if you want to build a smart energy city in the city of Bandung.

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