ANALYSIS OF SOLAR ENERGY POTENTIAL TO ACHIEVE NEARLY ZERO ENERGY COMMUNITY. (CASE STUDY: MALIOBORO STREET, YOGYAKARTA).

Anita Yuan[1*], Mohammad Kholid Ridwan[2], Bakti Setiawan[3]

[1] Master in System Engineering, Gajah Mada University
[2] Departement of Nuclear Engineering and Engineering Physics, Gadjah Mada University
[3]Department of Architecture and Planning, Gadjah Mada University
*Corresspondence : anita.yuan@mail.ugm.ac.id

Abstract

Various global, national, and local initiatives have been introduced to enhance community sustainability. One of these initiatives is the European Commission's proposal for buildings to achieve nearly zero energy consumption by optimizing energy efficiency and incorporating renewable energy sources, which has led to the concept of nearly Zero Energy Community (nZEC).

This study investigates the potential of solar energy as a photovoltaic power source for the sustainable development of the Malioboro Street area, as outlined in the RTBL Final Report. By analyzing 3D building data from OpenStreetMap (OSM) and Digital Elevation Model (DEM), the distribution of solar energy potential was mapped. ArcGIS Pro software was utilized to assess both the geospatial characteristics and the building data. The findings reveal a significant negative correlation between building density and average solar energy potential, with an R-squared value of 0.85. The achievable coverage degree through solar energy conversion systems ranges between 10.25% - 12.45% of the total energy demand for the area, which falls short of achieving energy independence within the nZEC framework. Future strategies, as well as an evaluation of key planning and geometric elements, are crucial for developing standards in urban planning and architectural design that are conducive to solar energy utilization.

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1. Introduction

The increase in human population and living standards also increases energy demand to produce more products, food, buildings, transport, and social activities facilities. Various concrete strategies have been developed at the world, regional, national and local levels as a step forward in implementing sustainable development in society, especially on three main issues: energy efficiency, energy savings and renewable energy systems (Visa et al. 2020)

The Indonesian government has contributed to this effort through Government Regulation No. 79 of 2014 on National Energy Policy. The regulation sets national targets for new and renewable energy utilization, aiming for 23% by 2025 and 31% by 2050. This promotes the establishment of a framework that addresses development, long-term management, and relevant policies to ensure a cohesive approach to sustainable development (Sekretariat Negara 2014).

The European Commission, through Directive 2010/31/EU, introduced the concept of nearly Zero Energy Building (nZEB). This concept refers to buildings with very low annual energy consumption, achieved by improving energy efficiency and integrating renewable energy sources, either installed on-site or in proximity. Over time, this idea expanded into the nearly Zero Energy Community (nZEC), which applies the same principles at the community level, encompassing groups of buildings within a district, village, city, region, or even a country (European Union 2010; Leo et al. 2019; Visa et al. 2020).

In Indonesia, although the nZEB concept has not been explicitly adopted, several regulations show a similar direction in terms of increasing energy efficiency and implementing green building principles through Government Regulation Number 16 of 2021 (PP No. 16/2021) and Regulation of the Minister of Public Works and Public Housing Number 21 of 2021 (Permen PUPR No. 21/2021). In PP No. 16/2021, there are provisions regarding energy efficiency and more efficient use of resources, encouraging the use of renewable energy in building operations, and emphasizing the importance of careful planning and efficient building management. Permen PUPR No. 21/2021 regulates the assessment of green building performance, one aspect of which is energy efficiency, encouraging the use of renewable energy. In addition to energy efficiency, this regulation also emphasizes improving environmental quality through building design and technology (Kementerian Pekerjaan Umum dan Perumahan Rakyat 2021; Peraturan Pemerintah 2021).

Photovoltaic (PV) technology is the most common solution for generating electricity. Photovoltaic technology can convert solar energy directly into electrical energy. The energy conversion process is static, silent, free of moving objects, safe, not requiring high surveillance and the most important unaffected damage to the environment (Al-khazzar 2017; Benner 2017).

In its application, the output characteristics of PV modules are heavily influenced by the amount of solar radiation. Any obstacle or shadow that prevents solar radiation from falling on the module must be avoided due to shading can reduces the maximum output of PV module by around 70% with only 2% of the module's surface is covered (Patel dan Agarwal 2008; Quasching 2016).

Daerah Istimewa Yogyakarta (DIY) is one of the provinces with the most populous cities in Indonesia after DKI Jakarta and West Java. The average building density in the city of Yogyakarta reaches 93%. The remaining vacant land/green open space in the city of Yogyakarta is about 5%, the rest is dominated by buildings, especially residential buildings (66.7% of the total city area) (Devi et al. 2020). The population density of Yogyakarta is estimated to reach 75% in 2020 and will increase to 87% in 2045. Meanwhile, the electrical energy consumed by the city reaches 1,056.5 GWh in 2021 or the highest compared to other regions in the DIY Province (34% of the total electrical energy consumption of the DIY Province) and this will continue to increase along with population growth (BPS Indonesia 2018; BPS Kota Yogyakarta 2022).

Malioboro Street is a key attraction for both domestic and international visitors in Yogyakarta, characterized by its historical sites and buildings that contribute to its unique charm. It has become a symbol of the city, encapsulated in the saying: "visiting Malioboro Street means visiting Yogyakarta." According to the Final Report on Building and Environmental Planning (RTBL), the vision for the Malioboro area is to develop it into a culturally based, humanistic, environmentally friendly, and sustainable service center. Sustainable development involves a moral obligation to ensure the well-being of future generations. The challenge in development lies in balancing the preservation of nature's limited resources while fairly distributing them over time and across different generations to protect their welfare (Kimpraswil Kota Yogyakarta 2013).

2. Methodology

Departing from the problem of building density, energy, and limited land availability, and the vision of sustainability. In this study, the author will investigate a dense area in the city of Yogyakarta to implement photovoltaic (PV) technology. The selected area is the Malioboro Street area. This area was chosen because it is a landmark of the city of Yogyakarta and is full of buildings with various functions, including residential areas, malls, hotels, government buildings, offices and traditional markets.

This research will calculate the solar energy potential by GIS-based simulation software and the effect of building density on the solar energy potential. Three-dimensional (3D) analysis is used in this study. Through that analysis, it will continue to calculate the coverage degree (CD) of renewable energy in that area in order to reach the concept of nearly zero energy community (nZEC). The presented technical workflow will enable stakeholders to facilitate decision making on the implementation of photovoltaic (PV) technology.

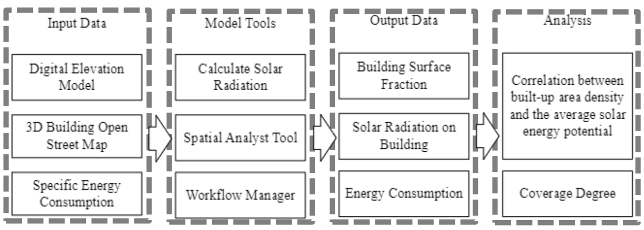


Figure 1. Framework of the methodology for nZEC analysis by exploiting regional solar energy sources (edited by auther).

2.1. Study Area

The case study area is located along Jalan Malioboro, Yogyakarta. The case study area is divided into 3 according to the *Kalurahan* or village, namely the Sosromenduran as area 1, Suryatmajan as area 2, and Ngupasan as area 3.

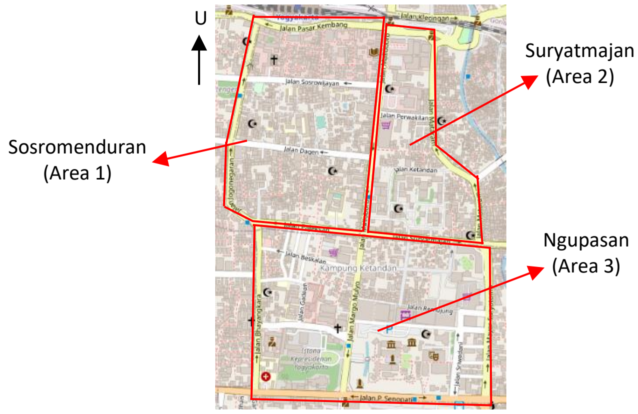


Figure 2. Study case area

2.2. Built-up Area Density

To illustrate the density of the built environment, the author employs the parameter known as Building Surface Fraction (BSF). BSF represents the proportion of the ground surface that is covered by buildings and influences surface reflectivity, flow regimes, and heat dispersion in the atmosphere. It can be understood as the ratio of the building's footprint area to the total plan area (%) as in Eq. (1) (Stewart and Oke 2012)

$$BSF = \frac{Building\ plan\ area}{Total\ plan\ area} \times 100\% \tag{1}$$

2.3. Estimation of Solar PV Generation Potential

The annual PV potential E (kWh/year), considering full PV deployment, was estimated according to Eq. (2)

$$E = A.\eta_r.PR.G \tag{2}$$

PV area (m^2) is represented as A, rated module efficiency as η_r, performance ratio as PR, and annual total radiation on the tilted surface (kWh/m^2/year) as G. The PV area is the resulting area after excluding rooftop spaces for module maintenance and shaded facade areas from shading systems or balconies (Budiarto et al. 2020; Panagiotidou et al. 2021).

2.4. Estimation of Energy Consumption

In calculating the electricity consumption of the case study area, researchers will focus on commercial buildings, which are categorized into shopping centers (malls, supermarkets, shops), hotels, and other buildings that include offices, schools, museums, pharmacies, and hospitals. To calculate the electricity consumption of these buildings, the Benchmarking Specific Energy Consumption Report by *Balai Besar Teknologi Konversi Energi* (B2TKE) BPPT in 2020 is used.

Specific Energy Consumption (SEC) refers to the measurement of energy usage within buildings, indicating the amount of energy consumed per unit of building area or per occupant. IKE is expressed in units of kWh/m^2/year. A number that shows the amount of energy consumed (in kWh) for every m^2 of building area conditioned with air conditioning per year or for the total building area, excluding parking (Balai Besar Teknologi Konservasi Energi 2020).

$$SEC = \frac{Energy\ consumption\ in\ one\ year\ (\ TOE\ or\ kWh)}{Total\ building\ area\ (m^2)} \quad (3)$$

2.5. Nearly Zero Energy Community (nZEC)

The concept of Nearly Zero Energy Community (nZEC) is defined and examined in terms of the energy generated from renewable sources and its consumption in residential, public, and commercial buildings within the built environment. This analysis also considers the infrastructure that connects these nearby buildings.

In Figure 3, an energy community is defined. It can take the form of a residential house, a single apartment within a collective housing unit, an administrative building, an educational facility, a commercial establishment, or a cluster of buildings serving small communities at the local level. Larger communities, such as cities, can be divided into multiple districts to identify one or more energy communities within each district (Visa et al. 2020).

Ion Visa et al. conducted research on nZEC at the R&D Institute of the University of Transylvania Brasov in the energy community. The Institute comprises 12 buildings conducting research activities from 29 R&D centers at the university, primarily focusing on various aspects of sustainable development. This research indicates that the rooftop PV technology at the R&D Institute of the University of Transylvania Brasov can supply 33% of the annual energy needs of a typical laboratory building. Furthermore, the share of renewable energy in the total energy consumption of buildings drops to 18% when accounting for the energy requirements of heating systems (Visa et al. 2018).

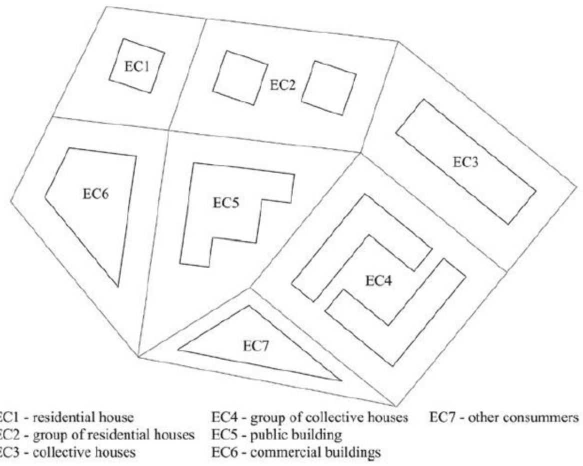


Figure 3. Energy communities within a community

2.6. Coverage Degree

In a sustainable community, one or more energy communities can be established, each characterized by its distinct energy project. When defining these energy communities, they may function independently or work together as clusters to reduce energy losses during both production and consumption.

The *coverage degree* (CD_i) by renewables can be calculated using Eq. 4

$$CD_i = \frac{E_{pi}}{E_{di}} \quad (4)$$

E_p represents the overall energy generated in renewable energy communities. E_p represents the overall energy demand within the energy communities.

Typically, CD ranges from 0 to 1. However, the coverage degree can exceed the unitary value, $CD_i > 1$, if the energy community exports the energy produced in excess. Building on the concept of nearly Zero Energy Building (nZEB), the notion of a Nearly Zero Energy Community was developed, with a range of $0{,}5 \leq CD \leq 1$ being considered acceptable (Visa et al. 2020).

3. Results & Discussion

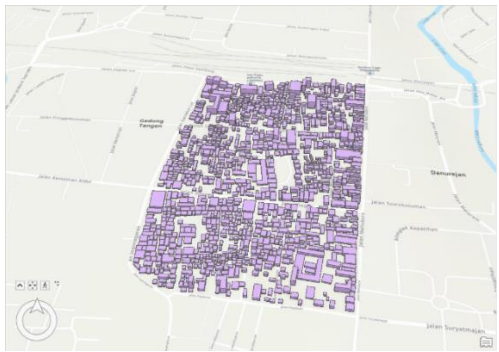
The main data are location and dimensions from two-dimensional OSM, building height data from three-dimensional building OSM, and DEM from the National Digital Elevation Model (DEM) website. The building data was obtained through the 3D building website Open Steet Map (*https://osmbuildings.org/).* The building population data spread over the case study area is obtained from the attribute table that is already available from the OSM data source and completed through field observations.

3.1. Building Surface Fraction

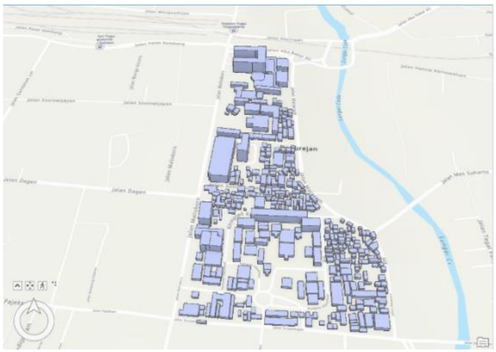
By using the *calculate geometry* tool available on ArcGIS software, the ratio of building plan area to total plan area (%) on Jalan Malioboro can be seen in Table 1.

Table 1. Building Surface Fraction

Area	Building Plan Area (m^2)	Total Plan Area (m^2)	Building Surface Fraction (%)
1	144.831,18	299.546,49	48,35%
2	73.263,67	153.191,88	47,82%
3	168.768,62	420.667,37	40,12%



(a)



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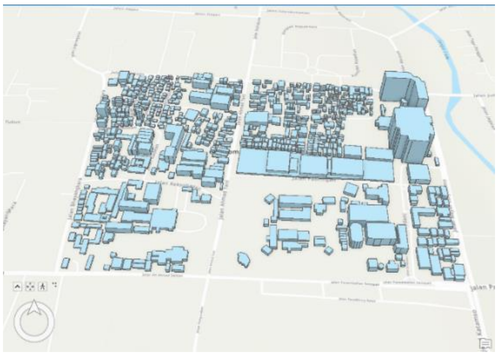


(c)

Figure 4. Layer vector building (a) Area 1, (b) Area 2, (c) Area 3

3.2. Building Electricity Consumption Calculation

The focus of the research is on commercial buildings, which are classified as Shopping Centers (malls, supermarkets, shops), hotels, and other buildings covering offices, schools, museums, pharmacies, and hospitals. The percentage of building population referred to the category are 13% buildings in Area 1, 23% buildings in Area 2, 30% buildings in Area 3. Specific Energy Consumption (SEC) for the building refers to the Benchmarking Specific Energy Consumption Report by B2TKE-BPPT in 2020.

Shopping Centers: 286,54 kWh/m^2/year
Hotel : 208,15 kWh/m^2/ year
Office Building : 180,95 kWh/m^2/year

Through Eq (3), electricity consumption in each area is obtained according to the categories referred to in Table 2.

Table 2. Building Electricity Consumption Calculation

	Electricity Consumption (kWh/year)		
	Area 1	Area 2	Area 3
Shopping centers	5.012,550	4.765.326	22.026.498
Hotels	2.214.358	1.850.745	1.306.710
Others	1.700.367	2.088.125	5.564.145
Total	**8.927.276**	**8.704.198**	**28.897.353**
Average	**56.501**	**107.459**	**138.264**

The percentage of electricity consumption calculated in this study, relative to total electricity consumption of Yogyakarta City (according to BPS Yogyakarta City 2024 data) which is correlated with the buildings that have been classified in this study are respectively 1.22% in Area 1, 1.19% in Area 2, and 1.22% in Area 3.

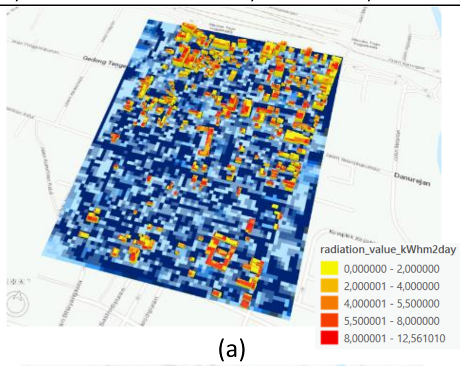
3.3. Solar Energy Potential

The table for the distribution of solar energy potential in Areas 1, 2, and 3 is shown below. All units use (kWh/m^2/day) except Building Surface Fraction (%).

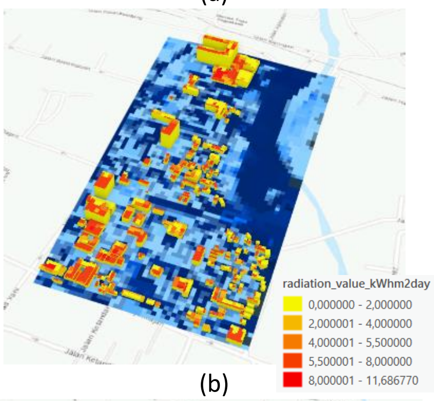
The solar energy received for the building indicates the moderate correlation (linear) with the geometric building surface fraction (BSF) parameter. The coefficient of determination is obtained $R^2 = 0{,}851$ for linear correlation between the solar energy of the accepted building and BSF.

Table 3. Distribution of Solar Energy Potential

Area	*Building Surface Fraction*	Min. value of solar energy	Max. value of solar energy	St. deviation	Average solar energy
1	48,35%	0	12,56	2,39	2,97
2	47,82%	0	11,69	2,57	3,37
3	40,12%	0	12,28	2,82	3,88



(a)



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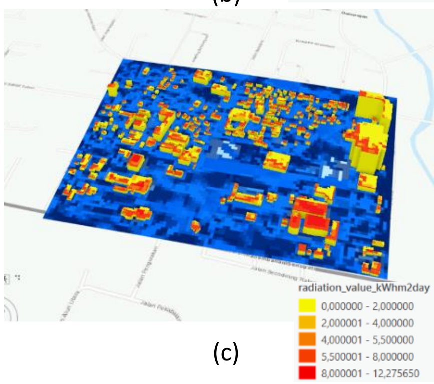

(c)

Figure 5. Distribution of Solar Energy Potential (a) Area 1, (b) Area 2, (c) Area 3

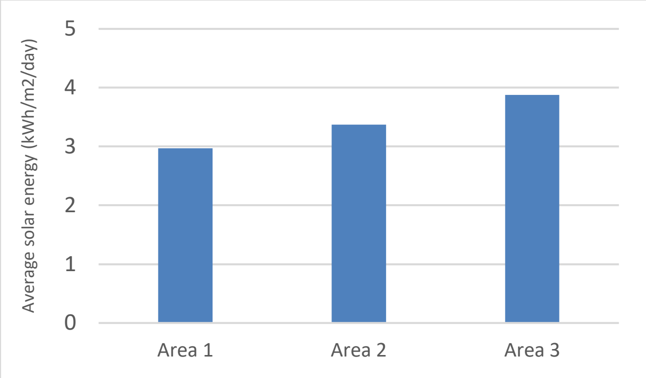

Figure 6. Average Solar Energy for each Area

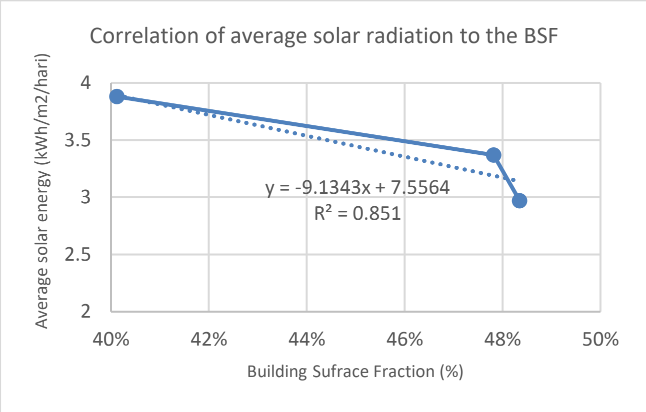

Figure 7. Correlation of average solar energy to the BSF

3.4. Solar PV Generation Potential

Through Eq (2), solar pv generation potential in each area is obtained according to the categories referred to in Table 3. In this study, the PV area considered for module installation is 15% of the total roof area of the building, the efficiency of the PV module is assumed to be 20% and the performance ratio (PR) is 75%. The annual solar energy used is the average value of the potential solar energy obtained from the simulation results.

Table 4. Solar PV Generation Potential

	Solar PV Generation (kWh/year)		
	Area 1	Area 2	Area 3
Shopping centers	426.683	460.270	2.449.442
Hotels	259.479	246.079	200.036
Others	229.200	319.376	979.821
Total	**915.363**	**1.025.726**	**3.629.301**
Average	**5.793**	**12.663**	**17.365**

3.5. Coverage Degree

Coverage Degree is calculated using Eq (4), considering the electricity consumption of buildings in Table 2, and photovoltaic power generation potential in Table 4, we get CD for each area in Table 5.

Table 5. Coverage Degree

Area	*Building Surface Fraction*	Consumption (kWh/tahun)	PV Generation (kWh/tahun)	*Coverage Degree*
1	48,35%	8.927.276,87	915.363,47	10,25%
2	47,82%	8.704.198,33	1.025.726,45	11,78%
3	40,12%	28.897.353,49	3.629.301,17	12,56%

Following these data, it can be estimated that the portion of energy that is fully met using solar energy conversion systems, according to electrical energy consumption data. Table 5 shows the highest level of coverage with energy generated using solar energy input reaching 12.56% in Area 3 which has a built-up area density of 40.12%. Meanwhile, areas with higher density of built-up areas have smaller CDs of 10.25% for Area 1 and 11.78% for Area 2.

In the building community in the case study area (Jalan Malioboro), the three areas are categorized as not achieving nearly Zero Energy Community (nZEC) by applying photovoltaic technology to the building (under conditions determined for research purposes), so that it requires not only electricity generation using renewable energy, but also improve the energy efficiency of buildings.

4. Conclusion

1. Coverage degree analysis is focused on building categories, namely shopping centers (malls, supermarkets, shops), hotels, and other buildings that include offices, schools, museums, pharmacies, and hospitals. The percentage of building population referred to the category are 13% buildings in Area 1, 23% buildings in Area 2, 30% buildings in Area 3.
2. The highest average value of solar energy potential is in Area 3 which has a building density of 40.12%, which is 3.88 kWh/m^2/day. Meanwhile, areas with higher building density have lower solar energy potential. Area 2 with a built area of 47.82% has a solar energy potential of 3.37 kWh/m^2/day and Area 1 with a built area of 48.35% has a solar energy potential of 2.97 kWh/m^2/day.
3. Received solar energy shows negative correlations (linear) with the building surface fraction. The coefficient of determination, $R^2 = 0{,}851$ for the linear correlation between received solar energy and BSF.
4. Based on the outcome, it is possible to estimate the percentage of energy that is completely generated using solar energy conversion systems. The Coverage Degree indicates that solar energy conversion systems alone can cover 10% to 12.56% of the energy demand with renewable sources. However, this value is insufficient to achieve energy independence through the nearly Zero Energy Community (nZEC) concept, so it is necessary to find ways to achieve this in the future, such as;
   - Using new construction materials or new design concepts in the future.

- Improve the energy efficiency of buildings by using energy-efficient electronic equipment.
- Supporting the use of renewable energy sources through the right policies to meet the energy requirements of buildings.
- Integrate aspects of occupant behavior, both through policies, education, and incentives that encourage energy-saving behavior among building occupants.

5. The application of PV technology in heritage areas such as Malioboro needs to be done carefully considering architectural aspects and related regulations. Zoning may also be necessary to designate which buildings are suitable for PV installation. Additionally, deploying PV technology in cultural heritage areas, often cultural centers with significant religious, philosophical, and cultural values presents intricate challenges. In such a complex PV implementation problem, the mapping and installation work will be a much simpler task compared to the socio-cultural inclusive process required.

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