



# Central Java Natural Condition for Agrivoltaic System Development

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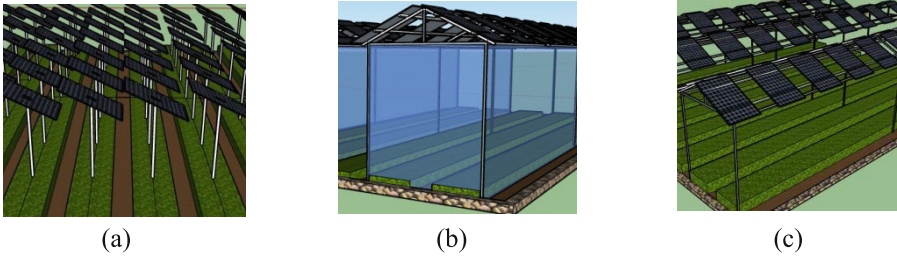
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**Abstract.** With population growth which increases every year, it will also be accompanied by a reduction in natural resources and energy. These natural resources are in the form of food needs. With the increasing demand for food and energy needs, there must also be the development of technology in the field of electricity generation. One of them is the development of the agrivoltaic system. Agrivoltaic is a concept that combines land use with the generation of electrical energy needs. The purpose of this study is to find out with data on natural conditions in Central Java whether it can be used for the development of an agrivoltaic system. Researchers have conducted research with plants that are suitable for the agrivoltaic system and based on the available data, these plants are widely planted in Central Java, including: peanuts, tomatoes, and green beans. Data on the amount of land with plants suitable for agrivoltaic development of 4,800 hectares is expected to produce 2,400 MWp of energy. This study concludes that it can provide an overview of the natural conditions of Central Java so that it can be used as a reference for the development of the agrivoltaic system in the future.

**Keywords:** Growth population · Food and Energy · Agrivoltaic

## 1 Introduction

From year to year, the population of Central Java has grown every year, increasing by around 4.1 people or an average of 400 thousand, a total of 36.52 million people in September 2020. Based on this, the population of Central Java continues to increase. In a period of ten years, from 2010 to 2020, the population growth rate of Central Java is 1.17 percent per year [1]. There are basic needs that are increasing in demand every day, namely food and energy. Food is a very basic need and energy has also experienced a significant increase. There must be a solution that can secure food and energy growth [2], one of the solutions is agrivoltaic [3, 4]. Agrivoltaic is a concept that combines the use of agricultural land with the production of electricity from a photovoltaic mini-grid. The agrivoltaic system can not only change and preserve agricultural land but can also make crop production more effective and water use more efficient [5].



**Fig. 1.** (a) Solar panels are placed in the vacant land between the plants; (b) Solar panels are placed on top of the greenhouse media; (c) Solar panels are placed in a frame placed on top of the plant [6].

Agrivoltaic itself has three development patterns, namely the initial concept of agrivoltaic solar panels placed in empty rows on agricultural land (Figure a). The second concept uses a greenhouse structure, which is added to the top by solar panels at a certain distance (Figure b). The third concept is to build a panel structure on top of the plant by adding a framework (Figure c) [6]. Agrivoltaic systems are very effective in maximizing land production, especially when compared to renewable energy generation systems where solar panels are only installed on the ground or on the roof [7] (Fig. 1).

Central Java Province has an area of  $\pm 1,684,746.24$  hectares of agricultural land. The agricultural land is planted with many agricultural products, but only a few crops can be applied with agrivoltaic. These include peanuts [8], green beans [8], and marglope varieties of tomatoes [8, 9]. The amount of land with plants that can be used for agrivoltaic is  $\pm 166$  Ha (  $166,000,000 \text{ m}^2$ ). If all agricultural land is installed agrivoltaic, it can have a significant impact by generating  $\pm 83$  MWp of electricity. The amount of electricity can meet the energy needs of  $\pm 100$  thousand customers. The amount of energy of 83 MWp is obtained from the equation:

$$\frac{\text{land area for agrivoltaic system development}}{20.000 \text{ m}^2} = \dots\dots \text{MWp}$$

where:

MWp: Mega Wattpeak.

## 2 Material and Methods

East Java Province in the east, and the Java Sea in the north. Its area is recorded at 32,544.12 hectares or about 25.04% of the island of Java (1.70% of Indonesia's area). The total area consists of  $\pm 1,684,746.24$  Ha (30.80%) in paddy fields, and 2.25 million Ha (69.20%) is non-rice field land. According to the Climatology Station Class 1, Central Java in 2015 the temperature of Central Java was between  $23^\circ\text{C}$  to  $28^\circ\text{C}$ . Where places that are located close to the coast have relatively high average air temperatures and average air humidity varies from 69% to 83% [10].



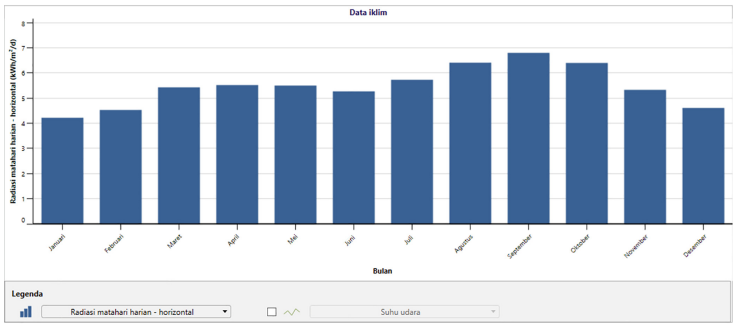


Fig. 2. Daily solar radiation horizontally in kWh/m<sup>2</sup>/s

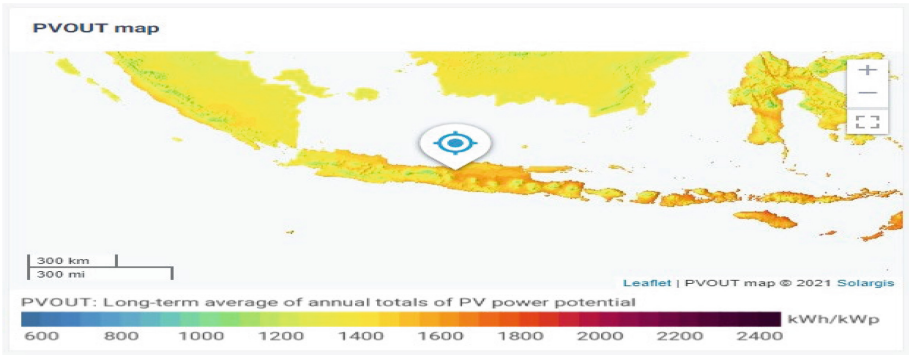


Fig. 3. Daily solar radiation in the territory of Indonesia

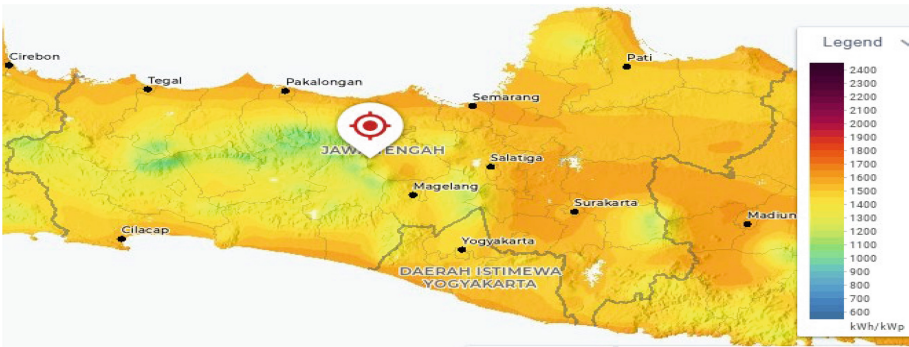
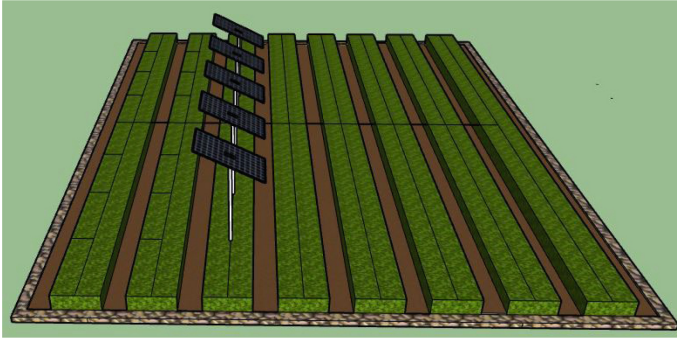


Fig. 4. Daily solar radiation in Central Java region



**Fig. 5.** System agrivoltaic development in agricultural land

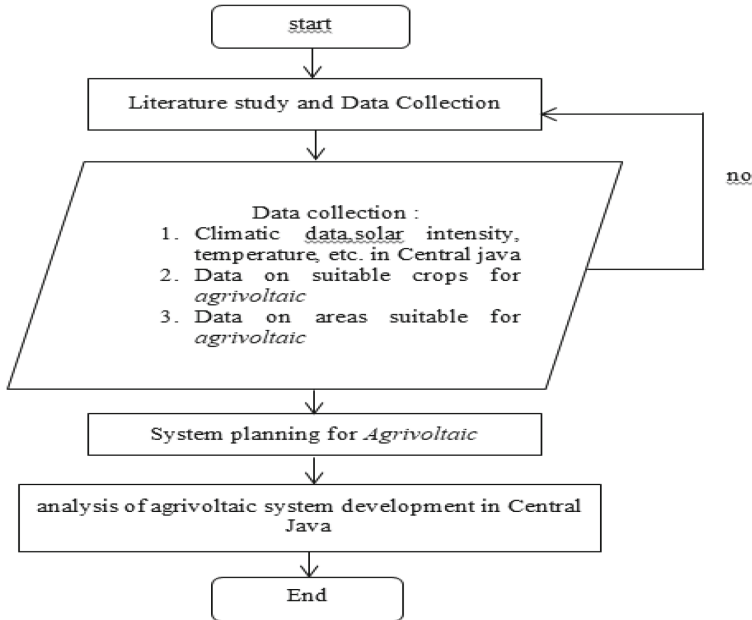
The development method from the initial agrivoltaic concept that is suitable for areas in Central Java and does not interfere much with the activities of farmers in land management is the concept of solar panels placed between plants on each mound. That way, agricultural equipment, and crop irrigation systems will not be disturbed by the development of this agrivoltaic system (Fig. 5).

Then with the daily solar radiation data in areas in Central Java, this data can be used as a reference for areas that have the potential for agrivoltaic development, namely in Semarang District, Kendal District, Batang District, Pekalongan District, Pemalang District, and Tegal District.

### 3 Result and Discussion

Agrivoltaic is suitable to be applied to agricultural land with plants that are tolerant of the shadow effects of solar panels. These include lettuce [8], arugula, Asian vegetables, chard, mustard greens, kale, sorrel, spinach, leeks, broccoli, cabbage, peanuts, sweet potatoes, taro, cassava, and sweet potatoes. Or plants that only need a little sunlight, such as cucumbers, radishes, pumpkins, cabbage, and green peppers. In the Central Java region, of course, not all of these plants are not planted, for plants in the Central Java region such as peanuts [8], green beans [8], and tomatoes of marglope varieties [8, 9] (Fig. 6).

By observing and analyzing data on harvested area, crop productivity the energy potential in all districts in Central Java, especially in the districts of Semarang, Kendal, Batang, Pekalongan, Pemalang, Tegal, it can be concluded that there is potential for the use and development of agrivoltaic systems (Table 2).



**Fig. 6.** The flowchart of analysis of agrivoltaic systems development in Central Java

The potential of agrivoltaic in Indonesia, especially in Central Java, is very wide open. Because in Central Java, many plants are suitable for shade, namely the placement of solar panels. Then the next factor is that the Central Java area has a lot of sunlight intensity, and the Central Java region still relies on fossil fuels for power generation.

Then the intensity of these cities ranges from 1500–1700 kWh/kWp. The potential development of the agrivoltaic system itself totals 83 MWp. Of the 83 MWp obtained 29 MWp was from land with peanut plants, then 52 MWp obtained from mung bean fields and 2.5 MWp obtained from tomato fields. Then for the area with the most agricultural land, Semarang district with a land area of 1,999 ha and can produce power of approximately 1,000 MWp.

**Table 2.** Data on the number of plants planted in Central Java and Harvested area [12]

Number	City	Plants			
		Peanuts		Tomatoes	
		Productivity	Harvested area	Productivity	Harvested area
1	Cilacap	11,87	1,422	8,249	60
2	Banyumas	13,44	1,265	2,167	42
3	Purbalingga	15,35	231	23,170	142
4	Banjarnegara	14,90	1,314	90,970	399
5	Kebumen	11,79	2,344	4,710	95
6	Purworejo	11,84	1,139	1,117	20
7	Wonosobo	14,46	153	127,540	812
8	Magelang	13,28	541	162,580	980
9	Boyolali	13,32	2,757	16,272	122
10	Klaten	14,77	1,296	3,997	75
11	Sukoharjo	16,95	3,569	110	1
12	Wonogiri	12,27	26,645	4,932	53
13	Karanganyar	13,64	1,430	16,873	116
14	Sragen	18,15	6,498	30	1
15	Grobogan	18,14	798	788	13
16	Blora	13,70	1,097	8,340	100
17	Rembang	11,41	508	10,976	147
18	Pati	13,19	2,602	3,496	20
19	Kudus	14,81	376	51	3
20	Jepara	12,93	4,420	26	2
21	Demak	14,46	57	1,915	27
22	Semarang	16,96	1,449	175,627	538
23	Temanggung	15,93	288	64,272	460
24	Kendal	11,12	243	591	10
25	Batang	13,61	299	12,725	82
26	Pekalongan	15,16	228	5,874	25
27	Pemalang	14,29	61	7,061	85
28	Tegal	15,54	117	128,491	437
29	Brebes	14,25	147	20,885	140
City district					

(continued)

**Table 2.** *(continued)*

Number	City	Plants			
		Peanuts		Tomatoes	
		Productivity	Harvested area	Productivity	Harvested area
30	Magelang	13,11	1	—	—
31	Surakarta	14,48	8	—	—
32	Salatiga	14,29	3	—	—
33	Semarang	10,81	45	—	—
34	Pekalongan	—	-	—	—
35	Tegal	—	-	—	—
Total		464,22	57944 ha	3790	5007 ha
Potential of Agrivoltaic			28.972 MWp		2.504 MWp

## 4 Conclusion

With several criteria and the suitability of existing natural conditions, all regions in Central Java and in particular, namely Semarang Regency, Batang Regency, Kendal Regency, Pekalongan Regency, Pemalang Regency and Tegal Regency have enormous potential to be used as agrivoltaic land.

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