Evaluation Of Multi-Energy Harvesting In Aquaponics With IOT-Based Measurements

Rizka Reza Pahlevi, Aji Gautama Putrada

Abstract: Aquaponics is a combined concept of aquaculture and hydroponics that offers a symbiotic relationship between the aquatic environment and the hydroponic environment and can be a solution to land crisis and food security problems. However, the use of conventional energy sources in supplying aquaponics systems is contradictory to the problem of the energy crisis. The aim of this study is to evaluate the adequacy of energy harvested from solar panels and wind turbines in meeting energy needs in aquaponics systems based on internet of things (IoT)-based measurements. The monitoring system built is reliable and has a centralized energy harvesting interface. Tests for energy harvesting and energy consumption were carried out for three days. Based on the test results, the total energy harvested from solar panels and wind turbines can cover 307% to 345% of energy in aquaponics systems. Solar energy gains supply 295%, and wind energy supplies 28%.

Index Terms: Internet of Things, Energy Harvesting, Solar Panel, Wind Turbine, Aquaponics, Rotor Radius

1 Introduction

Geographical and topological conditions in agrarian countries are suitable for agriculture and fisheries. Conventional agricultural and fishery processes in agrarian countries, such as Japan, Indonesia, Thailand, and Australia use large open land [1]. The increasing population development causes the transfer of agricultural and fishery land (as productive land) to settlements [2]. This causes inequality in the need for food products to the population. To meet the needs of food products, especially vegetable and fish products, residents can use limited land by utilizing aquaponics technology [3], [4]. The term aquaponics is a combination of aquaculture and hydroponics [5]. Hydroponics is the cultivation of plants by dissolving the nutrients needed by plants in water [4]–[7]. Thus, plants do not use soil media, but use stone fiber media. Then, aquaculture is the cultivation of aquatic organisms, including fish, mollusks, and aquatic plants in a closed environment. Aquaponics is an aquaculture and hydroponic farming system that is run in one environment. The aquaponics system is a sustainable symbiotic system, where the transformation of micro-organisms from aquatic culture is used as nutrients for plant growth. On the other hand, the absorption of nutrients by plants can bioremediate water so that it can reduce pollutants in water used for the aquatic environment. Modern aquaponics uses recirculating aquaculture systems (RAS) aquaponics [5]. This form can reduce the toxicity of ammonia in water by utilizing biofiltration. Processes in RAS systems are beneficial for both types of environments. Plants get organic compounds from the results of filtered aquatic environmental waste. Then, the filtered aquatic environmental waste is very rich in nutrients and can fertilize plants. This filtering process converts ammonia compounds into nitrites which can be absorbed by plants [8]. Furthermore, the water is recycled back for a remediation process before entering the aquatic environment.

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To run the entire aquaponics system, supporting equipment is needed. One of the important equipment in an aquaponics system is a water pump. A water pump is needed to distribute water from the aquatic environment to the hydroponic environment. The operation of water pumps using conventional electric power, such as burning coal, is an energy crisis problem. In addition to the energy crisis, conventional electricity production produces air pollutant waste [9]. Thus, renewable energy that can be used as an energy source for aquaponics is needed. Solar and wind energy sources are environmentally friendly solutions that can be proposed [9]–[14]. The potential for solar energy and wind energy in agrarian countries is usually high. Countries like Indonesia can produce 500 GW of solar energy [15] and 9.29 GW of wind energy [16]. In implementing the system, a technology that can be used to measure and monitor the energy harvesting process in solar and wind energy sources is required. This measurement and monitoring process is needed to see the level of energy production against energy needs in the aquaponics system. The concept of internet of things (IoT) can be proposed as a solution for the measurement and monitoring system [6], [17]–[19]. The aim of this study is to evaluate the energy needs fulfillment by solar and wind energy harvesting of an aquaponics system using IoT-based measurements. In this study, the IoT system is installed on solar panels, as a solar energy harvester, and on a wind turbine, as a wind energy harvester. The measurement results are displayed on the interface as a place for user interaction. Furthermore, the amount of energy produced by both types of energy sources per day against the amount of energy required by the aquaponics system in a day is measured. In this research, we contribute to building an IoT-based solar and wind energy harvesting system. In addition, this study presents a discussion of the results of harvesting solar energy against wind energy to support aquaponics systems.

2 Related Works

Mahkeswaran et.al. discusses food safety issues that often occur in the world, including Singapore [7]. The issue is that the rapid growth of humans has resulted in a very high human need for food. The aim of this journal is to utilize aquaponics techniques to grow crops for human needs. By using the methodology, we create a smart and sustainable home aquaponics system consisting of various sensors, actuators, and microcontrollers that are connected to the internet so that they can monitor, control, and record the condition of fishponds and the quality of the surrounding air. The result of this test successfully demonstrates the efficacy of a home aquaponics system for growing healthy fish and plants with low operating costs and human intervention. Butt et al. discusses the problems with the increasing number of human population and the increasing need for food [20]. The rapid development of urban agriculture has made aquaponics techniques very popular. The aim of this journal is to integrate IoT technology with aquaponics to maximize results, reduce human error, and prevent unpredictable hazards. With the methodology with IoT, surveillance of aquaponics systems is easy to monitor and control, even from remote locations. The results of this test are data generated from supervision, stored in the Google spreadsheet cloud, and can be analyzed. Rizman discusses the problem of using energy in everyday life from non-renewable sources, such as coal, oil, and natural gas [21]. The purpose of this journal is a technique in energy harvesting to convert the use of non-renewable energy into renewable energy so that energy remains sustainable. The methodology uses energy generated from sunlight, heat, wind, and water. The result of this test is to get electrical energy that can be used for everyday life. Wang et al. discusses the problem of testing the theory of experimental implementation of orthogonal frequency division multiplexing (OFDM) [22]. The aim of this journal is the simultaneous transmission of data and at the same time harvesting energy from sunlight. With this methodology, solar panels can convert the modulated light signal into an electrical signal without the use of external electric power. The results of this test have the potential to power the user terminal or at least extend the operational time of the system itself.

3 METHODS

Energy harvesting measurement and monitoring systems are described in this chapter. In addition, it is also explained about the aquaponics system that uses a multi-energy system. Furthermore, the process of monitoring the energy harvesting system in the aquaponics system that has been built is described. Furthermore, the estimation process for energy harvesting measurements is presented to see the predictions of energy use in the aquaponics system and energy harvesting for the aquaponics system.

3.1 Multi-energy source for RAS aquaponics system

The aquaponics system with the RAS form was built using the nutrient film technique (NFT) hydroponic model. The NFT hydroponic model has the advantage that nutrient uniformity can be controlled. Water circulation from the aquatic environment is directed to the filter. This filtering process aims to get nitrite compounds to those needed in a hydroponic environment. Next, the filtered water is pumped into the hydroponic environment. The aquaponics system is as shown in Figure 1. Multi-energy harvesting is done using solar panels and wind turbines. The solar panel used has a specification of 100W with a voltage of 19.3 V, and a current of 5.18 A. Then, the energy in the solar panel is channeled to the control panel. Furthermore, the wind turbine used has a specification of 450W, five propellers, the peak wind speed is 2 m/s, and the rotor diameter is 1300 mm. The energy in the wind turbine is channeled to the controller. The results of energy harvesting from both sources are accommodated in a 12V 18Ah battery. The energy from the battery is converted from DC current to AC by a 500W inverter which can be used by the water pump. Furthermore, the multi-energy harvesting system is shown in Figure 2.

3.2 Energy harvesting monitoring system

The energy that has been harvested by solar panels and wind turbines needs to be monitored. Monitoring activities are carried out to measure the total energy that can be produced. Thus, calculations can be made between the energy that has been produced and that which will be consumed by the aquaponics system. The monitoring process is carried out by looking at the voltage and current produced by the solar panels and wind turbines. Therefore, this study uses the ina219 sensor. The ina219 sensor can perform current and voltage sensing simultaneously.

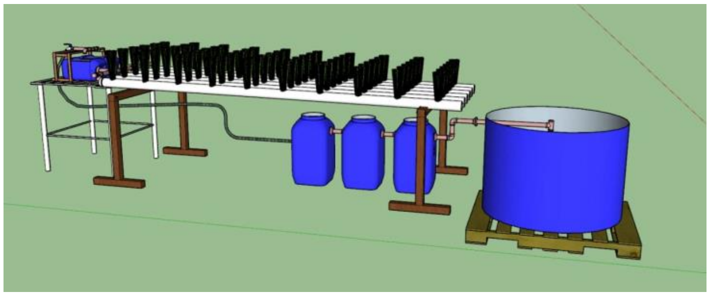


Figure 1: Aquaponics NFT system

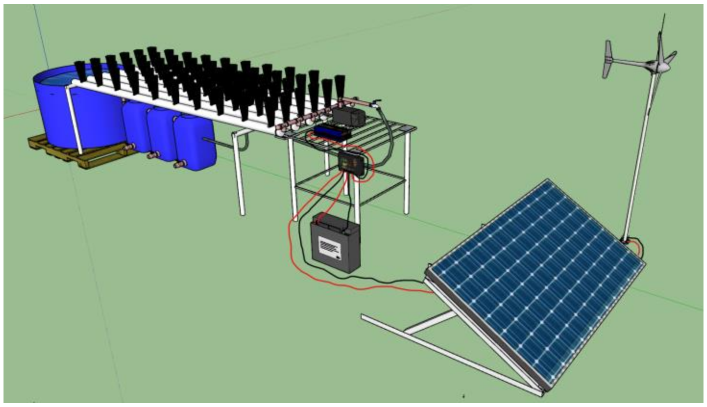


Figure 2: Multi-energy harvesting system

Embedded system devices are required for sensing and processing data. The embedded system device used is ESP8266. The ESP8266 is equipped with a wireless module that supports IoT systems. The ESP8266 periodically performs sensing on the ina219. After that, ESP8266 sends the data to the Node.js server via the message queuing telemetry transport (MQTT) protocol. Node.js is used as a server because it has flexibility in data management and interfaces. Furthermore, the MQTT protocol is used because it is lightweight and compatible with ESP8266. The sensing data is stored on the database server for historical purposes. The described process flow is shown in Figure 3. The ina219 sensor is also applied to the water pump to calculate the energy required by the water pump in the aquaponics system.

3.2 Energy harvesting estimation calculation

Calculation of estimated energy harvesting is done to get the total amount of energy per day. The total energy is theoretically defined as the sum of one Joule per second. In the context of electrical units, energy is described as one volt ampere. The equation in energy is shown as Equation 1.

$$ElectricityPower = voltagexcurrent = EnergyTime \quad (1)$$

However, in the context of electricity, the Volt Ampere rating will be fulfilled if the efficiency of the equipment used reaches 100%. At the test stage it is difficult to determine the level of efficiency of the device used. Therefore, we ignore efficiency and estimate calculations. Estimated energy harvesting in solar panels depends on the amount of irradiation time. The amount of solar radiation is strongly influenced by the geographical location of a place. In areas near the equator the average irradiation is 8-10 hours in one day. So, the measurement of the amount of energy harvested on solar panels in one day, as derived from equation (1), is described in the following equation

$$Energy = PowerxTime \quad (2)$$

If the reference specifications of the solar panels are used, then in one day irradiation can produce 800 Wh to 1000 Wh.

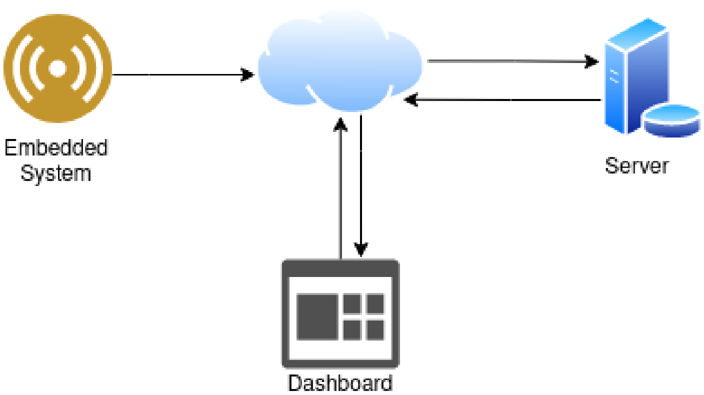


Figure 3: IoT process flow

The estimated energy harvested by a wind turbine depends on the wind speed. Meanwhile, wind speed depends on its geographical location. For example, sea breezes and land breezes on the coast blow almost all the time. However, theoretically the amount of energy obtained by the wind turbine can be calculated based on the radius of the rotor used and the wind speed. The equation for calculating the amount of wind turbine power P_{avail}, based on the rotor radius and wind speed, is described as follows [14]

$$P_{avail} = \frac{1}{2} xpx\pi r^2 xv^3 xC_p \quad (3)$$

where p is the air density, which is 1.2 kg/m3, *r* is the radius of the rotor, *v* is the wind speed in m/s, and Cp is the wind turbine coefficient defined by Betz, the maximum limit is 59%. Based on the specifications of the wind turbine, the documented power is 3.7 Watt.

4 Results and Discussion

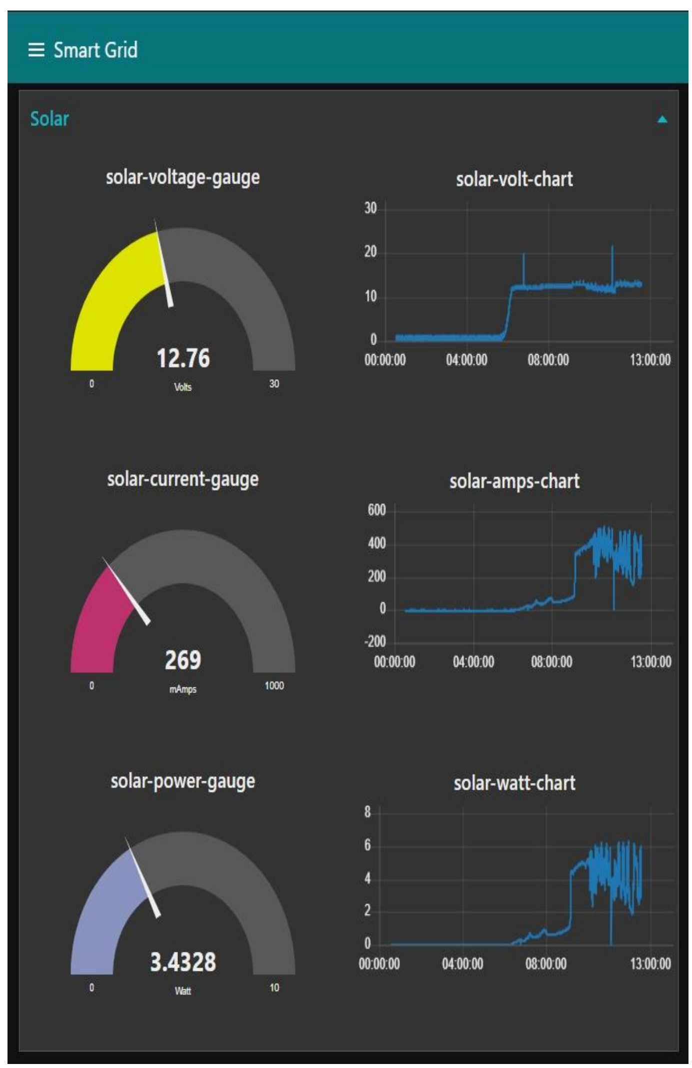
The test results of energy harvesting and monitoring systems are evaluated and discussed in this chapter. An IoT-based monitoring system is implemented on solar panels and wind turbines. Meanwhile, harvesting measurements from solar panels and turbines were carried out over a period of three days. These results are then compared with the energy requirements required by the aquaponics system.

4.1 Monitoring system

The implementation of the monitoring system is carried out using the IoT concept. The data from the ina219 sensing result is processed and sent by ESP8266 to the Node.js server. Data collection is carried out periodically every five seconds. The interface has also been designed to show the energy results obtained from the ina219 sensor, as shown in Figure 4. The MQTT protocol used is reliable in transmitting data, no data loss occurs. The server has successfully saved all the acquired data sent by ESP8266. The monitoring system scalable, meaning that the addition of new solar panels or wind turbines using this monitoring system can be done instantly.

4.2 Energy harvest and consumption

Measurements of harvesting solar energy and wind turbines were carried out for three days. The measurement location is in Bandung, Indonesia. In terms of lighting, the chosen location is on a hill, which allows getting an average of 9 hours of light in one day. In terms of wind, the location has two types of wind, namely mountain breezes and valley breezes. The average wind speed measured was 8-10 km/h (2.2-2.7 m/s).



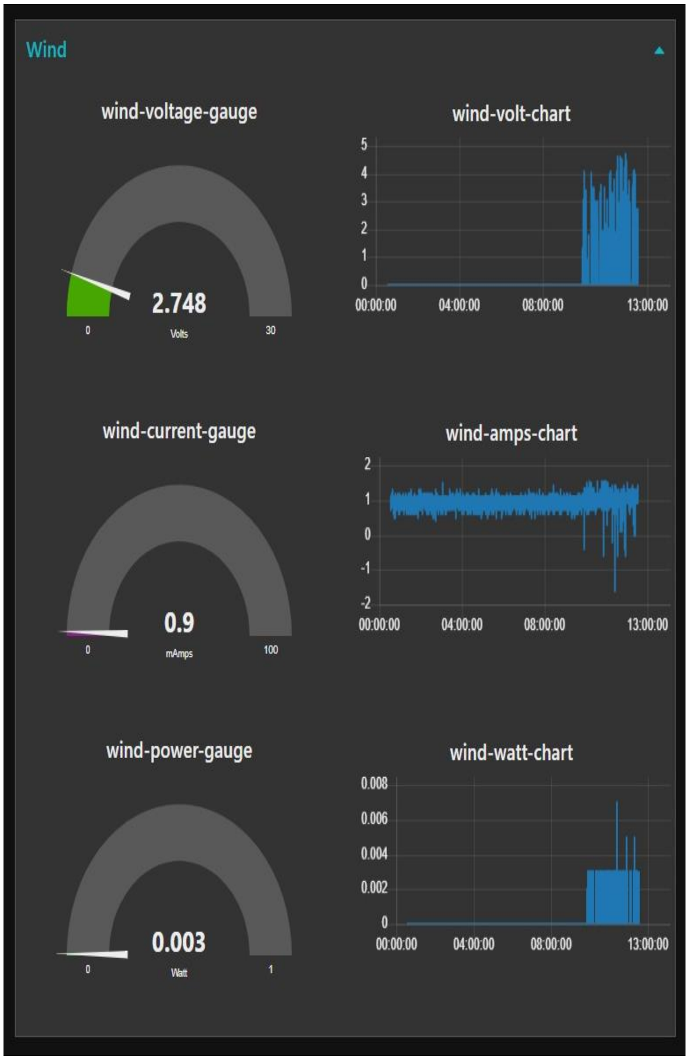


Figure 4: The IoT-based energy harvesting monitoring system dashboard

Harvesting solar panels received a total of 9.8 hours of light on the first day, 9.9 hours on the second day, and 9.6 hours on the third day. On the first day, solar panels get light at 7:15 A.M. and end at 5:07 P.M. In that period, the solar panels get an average of 13.6 V 4.79 A. Based on these results and equation (1), the total power obtained is 686.25 Watts. The energy harvested of solar panels on the first day is shown in Figure 5. Furthermore, on the second day, solar panels get light at 7:10 A.M. and ends at 5:05 P.M. In that period, the solar panels get an average of 13.6 V 4.79 A. Based on these results and equation (1), the total power obtained is 708.4275 Watts. The solar panel energy harvested on the second day is shown in Figure 6. Furthermore, on and on the third day, the solar panels get light from 7:35 A.M. and ends at 5:16 P.M. During this period, the solar panel obtained an average of 13.8 V 4.4 A. Based on these results and equation (1), the total power obtained was 706.0064 Watt. The acquisition of solar panel energy on the third day is shown in Figure 7.

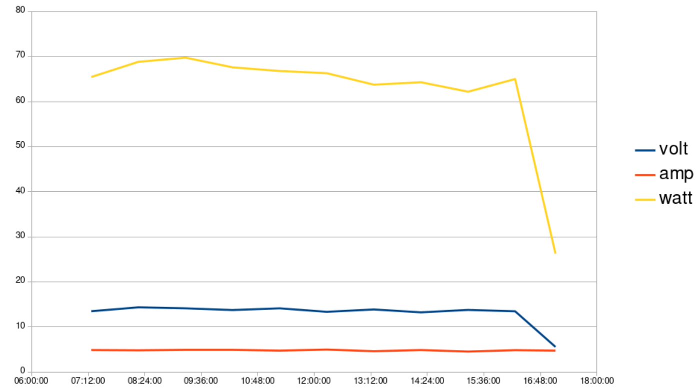


Figure 5: Solar panel power harvested on day 1.

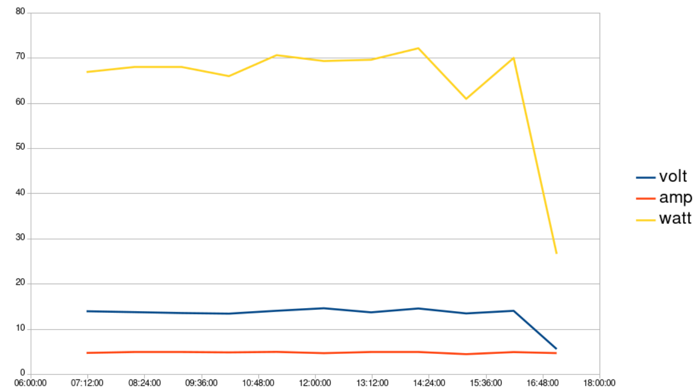


Figure 6: Solar panel power harvested on day 2.

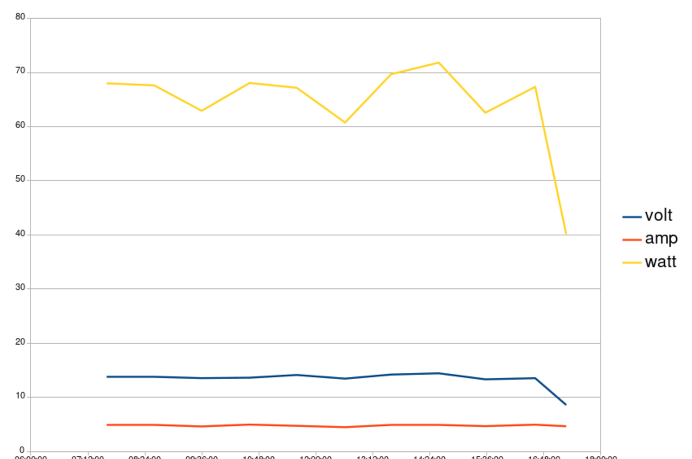


Figure 7: Solar panel power harvested on day 3.

Energy harvesting from the turbine is carried out during the day by utilizing valley winds. The fact is gusts of wind do not occur constantly. Wind energy harvesting begins at 8 A.M. and ends at 6 P.M. The total energy obtained on the first day is 40.45 Wh. On the first day there was a spike at 2 P.M. until 3 P.M. This happens because there is rain accompanied by wind. The wind energy harvested on the first day is shown in Figure 8. Furthermore, harvesting on the second day obtained a total energy of 44.55 Wh. On the second day there was also a spike in energy harvesting at around 1 P.M. until 3 P.M. This happened because it was cloudy and windy. The wind energy harvested on the second day is shown in Figure 9. Furthermore, harvesting on the third day obtained a total energy of 116.70 Wh. This significant increase occurred due to changes in the weather on the third day. On the third day it was cloudy and windy from 9 A.M. until 6 P.M. The wind energy harvested on the third day is shown in Figure 10.

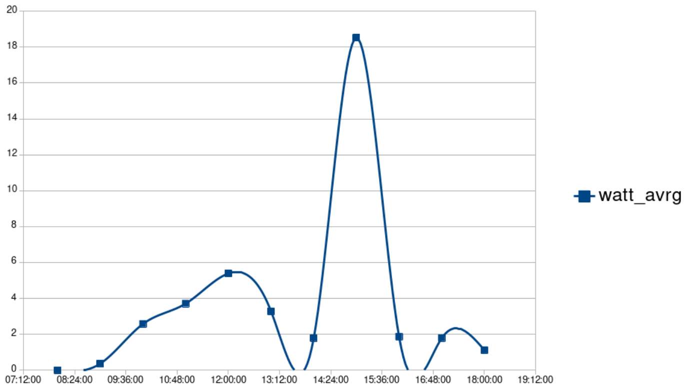


Figure 8: Wind turbine power harvested on day 1

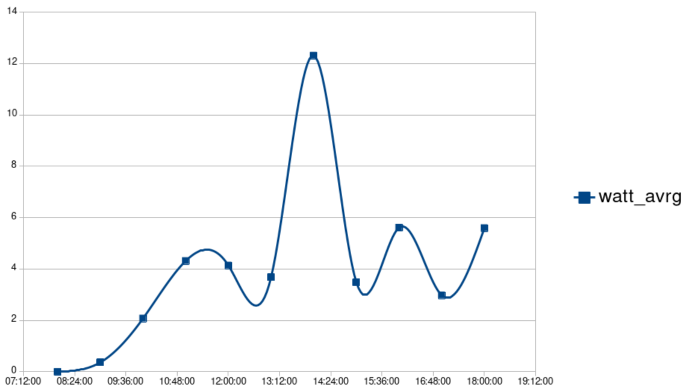


Figure 9: Wind turbine power harvested on day 2.

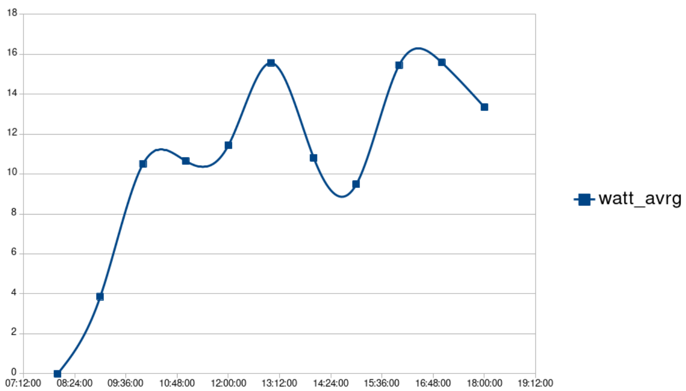


Figure 10: Wind turbine power harvested on day 3.

The aquaponics system uses an 8 W water pump. The water pump runs for 24 hours a day. Based on equation (2) the total energy consumed by the water pump in a period of 24 hours should be 192 Wh. However, the result data sent by the sensor is different. This difference is caused by the efficiency of the water pump. The energy consumption of the water pump on the first day was found to be 236 Wh, on the second day it was 238 Wh, and on the third day it was 238 Wh. Furthermore, a comparison is made between energy harvesting and energy consumption. The total energy harvested on the first day from solar panels and wind turbines is 726.70 Wh, this is 307% of the value of the first day's aquaponics energy consumption. The total energy harvested on the second day from solar panels and wind turbines is 752.98 Wh, this is 316% of the value of aquaponics energy consumption on the second day. The total energy harvested on the third day from solar panels and wind turbines is 822.70 Wh, this is 345% of the value of aquaponics energy consumption on the third day. The comparison of energy harvesting and energy consumption on 3 days of testing is shown by the bar chart in Figure 11. From the results of energy harvested from solar panels and wind turbines on energy use in water pumps, it can be concluded that the energy needs of the aquaponics system are fulfilled up to three times.

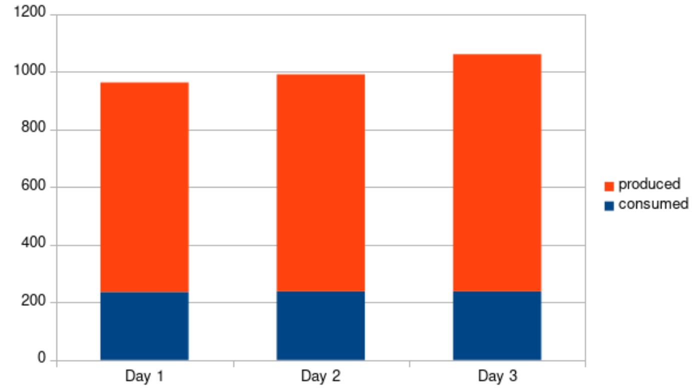


Figure 11: Three-day comparison of aquaponics energy harvesting and energy consumption

4.3 Discussion

The IoT-based energy harvest monitoring system has been successfully implemented. The monitoring system can receive power data sent by the ESP8266 and measured by the ina219 sensor. The server also provides an interface that can be used to view the harvesting results of solar panels and wind turbines. From the results of energy harvesting tests, it was found that solar penal harvests more energy than wind turbines. This happened due to several factors. The factor that greatly affects the wind turbine is the rotor radius. A large rotor radius provides great power at each rotation. Using equation (3), based on the wind turbine specifications and the wind speed of 2 m/s, the calculated wind power is 3.7 Watt. If it is replaced with a longer rotor, for example 1800 mm, the energy obtained will be exponentially 20 Watts. The selection of the rotor radius is important to consider. However, with a constant wind speed, the power efficiency will eventually decrease if the rotor radius and the wind turbine RPM are further increased [23]. Hence, apart from the rotor radius, wind mapping also becomes an important design step [24]. The use of solar panels as energy harvesters for aquaponics systems is sufficient. Solar panels have met an average of 295% of the total energy required for aquaponics systems. So, if solar panels are used, conventional power sources are not needed. However, using the proposed wind turbine for an aquaponics system is not sufficient. Wind turbines only meet an average of 28% of the total energy consumption. Thus, using a wind turbine requires additional conventional energy sources to support the aquaponics system. Both can also be applied together, but apart from saving energy, the investment value of the equipment also needs to be studied, considering that in renewable energy, economic viability is an aspect that is often discussed [25].

5 Conclusion

The IoT system that is built can carry out the process of monitoring energy gain from sunlight and wind. From the results of the tests that have been carried out, the total energy gain from solar panels and wind turbines can meet the energy needs of the aquaponics system. The total daily energy obtained is sufficient for 307% to 345% of the energy needs of the aquaponics system. Solar panels alone can meet the energy needs of 295%. However, wind turbines are only sufficient for 28%. From the results of the analysis, wind turbines require a rotor radius that is longer than that used in this study to increase the amount of energy obtained per rotation. In the future, research will continue to find other alternative energy sources that can be used in aquaponics systems. This is done to increase the potential of renewable energy sources in building aquaponics systems.

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