Design and Development of Smart Rainwater Harvesting Systems in Green Buildings Using Hybrid Energy and IoT

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Abstract. This research presents the design and development of a Smart Rainwater Harvesting (RWH) system integrated into a green building using hybrid energy sources—solar and wind—supported by Internet of Things (IoT) technology. This study used the VDI 2221 engineering design methodology to systematically analyze, select, and develop a suitable RWH system design powered by solar cells and wind energy. The main objective of this research was to conduct a comparative analysis of various RWH tool designs to identify the most efficient and sustainable configuration to be applied in coastal and deltaic environments. This research method employed quantitative analysis and VDI 2221 analysis, a method for engineering product development developed by the Verein Deutscher Ingenieure (VDI), the German Association of Engineers. This method has become an international standard in engineering design, especially in the fields of industrial engineering and in civil systems engineering. The research results indicate that there are three RWH design options for coastal areas, namely Model 1, Model 2, and Model 3. The best choice is Model 1, which utilises sturdy, rust-resistant, and wind-resistant materials and incorporates renewable energy and IoT technology. The wind power plant is capable of producing 32.42 kWh/day of electricity, while the harvested rainwater ranges from 43 mm to 1043 mm per month. A comprehensive design concept that aligns with green building standards and is feasible to implement an innovative and sustainable rainwater harvesting system.

1 Introduction

The availability of clean water in coastal areas is often a very crucial problem. Groundwater that tends to be brackish due to seawater intrusion and reliance on external water supplies makes coastal communities vulnerable to drought and clean water crises, especially during the dry season. One environmentally friendly and sustainable alternative solution is the implementation of a rainwater harvesting (RWH) system in homes and buildings in coastal

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areas. This system enables the capture and storage of rainwater for use in domestic needs, small-scale farming, and sanitation.

However, for the RWH system to function independently and efficiently in areas with minimal infrastructure, it needs to integrate with renewable energy sources, such as solar cells and small-scale wind turbines. Both of these energy sources can be utilised to power water pumps, filter systems, and charge electronic devices within the RWH system. To enhance its efficiency and effectiveness, this system can also be equipped with Internet of Things (IoT) technology, enabling the remote monitoring of water volume, water quality, battery condition, and rainfall in real-time. By utilising sensors and automatic control systems, RWH can operate intelligently and adaptively in response to environmental conditions. The integration of RWH, renewable energy, and IoT represents a potentially innovative solution to address clean water issues in coastal areas in a sustainable manner.

Several studies have shown that both energies could be used alternately or used in a hybrid manner. The use of alternative energy in a hybrid manner applied to ensure that energy shortages can be overcome.

The use of alternative energy in a hybrid manner has been carried out in several studies. Research conducted by Mawardi et al. (2021) demonstrates that alternative energies, specifically wind energy and solar energy, can be combined in building power plants [1]. Previously, research by Santosa and Mulyatno (2014) used a combination of wind and solar energy to light ship in Demak Waters, Central Java [2].

In addition to research on the use of alternative energy in a hybrid manner, many studies have examined the use of wind power and solar power individually. Research conducted by Busma et al. (2022) demonstrated efforts to assess the potential of wind power as a source of power generation [3]. Another study examining wind power as an alternative power source for power generation was conducted by Helmiyatinnisa et al. (2024), which sought to explore the conversion of wind power into electrical energy [4]. Edison's research (2023) discussed the harvesting of sunlight and its use for radio signal needs, as well as AI and business applications [5]. Ajiwiguna and Kirom's research (2024) examined the use of batteries to store solar energy that has been harvested and stored [6].

Previous research results have shown discrepancies. These differences are due to differences in research locations and the equipment used. Research by Lewi et al. (2024) showed that solar power plants (PLTS) can provide energy at peak times of around 237-238.08 W, occurring between 11:00 AM and 12:00 PM. Meanwhile, for wind power plants (PLTB), wind speeds are relatively stable, ranging from 2 to 7 m/s, with the highest peak of around 7.2 m/s occurring around 5:30 PM. At certain times, wind speeds below 2.5 m/s do not produce a voltage value of 0. The highest peak voltage reaches around 51.8 V at 5:30 PM [7].

Research by Prasetyo et al. (2024) revealed that the energy produced by PV panels, micro-hydro, and wind turbines was 2,426 kWh/year, 1,788 kWh/year, and 2,069 kWh/year, respectively. These results showed that for coastal areas the use of hybrid power between solar power and wind power is very possible [8].

Wind power and solar power can be utilized as alternative energy to replace electrical energy derived from fossil fuels or water. They can be used as alternative energy sources to power equipment used in rainwater harvesting. Rainwater harvesting is one way to reduce groundwater usage, making it a feasible option for buildings or structures with high activity levels. The rainwater harvesting process can use the roof of the building as a catchment area. The harvested rainwater can then be channelled through pipes to the storage area.

Research objectives are: a. To analyse and compare various alternative designs of Rainwater Harvesting (RWH) systems for application in green buildings, utilising renewable energy sources, specifically solar cells and wind energy. b. To design and develop an intelligent RWH system integrated with Internet of Things (IoT) technology to enhance the efficiency of rainwater collection and enable real-time monitoring and control.

2 Materials and Method

This research adopts the VDI 2221 methodology, a systematic and structured approach widely used in engineering design processes. The VDI 2221 method enables a logical progression from identifying the problems to developing detailed design solutions, making it particularly suitable for designing complex systems such as a smart Rainwater Harvesting (RWH) system. The research begins with the definition and analysis of the problem, where the inefficiencies and limitations of conventional rainwater harvesting systems in green buildings are identified. In this phase, user needs, environmental constraints, and performance criteria—such as sustainability, energy efficiency, and integration with renewable energy—are thoroughly examined.

Following this, the process proceeds to the functional and structural design stage. Here, the rainwater harvesting system is broken down into its essential components, including water collection, filtration, storage, energy supply, and intelligent monitoring. Each of these components is analysed in terms of its function and interrelation with the others, and conceptual design alternatives are then generated accordingly. These alternative concepts are critically evaluated based on specific criteria, which include feasibility, cost-effectiveness, reliability, and compatibility with green building principles.

To support the design and development process, a range of tools and technologies were employed. Software such as AutoCAD or SketchUp was used for mechanical design and modeling. Programming platforms such as the Arduino IDE or Python were used to develop the code required to operate microcontrollers and manage sensor data. Additionally, IoT platforms such as Blynk or Node-RED were utilized to build user interfaces for remote monitoring and data visualization.

The materials and components used in this research include standard rainwater harvesting infrastructure, which serve as the core elements for water collection and storage, such as gutters, filtration units, and storage tanks. For the energy system, photovoltaic solar panels and small wind turbines are combined to form a hybrid energy source, supported by charge controllers and battery storage units to ensure a consistent power supply.

The method that will be used is shown in the diagram below.

Fig. 1. Design and installation process flow.

The design process flowchart is the first step in creating rainwater harvesting tools, including surveying locations and conditions, collecting data, and developing multiple designs. Next is the selection of the best design, followed by the installation of the tool, testing, and evaluation to determine whether the tool has met the set needs. After selecting the best design, the next step is installation. After the installation process is carried out, the next step is to determine the function. This function is carried out to ensure that each part has met the specified requirements. This overall function is related to the system working on the tool or machine being made.

3 Results and Discussion

3.1 Rainfall

South Meruya is located in West Jakarta, the administrative city. Based on data from the Central Statistics Agency (BPS), West Jakarta receives sufficient rainfall for harvesting. The following presents rainfall data for the last 5 years.

Table 1. Rainfall 2019-2023.

Month	Rainfall (mm)				
	2019	2020	2021	2022	2023
January	382.2	692	332.8	214.1	170.9
February	270.1	1043.2	604.4	520.8	561.3
March	327.3	220.7	244.1	138.7	236
April	194.6	182.8	213.9	156.5	167.5
May	47.8	50.4	203.6	135	106.2
June	23.1	21.1	79.1	138.5	127.2
July	-	87.3	35.8	119.9	5.3
August	-	101	79.7	0.8	1.8
September	-	151.9	113.4	165.8	-
October	1	208.3	182.1	112.4	-
November	50.1	87.3	134.1	195.3	156.2
December	263.8	134.7	171.6	254.1	48.3

Source: West Jakarta BPS (2024).

Based on Table 1, it is evident that rainfall in West Jakarta varies significantly. Rainfall is quite high from December to March, with a variation of 48.3 mm to 1043 mm per month. High rainfall is the primary source of water in the RWH tool, which is harvested and stored in a tower with a capacity of approximately 1000 litres.

3.2 Sunlight

The amount of sunlight that shines on the West Jakarta area is quite good. This demonstrates the use of solar cells as an alternative energy source for rainwater harvesting.

Table 2. Duration of sunlight (hours).

Month	Sunlight (hours)				
	2019	2020	2021	2022	2023
January	43.2	43.0	15.7	38.0	3.1
February	60.8	43.0	30.4	49.0	2.1
March	50.7	9.0	38	63.0	4.5
April	55.5	57.0	41.1	62.0	5.5
May	65.9	47.0	40	62.0	4.2
June	62.8	56.0	30.6	55.0	3.5
July	69.6	57.0	38.4	65.0	4.5
August	67.3	67.0	40.9	64.0	6.1
September	82.0	77.0	52.3	79.0	7.5
October	86.1	66.0	44.9	76.0	6.7

Month	Sunlight (hours)				
	2019	2020	2021	2022	2023
November	71.3	58.0	26.1	44.0	3.3
December	53.1	40.0	25.6	45.0	4.2
Min	43.2	9.0	15.7	38.0	2.1
Max	86.1	77.0	52.3	79.0	7.5
Average	64.0	51.7	35.3	58.5	4.6

Source: West Jakarta BPS (2024).

Based on Table 2, we can see that the amount of sunlight in the West Jakarta area is sufficient to be used as alternative energy to drive the flow of harvested rainwater. Solar energy is an alternative source of electricity that can help reduce the amount of PLN electricity usage.

The amount of solar radiation and the amount of energy produced can be obtained through the global solar atlas website. The PV value produced is 1316.2 kWh/kWp in one year. The direct radiation value or DNI is 868.2 kWh/m^2 in one year. While the Global Horizontal Irradiation (GHI) value is 1646.1 kWh/m^2 per year. The average DNI value per month is shown in Figure 1..

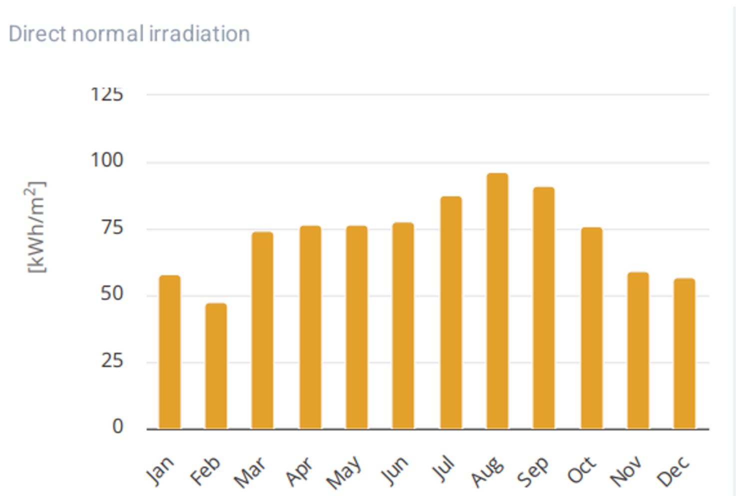

Fig. 1. Average DNI value in one year.

The instant power generated by a solar panel is calculated using a simple formula:

$$P=\eta\times Ir\times A$$

Where:
P: electrical power output (kW)
η: PV module efficiency (e.g. 15–22 %)
Ir: average daily or peak solar radiation (kW/m²)
A: panel area (m²)

3.3 Wind velocity

Wind power is another alternative as an additional resource. The large amount of wind power can be used as an alternative power source to channel water to the reservoir.

Table 3. Wind speed magnitude.

Month	Wind Speed (knots)				
	2019	**2020**	**2021**	**2022**	**2023**
January	1.6	1.7	3.1	1.3	2.5
February	1.4	1.5	3.8	1	2.4
March	1.6	1.8	3.2	0.9	2.1
April	1.4	1.6	2.9	0.8	2
May	1.4	1.4	2.6	0.8	1.6
June	1.3	1.4	2.5	0.8	1.8
July	1.3	1.5	2.4	0.8	1.9
August	1.3	1.7	3.1	0.8	2.2
September	1.3	1.7	2.7	0.8	1.7
October	1.4	1.7	2.6	0.8	2.2
November	1.4	1.6	3.1	0.8	2
December	1.4	2.3	2.5	1	2.3
Min	1.3	1.4	2.4	0.8	1.6
Max	1.6	2.3	3.8	1.3	2.5
Average	1.4	1.7	2.9	0.9	2.1

Based on Table 3, we can see that the wind speed in West Jakarta ranges from 0.8 to 3.8 knots, with an average speed of around 0.9 to 2.9 knots. The formula for the energy produced by the wind is:

$$P=0.5 \cdot \rho \cdot A \cdot v^{3} \cdot Cp$$

With:
P = electrical power generated (watts)
ρ = air density (1.225 kg/m³ at sea level)
A = turbine blade swept area = πr2πr2
v = wind speed (m/s)
Cp = turbine efficiency coefficient (theoretical maximum 0.59, generally 0.3–0.4)

With an average wind speed of 2.9 knots, which is equivalent to 1.49 m/s, for 8 hours, it will produce energy of approximately 4.05W × 8 hours = 32.42 kWh/day. The wind speed is quite small, but it can be utilised as a hybrid energy source in conjunction with solar cell energy to generate alternative electrical power, allowing it to be used to power water pumps to reservoirs. In addition, wind power can also be useful as an alternative fuel other than fossil fuels.

3.4 Design of wind and solar power generators

With the help of VDI 2221, researchers began to develop alternative tools used as rainwater harvesting materials. One of the most significant tools used is a tool used as an energy supplier. In this study, researchers attempted to combine solar power and wind power as a source of energy. The materials used will be explained as follows.

3.4.1 Solar panels

In solar power plants the existence of solar panels is quite essential, and solar panels can be made from various materials. Here is a picture of the materials used in solar panels.

a. Monocrystalline Silicon

b. Polycrystalline Silicon

c. Thin Film Solar Cell

d. Compound Thin Film

Fig. 2. Types of PV.

3.4.2 Wind turbines and generators wind turbines

There are several wind turbine generators commonly used, these are :

a. Savonius Wind Turbine Generator

Savonius wind turbine is one of the simplest types of wind turbine generators. Its drum-like shape makes it easy to install and does not require strong winds to generate electricity. Although its efficiency is not as good as that of other types of wind turbine generators, Savonius wind turbine generators are suitable for small-scale projects or home use.

b. Darrieus Wind Turbine Generator

The Darrieus wind turbine has a windmill-like shape with three to five blades. The strengths of this technology include its ability to generate electricity at low wind speeds and its suitability for medium- to large-scale projects, such as commercial wind power plants.

c. HAWT (Horizontal Axis Wind Turbine) Wind Turbine Generator

HAWT wind turbine is the most commonly used type of wind turbine generators. With a shape like a horizontal windmill, HAWT wind turbine is able to produce electrical energy with high efficiency. HAWT wind turbine generators are suitable for large-scale projects, such as commercial wind power plants or offshore wind energy projects.

d. VAWT (Vertical Axis Wind Turbine) Wind Turbine Generator

VAWT wind turbine generators are shaped like vertical windmills and usually have two to three blades. The advantage of VAWT wind turbine generators is their ability to generate electricity at various wind speeds. VAWT wind turbine generators are suitable for medium to large-scale projects, such as community wind power plants or hybrid wind energy projects.

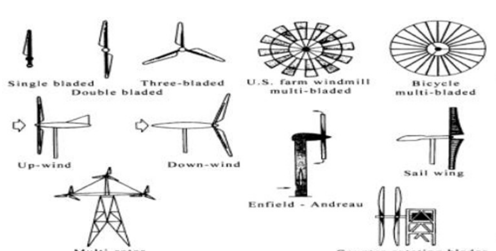

Fig. 3. HAWT wind turbine generator.

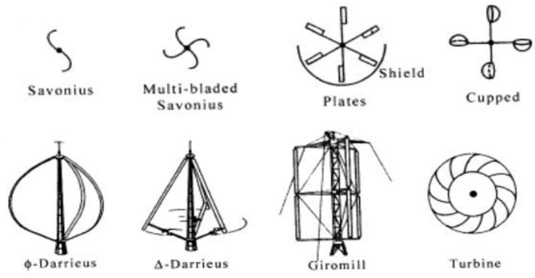

Fig. 4. VAWT wind turbine generator.

3.4.3 Design of PLTS and PLTS

To design a rainwater harvesting tool, VDI 2221 was utilised to determine the optimal design. The selection of the best design is based on demand and needs. The results of the demand and needs for rainwater heating tools utilising alternative energy sources are presented in Table 4.

Table 4. Demand (D) and Want (W) table.

No	Parameter	Demand (D) / Desire (W)	Spec Number	Specification number
1	Function	D	1, 2	Rainwater for : 1. Clean water 2. Drinking water
2	Design	W	1, 2	1. Compact design, 2. Doesn't take up much space
3	Material	D	1, 2, 3	1. Easy to get, 2. Durable, 3. Anti-rust
4	Energy	W	1, 2, 3	Sources from : 1. PLN, 2. Solar Energy 3. Wind Energy
5	Application	D	1	1. Use of IoT-based smartphones
6	Sensor	D	1, 2, 3	1. Temperature, 2. Humidity, 3. Ultrasonic
7	Security	D	1, 2	1. Safe for operators. 2. Do not use dangerous chemicals.
8	Ergonomics	W	1, 2	1. Easy to operate. 2. Special skills required for maintenance.
9	Assembly	D	1	Easy to assemble
10	Production	D	1, 2, 3	1. Strong and sturdy frame, 2. Can be produced by small industries, 3. Can be mass produced
11	Transportation	D	1	Easy to transport
12	Maintenance	D	1	Easy maintenance
13	Aesthetics	W	1 , 2	1. Beautiful to look at 2. Aesthetic
14	Cost	D	1	Cheap to maintain
15	Marketing	D	1	Easy to market

Table 4 presents the parameters of Wish (W) and Demand (D). Number 4 (Energy) lists three energy sources: energy from the state electricity company, solar cell energy, and wind energy. However, this study prioritises hybrid energy, which does not depend on fossil fuels. Therefore, the state electricity company, which currently relies on fossil fuels (not renewable energy, No. 4 energy, W), is being adjusted to rely solely on solar energy and wind energy. Regarding ergonomics, this is also not essential because the room conditions for this prototype design are quite spacious, specifically 16 m^2 (for two towers and panel rooms), making maintenance and ergonomics quite easy. Therefore, number 8, ergonomics, and special skills, W, are removed. Then, for aesthetics, this is also not necessary, as what is prioritised is strength and efficiency; therefore, number 13 (Aesthetics, W) is removed. After removing the wishes from the needs table, the results can be seen in Table 5.

Table 5. Table of Demands (D) and Wishes (W)

No	Parameter	Demand (D) / Desire (W)	Spec Number	Spec. number
1	Function	D	1, 2	Rainwater for : 1. Clean water 2. Drinking water
2	Material	D	1, 2, 3	1. Easy to get, 2. Durable, 3. Anti-rust
3	Energy	D	1, 2	Sources from : 1. Solar Energy 2. Wind Energy
4	Application	D	1	1. Use of IoT-based smartphones
5	Sensor	D	1, 2, 3	1. Temperature, 2. Humidity, 3. Ultrasonic
6	Security	D	1, 2	1. Safety for operators. 2. Do not use dangerous chemicals.
7	Assembly	D	1	Easy to assemble
8	Production	D	1, 2, 3	1. Strong and sturdy frame, 2. Can be produced by small industries, 3. Can be mass produced
9	Transportation	D	1	Easy to transport
10	Maintenance	D	1	Easy maintenance
11	Cost	D	1	Cheap to maintain
12	Marketing	D	1	Easy to market

After determining the design to be used, the next step is to select the materials required to build the chosen design. The required parameters are materials that are easy to obtain, strong enough, practical, and not too expensive. The materials that can be used are listed in Table 6.

Table 6. Type of material used.

No	Tool Element Solution Matrix	Material A and Value weight	Material B and Value weight	Material C and Value weight
1	Water reservoir tower	Steel Spot (weight 3)	Reinforced Concrete (weight 2)	Fiber Reinforced Plastic (weight 1)
2	Tower container	Polyethylene (HDPE) (weight 3)	Stainless steel (weight 2)	Concrete (weight 1)
3	Pipe	Iron (weight 2)	PVC material (Weight 3)	Rubber (weight 1)
4	Filter a.	Nano Filter, Palm Fiber (weight 3)	Sand (weight 1)	Gravel (weight 2)
5	Filter b.	Artificial filters (weight 2)	Soil (weight 1)	Zeolite, Activated charcoal (weight 3)
6	Sensor	Temperature, RH, Ultrasonic. Rain, wind speed sensors (weight 3)	Temperature, RH, Ultrasonic (weight 2)	No sensor (weight 1)
7	Water source	Rainwater (weight 3)	Groundwater (weight 1)	Drinking water company (weight 2)
8	Energy	Solar Cell, Wind Energy (weight 3)	State Electricity Company (weight 1)	Biogas (weight 2)
9	Battery	Lithium Ion (weight 3)	Lead Acid Battery (weight 2)	GEL Battery (weight 1)
10	Platform	Ubidot (weught 1)	Blynk (weight 3)	ThingSpeak (weigh 2)
11	Pole	Wood (weight 1)	Galvanized (weight 2)	Steel (weight 3)
12	Solar Cell	Monocrystalline Silicon (weight 1)	Thin Film Solar Cells (weight 2)	Polycrystalline Silicon (weihjt 3)
13	Wind energy	Horizontal Axis Wind Turbines (HAWT) (weight 1)	Hybrid Wind Turbines (weight 2)	Vertical Axis Wind Turbines (VAWT) (weight 3)

Note: Model 1., Model 2., Model 3:

Table 6 lists the materials required to produce a prototype design for rainwater harvesting, incorporating sensors, IoT, and hybrid energy. From the table, the best choice is made from the three types, namely
Model 1 : 1A, 2 A, 3B, 4A, 5C, 6A, 7A, 8A, 9A, 10 B, 11C, 12C, 13C.
Model 2: 1B, 2 B, 3C, 4C, 5B, 6B, 7B, 8C, 9C, 10C, 11B, 12A, 13A.
Model 3: 1C, 2C, 3A, 4B, 5A, 6C, 7C, 8B, 9B, 10A, 11A, 12B, 13B.

Next, from Options 1, 2 and 3, then referring to the parameters that have been set (materials that are quite easy to get, strong enough, practical and not too expensive) then Option 1 is chosen, because it uses materials that are quite strong and easy to obtain, namely (Steel spot, HDPE), the price is not too expensive but strong enough (Polycrystalline Silicon, Vertical Axis Wind Turbines (VAWT). Furthermore, the sensor is adjusted to the needs, namely Temperature, RH, Ultrasonic. Rain, and wind speed sensors. The platform chosen is Blynk, due to its ease of download from the Google Play Store and its fairly attractive appearance.

Based on the results above, it can be seen that the manufacture of water harvesting equipment (RWH) can be done by selecting the appropriate materials. The use of VDI 2221 as a tool to help choose the appropriate design demonstrates that VDI 2221 aids in making the right choice. Based on the explanation above, the best choice is model 1, which is then depicted in Figure.

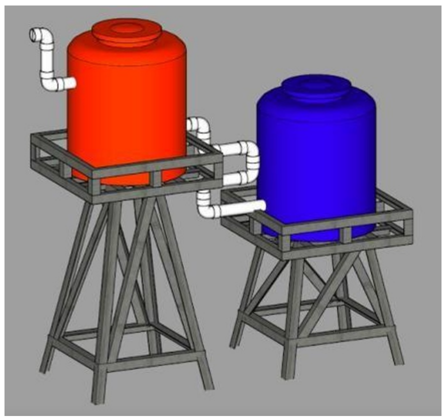

Fig. 4. Analysis results with the choice of using Model.

3.5 Discussion

The design results show that rainwater harvesting can be implemented in buildings and utilised as an alternative energy source to generate electricity. The results of this study indicate that creating a green building can be achieved by carrying out the required design. In this study, a green building is completed with a rainwater harvesting design and the utilisation of new renewable energy sources, including wind energy and solar energy.
Research demonstrates the use of hybrid electric power generated from two electricity sources: wind energy and solar energy.

The development of wind energy in Indonesia is currently relatively low, but it has enormous potential. One reason is that the average wind speed in Indonesia is relatively low, ranging from 3 m/s to 5 m/s, which makes it difficult to generate electricity on a large scale. Wind power plants are one form of alternative energy that is worthy of development. The results of Wahyudi et al.'s (2023) research showed that, based on the calculation of the combined power of wind turbines and solar panels, a power of 746.6 kW was obtained. Thus, with this power, it has met the power requirement of 720 Wh. From the results of the calculating the strength analysis of the turbine shaft material with SS 304 type material using SolidWork software, it is known that the permissible stress on the SS 304 material is 200 MPa, so the results of the torsional stress with a load of 1217 Nm produce a yield strength of 1.723e+002 N/mm2 (MPa), and a maximum torsional stress of 1.723e+000N/mm2 (MPa).

Rainwater harvesting (RWH) is a highly beneficial water conservation technology, particularly for individuals in areas prone to droughts. Rainwater, directly captured from the atmosphere, is a source of clean water with numerous uses in everyday life. When global warming occurs, resulting in climate change, one of its impacts is a prolonged dry season, leading to a shortage of water supplies, including in coastal areas around Indonesia. The use of IoT-based RWH tools is a practical solution for addressing reduced soil absorption capacity, which causes a decrease in groundwater levels. In addition to mitigating drought during the dry season, RWH also plays a crucial role in reducing the volume of rainwater runoff into rivers during the rainy season. When it rains, most of the water flows directly into the river without having time to seep into the ground. If the river capacity is insufficient, this can cause flooding that is detrimental to the community around the river flow. With the concept of rainwater storage, rainwater can be collected first, then utilised, and some of it is gradually discharged into the ground, thereby reducing the likelihood of excessive runoff and helping to maintain hydrological balance in coastal areas. The design method for making rainwater is the VDI 2221 approach, which functions to solve problems regularly and optimize the use of raw materials and efficiency in the production process. This method involves several design stages, including a wish list, concept design, form design, and detailed design. This method is commonly used to design tools and machines that aim to provide convenience for planners through simple working mechanisms and affordable production costs. Additionally, this design aims to understand the filtering process carried out by the RWH tool and identify its components and their functions. Additionally, when extreme rain occurs, this system acts as a runoff damper, reducing the load on the drainage system and minimising overflow. . It is important to note that rainwater collection and storage systems require regular maintenance to ensure proper function and durability. Research is needed to develop durable technology with minimal maintenance and efficient energy sources, such as solar cells [9]. The use of hydraulic equipment, including rainwater harvesting systems, is gradually integrating IoT sensor technology and utilising environmentally friendly energy sources, such as solar panels.

RWH from PV systems can contribute to a higher availability of water resources for society in the Sahel Region, increasing resilience to climate change. With the rapid development of strategies for renewable energy generation in the Sahel and Sub-Saharan Africa, and the ongoing implementation of solar energy plants, there is an urgent need to better evaluate the potential of joint energy and rainwater harvesting in field trials. The system is designed to collect rainwater from both flat and pitched roofs using a gutter connected to a downspout at a lower roof level. Another alternative considered is the use of greywater, which, when combined with rainwater, maximises the amount of water content through the turbine. A water flow sensor sits in the gutter to measure the flow rate. The sensor has a type of pinwheel to calculate the quantity of liquid that goes through it. The selection of the best turbine depends on specific characteristics, such as the available head and flow.

According to Carter et al., during average rainfall in the UK, a single turbine can produce a maximum of 7.21 V of DC voltage, or 50.49 V during heavy rain — enough energy to power a mobile device charger or a vacuum cleaner, respectively. Therefore, this proves a high potential in rainwater energy harvesting as a renewable energy source. It was also concluded that a positive correlation existed between the number of turbines in a downpipe and the number of pipes surrounding the building, as well as the voltage output of the entire system.

With this rainwater harvesting system, it is possible to collect up to 1,678 m³ of rainwater per year. For this reason, the result is considered feasible to install rainwater storage systems, allowing freshwater consumption to be reduced by 0.6% per year. Considering the feasibility of installing rainwater storage systems and solar power generation plants, the energy supply to the national grid system will be significantly reduced, resulting in a decrease in electricity demand from conventional sources [10].

The quantity of rainwater collected in this research using just two solar panels demonstrates great potential for widespread use as a supplementary water supply. This method of rainwater and fog harvesting can be effectively applied to solar power plants which are widely spread in Jordan, for use in cleaning solar panels, agriculture, recharging groundwater, and reducing stormwater discharge to assess and manage the risk of environmental damage. Rainwater and fog harvesting systems offer a higher level of efficiency and cost-effectiveness compared to other methods, especially when seamlessly integrated into the infrastructure of solar power plants. The benefits of solar panels by producing clean energy are not negotiable, but combining energy production with water harvesting in solar power plants would offer even more advantages in enhancing the global environmental situation [11].

Some physicochemical parameters of rainwater may meet the standards for human consumption, but if pathogenic microorganisms contaminate it, it poses a risk to public health if consumed without prior treatment. Therefore, it is mainly used for irrigation and flushing toilets. However, this system has been implemented primarily in rural areas to meet their basic needs, including human consumption, as these areas lack access to the central drinking water system. Given this scenario, treatment technologies being developed should be easy to operate and maintain, such as solar disinfection and filtration for drinking water purposes. This study provides a global overview of the progress in research related to rainwater harvesting systems [12].

The results indicate that the hybrid solar rainwater harvesting system offers a promising solution for sustainable energy generation, with applications ranging from residential rooftops to large-scale commercial installations. This research contributes to the advancement of renewable energy technologies and highlights the importance of innovative approaches in meeting growing energy demands while mitigating environmental impacts [13]. Hybrid combinations of wind power, solar power, geothermal power, hydroelectric power, tidal power, biomass-generated power, power from the incineration of solid waste, and many other technologies could be considered, depending on local interests and resources. Besides being pollution-free, they incur no recurring costs..

The results showed that the implementation of RHS at X Boarding House succeeded in saving clean water bills by up to 58% with benefit value of IDR 8,093,176. This shows that the RHS is an effective solution in reducing water costs for PDAM bills. The design of the RHS utilises the roof as a catchment area, and the tank system, placed above ground, was designed to take into account ease of operation and maintenance. The Benefit-Cost Ratio (BCR) analysis indicates that the RHS at X Boarding House is feasible to build, with a value of 1.388, which exceeds 1, indicating that the benefits outweigh the costs. Determining the economic value of using rainwater as an alternative to conserve clean water reveals that RHS can be a viable solution to address problems, particularly water scarcity during the dry season when clean water supplies are decreasing [14].

The highest rainwater harvesting potential belongs to the two power plants located in the Sungurlu district, Derekisla and Alembeyli, which have a potential of 10,129 m^3/year and 11,591 m^3/year, respectively. The total rainwater harvesting potential of the power plants been licensed since 2016 in Çorum has been calculated as 56388 m3/year. This study presented an innovative approach to rainwater harvesting from solar power plants with a large surface area, utilising the obtained water for panel cleaning and agricultural purposes, thereby combating climate change and drought [15]. All localities demonstrated a need for an increase in the size of the reservoir by the end of the century to meet the non-potable water demand of residents. The increase in annual simulated rainfall regimes demonstrated this. Regarding the photovoltaic energy system, all localities indicated that there was no need to change the number of panels to meet the energy demand from the hydraulic pump until 2100. The Ciberang River has potential as a renewable energy source, with a 60% discharge of 5.8 m^3/s. Capacity of energy that can be produced with the assumption of height of 159 meters, efficiency of generator 0,95 and efficiency of turbine 0,85 is equal to 45.813.400,21 kwH/year. Some parameters need to be considered for future work, including a more accurate analysis result and recorded data on water discharge at a specific location on the Ciberang River for one year.

This research was limited to a single research area, South Meruya, so the results will only have an impact on that area. The study also demonstrated that utilizing alternative energy sources can help reduce electricity use for distributing harvested water.

4 Conclusion

A comprehensive design concept aligns with green building standards and demonstrates the feasibility of implementing a smart and sustainable rainwater harvesting system. The results of this research are a design model for rainwater harvesting and the use of alternative resources to replace electricity produced by the state electricity company. This design can be applied on a household and medium scale, such as small and medium businesses, in coastal and delta areas. The research results indicate that there are three RWH design options for coastal areas, namely Models 1, 2, and 3. The best option is Model 1, which utilises sturdy, rust-resistant, and wind-resistant materials, along with renewable energy and IoT technology. A comprehensive design concept that aligns with green building standards and demonstrates the feasibility of implementing a smart and sustainable rainwater harvesting system. Future research should focus on optimizing Smart RWH systems through advanced IoT and AI integration for predictive rainfall and demand management, optimizing solar-wind hybrid energy with smart storage, and integrating real-time water quality monitoring and automated treatment

References

1. Mawardi, M. K. Wiguna, S. M. Katjong, and F. Azis, "Teknologi hybrid energi angin dan energi matahari sebagai sumber energi listrik," J. Electr. Engginering, vol. 2, no. 2, pp. 100–106, 2021. https://doi.org/10.61141/joule.v2i2.196
2. A. W. B. Santosa and I. P. Mulyatno, "Pemanfaatan Tenaga Angin Dan Surya Sebagai Alat Pembangkit Listrik Pada Bagan Perahu," Kapal, vol. 11, no. 3, 2014. https://doi.org/10.14710/kpl.v11i3.7670
3. R. Busma, S. Dewi, Yusnaini, Nurhani, and B. Mukhlis, "Analisa Penggunaan Energi Angin Sebagai Pembangkit Listrik Alternatif Di Kota Palu," Foristek, vol. 13, no. 2, pp. 67–74, 2022. https://doi.org/10.54757/fs.v13i2.145
4. Helmiyatinnisa, Sudarti, and Yushardi, "Navigasi Inovatif: Mengeksplorasi Angin Sebagai Solusi Energi Masa Depan," J. Penelit. Ilm. Multidisiplin, vol. 8, no. 6, pp. 24–30, 2024. https://sejurnal.com/pub/index.php/jpim/article/view/2047/2373
5. G. Edison, "Revolutionizing Energy Harvesting: Solar Cell Integration with Radio Waves for AI, IT, and Business Applications," Int. J. Multidiscip. Sci. Arts, vol. 2, no. 2, pp. 178–187, 2023. https://doi.org/10.47709/ijmdsa.vxix.xxxx
6. T. A. Ajiwiguna and M. R. Kirom, "Uninterrupted Electricity Supply using Off-Grid Solar PV Systems for Remote Areas," Int. J. Technol., vol. 15, no. 5, pp. 1561–1572, 2024. doi: 10.14716/ijtech.v15i5.6089
7. A. E. Lewi, K. A. Widodo, and B. R. P. D. Palevi, "Perancangan Sistem Hybrid PLTS dan PLTB Off Grid pada Skala Rumah Tinggal di Daerah Perbukitan," Magnetik, vol. 08, no. 2, pp. 280–290, 2024.
8. R. B. Prasetyo, F. U. Rahman, and A. B. Muljono, "Desain Sistem Pembangkit Listrik Optimal On-Grid Tenaga Surya , Bayu dan PLTMH Menggunakan Software Homer Di

Desa Sesela," JEBT J. Energi Baru Terbarukan, vol. 5, no. 3, pp. 47–59, 2024. doi: 10.14710/jebt.2024.24665

9. I. Ali, Suhardjono, and A. P. Hendrawan, "Pemanfaatan Sistem Pemanenan Air Hujan (Rainwater Harvesting System) di Perumahan Bone Biru Indah Permai Kota Kota Watampone dalam Rangka Penerapan Sistem Drainase Berkelanjutan," J. Tek. Pengairan2, vol. 8, no. 1, pp. 26–38, 2017. https://repository.ub.ac.id/id/eprint/171289/
10. J. Carter, A. Rahmani, M. Dibaj, and M. Akrami, "Rainwater Energy Harvesting Using Micro-Turbines in Downpipes," Energies, vol. 16, no. 4, pp. 1–20, 2023. doi: 10.3390/en16041660
11. P. E. Murillo-alvarado and M. A. C. Gil, "Rainwater Harvesting Systems That Reduce Water Consumption With Optimal Locations of Solar Concentration Power Plants," Front. Energy Res., vol. 10, no. 880727, pp. 1–10, 2022. doi: 10.3389/fenrg.2022.880727
12. I. Alazzam, K. Shatanawi, and R. Al-Weshah, "Rainwater and fog harvesting from solar panels," Glob. J. Environ. Sci. Manag., vol. 10, no. 3, pp. 955–968, 2024. doi: 10.22034/gjesm.2024.03.02
13. R. M. H. Gabriela and C. T. J. Vladimir, "Rainwater harvesting system as a strategy for adaptation on climate change : A review Rainwater harvesting system as a strategy for adaptation on climate change : A review," Earth En ddviron. Ser., vol. 1121, no. 012007, pp. 1–11, 2022. doi: 10.1088/1755-1315/1121/1/012007
14. S. B. Deode, S. R. Kolhe, P. G. Tilekar, and R. B. Wakte, "Review Paper on Three in One Generator," Int. J. Sci. Res. Dev., vol. 7, no. 09, pp. 323–325, 2019. https://ijsrd.com/Article.php?manuscript=IJSRDV7I90137
15. E. R. Gulo and A. F. Mustafa, "Rainwater as an alternative to saving urban clean water which has economic value : Interaction human and conservation," J. Sustanability, Soc. Eco-Welfare JSSEW, vol. 2, no. 2, pp. 94–110, 2025. https://doi.org/10.61511/jssew.v2i2.2025.1279