Policy and Projection of Solar PV Waste Management: Indonesia Case

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Abstract

Indonesia is a tropical country where the equator passes, and the sun tends to shine longer than other countries. Solar energy is one of the sources of energy that Indonesia is currently developing. Thus, solar energy has considerable potential to be developed in Indonesia. According to the Institute for Essential Service Reform (2021), the potential for solar power in Indonesia reaches 207,898GW using 4.34% to 24.43% of the total land area. The Photovoltaic (PV) Module and Inverter are the two primary parts of a PV system. PV Modules are anticipated to last 25 to 30 years, while Inverters are anticipated to last 10 to 15 years. PV Modules and Inverters are not designed with reuse in mind when entering the end of life of the product, therefore, some of the materials used to produce PV Modules and Inverters will be discarded because they cannot be reused. Indonesia will produce a significant amount of electronic waste due to the lifespan of a PV system. This study was conducted based on examining information from papers, journals, research reports. This research will discuss the policy, regulation, the projection of Solar PV waste in Indonesia in the future and classify the different kinds of hazardous waste in PV systems.

Keywords
Solar Energy, Hazardous Waste, Solar PV Projection, Renewable Energy and Waste Management.

1. Introduction

Greenhouse gas emissions in Indonesia are expected to continue to increase in 2021-2030. This is in line with the increasing use of fossil fuels such as coal, oil and natural gas. According to data released from the Ministry of Environment and Forestry on 2021, Indonesia produces greenhouse gas emissions of around 1.9 billion tons of carbon dioxide (CO2) (Laporan KLHK 2021). In 2021, Indonesia managed to reduce emissions by 69.5 million tons of CO2 equivalent (CO2e) in 2021 where previously in 2019, Indonesia produced greenhouse gas emissions of around 1.9 billion tons of carbon dioxide (CO2) (Laporan Kinerja Ditjen EBTKE 2021). This achievement consisted of several factors, namely the implementation of new and renewable energy, energy efficiency, low carbon fuels, clean generation technology and others. In this implementation, the new and renewable energy sector contributed to the largest emission reduction with a reduction of 30.34 million tonnes of CO2e. It is anticipated that the energy supply of renewable energy will continue to grow considerably in order to satisfy the energy demand, and reduce greenhouse gas emissions all at once (Madsuha et al. 2021). In Indonesia, solar energy has considerable potential to be developed. According to the Institute for Essential Service Reform (2021), the potential for solar power in Indonesia reaches 207,898GW using 4.34% to 24.43% of the total land area. However, the PV systems are expected to last around 25 to 30 years. After the system reach its lifespan, the system had to be dismantled since it would no longer be able to absorb energy as effectively because of the degradation over the years and will cause a lot of waste, especially the hazardous one (Fthenakis 2000).

1.1 Objectives

This research will discuss the policy, regulation, the projection of Solar PV waste in Indonesia in the future and classify the different kinds of hazardous waste in PV systems.

2. Literature Review

2.1 Renewable Energy

The utilization of renewable energy sources, such as those provided by the sun, wind, water, and other elements of the plants and the heat on earth. These fuels are converted into useful forms of energy using renewable energy technologies, most frequently electricity but also heat, chemicals, or mechanical power (Alrikabi 2014). Utilizing renewable resources has the primary benefit of year-round availability and may obtain energy for many decades with a one-time investment without harming the environment. Geothermal, hydroelectric, solar, and bioenergy are examples of renewable energy sources.

2.1.1 Solar Power Plant

Sunlight is the source of solar energy. Solar power plant works when sun shines onto the solar modules, the energy will be converted into direct current (DC) power. The inverter will then change the direct current (DC) power into an alternating current (AC) power. By employing solar energy, consumers may save their electricity prices and lessen the greenhouse gas emissions that fossil fuel power plants can cause, which will help to lessen the effects of climate change. Additionally, because users just need to make sure that the solar modules are maintained clean, maintenance expenses for solar power plants are also rather inexpensive.

2.2 Hazardous Waste

Hazardous waste refers to waste that is likely to cause health impacts on ecosystems and humans. These wastes pose a potential risk to human health or living organisms, as they are non-biodegradable or persistent and highly toxic or even lethal at very low concentrations. The threat to public health and the environment from a particular hazardous waste depends on the quantity and characteristics of the waste involved (Kanagami 2020). According to the Environmental Protection Agency (EPA), there are more than 450 registered wastes that are known to be hazardous grouped as F-List, K-List, P-List and U-List. (1) F-List, contains hazardous waste from non-specific sources, namely various industrial processes that may have and produce such waste. This list comprises solvents commonly used in degreasing, metal processing baths and sludges, waste water from electroplating operations, and chemicals containing dioxins or their precursors. (2) K-List, containing hazardous waste produced by certain industrial processes. Examples of industries that produce K-listed waste are wood preservation, pigment production, chemical production, petroleum refining, iron and steel production, production of explosives and pesticide production, (3) P and U-List, containing commercial chemical products that are disposed of, chemicals that do not meet specifications, container residue, and residue from material spills. An example of a hazardous waste listed under P or U is pesticides that are not used during their useful life and must be disposed of in large quantities (Kanagami 2020). Waste regulation has a beneficial impact on lowering the dangers posed by some toxic chemicals. If waste is contaminated, the metals lead (Pb), beryllium (Be), and mercury (Hg), which are harmful to people and potentially damaging the ecosystem, can cause neurological damage to the brain, disability, renal damage, and other negative effects (Wibowo et al. 2021).

2.3 Linear Regression

Linear regression is an approach to modeling the relationship between two variables by adjusting the linear equation of the observed data. The linear regression approach is useful for forecasting based on past relevant data (Bingham 2010). The simple linear regression equation is mathematically expressed in notation 1.1.

$$\hat{y} = a + bx \tag{1.1}$$

Where $\hat{y}$ is the variable response (dependent) or the variable to be predicted, x is the predictor variable (independent), a and b are the regression parameters. The value of a and b can be obtained from equations 1.2 and 1.3.

$$a = \frac{(\sum Y_i)\left(\sum Xi^2\right) - (\sum X_i)(\sum X_i Y_i)}{n\sum Xi^2 - (\sum Xi)^2} \tag{1.2}$$

$$b = \frac{n(\sum X_i Y_i) - (\sum Y_i)(\sum X_i)}{n\sum Xi^2 - (\sum Xi)^2} \tag{1.3}$$

Notation a shows the value of the intercept constant and notation b is the regression coefficient. The value of n is the amount of data, x is the value of the variable that can affect it, and y is the predicted value.

3. Methods
This study is descriptive research that aims to present the future waste management of PV system in Indonesia. This study will discuss the policy, regulation and projection of Solar PV waste in Indonesia. The waste projection will be using linear regression. The data was obtained from literature review and reports.

4. Data Collection
Primary data of PV system components that has been installed in Indonesia uses a case study from one of the solar power plant construction EPC company in Indonesia. While the secondary data were collected from peer literature review and reports.

5. Results and Discussion
5.1 Solar PV Waste Management Policies
In supporting the development and management of environmentally aware, the government in Indonesia encourage for every owner of solar power plant to aware the waste that will be generated after the solar power plant has reached their lifetime. At this time, Indonesia does not yet have the infrastructure and technology to handle the waste from PV systems. However, the government has prepared a number of key laws that may be used in the future to control PV system waste. Policies for the use of solar energy in Indonesia have been regulated through laws and their derivative regulations. The management of hazardous waste is included in the environmental management aspect follows the environmental aspect policy of Energy, Electricity, Protection and management of the environment (Law no. 22 of 2021), Specific Waste Management, Implementation of Environmental Protection and Management, Procedures (Law no. 27 of 2020) and Requirements for the Management of Hazardous and Toxic Wastes (Regulation of the Minister of Environment and Forestry no. 6 of 2021). According to Ministry of Energy and Mineral Resources of Indonesia (2022), on waste handling, recycling can be a solution in handling solar module waste. In general, solar module recycling can be divided into 5 stages: (1) Module waste collection, (2) Waste transport, (3) Disassembling the waste module, (4) Module waste separation and purification, and (5) Increasing the value of waste and reuse (Figure 1).

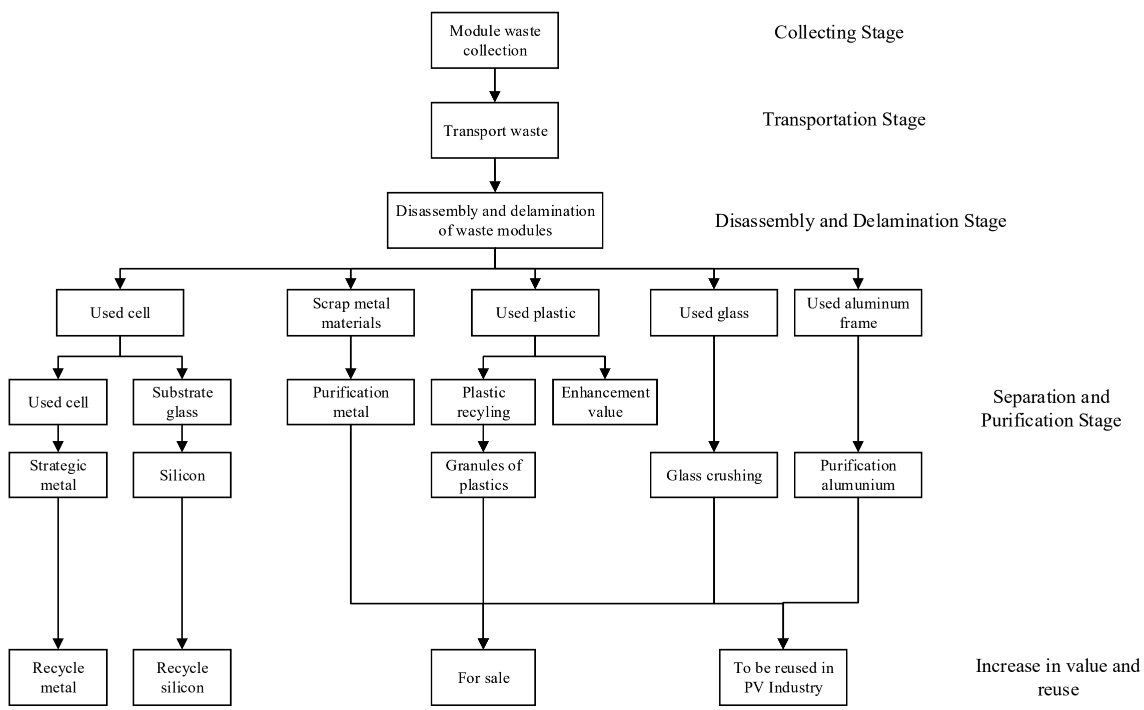

Figure 1. Stage of PV Modules Recyle (Ministry of Energy and Mineral Resources of Indonesia, 2022)

5.2 Waste Projection of Solar PV Systems
Calculation of estimated PV system waste to be generated is based on the number of main components solar power plant that has been installed from 2018 to 2023 obtained from Company A in Table 1. The forecasting model in this

research considers fixed loss. PV module lifetime is assumed to be 25 year and inverter 10 year (Table 2). Calculation of the estimated PV system waste generated is carried out using the linear regression method (Table 3). Based on the calculation results, it is estimated that the amount of waste generated by the PV module (Table 4) and inverter when it enters its lifetime is 72,277 tons and 190 tons in figure 2.

Table 1. Number of Components Installed

Year	PV Module	Inverter
2018	65334	136
2019	8430	23
2020	69167	173
2021	22982	91
2022	36892	234
2023	10584	46

Table 2. Linear Regression Notation for PV Module and Inverter

Parameter (PV Module)		Parameter (Inverter)	
a	35.565	a	117,17
b	6.919	b	27,59
y = 35.565 + (6.919)x		y = 117,17 + (27,59)x	

Table 3. Estimated PV Module Waste (2044-2052)

Year	PV Module Waste Forecasting	Total Waste (ton)
2044	73.764	2.139
2045	142.931	4.145
2046	165.913	4.811
2047	202.805	5.881
2048	213.389	6.188
2049	290.465	8.423
2050	374.460	10.859
2051	465.373	13.496
2052	563.204	16.333
Total		72.277

Table 4. Estimated Inverter Waste (2029-2037)

Year	Inverter Waste Forecasting	Total Waste (ton)
2029	159	14
2030	332	30
2031	423	38
2032	657	59
2033	703	63
2034	1.013	91
2035	1.351	122
2036	1.717	155
2037	2.110	190
Total		190

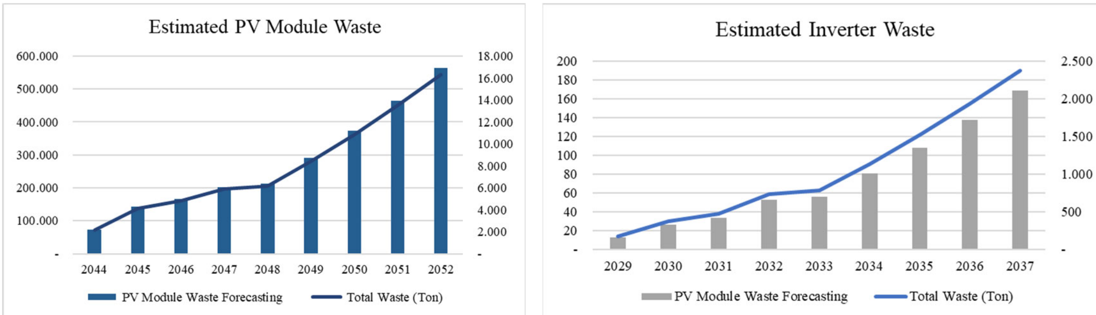

Figure 2. PV Module and Inverter Estimated Waste

5.3 Classification of PV System Hazardous Waste

The following are some potential sources of hazardous waste in solar modules (Table 5): (1) Tin and lead are among the components included in solar modules made of crystalline silicon. (2) Zinc and copper may be present in thin-film solar panels. Indium, gallium, selenium, cadmium, and tellurium may also be included in thin film solar modules. Lead acid and lithium batteries are the two types of batteries used in solar systems. Even though lead acid batteries are an outdated technology, they are nevertheless commonly utilized because of their many benefits over alternative energy storage technologies. Lead (Pb), a kind of heavy metal that is hazardous to the environment and human health, makes up as much as 65% of the components of lead acid batteries. Human brain and kidney damage results with a certain level of exposure, and children's brain development is also affected. When a battery is destroyed, the lead and liquid acid inside it settle and need to be handled carefully to prevent environmental pollution. Lithium batteries tend to be safer and have a higher energy density than lead acid batteries because it doesn't have a memory effect and doesn't need planned cycles to increase battery life. Compared to other types of lithium batteries, cobalt-type batteries (lithium-nickel-manganese-cobalt-oxide (LNMC), lithium-cobalt-oxide (LCO), and lithium-cobalt-aluminum-oxide (LNCA)) have a higher energy density but are also more expensive. Lithium-manganese-oxide (LMO) and lithium-iron-phosphate (LFP) are the most often utilized lithium in solar plants. Because lithium batteries, unlike lead acid batteries, do not contain important metals, this sort of battery waste is often overlooked and there aren't many firms that can handle its treatment. Additionally, because this kind of battery does not include heavy metals, it is less detrimental to the environment. However, there is a significant risk associated with using this kind of battery which has a high energy density that will might result in fatal damage if connected in large numbers (runaway heat). (Ministry of Energy and Mineral Resources of Indonesia, 2022)

Table 5. Classification of PV System Hazardous Waste
(Ministry of Energy and Mineral Resources of Indonesia, 2022)

No	Waste Type	Sources of hazardous contamination	Hazardous Waste Code	Description
1	Solar Module	• Lead • Copper • Zinc • Tin	Not registered	The Ministry of Environment and Forestry has not yet registered or designated the hazardous waste code for solar modules.
2	Battery: • Lead Acid • Lithium Ion • Zinc Air	• Lead • Explosive and flammable materials	A102d	
			B326-1	Use of old batteries, out-of-date, and non-technical standards batteries, as well as dry cell batteries

		• Corrosive materials (sulfuric acid)	B327-1	Wet cell batteries: Old or ineffective batteries as well as batteries that have reached their expiration date.
3	Electronic components (Inverter, Solar Charger Controller, and Battery Management System)	• Mercury, • Heavy metals (lead, copper, zinc and tin)	A328-1, A328-2, B328-4, B328-5	Mercury contactor/switch, Fluorescent lamp (Hg), Printed circuit board (PCB), Waste metal wires & their insulation.

As part of the construction of the solar system network, leftover cables and wrapping are appropriately preserved so that they may be reused if necessary. Copper is particularly common in the cables. In order to properly manage hazardous waste, copper must be isolated from other heavy metals. Copper may contaminate water and soil and endanger the life of living creatures if segregation and management are not done as prescribed. Printed circuit boards, which can include heavy metals like lead, tin, and copper, the scrap from other solar system components found in the inverter, solar charger controller, and battery management system.

6. Conclusion

As one of the nations strategically located on the equator, Indonesia has the potential to develop solar energy because the sun shines for a longer period of time there. At the moment, Indonesia is actively working toward a goal of 23% new and renewable energy by 2025 and reaching emission-free by 2050. Indonesia is progressing in the implementation of innovative and sustainable energy, particularly in the energy from solar power plants. Despite the fact that solar energy has no emissions, the parts of a power plant system eventually create hazardous waste, and such as mercury, lead, tin, and zinc, which can have a harmful impact on the ecosystem and human health. The estimated waste that will be generated from the PV system from one of the solar power plant installers in Indonesia is 72,277 tons for the PV module and 190 tons for the inverter.

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Biography

Nadya Tamara Genta Maharani is a master's degree student in the Industrial Engineering department at Universitas Indonesia, concentrating in Industrial Management. She completed her bachelor's degree at Universitas Trisakti, Indonesia, majoring in Industrial Engineering. She has 2 years' experience as Partner Relation Officer in the Building Management Industry which is her first experience. She continued her career in Renewable Energy EPC company in Indonesia until present as Project Engineer.

Rahmat Nurcahyo is currently active as a professor in Industrial Engineering Department, Universitas Indonesia. He completed his higher education at the University of Indonesia's Mechanical Engineering program in 1993. He continued his education at the University of New South Wales, where in 1995 he obtained his master's degree (M.Eng.Sc.). In 2012, he received his doctorate from the Universitas Indonesia's Faculty of Economics. He is an International Register of Certificated Auditors and a member of Ikatan Sarjana Teknik Industri dan Manajemen Industri Indonesia (ISTMI).

Djoko Sihono Gabriel is currently active as a professor in Industrial Engineering Department, Universitas Indonesia. He earned his Bachelor of Engineering in Industrial Engineering at Bandung Institute of Technology, an engineer (Ir.) profession in Industrial Engineering at Bandung Institute of Technology, a Master of Engineering in Industrial Management at Universitas Indonesia, and a Doctoral degree in Mechanical Engineering at Universitas Indonesia. He is a professor in Industrial Engineering department at Faculty of Engineering, Universitas Indonesia with a major in industrial management, especially in material engineering management.