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Article

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Solar Cell Manufacturing Cost Analysis and its Impact to Solar Power Electricity Price in Indonesia

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ABSTRACT

World energy consumption continues to increase, with a growth of 1.3% annually during 2011-2021. To deal with that situation, in 2021, Indonesia Electricity Stated-Own Company (PLN) issued a report about the electricity supply business plan (RUPTL) 2021-2030. The power plant projected to grow is solar photovoltaic (PV), reaching 4.6 GW within 10 years. However, in reality, the achievement of developing solar power plants is still 0.02 GW. Several factors that caused low realization are the solar power plant component industry needs to be better developed, and the regulated electricity price based on Presidential Decree 112/2022 needs to be increased. This study aims to determine the cost structure of solar module manufacturing and the impact on electricity prices. The calculation method used is financial modeling with economic parameters such as Internal Rate of Return (IRR), payback period, and Net Present Value (NPV) as parameters for project feasibility. The results of this study show that the economic price of solar power plants in Indonesia is USD 0.149/kWh. Meanwhile, based on a sensitivity analysis using electricity prices based on Presidential Decree, reducing solar module costs up to 50% still does not make the project feasible.

Keywords: Solar Cell, Solar Module, Solar Power Plant, Economics, Policy
JEL Classification: G0, G3

1. BACKGROUND

World energy consumption continues to increase, with a growth rate of 1.3% every year from 2011 to 2021. The current supply of world energy is at 80% supplied by fossil energy (BP, 2022). The massive consumption of fossil fuel resulted in an increasing global warming threat, in the year of 2015 Paris Agreement was signed in hopes of limiting the world increasing temperature which is at +2°C until 2050 (Delanoë et al., 2023). Energy transition option from fossil energy to renewable energy is an important agenda to reduce the global warming threat (Qadir et al., 2021). European Countries are actively trying to minimize greenhouse gasses, using various incentives to reach 30% renewable energy consumption by 2030 (Muhammad et al., 2023).

An attempt to increase the renewable energy portion is also made by developing countries such as Indonesia. In the year of 2021, the State Electricity Company (PLN) issued a Plan of Electricity Supply Availability (RUPTL) 2021-2030. This document is regarded as Green Energy because of renewable energy portion reached 51.6% in the year 2030 (PLN, 2022). There are several projections of renewable energy development, but for solar energy, within the next 10 years, are projected to build a 4.6 GW solar photovoltaic (PV) power plant. Indonesia is one the countries with strategic solar energy potential, which is located on an equator line region with a level of 4.5 kWh/m²/day −5.1 kWh/m²/day solar radiations (Veldhuis and Reinders, 2013). Based on (National Energy Council, 2022), Indonesia's solar energy potential is 3,294 GWp, and its power plant capacity is just

0.2 GWp or 0.01% from total its potential. Several factors cause the low utilization of solar PV in Indonesia, such as the Indonesia Government still subsidizing fossil energy usage and the poorly built solar PV manufacturing industry (Ministry of Energy and Mineral Resources, 2019). Based on Industrial Ministry, most solar PV power plant components are imported, so the government targeted that in 2025 the local content value can reach up to 90% (Consulate General of The Republic of Indonesia, 2021). The high local content target impacts the solar PV power plant investment costs. Meanwhile, in several countries, the components price such as PV modules, tracking systems, inverters, and system balance sink significantly (Imteyaz et al., 2021).

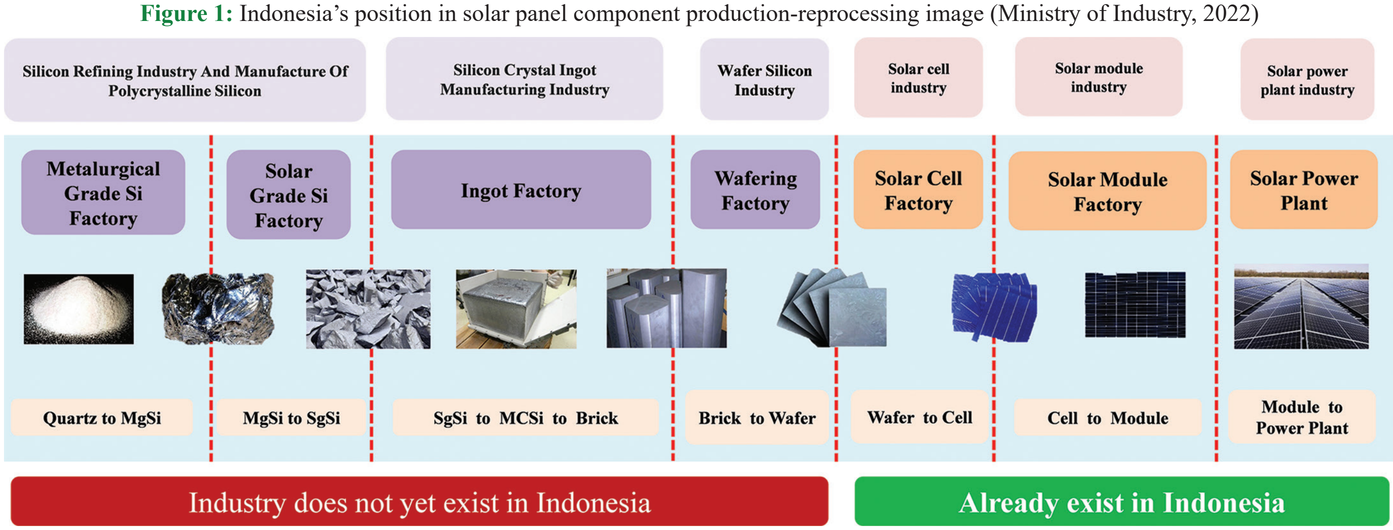
The primary factors influencing the commercialization of solar PV technology are efficiency, stability, and price, as discussed by (Pourjafari et al., 2022). Solar cell components play a crucial role in the solar module business. According to (Shiradkar et al., 2022), the cost of solar cells can account for a significant proportion, ranging from 50% to 60%, of the whole production cost of solar modules. Several research have been conducted to analyze the manufacturing cost of solar PV technology. For instance, (Kumar et al., 2017a) conducted a study on the economic evaluation of solar cell manufacture. In addition, (Shiradkar et al., 2022) provide a comprehensive analysis of the structural components comprising the end-to-end manufacturing cost within the solar PV business in India. According to (Gul et al., 2022; Liu et al., 2022; Ud-Din Khan et al., 2022), Conducting an investigation on the techno-economic aspects of solar PV systems incorporating storage systems. Several noteworthy research (Mah et al., 2018; Shukla et al., 2018; Tarai and Kale, 2018) have examined policies aimed at promoting the adoption of solar power in India and China. The aforementioned literature sources can offer valuable perspectives that can inform our research. The economic feasibility of the solar business is assessed by considering the entire value chain, from the upstream sector to the downstream sector. In this study, the evaluation of the solar PV power electricity price is a key factor in determining the economic viability. In order to promote the solar PV business, it is imperative to assess the transparency of production costs within this sector. This evaluation is necessary as manufacturing costs have the potential to influence power prices. This study intends to investigate the structural costs associated with solar PV modules and their impact on the overall generation costs of solar PV systems.

1.1. Status of Solar PV Manufacturer Industry in Indonesia

Currently, there has been a notable surge in the demand for solar energy, leading to the establishment of a more stable and robust solar energy market in Indonesia. There have been reports indicating that numerous organizations have been successfully marketing and selling a significant quantity of solar energy packages. The utilization of solar energy necessitates the inclusion of a crucial element, such as a solar module. According to (Andor Mulana Sijabat and Mostavan, 2021), the recorded solar module production capacity of Indonesia, as documented by the Indonesian Solar Module Manufacturers Association (APAMSI), amounts to 546 MWp. The Figure 1 illustrates the solar panel sector as a complex network of interconnected companies, encompassing many stages ranging from the extraction of raw materials through the processing of solar energy. In Indonesia, the solar panel sector has the capability to undertake manufacturing processes up to the stage of solar cell production, specifically limited to the cell printing process. The primary focus of numerous enterprises lies on the production of solar modules, with a significant reliance on imported raw materials (IESR, 2020).

Based on data provided by the Indonesian Statistics, specifically under the H.S. Code 85414300, the import value attributed to solar cells amounts to arround 75.4 million USD. Notably, a significant majority, accounting for 99% of the total import volume, is sourced from China (Indonesian Statistic, 2023). The present challenge lies in the requirement for an increased demand for solar panels. As an illustration, P.T. Adyawinsa possesses a cumulative production capacity of 25 MWp. However, the solar module productions in the year 2022 amount to merely 2.2 MWp, constituting a mere 9% of the overall solar panel production capacity. The lack of supportive policies implemented by PLN for solar panel development is also a contributing factor to this issue. According to (Bagaskara et al., 2023), a policy has been implemented to restrict the utilization of solar power plants, particularly on rooftops, to a

Figure 1: Indonesia's position in solar panel component production-reprocessing image (Ministry of Industry, 2022)



mere 10-15% of the total installed energy capacity. The advocacy for the issuance of Presidential Regulation 112/2022 is aimed at expediting the progress of renewable energy production in order to meet the growing demand for power. It is anticipated that the implementation of these regulations will lead to a rise in the auctioning of renewable energy projects, particularly those pertaining to solar power plants. According to a report by (Katadata, 2022), the Indonesia Solar Energy Association (AESI) has expressed the view that the current pricing remains insufficiently high.

Table 1 shows a list of solar power plants built by the Indonesia Power Producer (IPP) since 2016. Indonesia set local content policies based on Industrial Ministry Policies No. 5/2017, the minimum number of solar power plant local content ranging from 40.68% to 45.9%. Out of 11 solar power plant projects, only 4 solar power plant projects have already local content value above 40%. The highest local content projects tend to have higher electricity costs, which are above cUSD 20/kWh or still below the regulated price set by MEMR No. 17/2013, which stated that the highest solar power plant electricity price is cUSD 25/kWh. This situation will be different with electricity price from lower local content project, which has electricity price arround cUSD 10/kWh. By implementing this policies has triggered many companies requested a relaxation for local content policy in their solar power plants (Ministry of Energy and Mineral Resources, 2023). The determination of energy prices is now governed by Presidential Decree No. 112/2022, which is incongruent with the prevailing costs of solar power plant generation. The inadequate development of the solar power plant industry in Indonesia is the primary reason for its current limitations. This study aims to provide a comprehensive evaluation and empirical evidence regarding the economic implications of solar power plants, including the associated costs, as well as the consumer's willingness to pay for solar module components.

2. METHODOLOGY

The research framework of this study is depicted in Figure 2. The analysis of current situations solar PV industry is aims to dig out the research gaps. Numerous discussions have been conducted among stakeholders and vendors. They were from the government and solar PV manufacturing companies. Interview to government were conducted along with the Ministry of Energy and Mineral Resources and the Ministry of Industry. This interview is necessary to know the current status regarding policies and challanges in the Indonesia solar PV industry. The interview in solar PV manufacturing companies is aims to find out the business processes of solar module production. The information obtained from the company was the solar PV value chain. The acquisition of investment expenses is derived from multiple vendors that offer technological solutions for solar module manufacturing facilities.

The data that is obtained serve as an input for the calculation of the production cost of a solar module. Capital expenditure (capex) and operational expenditure (opex) become the calculation basis to determine solar module economic prices. The result obtained from the examination of solar module manufacturing costs can be characterized as an economic price. In addition, the monetary value of internal rate of return (IRR), net present value (NPV), and payback duration is also obtained. The cost of solar modules serves as the fundamental factor for determining the financial input required for investing in a solar power plant. The techno-economic study of solar power plants yields several outcomes, including energy prices, internal rate of return (IRR), net present value (NPV), and payback period. A sensitivity analysis was conducted, incorporating variables such as the pricing of power, solar modules, and solar cells.

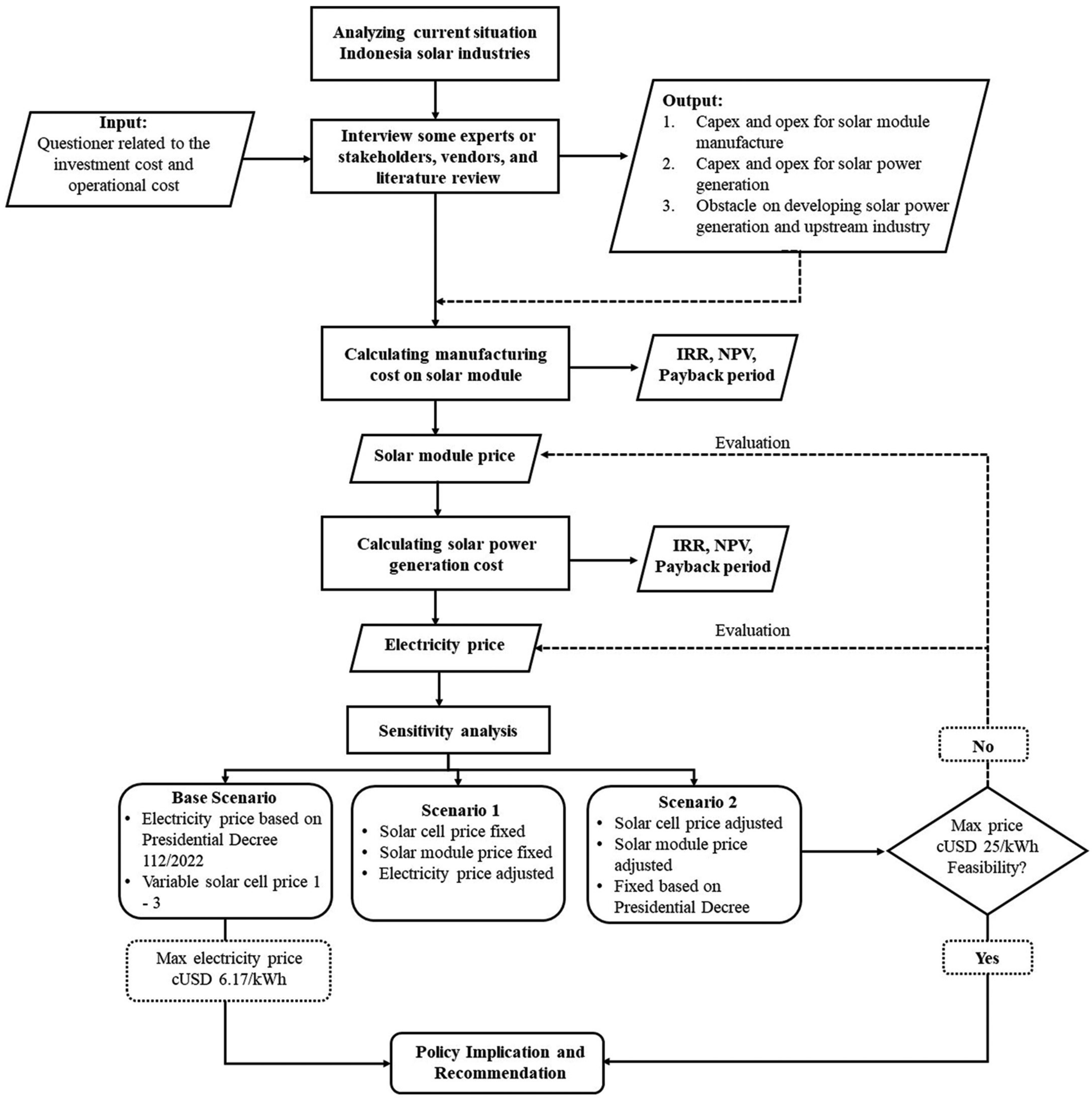
2.1. Techno-economic Analysis Approach

Techno-economic calculations are divided into two parts. The first is an analysis of upstream industries, and the second is an analysis of downstream industries. The calculation is limited to solar modules only, as shown in Figure 3, a production process starting from solar cell manufacturing until it can be used as a solar PV power plant. The solar module factory employs equipment technologies for several processes, including the connection of solar cells, framing, trimming, and lamination. Choosing an automated technology will affect investment costs, production flow chart of this solar module will become the basis for determining module production costs. The primary input to produce a solar module is a solar cell. The calculation obtained from the upstream industry becomes an input for the downstream industry analysis, downstream industry are solar power plants, and their main components are solar modules, inverters, electrical components, racks, etc. Financial modelling is carried out for the upstream Industry (solar module factory) and downstream industry (solar PV power plant). Various parameters are used as a basis to construct financial modelling and are explained in the following sub-chapter.

Table 1: List of solar power plants in Indonesia operated by IPP (Ministry of Energy and Mineral Resources, 2023)

No.	Solar power plant	Location (province)	Capacity (MWp)	COD	Local content (%)	Electricity price (cUSD/kWh)
1	Oelpuah Kupang	East Nusa Tenggara	5	2016	45.33%	25
2	Gorontalo	Gorontalo	2	2016	>40%	22.95
3	Jakabaring	South Sumatera	2	2018	-	IDR 1.210, (JCM Project)
4	Pringgabaya	West Nusa Tenggara	5	2019	15.70%	10.4
5	Sengkol	West Nusa Tenggara	5	2019	15.70%	10.32
6	Selong	West Nusa Tenggara	5	2019	15.70%	10.61
7	Maumere	East Nusa Tenggara	2	2019	>40%	24.98
8	Hambapraing	East Nusa Tenggara	1	2019	>40%	24.98
9	Likupang	North Sulawesi	15	2019	15.06%	10.597
10	Sambelia	West Nusa Tenggara	5	2019	15.12%	10
11	Isimu	North Sulawesi	10	2020	15.95%	10.469

Figure 2: Research framework



The parameter used to obtain electricity economic price is the internal rate of return, payback period, and net present value (NPV). IRR is the annual rate of return or discount rate that made NPV equal to zero, the equation used to determine IRR is equation (1) (Khan et al., 2023; Li et al., 2023; Vazquez-Sanchez et al., 2023).

$$0 = NPV = \sum_{i=0}^{n} \frac{R_{i,total} - C_{i,total}}{(1+IRR)^{i}} \quad (1)$$

Wherein $R_{i,\ the\ total}$, is revenue at year *I, and* $C_{i,\ the\ total,}$ is total costs at year *i*. Payback Period (PP) is determined by using Equation 2.

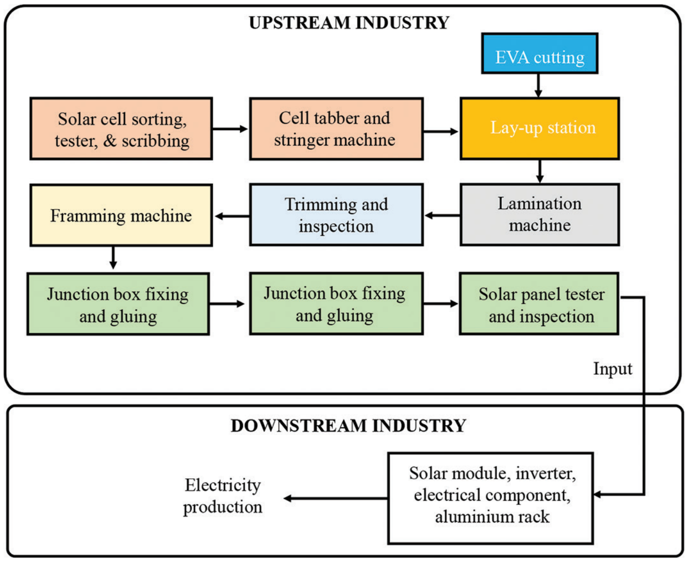
$$PP = \frac{Total\ investment}{net\ profit} \quad (2)$$

NPV is calculated to measure the project feasibility, when the NPV is positive, the project has good economic value. Conversely, if the NPV is negative, the project is not economical enough to be developed (Vazquez-Sanchez et al., 2023). C_i is net cash flow at a year *i*. This value is the difference between in-cash flow dan out-cash flow, *r* is the discount rate, *N* is the total lifetime of factory operations, and *n* is the current year.

$$NPV = -Total\ investment + \sum_{n=1}^{N} \frac{C_i}{(1+r)^{n}} \quad (3)$$

To determine economic electricity costs from electricity generator, a levelized cost of electricity (LCOE) equation used through solar power plant as represented in equation 4, wherein total costs are

Figure 3: Solar Module production scheme, from solar cell to solar module-reprocessing image (Ali, 2019)



divided by the total of net electricity production (W_{net}) (Cormos et al., 2023).

$$LCOE = \frac{Annualized\ total\ investment + Total\ fixed\ \&\ variable\ cost}{W_{net}} \quad (4)$$

2.1.1. Cost assessment on solar module manufacturing

Several crucial elements in this calculation, such as the factory lifespan, are set at 15 years. The discount rate applied to the solar module factory is 12%. The solar cell employed in this study is monocrystalline type, with a power output of 4.5 watts per piece. The aforementioned solar cell is a product originating from China, characterized by dimensions measuring 0.156 m × 0.156 m, and exhibiting an efficiency of 20%. Table 2 serves as a comprehensive parameter utilized in the realm of financial modelling. Solar cell price is set as variable, so the value is different among scenario.

2.1.1.1. Solar module factory investment cost

The total area needed to build the factory building is 20,000 m^2. The factory is located in the Cikarang region, West Java Province. Land value costs are based on the official website of the land value zone mapping by Ministry of Agrarian Affairs and Spatial Planning (Ministry of Agrarian Affairs and Spatial Planning, 2023). The investment cost gathered from some stakeholders consists of the parking area, warehouses, office buildings, and room to process solar module production. Based on the land value zone mapping, the costs in the Cikarang region vary but mostly cost IDR 1,000,000/m^2. Thus total investment cost for land is IDR 20,000,000,000 (USD 1,351,350). Table 3 shows solar module factory investment cost with a production capacity of 50 MWp each year. These investment costs are divided into several parts, namely staging, civil work, site preparation, electrical work, engineering procurement and construction (EPC), and other costs. The total investment costs are USD 13,894,794, and for technology cost is USD 3,258,750 as for details are in Table 3. The amount of the costs is acquired from the interview results with EPC company.

Table 2: Parameter used in the calculation of solar module factories

No.	Parameters	Value	Source
1	Economic parameter		
	USD to IDR	IDR 14.800	
	Corporate tax	22%	Act No. 7/2021
	Factori lifespan	15 years	(Kirk, 2009)
	Escalation	3%/year	Based on 5 years average, Indonesia's inflation
	Debt to equity	20:80	
	Discount rate	12%	(Kumar et al., 2017b)
	Loan payment period	10 years	
	Nominal interest rate	10%	Common interest rate use in Indonesia
	Depreciation rate	15%	(Kirk, 2009)
	Capacity factor	80%	
	Factory solar module capacity production	50 MWp/ year	
	Solar module price	Variable	
2	Solar module specification		
	Nominal efficiency	20%	(Ramasamy et al., 2022)
	Dimension		
	Length	2 m	
	Width	1 m	
	Area	2 m^2	
	Total area needed for 1 kW	5.41 m^2	
3	Solar cell specification (monocrystalline)		
	Dimension		
	Length	0.156 m	
	Width	0.156 m	
	Power	4.5 w per piece	
	Total solar cell for 1 module	82 cells	
	Power generation in 1 module	370 Wp	
	Solar cell price	Variable	

The working capital costs are needed to guarantee factory to keep operating. The working capital cost is USD 1,986,055, which consists of variable costs and fixed for a month of operation. So the required investment to build a solar module factory is USD 15,880,849 (IDR 235,036,567,745). The construction period for this solar cell factory is 2 years, wherein the amount of capex issued in the 1st year is 80% and the remaining 20% in the following year.

2.1.1.2. Solar factory fixed and variable cost

The variable costs of solar module production are represented in Table 4. Some lists of these costs refer to the report of the U.S. National Renewable Energy Laboratory (NREL) with the amount of the cost obtained from interviews with vendors providing solar module components. Variable costs are calculated annually, which will be the value of the cash flow. Among the seven components of this variable cost, the cost of the solar cell is the one that becomes the input variable. The price of solar cells will be divided into several scenarios to achieve an economical price. Based on the size

Table 3: Investment costs estimation

No	Components	Amount	Unit	Total Cost (USD)
1	Staging			
	Temporary building	1	Lot	20,270
	Pre-construction survey (soil test, geotechnical test)	1	Lot	33,784
	Subtotal			54,054
2	Civil work	Area (m^2)	Cost per m^2 (USD)	Total cost (USD)
	Parking area	3,975	67.5	268,581
	Office	2,000	405.41	810,811
	Processing plant	3,000	472.9	1,418,919
	Warehouse	12,000	84.4	1,013,514
	Security office	25	405.4	10,135
	Fence	1,500	47.3	70,946
	Drainage	300	67.5	20,270
	Subtotal			3,613,176
3	Site preparation	Area (m^2)	Cost per m^2 (USD)	Total cost (USD)
	Land (buy)	20,000	67.5	1,351,351
	Clearing	20,000	6.7	135,135
	Grading	20,000	47.3	945,946
	Compaction	20,000	6.7	135,135
	Subtotal			2,567,568
4	Electrical work	Amount	Unit	Total cost (USD)
	Penangkal petir	1	Lot	27,027
	CCTV	1	Lot	67,568
	Electricity network	1	Lot	1,722,973
	Subtotal			1,817,568
5	EPC	Amount	Unit	Total cost (USD)
	Crane (2 unit @20 ton)	1	Lot	30,000
	Forklift (5 units)	1	Lot	45,000
	Soldering machine	2	Set	500,000
	Laminator machine	2	Set	1,000,000
	Framming machine	4	Set	1,200,000
	Sun simulator	4	Unit	100,000
	Engineering design	1	Lot	143,750
	Lasser cutting	1	Unit	100,000
	Solar cell testing	5	Unit	60,000
	Solar module testing	4	Unit	80,000
	Subtotal			3,258,750
6	Other	Amount	Unit	Total cost (USD)
	Working capital	1	Lot	2,516,112
	Permit	1	Lot	67,568
	Subtotal			2,583,679
	Total investment cost			13,894,794

of the solar cells in Table 4, 222 pieces of solar cells are needed for every kW of solar panels. In 1 kW of solar module requires an area of about 5.4 m^2. The area size affects the amount necessary for the front glass, back sheet, aluminium (Al) frame, junction box, and polyolefin film.

The total manpower needs for solar panel factory are shown in Table 5, wherein the total costs per year for labor is USD 619,865.

Fixed costs are calculated using the assumptions in Table 6. There are four components of fixed costs starting from R&D costs, marketing costs, insurance cost, and operational and maintenance costs.

2.1.2. Cost assessment on solar power generation

Various criteria are employed in the economic calculation pertaining to solar power plants (Table 7), including the lifespan of the power plant, which is typically set at 25 years (Sodhi et al., 2022). The aggregate land area necessary for a 50 MWp solar power facilities amounts to 300,000m^2. The exclusion of land value expenses in this calculation is attributed to the utilisation of a land incentive programme administered by the government. Consequently, the electricity price employed in our analysis are used based on Presidential Decree No. 112/2022. The cost breakdown assumptions was conducted by utilising data derived from solar panel manufacturing facilities. The present analysis involved the integration of calculations from the initial stages of solar module production at upstream manufacturers, culminating in the establishment of a fully operational solar power plant. The electricity price is considered as a variable in this calculation, initially relying on prices determined by regulatory measures to ascertain the economic price. According to (Boretti et al., 2020), the typical capacity factor of solar power plants is below 30%. The calculation involved the utilisation of a solar power plant with a capacity factor of 16%, taking into account Indonesia's peak sun duration of 4 h (Febrian et al., 2023; IESR, 2021). The component that has been taxed is eligible for a tax incentive in accordance with Ministry of Finance Regulation No. 35/2018, which exempts it from taxation for a period of 5 years.

Table 4: List of variable costs for producing solar panel

No	Variable cost	Cost	Unit	Sources
1	Cell cost			
	Solar cell cost per piece	15,000	IDR/piece	Based on the interview, and become a variable of calculation
	Total cells in 1 kW	222	Pieces	
	Cell cost in 1 kw	225.2	USD	
	Cell cost in year	9,009,009	USD/year	
		133,333,000,000	IDR/year	
2	Front glass			
	Glass price	7.8	USD/m^2	Based on the survey and (Aleina, 2023)
	Glass area per kW module	5.4	m^2	
	Glass cost per kW module	42.2	USD	
	Annual glass cost	1,687,296	USD/year	
		24,971,980,800	IDR/year	
3	Backsheet			
	Backsheet price per m^2	5	USD/m^2	(Bellini, 2020)
		74,000	IDR/m^2	
	Backsheet cost per kW module	400,192	Rp	
	Annual back sheet cost	16,007,680,000	IDR/year	
		1,081,600	USD/year	
4	Al frame			
	Edge sealant	15	USD/kW	Based on the survey and (Smith et al., 2021)
		222,000	IDR/kW	
	Edge sealer costs a year	8,880,000,000	IDR/MW	
	Frame	250,000	IDR/2.5 m	
		100,000	IDR/m	
	1 kW needs 10 meters of frame	1,000,000	IDR/kW	
	Frame cost a year	40,000,000,000	IDR/year	
	Sub total cost	48,880,000,000	IDR/year	
		3,302,702.70	USD/year	
5	Junction box			Based on the survey and (Smith et al., 2021)
	Junction box 1 kW	1,788,888	Rp/kW	
		121	IDR/kW	
	Annual junction box cost	71,555,520,000	IDR/year	
		4,834,832.43	USD/year	
6	Polyolefin Film			Based on the survey and (Smith et al., 2021)
	Polyolefin Film	4	USD/m^2	
		59,200	IDR/m^2	
	Polyolefin Film per kW	320,154	IDR/kW	
	Annual polyolefin film cost	12,806,144,000	IDR/year	
		865,280	USD/year	
7.	Electricity cost	15	kWh/72-cell module	(Smith et al., 2021)
		0.21	kWh/cell module	
	Electricity price	IDR 1,699 (USD 0.11)	Per kWh	(PLN, 2023)
	Annual electricity consumption	1,851,852	KWh/year	
	Total electricity cost	3,146,296,296	IDR/year	
		212,588	USD/year	

Table 5: Manpower to operate solar module factory (USD)

Manpower	Shift	Total manpower	Salary	Total	Annual salary cost
Head of the factory	1	1	1,689	1,689	20,270
Production manager	1	1	811	811	9,730
Marketing manager	1	1	811	811	9,730
HR manager	1	1	811	811	9,730
Security	3	3	304	2,736	32,838
Cleaning service	1	10	236	2,365	28,378
Production staff	3	40	338	40,541	486,486
Marketing staff	1	2	473	946	11,351
HR staff	1	2	473	946	11,351
Total				51,655	619.865

2.1.2.1. Solar power investment cost

Table 8 presents the major investment cost associated with the establishment of a solar power plant. The investment cost encompasses several key components, namely the expenses associated with solar modules, inverters, installation, aluminium racks, and other electrical components. Table 8 presents the comprehensive investment cost of a solar power plant with a capacity of 50 MWp, amounting to USD 54,527,027. The variability of the cost associated with investing in solar modules arises from the integration of the price inside the economic calculation conducted at the solar module plant. The duration required for the completion of the solar power plant project is 1 year.

2.1.2.2. Solar power plant fixed and variable cost

The economic evaluation of solar power plants covers the assessment of operations and maintenance (O&M) expenses, which have been estimated in the range of to USD 6.34 per megawatt-hour (MWh) according to the (EIA, 2022). The annual operational and maintenance (O&M) expenses for the solar power plant amount to USD 2,510,640.

2.2. Sensitivity Analysis

This study employs multiple scenarios, as illustrated in Table 9. The base scenario corresponds to an ongoing situation in Indonesia. The cost of a single solar cell is USD 1.01 per piece, while the price of a solar module is USD 655 per kw. The electricity bill issued by PLN is in accordance with Presidential Decree No. 112/2022. In the first scenario, the pricing of solar cells and solar module components remains fixed, reflecting the prevailing market conditions. However, the electricity price is adjusted to align with the economic price of up to USD 0.25 per kilowatt-hour. Scenario 2 aims to ascertain the appropriate pricing of electricity to be supplied to PLN, utilising the Levelized Cost of Electricity (LCOE) derived from solar power plants.

In Scenario 2, the prices of solar cells range from USD 0.88 per piece to USD 1.35 per piece. The determination of the minimum price for a solar cell at USD 0.88 per piece is derived from the research conducted by (Kumar et al., 2017a), the economic threshold for solar cells stands at a minimum of USD 20/Wp (equivalent to USD 0,88 per piece). Additionally, the manufacturing process incurs a cost of USD 0.09 each cell. This implies that in the event that Indonesia establishes its own solar cell manufacturing facility, it would be able to procure solar cells at the most competitive price of USD 0.88 per unit. When comparing solar cell prices, it is seen that the greatest price corresponds to the import price, reaching a maximum value of USD 1.35 per unit of solar cell. In order to assess the impact on electricity costs, two scenarios involving solar module pricing are employed as input. Specifically, the price of the solar module is set at USD 337/kW, which represents the prevailing cost in the upstream solar module component business. According to the study conducted by (Ramasamy et al., 2022), the cost of solar modules in developed sectors is approximately USD 0.35 per watt or USD 350 per kilowatt. The solar module market exhibits a peak price of USD 655 per kilowatt (kW), although the cost of power is determined in accordance with the regulations outlined in Presidential Decree No. 112/2022.

Table 6: Fixed cost assumption

No	Cost component	Value	Sources
1	R&D cost	3% from revenue	(Smith et al., 2021)
2	Marketing cost	5% of revenue	Commonly used in factory
3	Insurance	1% from investment	(Towler and Sinnott, 2022)
4	O&M	4% of the total investment cost	(Towler and Sinnott, 2022)

3. RESULTS AND DISCUSSION

3.1. Solar Module Manufacturing Cost Breakdown

Based on the economic analysis of solar module manufacturing, the most significant cost component is attributed to solar cells, accounting for 39.3% of the overall cost incurred in the production of solar modules. The computation employs a solar cell price of USD 0.88 per unit. The findings of this study suggest that solar cells play a significant effect in influencing the pricing. This finding is consistent with the assertion made by (Falah, 2023) that the greatest proportion of the cost of goods sold (COGS) for solar modules is solar cell, accounting for 43% of the overall cost. The elevated expense associated with solar cells cost due to the absence of an integrated solar cell component industry. The procurement of solar cells necessitates their importation from foreign sources in order to meet the demand. The production cost of a 1 kW module amounts to USD 610 (equivalent to IDR 9,040,307). By employing the price of USD 675 per kilowatt (kW) for solar modules, a profit margin of 11% is achieved (Figure 4).

3.2. Base Case Scenario Analysis

Table 10 displays the outcomes of the calculation performed in the base scenario. The findings indicate that solar module companies can achieve economic viability by examining the prevailing circumstances in Indonesia and considering the costs of imported solar cells. The IRR gain 14%, payback period 8.6 years, and NPV USD 1,525,677. The findings suggest that the solar component manufacturing industry, utilising a solar module priced at USD 655/kW, has favourable economic returns. The aforementioned values demonstrate an inverse relationship with the economic performance of the solar power plant. Specifically,

Table 7: Component parameters used in economic calculating of solar power plants

No.	Parameters	Value	Source
	USD to IDR	IDR 14.800	
	Corporate tax	Tax holiday 5 years	Ministry of Finance Regulation No. 35/2018
	Plant life	25 years	(Shafie et al., 2022; Sodhi et al., 2022)
	Escalation	3%/year	Based on 5 years average, Indonesia's inflation
	Electricity price	Variable	
	Capacity factor	16% (average Indonesia peak sun hour is 4 h)	(IESR, 2021)
	Depreciation	10%	
	Debt to Equity Ratio	100% Equity	
	Discount rate	12%	(Suleiman and Shan, 2016)

the IRR is calculated to be −5.6%, the payback period 68 years, and the NPV is determined to be -USD 35,816,914. The economic viability of power plants is influenced by the input pricing of solar modules from the factory. Furthermore, the economic feasibility of solar power projects requires a price higher than the government regulated price. This fundamental scenario offers a comprehensive perspective on the interplay between products in the upstream industry and the economic aspects of a solar power plant project. Furthermore, it offers an analysis of the price regulation policy governing the purchase of electricity by PLN from solar power providers. In the above scenario, the aggregate investment cost for a single megawatt (MW) of solar power infrastructure amounts to USD 1,090,540. The investment cost is comparable to the capital outlay of a solar power facility in Mahakam Ulu District, which the value was USD 1,013,514 per megawatt (Priambodo, 2021).

Figure 4: Price Structure of solar module production (author's estimation)

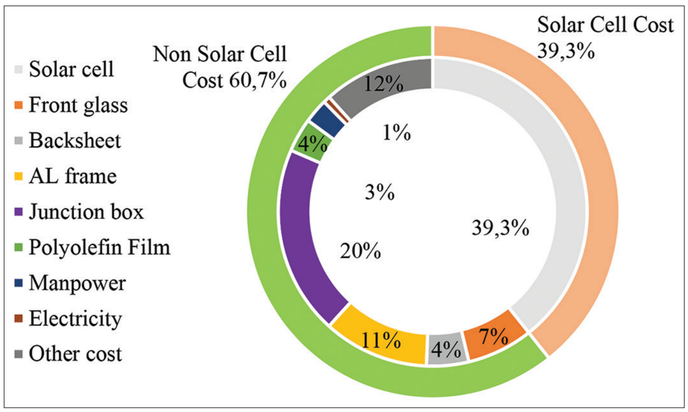


Table 8: Total investment costs of solar power plant

Component	Investment per kW	Total cost (USD)
Solar investment cost		
Solar module	Variabel	33,783,783.78
Inverter	USD 80/kWp	4,000,000
Installation cost	USD 33.78/kWp	1,689,189.19
Rack Alumunium	USD 90/kWp	4,500,000
Electrical	USD 13/kWp	6,500,000
Civil work		
Land clearing	USD 7/m^2	4,054,000
Compaction	USD 7/m^2	
Total		54,527,027

3.3. Sensitivity Analysis on Scenario 1

(Figure 5a) is the sensitivity analysis between electricity prices and power plant economic parameters. From scenario 1, the limit of electricity economical prices for solar power plants can be seen. By using the parameters in Table 8, the minimum electricity price to produce an IRR value above 12% and a positive NPV is USD 0.149/kWh. The payback period for this power plant project is 8.6 years. Meanwhile, in (Figure 5b), the NPV shows a positive value. As a result, the economic price of electricity based on LCOE is above the economic price of electricity set by the government in Presidential Decree No. 112/2022. Nevertheless, it should be noted that the minimum price mentioned remains lower than the maximum price stipulated in Ministry of Energy and Mineral Resources Regulation No. 17/2013, which sets a maximum price of USD 0.25/kWh.

3.4. Sensitivity Analysis on Scenario 2

Scenario 2 presents an in-depth assessment of the purchasing power of solar cells in relation to solar module factories and the corresponding pricing of solar modules for solar power plants. Figure 5 (a) illustrates the sensitivity analysis of the solar cells price per piece, payback period, and IRR. The graph illustrates that the upper limit for purchasing solar cells is USD 1.11 per piece. By utilising the upper limit price IRR gain 12.06%, the payback period 9.6 years, and NPV USD 41,453 (as depicted in Figure 5 (b)). The estimation of the maximum purchasing power for this solar cell is based on a solar module price, whre the price set at USD 655/kW. The purchasing power of the solar cell is contingent upon the prevailing market price of the solar module. Undoubtedly, a reduction in the price of solar cells would inevitably lead to a corresponding decrease in the selling price of solar modules. Given the hypothetical scenario in which Indonesia undertakes the development of its solar cell industry, it is postulated that the resulting economies of scale would lead to a reduction in the price of solar cells to USD 0.88 per piece. Consequently, this decrease in cost would impact a decreased price of solar modules, amounting to USD 621/kW. In this context, it is assumed that the solar module factory would achieve a satisfactory IRR of 12,83%, NPV USD 599,522, and payback period 9.2 years. Even the solar cells is diminished to USD 0.34 per unit, it is feasible to get a maximum reduction in the price of solar modules only USD 489/kW.

The economic viability of a solar power plant is undeniably influenced by the calculations conducted in the upstream sector.

Table 9: Several scenarios were employed in the calculation

Variables	Base Scenario	Scenario 1	Scenario 2
Solar cell price (current estimated import price)	USD 1.08/piece (IDR 16,000/piece)	USD 1.08/piece (IDR 16,000/piece)	The price is varied from USD 0.88/piece to USD 1.35/piece (IDR 13,000/piece to IDR 20,000 per piece)
Solar module price	USD 655.4/kW (IDR 10,000,000/kW)	USD 655.4/kW (IDR 10,000,000/kW)	The price used is USD 135/kw (IDR 2,000,000) to USD 655.4/kW (IDR 10,000,000/kW)
Electricity price	Based on Presidential Decree No. 112/2022, for solar power plants with a capacity of more than 20 MWp, the price is USD 0.06/kWh (IDR 977) years for 1-10 and USD 0.04/kWh (IDR 586/kWh) years for 11-30.	The price are varied based on MEMR Regulation max electricity price for the solar power plant is USD 0.25/kWh (IDR 3,700/kWh)	Fixed based on Presidential Decree

Figure 5: Relationship curve between electricity prices and economic parameters (a) Payback period, electricity price and IRR, (b) NPV, electricity price, and IRR

Note:

- Solar module price is fixed at USD 655/kW
- Solar cell price is fixed at USD 1.08/piece

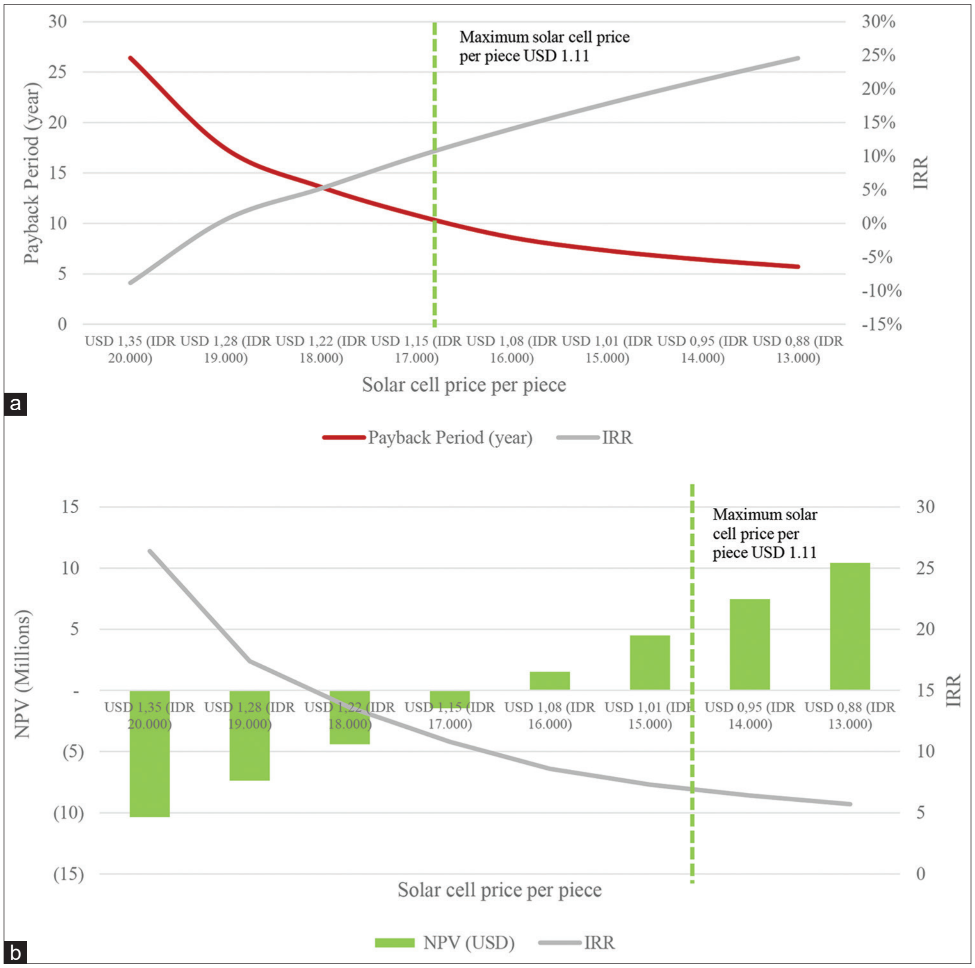
Table 10: Economic calculation result on base scenario

Economic parameter	Solar module factory	Solar power plant
IRR	14%	−5.6%
Payback period	8.6 years	68 years
NPV	USD 1,525,677	−USD 35,816,914

- Solar cell price is USD 1.08/piece (IDR 16,000/piece).
- Solar module price is USD 655.4/kW (IDR 10,000,000/kW).
- Electricity price is based on Presidential Regulation 112/2022 for solar power plants with a capacity of more than 20 MW The prices are USD 0,06/kWh (IDR 977) in years 1-10 and USD 0.04/kWh (IDR 586/kWh) in years 11-30

(Figure 7a and b) present a sensitivity analysis regarding the price of solar modules, internal rate of return (IRR), and payback period. According to Presidential Decree 112/2022, the cost of energy for solar power plants remains unaffected by any modifications made to the price of solar modules, so implying that such adjustments do not exert any influence on the financial viability of solar power plants. The current electricity price stipulated in this legislation remains insufficiently low. Based on the calculation, it is evident that the minimum solar module price of USD 135/kW remains insufficient to render solar power plants economically viable. The IRR remains negative at −0.81%, it is indicating that the project is not generating a positive return. The payback period is estimated to be 30 years, suggesting that it will take a considerable amount of time to recoup the initial investment. Additionally, the NPV is calculated to be -USD 12,929,398. This suggests that the cash inflows generated by the enterprise are insufficient to offset the initial investment. The current regulations, particularly those pertaining to the pricing of electricity procured by PLN, must possess sufficient competitiveness in order to stimulate growth in the solar power plant business. Based on the findings, it is evident that despite governmental efforts to promote and incentivize upstream companies, particularly in relation to solar cell components, has not achieved sufficient profitability in implementing solar power plant projects. In addition to promoting the development of the upstream industry, it is imperative to undertake a revision of Presidential Decree 112/2022. The economic viability of the project is significantly influenced by the cost of energy, as depicted in Figure 7. The solar power plant must be able to generate electricity at a minimum price of USD 0,149 kWh in order to be financially feasible.

Figure 6: Sensitivity analysis (a) Solar cell price, IRR, and payback period, (b) Solar cell price, IRR, and NPV



Note:

- Electricity price based on Presidential Decree No. 112/2022
- Solar module price fixed at USD 675/kW

In contrast, the price established by the government is far lower than the prevailing economic price. By utilising the given parameters, specifically the solar cell price of USD 1.08 per piece and the solar module price of USD 675, the outcome of the calculation yielded the generation cost USD 0.069/kWh (equivalent to IDR 1.015/kWh). The generation cost surpasses the electricity price due to the elevated selling price of energy, which is aimed at achieving favourable economic outcomes for the project, such as a minimum IRR 12% and a positive NPV.

3.5. Policy Analysis and Recommendation

The findings of this calculation suggest that the Presidential Decree No. 112/2022 should be reviewed to maintain competitiveness. The analytical findings indicate that the current price of USD 0.066/kWh for solar power plants is insufficient from an economic standpoint. Despite the provision of subsidies by the government to support the upstream industry, an examination of the sensitivity analysis pertaining to solar module prices reveals the necessity for further cost reduction in solar power plants. It is imperative for the government to undertake a comprehensive reassessment of the power pricing, which has been established in accordance with the existing regulatory framework. The majority of solar power plant component highly depend on imported items. Specifically, approximately 66% of the total investment cost associated with procuring solar modules. The implementation of Presidential Decree for the downstream sector will inevitably have an impact on economic viability of power plants project. Establishing a pricing scheme that is excessively low will have a detrimental impact on the overall investment climate. In a study conducted by (Rachman et al., 2015), an analysis was carried out to assess the economic viability of solar power plants in South Sulawesi, Indonesia. The findings of the study indicate that the expenses associated with establishing and operating such power plants vary between USD 0.19/kWh and USD 0.23/kWh. If the necessity of utilizing MEMR regulation 17/2013 as a point of reference persists, it would be appropriate to use the prescribed maximum electricity price of USD 0.25/kWh. In a recent investigation by (Zhang et al., 2022), an examination was undertaken to identify the variable that exert an influence on the investment climate pertaining to solar power plants. Among the variable identified, the feed-in-tariff policy emerged as a significant influencing factor. A marginal increase of 1% in electricity tariffs is expected to have a beneficial effect on the overall investment in solar power facilities, resulting in a growth of 7%.

Figure 7: Sensitivity Analysis (a) Solar module price, IRR, and payback period, (b) Solar module price, NPV, and payback period

Note: Electricity price based on Presidential Decree No. 112/2022

Among the ASEAN countries, Vietnam has emerged as a leading proponent in the establishment and advancement of solar power infrastructure. Notably, Vietnam has achieved a significant milestone by successfully installing solar power plants with a combined capacity of 16.5 GW, as reported by (Sreenath et al., 2022). According to (Do et al., 2021), it is crucial to prioritize the initial phase of fostering the investment environment for solar power plants. One effective approach involves offering appealing feed-in-tariffs. Table 11 presents a comparative analysis of policies aimed at promoting the use of solar power plants. Notably, in 2021, Vietnam implemented a feed-in tariff (FIT) policy that was relatively lower in comparison to the one adopted by Indonesia. One notable distinction between Vietnam and Indonesia is in their respective approaches to local content policies. Specifically, Vietnam's lack of implementation of such policies has resulted in its continued reliance on imports. In Indonesia, minimal local content criteria are implemented. Table 1 illustrates a positive correlation between projects with higher local content values and the resultant increase in electricity selling prices. This phenomenon can be attributed to the higher prices 20-30% of domestic component compared to their imported counterparts, as noted by (Falah, 2023).

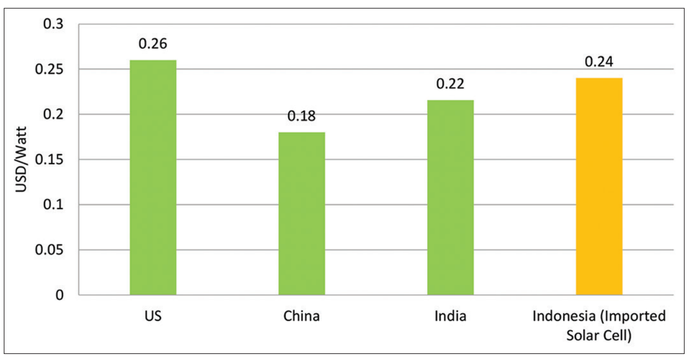
In contrast to Vietnam, India exhibits a propensity for providing substantial incentives to the solar power plant component industry. Various incentives, such as those aimed at promoting the utilization of solar modules with high quality. According to (Shiradkar et al., 2022), there is a positive correlation between the efficiency of solar modules and the incentives acquired by Indian Government. Furthermore, the Government of India imposes comparatively elevated import tariffs of 25% on solar cell imports and 40% on solar module imports as a means to safeguard domestic products. The imposition of this tariff was intended to restrict the importation of solar cell goods from China, which are known has lower prices (Figure 8). According to the findings of (Shiradkar et al., 2022; Woodhouse et al., 2019), a comparison of solar cell production costs reveals that Indian manufacturing expenses amount to USD 0.22 per watt, whilst solar cell from China are comparatively lower at USD 0.18 per watt. According to the calculations, the cost of importing solar cells in Indonesia amounts to USD 0.24 per watt. In this particular scenario, it is imperative to deliberate over the feasibility of establishing a solar cell manufacturing facility, taking into account the potential competition products originating from China, which may pose a challenge to the solar cell sector in Indonesia. The implementation of import duty levy policies has the potential to enhance the competitiveness of local prices. The effective implementation of this strategy requires an evaluation to domestic manufactur readiness. As we can learn from India, the import levy policy is facing resistance in the Indian market, as it is not yet prepared to embrace it. According to a short-term forecast, the demand for solar power in India is projected to reach 140 GW by the year 2031 (Asian Power, 2022).

In contrast to China, it offers numerous advantages for the solar cell manufacturing industry. China does not impose import tariffs,

Table 11: Policies comparison to encourage the development of solar power plants

Countries	Feed-in tariff for solar PV power plant	Current policy		Source
		Upstream industries	Downstream industries	
Vietnam	• In 2020 the rate of USD 0.07 – 0.083/kWh • In 2021 minimum rate was USD 0.052/kWh and USD 0.058/kWh	Does not apply local content requirements for the PLTS industry	• Tax exemption incentives (4 years) • Land lease exemption • Exception of import tariffs • Foreign funding is allowed • Net energy metering	(Do et al., 2021; Govindarajan et al., 2023; Sreenath et al., 2022)
Indonesia	Maximum rate USD 0.066/kWh	Implement local content requirements	• Tax holiday and allowance • Land lease exemption	(Halimatussadiah et al., 2023)
China	applies auction system policy	• Innovation fund for small technology-based firms • Energy subsidy • Low labor cost	• Loan guarantee by the government • Loan and credit facilities • Refund of electricity fees • Exemption of land fee and tax	(Gang, 2015; Puttaswamy and Ali, 2015)
India	Using an auction scheme, electricity purchase prices are generally low (USD 0.024 – 0.028/kWh) and high capacity (350 MW – 1.6 GW	• Provides incentives for solar module cUSD 0.7 – 0.02/Wp • Basic Customs Duty (BCD) is 25% for imported solar cells and 40% for imported solar module • The incentive for the semiconductor industry in the form of a 30-50% up-front capex reduction	-	(Garg, 2022; Shiradkar et al., 2022)

Figure 8: Comparison of solar cell manufacturing costs in several countries



resulting in lower prices for their products. The primary distinction between these nations is in the implementation of their feed-in tariff policies. Unlike India and China, which do not prescribe fixed rates for electricity generated from renewable energy facilities, they instead employ an auction system. By utilizing this scheme, it is possible to establish a competitive selling price that is determined by the economic value of the project. One potential drawback is that the cost of electricity procured by PLN may significantly increase.

4. CONCLUSION

According to the findings of this research, the assessed investment value for a solar module factory with capacity of 50 MWp amounts to USD 15,880,849. The solar power plant incurs a total investment cost of USD 54,527,027, assuming a module price of USD 655 per kilowatt. The sensitivity analysis reveals that the utilisation of the business-as-usual scenario yields favourable economic outcomes for the solar module plant. Specifically, the IRR is at 14%, the payback period 8.6 years, and the NPV amounts to USD 1.5 million. Nevertheless, there exists an inverse relationship between the aforementioned factor and the economic aspects of power plants. The pricing structure for electricity, as stipulated in Presidential Decree No. 112/2022, necessitates further upward adjustment. Applying the current electricity price yields IRR of −5.6%, a payback period of 68 years, and a NPV of -USD 35.8 million. Scenario 1 presents a comprehensive analysis of an economically justifiable price within the context of prevailing conditions. The sensitivity analysis reveals that the prevailing cost of electricity is at USD 0.149/kWh, leading to an IRR over 12%, a positive NPV, and a payback period of 8 years. Scenario 2 demonstrates that the provision of incentives by the government to the upstream industrial sector without considering investment climate, does not yield improvements in the economic viability of solar power plants.

Benchmarks have been conducted in several countries, wherein fiscal incentives have been provided to the solar power generation sector. Notably, China and India have adopted an auction mechanism to determine the pricing of electricity derived from renewable energy sources. In the context of Indonesia, it is imperative for the government to undertake a comprehensive evaluation of Presidential Decree No. 112/2022, which pertains to the establishment of the selling price for energy supplied to PLN. Such a review is crucial in order to foster heightened investor enthusiasm for the expansion of commercial ventures within this particular industry.

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