Developing Class 4 Cost Estimate model by Analyzing Historical Databases for Solar Farm Project in Indonesia [1,2]

Tengku Rizki Fahril Mukti

ABSTRACT

Indonesia's energy consumption is approximately 2 billion barrels of oil equivalent per year, around 85% of which is from Non-Renewable Energy and sourced from imports, leaving Indonesia in an energy-dependent situation. Indonesia's location near the equator gives an advantage with the abundance of RE sources, especially Solar, but its potential is underutilized. The Indonesian Government set a target of 53% of energy produced from renewable sources in 2050, with solar energy as its centerpiece. Solar energy's future is bright; investment in this sector is expected to increase, and it is imperative to facilitate the progress by providing a Parametric Model (CER) as a tool to estimate a Solar Farm project (Class 4 for Feasibility study). By doing so, the company can expedite the decision-making process and develop a new business case fast & efficiently.

Keywords: AACE, CAPEX, CER, Cost Estimate, Indonesia, Parametric Model, Renewable Energy, RUEN, Solar PV.

INTRODUCTION

1.1. Indonesia's Energy landscape and its challenges

As per 2024's data[3], Indonesia consumes approximately 2 billion BOE (Barrel Oil Equivalent) of energy annually, an increase 7.46% from the prior year. From that figure, Coal (40.4%), Crude (28.58%) and Natural Gas (16.03%) constitute 84.65% of energy source, just miniscule amount of percentage sourced from renewable energy (15.35%), comprised mostly of Biofuel (4.49%), Biomass (3.46%), Hydropower (2.53%), Geothermal (1.55%) and very small percentage of Solar PP & Solar PV (0.30%). This

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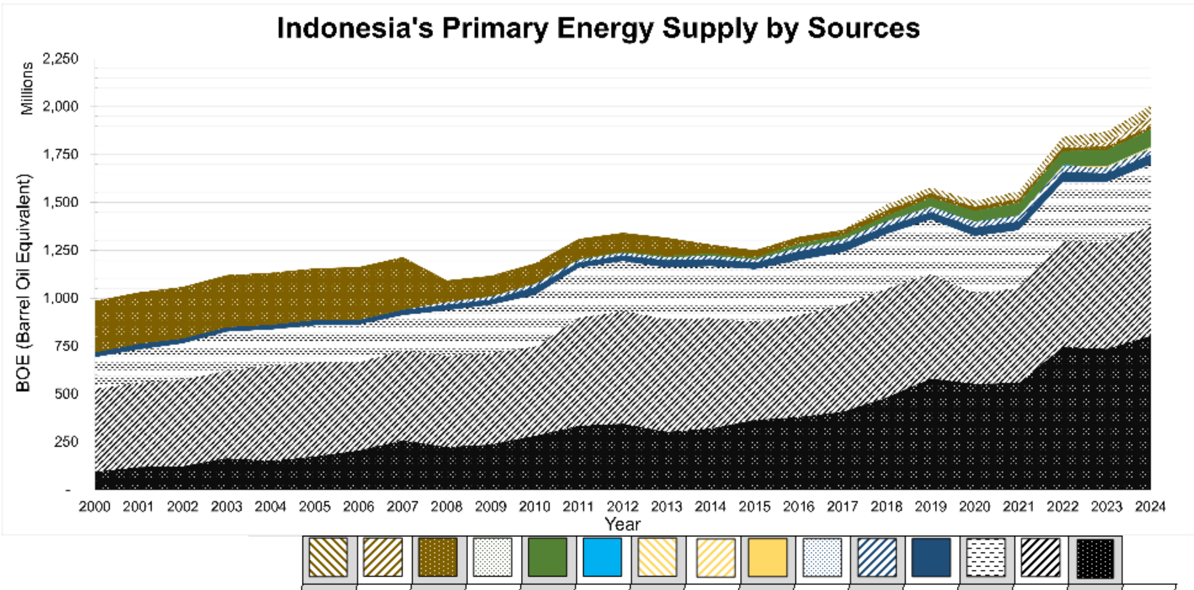
[2] This paper was originally prepared during a 6-month long Graduate-Level Competency Development/Capacity Building Program developed by PT Mitrata Citragraha and led by Dr. Paul D. Giammalvo to prepare candidates for AACE CCP or other Certifications. https://build-project-management-competency.com/our-faqs/.

[3] Ministry of Energy and Mineral Resources, Republic of Indonesia. (2025). *Handbook of Energy & Economic Statistics of Indonesia 2024*. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2024.pdf

figure shows how heavily reliant this country is on non-renewable fossil fuels and their derivative product.

Indonesia's reliance on coal as the first and main energy source is not without reason; it is rich in coal and one of the largest coal producers (1st in the world) and exporters (2nd in the world)[4], the regulation is well-shaped to foster and sustain this status[5]. While it may be beneficial to source energy locally, it is neither economically nor environmentally sustainable[6].



	Other Renewables*	Industrial Biomass	Traditional Biomass	Biogas	Biofuel	Wind	Solar Water Heater	Solar Powered Public Street lighting & energy saving lamp	Solar PP & Solar PV	Direct Use of Geothermal	Geothermal	Hydropower	Natural Gas & Product	Crude oil & Product	Coal	**TOTAL**
Million Barrel Oil Eqv.	56.32	53.15	16.32	0.60	90.18	1.15	2.42	0.05	5.99	0.00	31.14	50.83	321.93	573.86	803.86	2007.8
Percentage	2.80%	2.65%	0.81%	0.03%	4.49%	0.06%	0.12%	0.00%	0.30%	0.00%	1.55%	2.53%	16.03%	28.58%	40.04%	100%
Renewable / Non-Renewable	15.35%												84.65%			100%

Figure 1. Indonesia's Primary Energy Supply by Sources 2000 – 2024 [2,7,8,]

[4] IEA, World Energy Balances, IEA, Paris https://www.iea.org/data-and-statistics/data-product/world-energy-balances, License: Terms of Use for Non-CC Material

[5] Andi, D.(2021). *Porsi batubara di RUPTL 2020-2029 naik, transisi energi bakal sulit terlaksana* . https://industri.kontan.co.id/news/porsi-batubara-di-ruptl-2020-2029-naik-transisi-energi-bakal-sulit-terlaksana

[6] Perdana, A. P.(2025). *Coal Sustainability Challenges and Post-Mining Economy*. https://www.kompas.id/artikel/en-tanda-tanya-keberlanjutan-batubara-dan-dampaknya-pada-lingkungan

[7] Ministry of Energy and Mineral Resources, Republic of Indonesia. (2014). *Handbook of Energy & Economic Statistics of Indonesia 2014*. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-economic-statistics-of-indonesia-2014-it06jkm.pdf

[8] Ministry of Energy and Mineral Resources, Republic of Indonesia. (2019). *Handbook of Energy & Economic Statistics of Indonesia 2018*. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2018-final-edition.pdf

In contrast to Indonesia's wealth of coal, oil is mostly imported. Daily, "*Indonesia needs 1.5 to 1.6 million Barrels of oil, while it barely produces 600 thousand barrels domestically*"[9]. This condition causes a deficit in the trade balance[10] and volatility in the rupiah exchange value relative to the U.S. Dollar[11]. Sooner or later, Indonesia has to wake up from its delusion of former glory as an oil-exporting nation and OPEC member. Based on sector [2], in 2024, Industrial (45.94%) and transportation (36.11%) were the main sectors that consumed energy in Indonesia. The Industrial sector consumes energy in the form of coal (58.45%), gas (14.65%) & electricity (12.42%). In comparison, transportation mostly uses energy in the form of oil (99.89% in total, 53.83% as pure petroleum derivative, and 46.06% as B30) with only 0.05% from electricity.

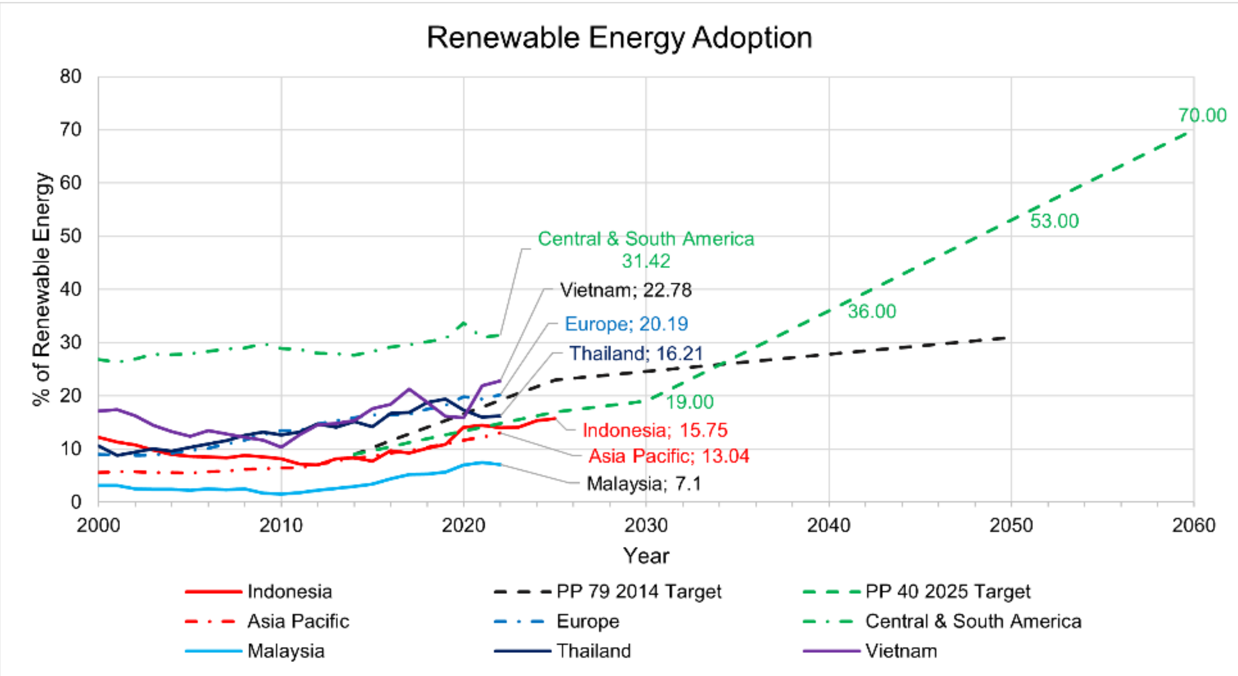


Figure 2. Renewable Energy Adoption, Indonesia vs Region [12,13,14]

[9] Hanafi, M.(2026). *Stok BBM RI Hanya Cukup 20 Hari, Realistiskah Capai 90 Hari?*. https://www.dw.com/id/stok-bbm-indonesia/a-76245335

[10] Badan Pusat Statistik. (2026). *Surplus Neraca Perdagangan di Awal Tahun 2026*. https://www.bps.go.id/id/news/2026/03/03/870/surplus-neraca-perdagangan-di-awal-tahun-2026.html.

[11] Reforminer. (2021). *Pengaruh Sektor Migas terhadap Nilai Tukar Rupiah*. https://reforminer.com/pengaruh-sektor-migas-terhadap-nilai-tukar-rupiah/

[12] IEA, IRENA, UNSD, World Bank, WHO. (2022). *Tracking SDG 7: The Energy Progress Report*. World Bank, Washington DC.

[13] Kebijakan Energi Nasional, PP No. 79 (2014). https://peraturan.bpk.go.id/Download/33346/PP%20Nomor%2079%20Tahun%202014.pdf

[14] Kebijakan Energi Nasional, PP No. 40 (2025). https://peraturan.bpk.go.id/Download/393113/PP%20Nomor%2040%20Tahun%202025.pdf

1.2. Slow Adoption of renewable energy and the need to expedite

The Indonesian Government has issued 2 (two) regulations (in the form of Peraturan Pemerintah/PP), PP No. 79 Tahun 2014 and its update/revision, PP No. 40 Tahun 2025. Both regulations are issued as a sign of commitment to set the energy mix target, especially the percentage of renewable energy. Although the target has been stated, the Indonesian Government cannot keep up with its promises, as PP No. 40 Tahun 2025 revised the renewable energy target percentage from 23% to 17-19% in 2025[15], while the realization is only 15.75%[16]. The sluggish adoption of renewable energy put Indonesia behind some of its Southeast Asian counterparts (Thailand & Vietnam). The target and realized levels of renewable energy, along with comparisons to neighboring countries, are shown in Figure 2. PP No. 40 Tahun 2025 sets targets for RE (Renewable Energy) of 53% in 2050 and 70% in 2060. Indonesia clearly has to build a well-prepared plan and do it consistently to achieve that target.

1.3. Indonesia's potential renewable energy sources and Solar as a possible option

Indonesia has abundant potential for renewable energy. It is strategically positioned near the equator, has relatively fertile soil, and lies at the junction of 4 tectonic plates (Indo-Australian, Eurasia, Philippine Sea Plate, and Pacific Plate). Among the options are Solar, Wind, Hydro, Ocean (current/wave), Bioenergy & Geothermal.

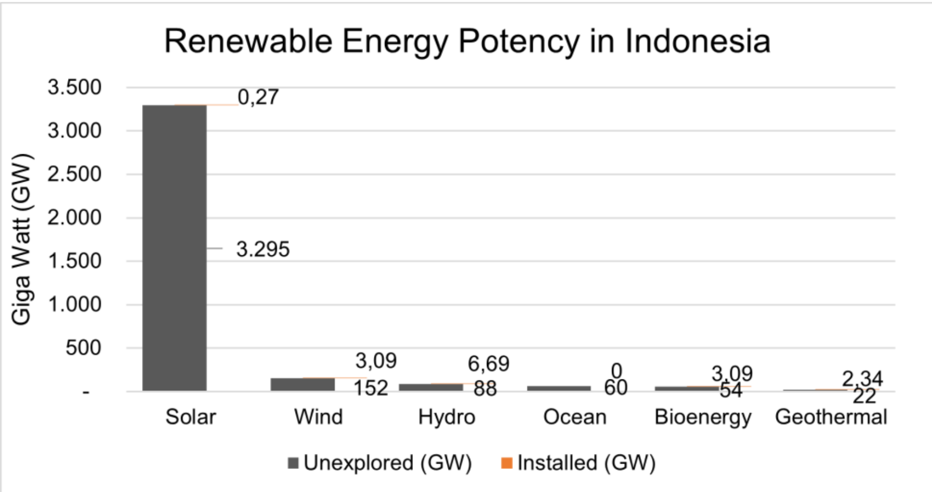


Figure 3. Renewable Energy Potency in Indonesia 2023[17]

[15] IESR.(2024). *RPP KEN Pangkas Target EBT Menjadi 19 Persen di 2025*. https://iesr.or.id/rpp-ken-pangkas-target-ebt-menjadi-19-persen-di-2025/

[16] Fundriko, B.A.(2026). *Bauran Energi Terbarukan 2025 Baru 15,75 Persen, IESR: Tak Sesuai Target*. https://www.suara.com/news/2026/01/19/132743/bauran-energi-terbarukan-2025-baru-1575-persen-iesr-tak-sesuai-target

[17] Ministry of Energy and Mineral Resources, Republic of Indonesia. (2023). *Miliki Potensi EBT 3.686 GW, Sekjen Rida: Modal Utama Jalankan Transisi Energi Indonesia*. https://www.esdm.go.id/id/media-center/arsip-berita/miliki-potensi-ebt-3686-gw-sekjen-rida-modal-utama-jalankan-transisi-energi-indonesia.

From Figure 3, it can be inferred that the most underutilized renewable energy in Indonesia is Solar (<0,01%). "*Indonesia has high global horizontal irradiation, 3.6 - 6 kWh/m2/day, and PV electricity potential, 3 – 4.6 kWh/kWp/day*"[18,19] but its potential has not yet been fully realized.

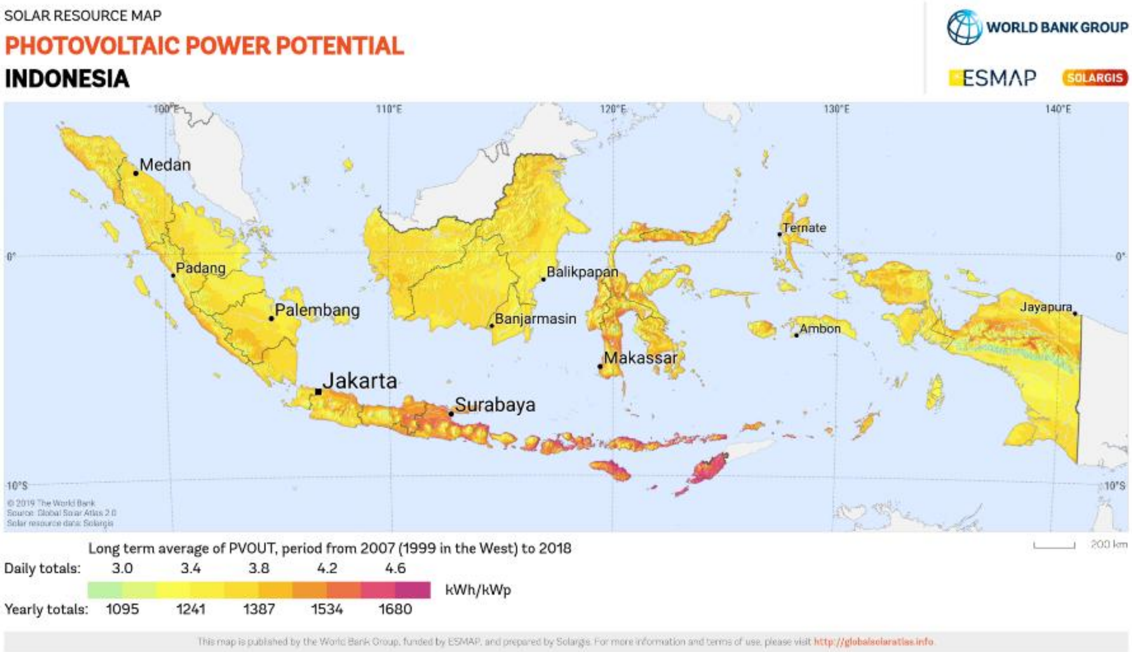


***Figure 4. Photovoltaic Power Potential**[18]*

"*Each of the renewable energy options/technologies has its strengths, weaknesses, opportunities, and threats.*"[20] For Solar PV, the SWOT analysis can be shown as follows.

***Table 1. SWOT Analysis of Solar PV** [19]*

Strength	**Weaknesses**
>Renewable, Clean & Abundant Resource >Scalability & Modularity >Dispersed Generation (Energy Resilience) >Non-Mechanical, Easily Maintained, Long Lifespan >Applicability on existing space, roof/ façade	>Variable renewable energy (VRE) >Upfront Cost >Need for power storage >Need for redundant power generation source
Opportunities	**Threats**
>In the process of technological advancement >Declining trend of equipment cost >Accessibility of energy & electrification	>Market & Policy uncertainties >Material & some processes competing with the Semiconductor sector

[18] IESR.(2019). *Harnessing Indonesia's Solar Potential: Yellow is The New Black*. https://iesr.or.id/harnessing-indonesias-solar-potential-yellow-is-the-new-black/
[19] ESMAP. (2020). Global Photovoltaic Power Potential by Country. https://documents1.worldbank.org/curated/en/466331592817725242/pdf/Global-Photovoltaic-Power-Potential-by-Country.pdf
[20] Huda, R. N. (2023). The Assessment of New and Renewable Energy and Energy Efficiency Feasible Alternatives and Policies in Indonesia; *PM World Journal*, Vol. XII, Issue IX, September.

>High versatility of electricity as a product output >High interoperability with new energy storage technology	

The traits that favorably and uniquely differentiate Solar PV from other RE are its scalability and modularity, Non-Mechanical design, ease of maintenance, and applicability to existing space, roof/façade. These traits are highly valued and increase the likelihood that PV will be widely implemented. Solar PV can also be a way to electrify Indonesia's vast & secluded Archipelago.

Although it has promising traits, some factors have to be taken into account. Solar PV is a long-term investment with somewhat high upfront cost; market & policy uncertainties can hinder the investment in Solar PV. The intermittency of Solar PV means it needs a backup energy source/storage to work reliably, and a new threat has just emerged: the possibility of material scarcity due to its shared processes and technology with semiconductors.

Nevertheless, weighing the pros and cons, Solar PV remains a viable option and could even serve as a silver bullet to get Indonesia back on track to achieve its 2060 RE adoption goal.

1.4. Solar PV investment

As discussed before, the Indonesian Government has PP No. 40 Tahun 2025, which states the energy mix target, while for its implementation, the Government issued RUEN (Rencana Umum Energi Nasional/General Plan of National Energy). The last RUEN was published in 2017 as PP No. 22 Tahun 2017. This plan seems obsolete, as it still refers to PP No. 79 Tahun 2014 for its target, and so many deviations in energy supply, demand, and price parameters that have changed[21]. Indonesia needs a new RUEN sooner. PP No. 73 Tahun 2023 (guideline for RUEN formation) states that RUEN shall be evaluated every 5 (five) years, and if discrepancies are found, then the assumption should be updated.

The latest available reference for the Solar PV wattage generation target can be found in Kepmen ESDM No. 85.K/TL.01/MEM.L/2025, Rencana Umum Ketenagalistrikan Nasional/General Plan of National Electricity. It states a target of 108.7 GW of Solar PV Plant by 2060, by which time 41.5% of electricity generated by RE and 24.6% of installed plant capacity will be from Solar PV.[22] To realize that target, a massive amount of investment is needed.

[21] UNDP. (2020). *Review Rencana Umum Energi Nasional dengan remodeled sistem dinamik*. https://un-pageindonesia.org/assets/uploads/34bfc-sub-model-energy-lcdi-exum.pdf

[22] Rencana Umum Ketenagalistrikan Nasional, Kepmen ESDM No. 85.K/TL.01/MEM.L/2025. (2025). https://gatrik.esdm.go.id/assets/uploads/download_index/files/28dd4-rukn.pdf

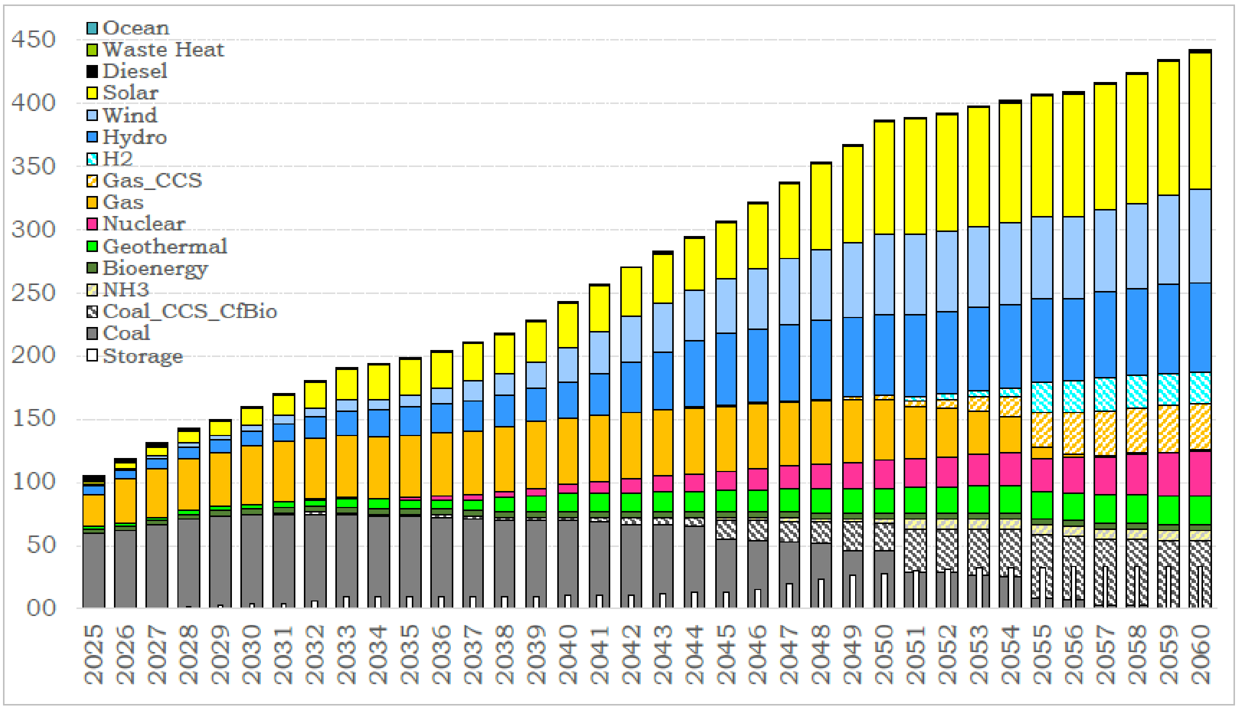


***Figure 5. Projection of Installed Electricity Plant (in GW) 2025-2060*[21]**

1.5. Cost Estimation of Solar PV Project

Based on IESR's 2025 study across several locations in Indonesia, 165.9 GW of Solar PV ground-mounted utility-grade is economically viable. [23] To realize the investment, each Solar PV project needs to undergo a prudent economic analysis process, where CAPEX is needed as its input.

Generally, Solar PV CAPEX in Indonesia is estimated at around 1,170-1,530 USD/kW in 2019[24]. There is scarce literature on the CAPEX value of this project relative to plant size and projected future CAPEX; this data is needed as each project varies in size and deployment time.

To obtain a valid CAPEX value, a cost-estimation process is needed. "*The AACE RP 18R-97 defines five estimate classes based on the maturity level of the project for process industries.*"[25] Using this framework, the needs of data and methodology for getting a certain estimate accuracy can be determined. In a project feasibility study, a class 4 estimate is needed. To get that estimate, equipment-factored or parametric

[23] IESR.(2025). *Unlocking Indonesia's Renewables Future: the Economic Case of 333 GW of Solar, Wind and Hydro Projects*. Jakarta: Institute for Essential Services Reform (IESR).

[24] Simamora, P., & Fabby, T. (2019). Apa yang Membuat Biaya Pembangkitan PLTS Skala Utilitas Bertambah Murah?. https://iesr.or.id/wp-content/uploads/2019/08/IESR-Briefing-Paper-Biaya-Pembangkitan-PLTS.pdf

[25] AACE International. (2020). AACE International Recommended Practice No. 18R-97 Cost Estimate Classification System – As Applied in Engineering, Procurement, And Construction For The Process Industries.

models can be utilized, and are expected to have an accuracy of (L: -15% to -30%, H: +20% to +50%).

Table 2. Table 1 of AACE 18R-97 – Cost Estimate Matrix for Process Industries[24]

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

The importance of RE, especially Solar PV, to achieve Indonesia's energy independence and resiliency cannot be denied; the need for CAPEX to support the feasibility study process and realize the project is critical.

The purpose of this paper is to develop a parametric model for Solar PV's CAPEX project in correlation with plant size and deployment years based on similar historical data in Indonesia.

This study aims to answer the following questions:

1. Has the historical project data SPI & CPI met the quality metrics of validity, precision, reliability, and accuracy, and can it be used to improve future project performance?

2. What is the appropriate parametric model for the cost estimate of the Solar PV project based on its plant size and year of deployment?

3. Has the proposed model met the requirements for CAPEX Class 4, and can it be utilized in the feasibility study phase?

METHODOLOGY

For this study, the seven-step engineering economy analysis procedure[26] is adopted. The process is illustrated as follows:

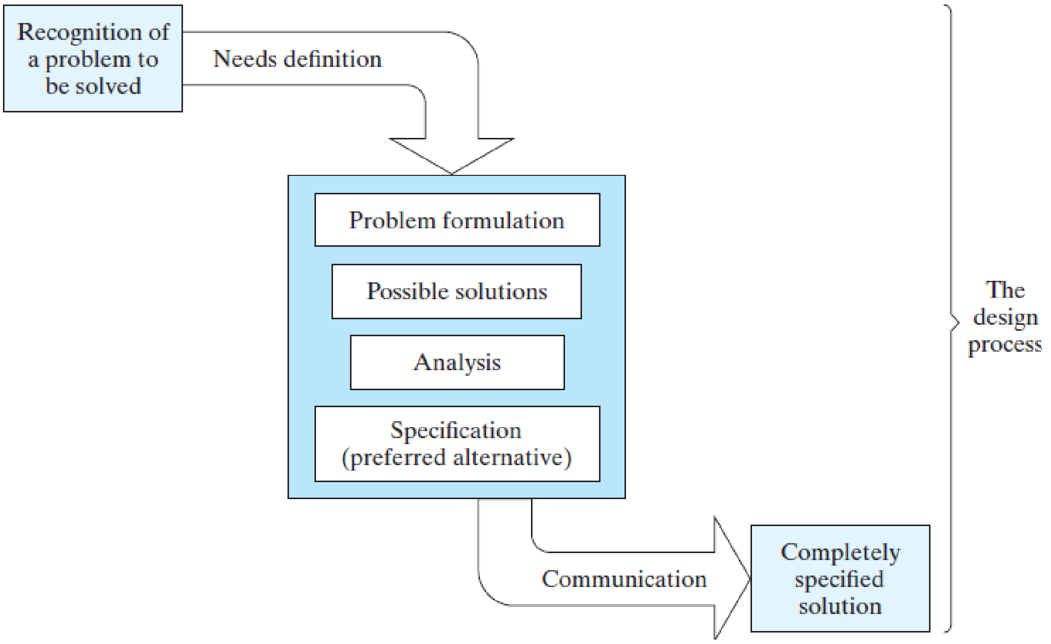


Figure 6. Engineering Economy and Design Process[25]

2.1. Step 1 - Problem Definition

To analyze/estimate the cost of a PV Solar Farm project, the company usually relies on a certain rule of thumb (1 million USD/1 MWp, for example), though this rule of thumb gives a quick approximate value, the source of the study, its validity, and implementation for this company need to be questioned, as the environment/study location might differ. The challenges that need to be faced in the cost estimation of the PV Solar Farm project in Indonesia are:

a. Current company practice: reliance on a single point of reference/rule of thumb, that does not account for accurate historical data & market trends.
b. The absence of a parametric model as a tool for estimating project costs, especially one tailored to the company's experience, results in a more accurate outcome.

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[26] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2020). *Engineering Economy Seventeenth Edition Global Edition* (17th ed.). Pearson Education.

c. The need for a fast & reliable decision tool: as renewable energy demand & business schemes grow, parametric modeling can serve as a quick decision tool to provide economic sense of a project/business model.

The study aims to develop a parametric model for the PV Solar Farm project in Indonesia to support cost estimation based on capacity installed and year of deployment. The model will be developed using the historical company's data (AACE level 4 – level 2) for the past 5 years (2021 - 2025).

PV Solar Farm Infrastructure

PV solar farm system comprises equipment and can be simplified as follows:

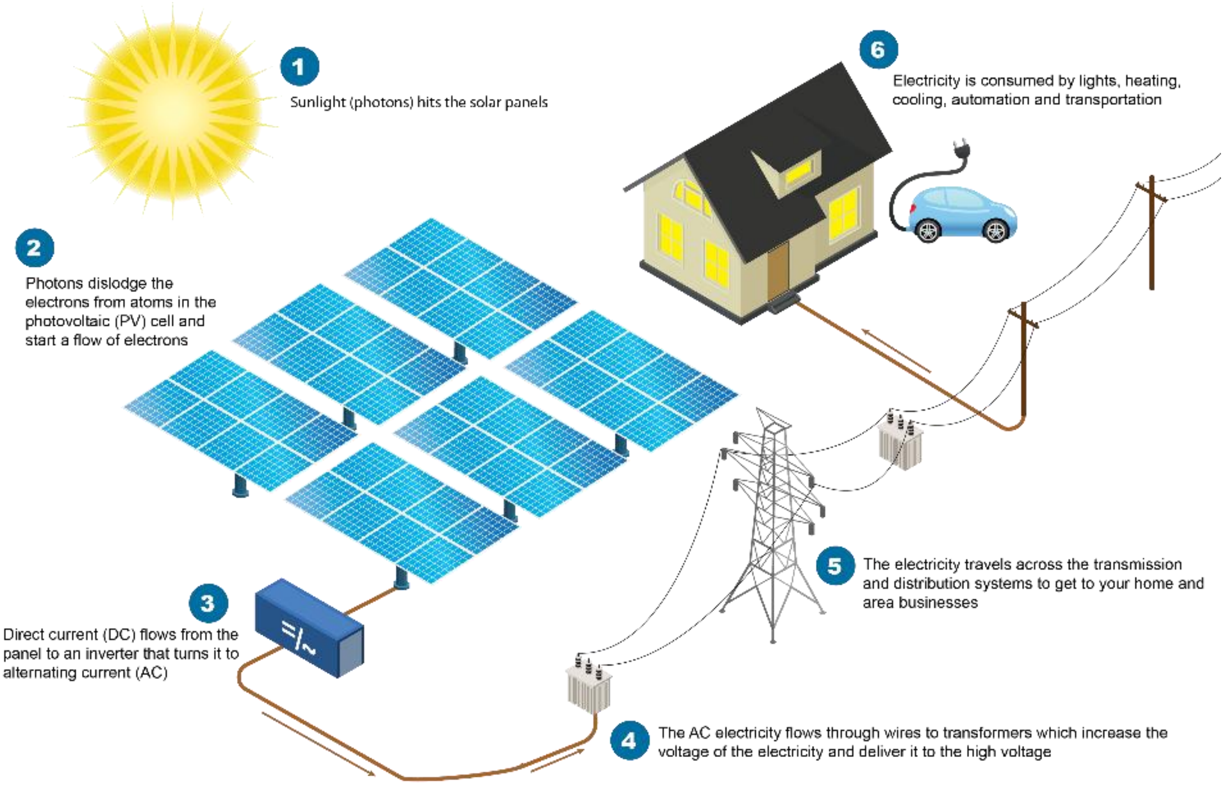


Figure 7. Solar Farm On-Grid Facilities Illustration [27]

The cost being evaluated for the development of parametric modeling for this study comprises:

[27] cidersolarfarm.com.(2026).*How Solar Power Works.* https://www.cidersolarfarm.com/about/how-solar-works/

1. **Conceptualizing, Engineering, Design & Project Management**
   The cost consists of man-hours spent on planning & designing the facility and executing the project (construction of the PV Solar Farm). The cost of maintaining and operating the facilities is not included in the analysis.

2. **Construction Work & Hand Over (Commissioning)**
   The types of PV Solar Farm facilities being evaluated are ground-mounted type (non-elevated) and rooftop, both of which are fixed-tilt. Changes in the type of PV Solar Farm can affect the amount of civil work required (differences in mounting/gear systems and foundation), and may influence the project cost. [28]
   The Civil work consists of site preparation, foundation, mounting structure, and stair/platform for maintenance purposes. The land acquisition cost (buying/lease) is not included in the analysis.

   For this study, the scope of electrical work being evaluated is the construction of an On-Grid type PV Solar Farm; no power storage means is included in the system. For this system, the biggest part of the electrical work is procuring the PV Module. SNI compliance Mono/Poly-Crystalline Silicon type is being used in the analysis. Other electrical work in the PV Solar Farm, such as inverters, cabling, grounding and bonding, transformers, switchgear, SCADA/Monitoring system, installation, and certification, is also included in the analysis.

The WBS for the On-Grid PV Solar Farm project, as per Omniclass ®, is presented as follows:

[28] Hailer, M. (2025). *Choosing the right ground mount structure: comparing typologies and optimizing project costs*. https://pvcase.com/blog/ground-mount-structure-optimizing-project-costs

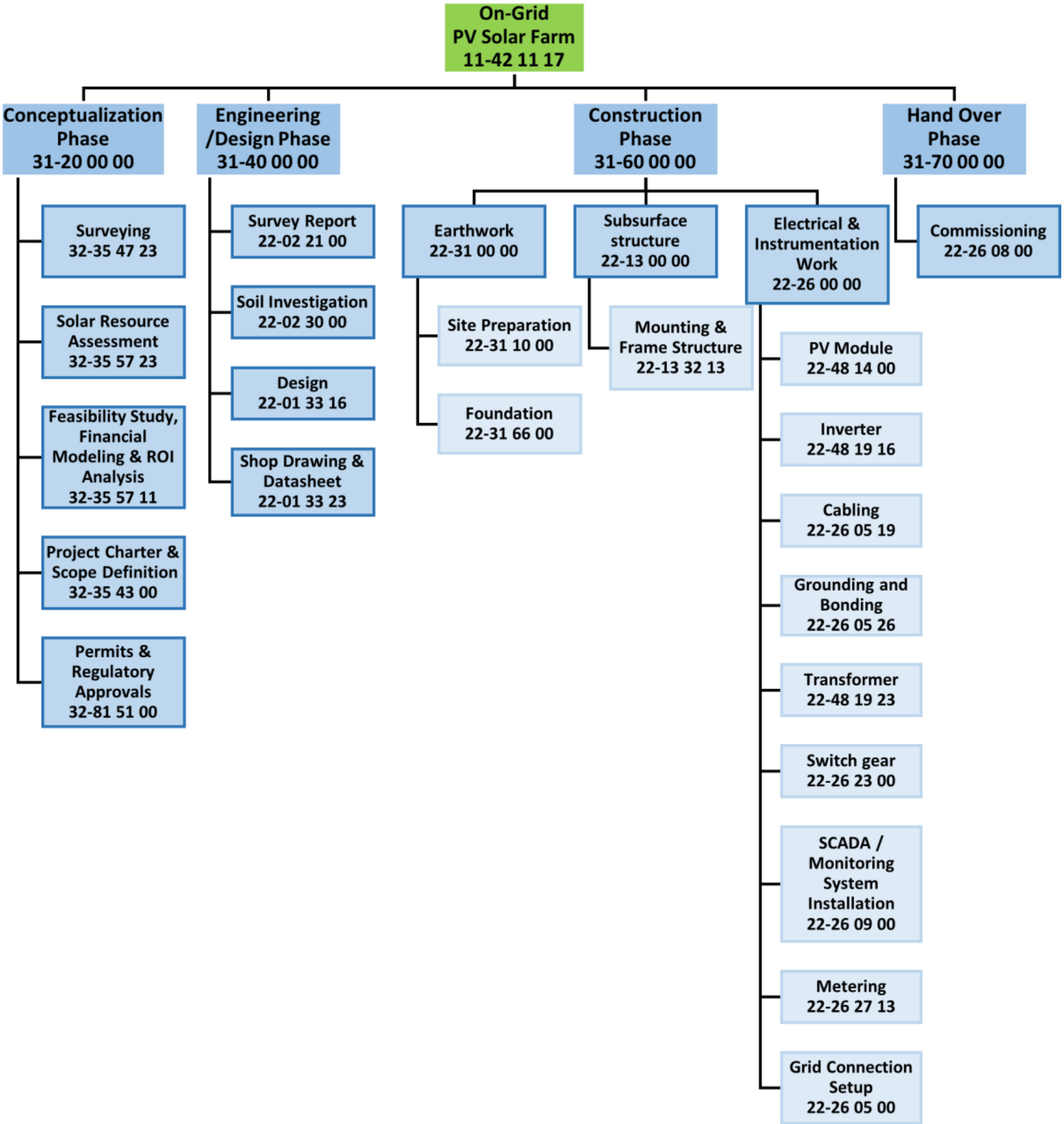


Figure 8. Solar Farm On-Grid Facilities Omniclass® WBS

2.2. Step 2 – Identify The Feasible Alternative

Parametric Cost Estimating

"*Parametric cost estimating is the use of historical cost data and statistical techniques to predict future costs. Statistical techniques are used to develop cost estimating relationships (CERs) that tie the cost or price of an item to one or more independent* *variables (cost drivers)"* [25]. *"The major advantage of using a parametric methodology is that the estimate can usually be conducted quickly and be easily replicated."*[29].

"*CER is being developed by regression analysis between a dependent variable and one or more independent variables*"[28]. The process of developing the model is simply put as follows:

1. Dependent variable, in this case, price/cost being calculated or gathered by historical data and being put on the Y axis;
2. The value of the independent variable, which might correlate or affect the dependent variable (volume/weight/capacity/power/etc.) for each respective dependent variable being put in the X axis;
3. The relationship between Y and X is then described using a mathematical formula.[28]

The step diagram of developing a parametric cost estimating is presented as follows:

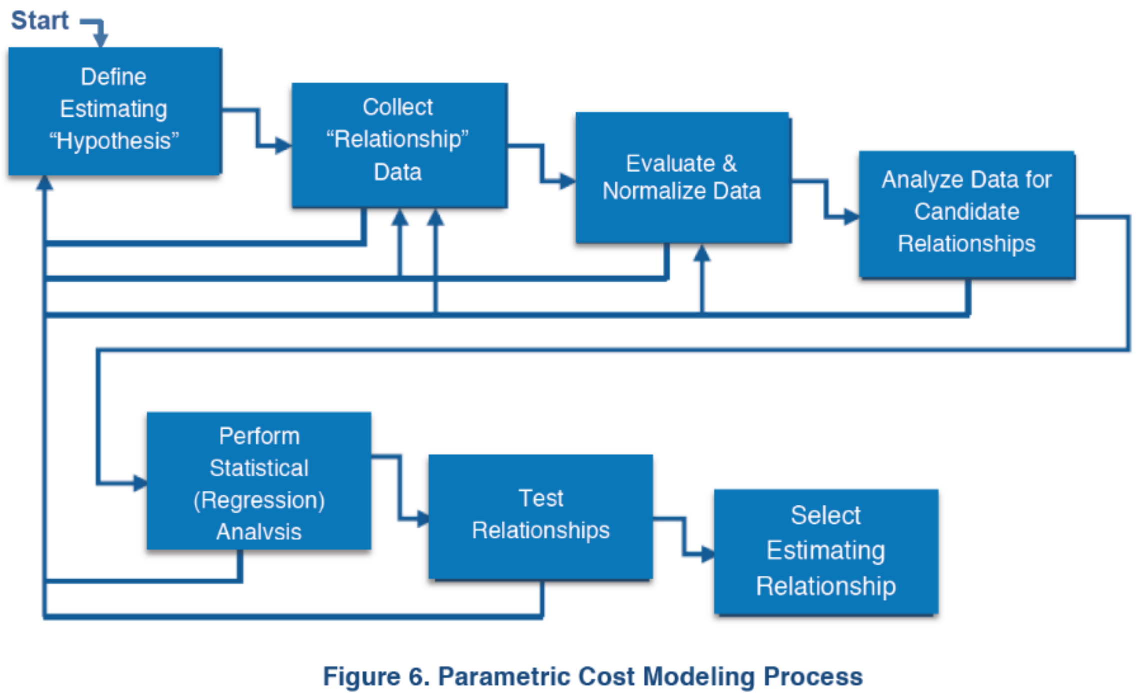


Figure 9. NASA Cost Estimating Handbook Version 4.0 Figure 6. Parametric Cost Modeling Process[28]

[29] U.S. National Aeronautics and Space Administration. (2015). NASA Cost Estimating Handbook V.4.0.

2.3. Step 3 – Development of The Feasible Alternative

2.3.1. Historical Project Data

Data collection is essential and critical when developing a CER, and it affects the validity of the model being generated. As described before, in this study, 36 data points from the project's history were gathered, with specific criteria:

1. Type of Solar Farm: The facility is an On-Grid type (working with utilities), with no additional power storage included in the analysis. The Solar Farm is being installed on ground level (non-elevated) or on the rooftop.
2. Time Frame: The data gathered from the project from 2020 through 2025
3. Source of Data: the data collected from a subsidiary company of NOC in Indonesia, which focuses on NRE (New Renewable Energy). The project is being built in Indonesia.

The collected data was then normalized to account for inflation and the project's location. The template for the raw data-gathering process being used for this project is presented in the table below.

Table 4. Table for gathering historical data

2	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4				Planned						As Built						
5	No.	Project	Capacity of Solar Farm	Start Date	Finish Date	Duration Planned	Auth. for Expenditure (AFE) Cost	Average Cost of Gold	AFE Gold Eqv. (BCWP)	Actual Cost of Work Performed (ACWP)	Average Price of Gold	Actual Cost of Work Performed (ACWP) gold eqv.	Actual Finish Date	Actual Duration	As Built CPI (BCWP/ ACWP)	As Built SPI (BCWP/ BCWS)
6			MWp	MM/YY	MM/YY	Days	USD	USD/Oz.	Oz.	USD	USD/Oz.	Oz.	MM/YY	Days		
7	1	Project 1	1.34	Sep-20	Mar-21	179	1,248,918	1770	706	577,506	1,770	326.35	Sep-21	369	2.16	0.49
8	2	Project 2	2	Sep-20	Mar-21	179	1,678,066	1770	948	761,144	1,770	430.13	Mar-22	563	2.20	0.32
16	3	Project 3	0.05	Sep-22	Sep-22	13	63,712	1801	35	33,673	1,801	18.70	Sep-22	13	1.89	1.00
29	4	Project 4	0.036	Nov-22	Mar-23	125	56,883	1943	29	26,329	1,943	13.55	Jan-23	45	2.16	2.78
36	5	Project 5	1.77	May-24	Sep-24	119	641,375	2387	269	1,222,965	2,387	512.34	Nov-24	188	0.52	0.63
39	6	Project 6	0.025	Apr-23	Sep-23	149	25,864	1943	13	19,417	1,943	9.99	Sep-23	163	1.33	0.91
40	7	Project 7	0.0216	Apr-23	Sep-23	149	38,375	1943	20	16,643	1,943	8.57	Sep-23	176	2.31	0.85
41	8	Project 8	0.048	Apr-23	Sep-23	149	58,308	1943	30	37,100	1,943	19.10	Aug-23	148	1.57	1.01
42	9	Project 9	0.0252	Apr-23	Sep-23	149	33,263	1943	17	19,417	1,943	9.99	Sep-23	154	1.71	0.97
43	10	Project 10	0.077	Apr-23	Sep-23	149	87,424	1943	45	59,637	1,943	30.70	Sep-23	149	1.47	1.00
78	Mean (Average) (P50)						16		97.84			60.71			1.93	0.90
79	Median							17	27.81			13.20			1.80	0.79
80	Standard Deviation						18		213.22			130.48			0.87	0.48
81																
82	P50 + 3σ							23	1202.81			649.83			4.70	2.05
83	P50 + 2σ						23		989.58			519.35			3.83	1.57
84	P50 + σ							22	776.36			388.87			2.96	1.08
85	P50 (Mean)						19		563.14			258.39			2.09	0.60
86	P50 - σ							25	349.92			127.91			1.21	0.12
87	P50 - 2σ						26		989.58			519.35			3.83	1.57
88	P50 - 3σ							27	1202.81			649.83			4.70	2.05
89																
90	Upper Specification Limit = Median or Mean (your choice) +5%						2		102.73			63.75			1.98	0.95
91	Lower Specification Limit = Median or Mean (your choice) -5%							21	92.94			57.68			1.88	0.85

Explanation for each cell presented as follows:

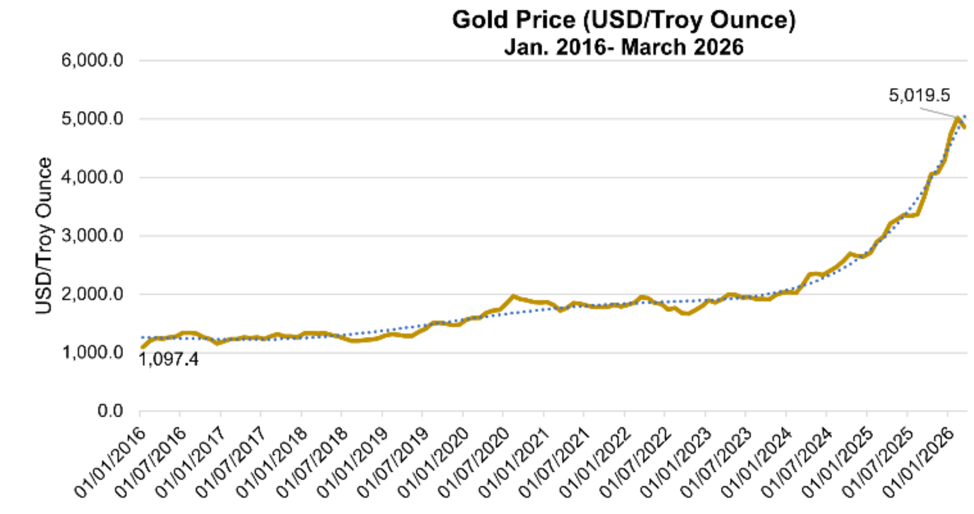
(4.0) No. : number of project lists
(4.1) Project: name of project that has been made anonymous
(4.2) Capacity of Solar Farm: capacity of solar farm installed in MWp
(4.3) Start Date Project Start Date, the issuance of the work order/notice to proceed
(4.4) Finish Date: Planned Finish Date, the date of the project prescribed to be in the operation stage.
(4.5) Duration Planned: Planned duration in days for completion of the project (BCWS)
(4.6) Authorization for Expenditure (AFE) Cost: the original approved budget, then normalized for geographical effect by applying CCI (Construction Cost Index) to DKI Jakarta,
(4.7) Average cost of gold (planned): the price of gold at the mid-year of planned construction time

(4.8) AFE Gold Equivalent (BCWP): the weight of gold equivalent to AFE in ounces(oz), (28.35 gr/oz)
(4.9) Actual Cost of Work Performed (ACWP): the total cost of the project finished
(4.10) Average price of Gold (As Built): the price of gold at the mid-year of actual construction time
(4.11) Actual cost of work performed (ACWP) gold equivalent: the weight of gold equivalent to ACWP in ounces(oz), (28.35 gr/oz)
(4.12) Actual Finish Date: the finish date of the project
(4.13) Actual Duration: the duration of the project
(4.14) As Built CPI (BCWP/ACWP): Cost performance Index (BCWP/ACWP) equivalent to (Authorization for Expenditure Cost / Actual of Work performed)
(4.15) As Built SPI (BCWP/BCWS): Schedule Performance Index (BCWP/BCWS) equivalent to (Duration Planned/Actual Duration)
(4.16 & 4.19) Mean (P50): average of the data being measured
(4.17) Median: median of the data being measured
(4.18) standard deviation: standard deviation of the data being measured
(4.20) Upper Specification Limit (USL): upper boundary for performance target, specified on contract document. For this paper, a +5% of the median value is used.
(4.21) Upper Specification Limit (USL): lower boundary for performance target, specified on contract document. For this paper, -5% of the median value is used.
(4.22 to 4.27) control limit, based on the range of standard deviation (0 to ±3Sigma or σ)

2.3.2. Gold Price Data and Forecasting

For purposes of normalizing and predicting the cost of a solar farm project, valid gold price data is needed. Gold has long been used to preserve value as a safe haven and is often used as an inflation hedge[30]. While the price of a product/service changes over time in fiat currency, its price relative to its gold-weight equivalent is somewhat stable.

[30] Binh, N. T. T. (2024). Comparative Analysis of Gold, Art, and Wheat as Inflation Hedges. *Journal of Risk and Financial Management*, *17*(7). https://doi.org/10.3390/jrfm17070270



Year	Average Price
2016	1,248.34
2017	1,257.13
2018	1,269.14
2019	1,392.18
2020	1,769.59
2021	1,799.58
2022	1,800.80
2023	1,942.74
2024	2,387.04
2025	3,434.78
2026	4,875.39

*2026 for 3 month average (Jan. to Mar. 2026)

Figure 10. Gold Price (Jan. 2016 to March 2026) [30]

The yearly average gold prices data and the gold price curve from Jan. 2016 to March 2026 shown earlier were derived from the World Gold Council's monthly gold prices [31], and are used for analysis in this paper. 10-Year data (from 2016 to 2026) is being processed to view the trend in gold prices and as a basis for normalized project prices across different timeframes.

The Gold Price data is being analyzed using the @RISK Time Series Feature by Lumivero software to generate forecasted prices through 2028. "*The data being processed using 3 (three) time series functions: ARMA (autoregressive moving average) processes, GBM (geometric Brownian motion) and its variation, and the ARCH (autoregressive conditional heteroscedasticity) process and its variation.*"[32]. AIC (Akaike Information Criterion) is used to select the best model, which was generated by the program (in this case, the ARMA, MA(1) model is the best)[33].

[31] World Gold Council.(2026).*Gold Spot Prices*. https://www.gold.org/goldhub/data/gold-prices
[32] Time series functions. (n.d.). lumivero.com. https://help-risk.lumivero.com/v8/en/@RISK/Function/Time-Series-Functions.htm
[33] Ahmad.(2023). *Why Akaike Information Criterion (AIC) is a better tool than ACF and PACF for identifying lags in time series analysis?*. https://medium.com/@iamryanahmad/why-akaike-information-criterion-aic-is-a-better-tool-than-acf-and-pacf-for-identifying-lags-in-a86cf6ac63d2

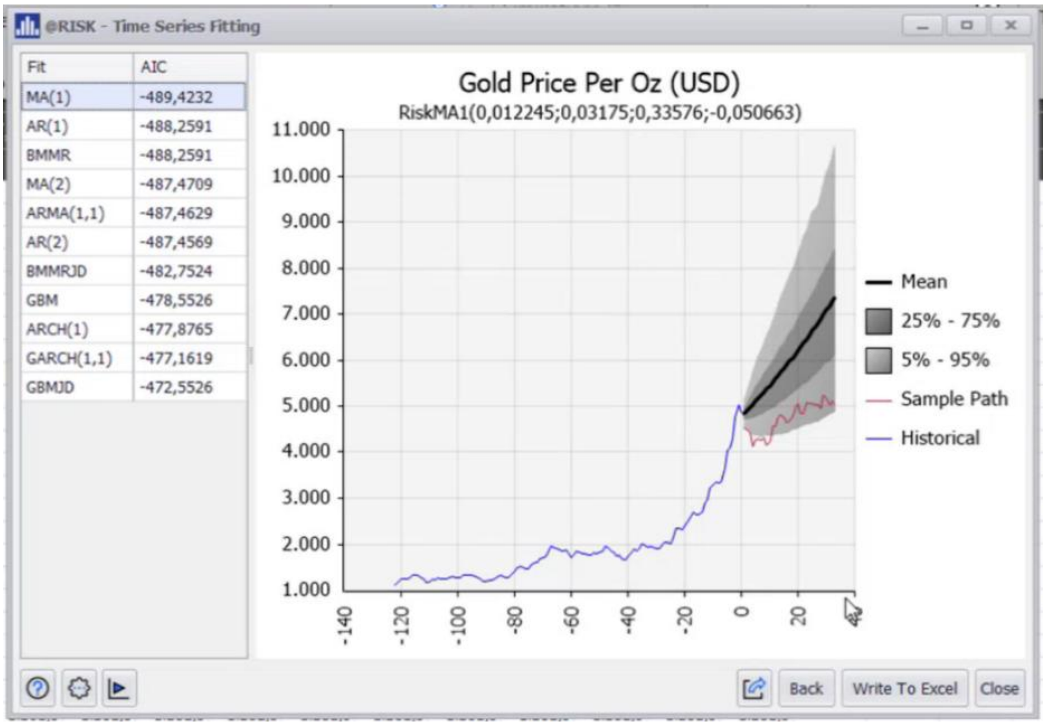


Figure 11. @RISK Time Series processing Gold Price (Jan. 2016 to March 2026)

The model results and forecasted gold price are shown in Figure 12. The forecasted price is presented with 5% to 95% probability. For cost estimation, a 80% probability is used.

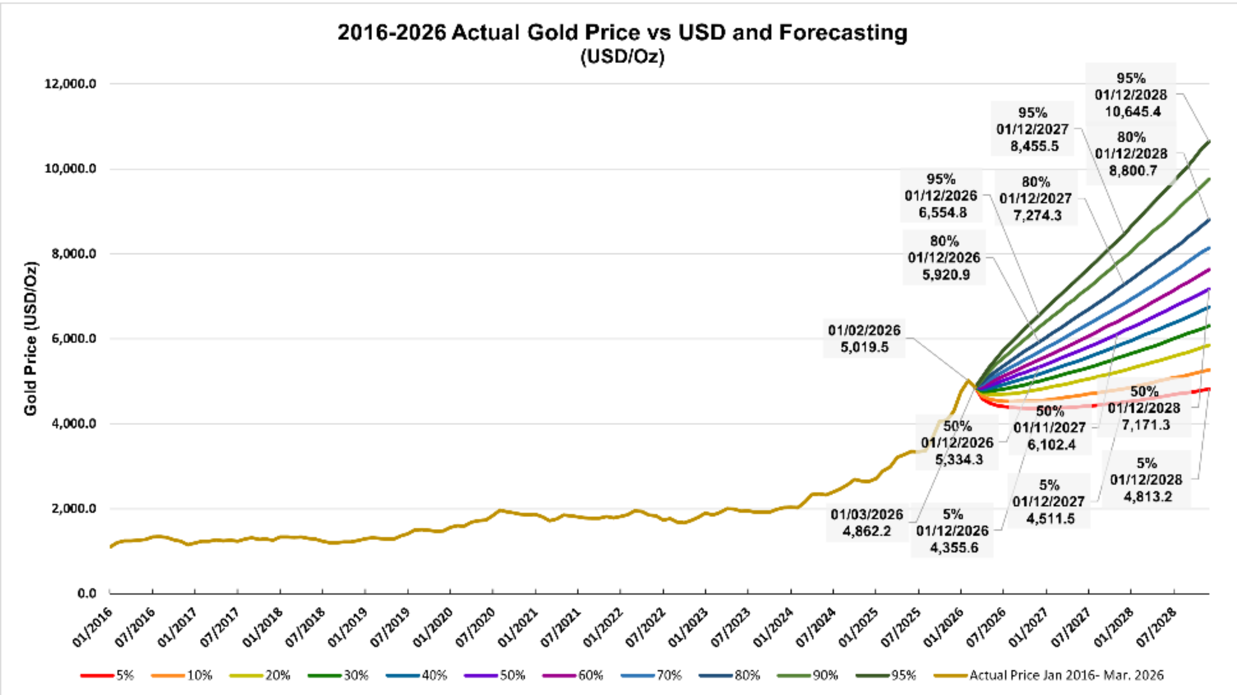


Figure 12. Actual & Forecasted Gold Price (Jan. 2016 to Dec. 2028)

2.3.3. Model Formulation

After the data were gathered and normalized, a mathematical model of the relationship between the solar farm's installed capacity and the project's cost can be generated. Four models/mathematical equations were formulated and assessed for their fitness to the normalized project price (in ounces of gold). To account for changing prices over the time of project deployment, a second formula was introduced to escalate the price. The formula takes the year of deployment as input and produces the price of gold for that year. The basic formula shape is presented as follows:

$$C(x,y) = f(x).\,g(y)$$

Equation 1 – basic formula

C : cost of the project (USD)
x : installed solar farm capacity (MWp)
y : year of installation (2020 to 2028)
f (x) : cost of project (for x MWp) in troy ounce of gold
g (y) : price of gold in year y (2020 to 2028)

2.3.3.1. Gold price formulation (g (y))

Using the trendline function in Microsoft Excel®, the actual gold prices data from 2020 to 2026 and the forecasted (80% probability) from 2026 to 2028 are plotted to find the equation that best fits.

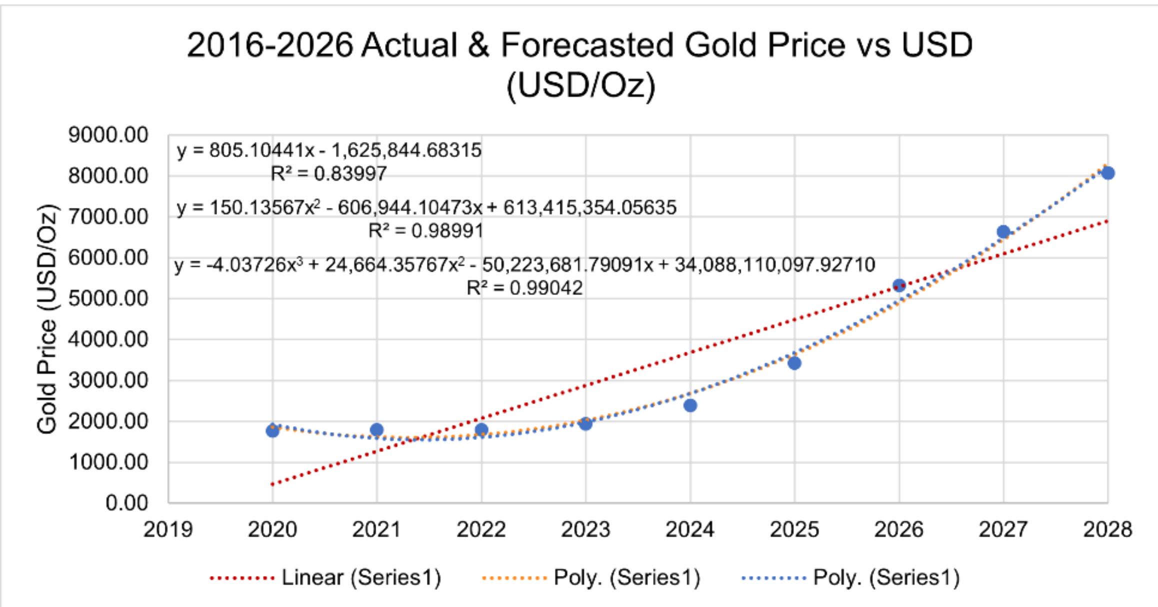


Figure 13. Gold Price Function 2020-2018 (Jan. 2016 to Dec. 2028)

Polynomial 2nd order being chosen to mimic the price of gold (USD/Oz) for the period of 2020 to 2028 (although 3rd order has higher R^2, the complexity of the function vs its accuracy compared to 2nd order is minuscule), the formula gives high R^2=0.9899, thus it can be inferred :

$$g(y) = 150.13567y^2 - 606{,}944.10473y + 613{,}415{,}354.05635$$

Equation 2 – Formula for Gold Price

g (y) : cost of gold in year y (2020 to 2028)
y : year of installation (2020 to 2028)

For manual calculation, instead of using the formula above, the table below can also be used as a reference for the average gold price from 2020 to 2028.

Table 5. Yearly Average Gold Price (Actual & Forecasted)

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028
Gold Price (USD/Oz)	1769.59	1799.58	1800.80	1942.74	2387.04	3434.78	5320.73	6646.38	8078.07

2.3.3.2. Cost of project formulation

Four models/mathematical equations were formulated and assessed for their fitness to the normalized price (in ounces of gold).

a. **Model 1 – Linear Model**
The linear model is expressed as follows:

$$f(x) = C_1 + C_2x$$

Equation 3 – Linear Model

f (x) : cost of project (for x MWp) in troy ounce of gold
x : Installed Capacity of Solar Farm (MWp)
C_1 & C_2 : coefficient to be estimated

b. **Model 2 – Power Model**
The power model is expressed as follows:

$$f(x) = C_1 + C_2x^{C_3}$$

Equation 4 – Power Model

f (x) : cost of project (for x MWp) in troy ounce of gold
x : Installed Capacity of Solar Farm (MWp)
C_1, C_2 & C_3 : coefficient to be estimated

c. Model 3 – Logarithmic Model

The Logarithmic model is expressed as follows:

$$f(x) = C_1 + C_2 \log(x)$$

Equation 5 – Logarithmic Model

f (x) : cost of project (for x MWp) in troy ounce of gold
x : Installed Capacity of Solar Farm (MWp)
C_1 & C_2 : coefficient to be estimated

d. Model 4 – Exponential Model

The Exponential model is expressed as follows:

$$f(x) = C_1 + C_2 \exp(C_3 . x)$$

Equation 6 – Exponential Model

f (x) : cost of project (for x MWp) in troy ounce of gold
x : Installed Capacity of Solar Farm (MWp)
C_1, C_2 & C_3 : coefficient to be estimated

2.4. Step 4 – Selection of The Criteria

2.4.1. Model Validation

Each of the model being generated need to be evaluated for its accuracy (how well the model fits) and ease of use. Model validation will be based on R-Square (R^2) and Mean Squared Error (MSE), as these are the most commonly used statistical methods.

2.4.1.1 Coefficient of Determination (R^2)

"*R^2 or coefficient of determination is considered as a summary measure that indicates how well the regression line fits the data.*"[34], how well the independent variables explain the dependent variable.

R^2 is calculated as:

$$R^2 = 1 - \left(\frac{SS_{res}}{SS_{tot}}\right)$$

Equation 7 – R^2 Formula

[34] Romeo, G.(2020). *Elements of Numerical Mathematical Economics with Excel Static & Dynamic Optimization*. Elsevier.

SS_{res} : the sum of squared residual (sum of squared estimate of errors, differences between actual data and calculated/estimated value)

SS_{tot} : the total sum of squares (the sum of all squared products of differences between the observation data and the overall means)

Interpretation :

- The value of R^2 ranges from 0 to 1
- A higher R^2 value (closer to 1) implies a more successful regression model.
- For R^2 values ranging from 0 – 0.25, it means weak correlation, for R^2 values ranging from 0.25 – 0.64, it means moderate correlation, and if R^2>0.64, it means strong correlation[35]

2.4.1.2. Mean Squared Error (MSE)

Mean Squared Error (MSE) is the average squared value between the calculated /estimated value and the actual data /observation value. The higher the MSE is, the farther the observation data is from the calculated/estimated value, and vice versa.
MSE is calculated as:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2$$

Equation 8 – MSE Formula

Interpretation :

- The value of MSE ranges from 0 to infinity
- A larger value of MSE implies a further regression model from observation/actual data, reflecting a lack of accuracy, and vice versa.

FINDINGS

3.1. Step 5 – Analysis of Alternative

3.1.1. Historical Project Performance

The project data (36 in the population) is being traced to the CPI-SPI graph for assessment. Certain control limits are introduced:

a. Upper and Lower Specification Limit (USL and LSL)

[35] Devore, J.(2010). *Probability and Statistics for Engineering and the Sciences 8th Edition*.CENGAGE Learning.

These limits are specified in the contract, the target that has to be achieved to categorize the project as a successful one; the boundary for CPI and SPI is ±5% (0.05) from a perfect score 100% (1.0)

b. Upper and Lower Control Limit (UCL and LCL)
Derived from statistical analysis, this one shows how the data spreads from its mean value, how concentrated/consistent the data is. UCL specified as +3σ (3xsigma) and LCL specified as -3σ (3xsigma).

The graph separated into 4 (four) quadrant based on combination of CPI and SPI values, they are: **Upper Right Quadrant** (SPI>1, CPI<1) means ahead of schedule and over budget, **Lower Right Quadrant** (SPI>1, CPI>1) means ahead of schedule and under budget, **Lower Left Quadrant** (SPI<1, CPI>1) means behind schedule and under budget and the last one is **Upper Left Quadrant** (SPI<1, CPI<1) means behind and over budget. After tracing project data, it can be inferred that the projects were executed mostly behind schedule and under budget (Lower Left Quadrant). The late delivery of the project (Low SPI) means the need for control and monitoring of project performance, especially to the subcontractor, as the project is mostly done via 3rd party (The company hires a subcontractor to erect the facility, then the company sells the electricity to the end user/another company).

For CPI, the under budget doesn't always mean good execution, the excess value of CPI happened because there is a gap on planning (a combination of the decision on size of facilities that highly optimistic and the cost estimate that tend to overestimate) and execution/realization (the facilities being deployed below the size that planned before, the cost of the project lower than initially estimated). In conclusion, targeting the bullseyes, the SPI efficiency needs to be improved by ±19%, and the CPI efficiency needs to be improved by ±77%.

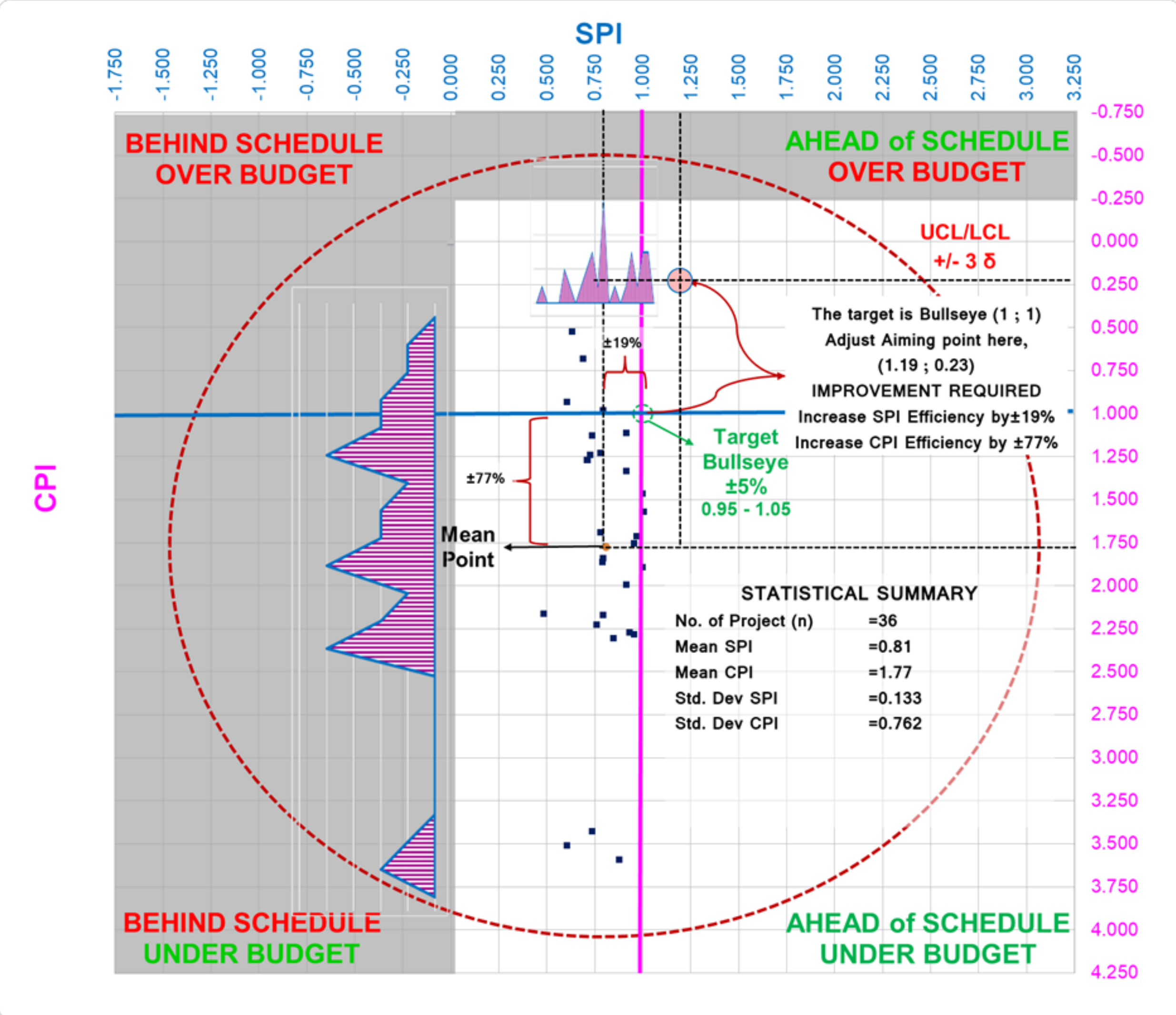


Figure 14. Project Historical Performance SPI-CPI

3.1.2. Formula for Solar Farm Project

For processing, the Excel add-in Solver® is used; the tool optimizes a solution based on user-defined constraints. In this case, we optimize to minimize the MSE value for each function. The developed function of the cost of the project in Troy ounces of gold for every model type is presented as follows:

Linear Model :

$$f(x) = 5.586 + 241.490x$$

Equation 9 – Linear Model – Cost of Construction in Oz of Gold

Power Model :

$$f(x) = 278.675x^{0.811}$$

Equation 10 – Power Model – Cost of Construction in Oz of Gold

Logarithmic Model :

$$f(x) = 336.001 + 193.365\log(1.598x)$$

Equation 11 – Logarithmic Model – Cost of Construction in Oz of Gold

Exponential Model :

$$f(x) = 73.911e^{x}$$

Equation 12 – Exponential Model – Cost of Construction in Oz of Gold

f (x) : cost of project (for x MWp) in troy ounce of gold
x : Installed Capacity of Solar Farm (MWp)

Table 6. Summary of Model Formulation

Parameter	(1) Linear	(2) Power	(3) Logarithmic	(4) Exponential
Basic Formula = Cost(x) =	$C_1 + C_2.x$	$C_1 + C_2.x^{C3}$	$C_1 + C_2.\log(C_3x)$	$C_1 + C_2.\exp^{C3.x}$
C_1	5.586	0	336.001	0
C_2	241.490	278.675	193.365	73.911
C_3	N/A	0.811	1.598	1
Number of Sample (n)	36	36	36	36
Standard Error	42.311	37.268	44.083	85.497
Mean Square Error (MSE)	1816.977	1428.828	7114.773	10495.935
Root Mean Square Error(RMSE)	42.626	37.800	84.349	102.450
Median Absolute Error (MAE)	1.602	2.723	61.109	63.841
Max Error	172.372	161.883	181.412	463.486
R^2	0.920	0.937	0.862	0.744
Adjusted R^2	0.918	0.935	0.858	0.737

3.1.1. Linear Model

- The model has the 2nd-lowest Standard Error, MSE, RMSE, and Max Error; and also gives the lowest MAE. This fact indicates that the model is a good fit.
- The model yields an R^2 of 0.92, the second-highest, indicating a strong correlation between the model and the actual data.

3.1.2. Power Model

- The model has the lowest Standard Error, MSE, RMSE, and Max Error, and the 2nd-lowest MAE. This fact means the model is the best fit among 3 others.
- The model yields an R^2 of 0.937, the highest and strongest with actual data among the models.

3.1.3. Logarithmic Model

- The model has the 2nd-highest Standard Error, MSE, RMSE, and Max Error. The Power and Linear Model are superior in this parameter.
- The model yields an R^2 of 0.862, lower (<0.9) than those of Linear and Power models, indicating a weak correlation between the model and the actual data.

3.1.4. Exponential Model

- The model has the highest Standard Error, MSE, RMSE, MAE & Max Error. This fact means the model is the worst among all.
- The model yields an R^2 of 0.744, the lowest, which means a weak correlation between the model and the actual data.

Based on the statistical assessment, the **Power Model** appears to be the most appropriate of 3 other alternatives presented, as it has the highest R-Square value, and the lowest Standard Error, MSE, RMSE, and Max Error.

Step 6 – Selection of the Preferred Alternative

The Power model is chosen as the most appropriate because it has the highest R-Square value, and the lowest MSE, RMSE, and Max Error. The formula for the cost of the Solar Farm project becomes:

$$C(x,y) = f(x).\,g(y)$$

$$C(x,y) = (278.675x^{0.811})(150.13567y^2 - 606{,}944.10473y + 613{,}415{,}354)$$

Equation 13 – Formula for the Cost of Solar Farm Construction

C : cost of the project (USD)
x : installed solar farm capacity (MWp)
y : year of installation (2020 to 2028)
f (x) : cost of project (for x MWp) in troy ounce of gold
g (y) : price of gold in year y (2020 to 2028)

As shown above, the equation comprises the cost of the project in troy ounces of gold (f(x)) and the actual or forecasted gold price with confidence level 80% (P-80) using @Risk Time Series feature presented with (g(x)). It provides a quick tool for the company to estimate the future project cost and build confidence, as the model has already been developed using internal historical company data.

Step 7 – Performance Monitoring

To ensure the model is relevant to current conditions and that the results produced by the formula are accurate, it is essential to regularly monitor and update the equation. Several actions must be taken.

7.1. Continuous Data Gathering and Benchmarking

As the company evolved and executed more projects, documenting project parameters, performance, and lessons learned became the top priority for enhancing the processes. Benchmarking against previous project data or other entities doing similar business is also one way to expedite the learning process.

7.2. Model Improvement & Feedback Loop

The data being gathered can be processed to improve the model accuracy. Continuous improvement and the integration of the most current real-world data are important. *"CERs established early must be periodically examined to ensure that they are current throughout the life of an estimate and that the input range of data being estimated is applicable to the system"*[28].

CONCLUSION & RECOMMENDATION

Since research has been done on this topic, we now need to revisit the question stated before and answer each of them.

1. Has the historical project data SPI & CPI met the quality metrics of validity, precision, reliability, and accuracy, and can it be used to improve future project performance? From Figure 14, the data have moderate accuracy and precision, as well as moderate validity and reliability. The data can be used for forecasting, updating the database, and improving with caution. From Figure 14, aiming for the bullseyes, the SPI efficiency needs to be improved by ±19%, and the CPI by ±77%.

2. What is the appropriate parametric model for the cost estimate of the Solar PV project based on its plant size and year of deployment?

From this research, the parametric model for the cost estimate of the Solar PV project based on its plant size and year of deployment is presented as follows:

$$C(x,y) = (278.675x^{0.811})(150.13567y^2 - 606{,}944.10473y + 613{,}415{,}354)$$

Equation 13 – Formula for the Cost of Solar Farm Construction

C : cost of the project (USD)
x : installed solar farm capacity (MWp)
y : year of installation (2020 to 2028)
f (x) : cost of project (for x MWp) in troy ounce of gold
g (y) : price of gold in year y (2020 to 2028)

The usage of the model is subject to certain conditions, which are :

i. The cost is estimated for the project in Indonesia (DKI Jakarta); IKK needs to be applied for other locations within Indonesia.
ii. The type of solar farm is Ground-mounted/rooftop, On-Grid type (No Storage facilities).
iii. The facility size being studied is 0 to 2.5 MWp; it is advised to only use this model for facilities within that range.
iv. The function g(y) is forecasted using the gold price from 2016 to 2026 and forecasted to 2028. The deployment year (y) range is 2026-2028. A recent forecasted gold price, or the most current one, can be applied to enhance the accuracy of the estimate, or to estimate a value outside the range.

3. Has the proposed model met the requirements for CAPEX Class 4, and can it be utilized in the feasibility study phase?

   To be classified as Class 4 Level Estimate that can be used for feasibility study purposes, the estimate produced by a parametric model is expected to have accuracy of L: -15% to -30% and H: +20% to +50%. For the formula generated in this study, the resulting accuracy range is between -26,67% and +50%; therefore, the formula is within the specified range and applicable for use in Class 4 Estimate.
   By applying the parametric model developed in this study, the company can expedite decision-making and quickly and efficiently evaluate new business schemes.

FOLLOW ON RESEARCH

Solar energy is a relatively new technology, and it presents a vast area of study that can become a great, meaningful topic. A topic on the cost of solar farms and the types of applications, such as floating solar farms and agrisolar (dual-purpose land for solar farms and farming), can be a nice case study.

Another interesting topic for solar farms is their potential to increase energy sustainability, independence, and resiliency, and the study of their life-cycle and economic aspects is also worthwhile. The possibilities are endless.

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APPENDIX

If any data is needed for next study purposes or verifying the processes, the reader can contact the author by email at tengkurizkifm@gmail.com

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Tengku Rizki Fahril Mukti is an engineer with nine years of professional experience in oil and gas sectors. During his career, he has an experience as a Design Engineer and Cost Estimator. He has been involved in several projects, including Fuel Terminal Facilities, Piping/Pipeline Construction, and Jetty Facilities throughout Northern and Southern Sumatera.

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