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Analysis of solar photovoltaic utilization in industrial sector for improving competitiveness in the smart grid

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Abstract

The industrial sector is the second largest energy consumer after the household sector, which is 35% of the total energy demand. In Indonesia by 2050, electricity demand in this sector will reach 660 TWh (Terra-watt hours) or 10 times from 2015. Moreover, the electricity tariff tends to keep increasing in the range of 3 - 10 percent per year. This paper develops solar PV rooftop financial scenario and analyzes the sensitivity factors to the LCOE (Levelized Cost of Energy), thus gaining the financial advantages and competitiveness in Smart-grid System. The results show that the solar PV rooftop in the industrial sector can provide an annual electric power circa 16% of the total electricity demand.

The payback period also can be achieved under 10 years, with return on investment continues to increase until the 20th year with positive NPV (Net Present Value). The NPV is derived from the electricity cost savings without using solar PV systems. The increased installed of solar PV capacity will boost the NPV. However, it is limited by the available land area and the economic value of the solar PV systems cost.

Keywords: Financial scenario, Solar PV, Industrial Sector, LCOE, Smartgrid

1. Introduction

The concept of smart grid is integration of several emerging technologies such as power generation technology dominated by renewable energy sources; energy storage technology including electric cars, utility grid infrastructure, weather sensors technology and loads which is bundled by information communication technology (ICT) to achieve balancing power between supply and demand, and making benefit for producers, customers, and prosumers in residential as well as industrial sectors. The smart grid concept [1], [2], [3] has been implemented in some countries [4], [5], especially in industrial sector [6], [7]. The Industry sector is the second largest energy user after the household sector, which is 35% of the total energy demand in Indonesia. With the abundant solar energy potential and increasing energy demand especially in the industrial sector, it is an opportunity for the industrial sector to develop solar photovoltaic (PV) power plants to enhance the competitiveness of an industry in the smart grid. In 2050, it is projected that the demand for electrical energy in the industrial sector in Indonesia will reach 660 TWh or 10 times from 2015 [8]. While utility grid's electricity tariffs in this sector tend to increase, thus solar PV in the industrial sector has a strategic role to ensure modern sustainable energy services and could increase financial benefits and enhance competitiveness. One approach is to implement the solar photovoltaic roof-top [9], especially in the industrial sector. Here are four factors that underline that statement.

1. Load profile and industrial location. Electrical energy consumption in industry sector during the day is high, this condition in accordance with the solar cycle. The duration of sun-irradiation which is possible to generate maximum power in tropical region is around 4 to 5.5 hours a day which ranges from 9:30 am to 2:00 pm. It shows that a portion of industrial consumption during the day that can be supplied from the

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solar PV roof-top.

2. Convenience of infrastructure and the experts.

The industrial areas generally consist of factory areas, parking, offices, and employees' homes with large roofs, supported by relatively uniform shapes, materials, and roof angles. The development of facilities and infrastructure in industrial areas, installation of electrical installations, as well as lightning protection system and grounding has also met high security standards. The condition of electricity infrastructure in the industrial area is usually stable, reliable, and the quality of power is well designed [10]. These conditions become the absolute requirement of the entry of the solar PV system into the utility power grid. In addition, the Industrial area is also supported by professional human resources, the presence of staff who is responsible for handling electrical trouble-shooting.

3. Environmental and social impacts. The massive utilization of solar PV in industrial areas will reduce fuel use, air pollutant and noise levels around the workplace can be reduced significantly.

4. Cost savings potential. The installation of solar PV roof-top in the industrial sector can provide long-term financial benefits, due to the increasing utility-grid tariffs in contrary the Cost of Energy (COE) of solar PV is cheaper.

The aim of this paper is to find out the optimum Levelized Cost of Electricity (LCOE) by developing several financial scenarios of solar PV investment in the industrial sector. The discussion of LCOE for financial analysis of various power plants (renewable energy or fossil fuels) has been reviewed by many researchers; but for solar PV power plant [11], [12], [13], [14] was analyzed in detail.

2. Methodology, Data, and Concept

This research uses triangulation method which is a combination between scientific method and naturalist. There are several steps that require scientific analysis, such as statistics, calculation and simulation of Levelized Cost of Electricity (LCOE) [15], [16]. This research is a predictable scientific method, due to develop planning of increasing the capacity of solar power plants to achieve its economy of scale and competitiveness in different conditions (scenarios).

Meredith, Shafer, and Turban mentioned five steps of the modelling process [17]: a. Identification of problems or opportunities; b. Model formation; c. Data collection; d. Model analysis follows its validation; e. Implementation and project management. It that can be shown in the fig.1 below.

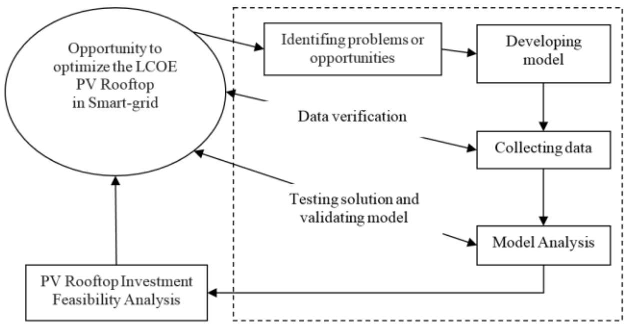

Fig 1. Modeling Process of LCOE PV rooftop in smartgrid

The model is a techno-economic calculation with its sensitivity analysis that can be used by stakeholders has the authority to make final decisions at the level of conceptual selection. The built model can be probabilistically analyzed by stochastic simulation in the SAM software application (System Advisory Model).

2.1 Input Process Output (IPO)

Fig. 2 below shows the parameters and variables needed to determine the feasibility of PV Rooftop system. These parameters and variables include the potential of solar power, usage life, investment cost, operating and maintenance costs, and interest rates.

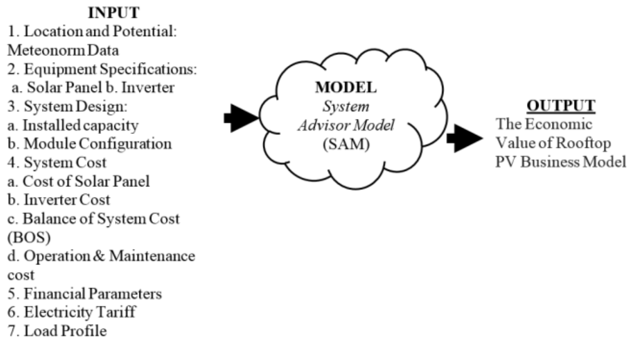

Fig 2. Input-Output scheme of SAM simulation

The use of probabilistic method requires a model with stochastic method first. The model starts with the calculation of LCOE and the feasibility of PV Rooftop system investment. The rate of decline in investment costs of PV Rooftop systems, the trend of increasing electricity prices. The raw data as mentioned in fig. 2 is calculated by using optimization of SAM. Then, a stochastic test of the variables mentioned in fig.3 is used to see the correlation of those variables with the level of PV Rooftop investment. Stochastic simulated input data is statistically calculated using Minitab.

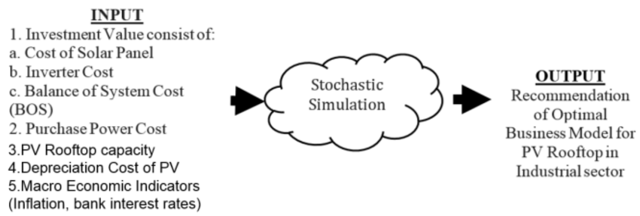

Fig. 3 Input-Output scheme of stochastic simulation

The stages of model analysis can be described in the work flow as seen in fig.4.

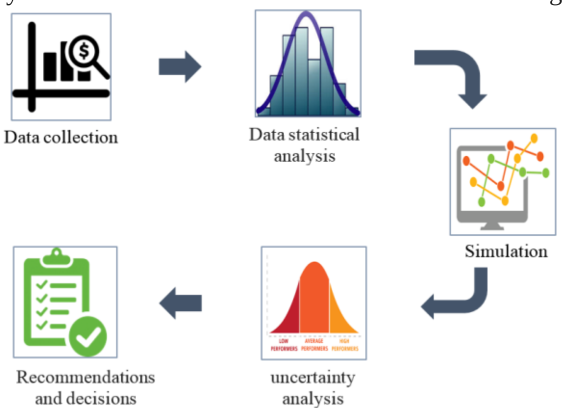

Fig 4. Phase of analysis model

Stochastic simulations are performed to examine the effect of uncertainty on one or more input variables on the output metric. For example, stochastic simulations can be used to explore how uncertainty levels in component installation costs affect energy costs over the life of a project.

In the SAM application, to perform stochastic simulations, the steps should be performed:

1. Select one or more result variables to be used as output metrics for analysis, and one or more input variables.

2. For each input, select the probability distribution from the list (normal, log-normal, etc.) and SAM generate samples with parameter values using the Latin Hypercube Sampling (LHS) method. For an analysis involving more than one input parameter, we can define an optional correlation coefficient for modeling the restricted input parameter.

Before performing stochastic analysis, it is necessary to analyze the input data collected to see what kind of data is normally distributed, lognormal, and others. In this process Minitab is used to test the data normality and correlation, to obtain the average input and standard deviation as input for stochastic simulation by SAM.

2.2 Solar radiation data

This data includes daily global irradiance, daily temperature, radiation, precipitation, sunshine duration, and other data. Fig.5 shows the diffuse radiation and global radiation data in Indonesia is around 70 - 80 kWh/m^2 and 40 – 65 kWh/m^2, respectively.

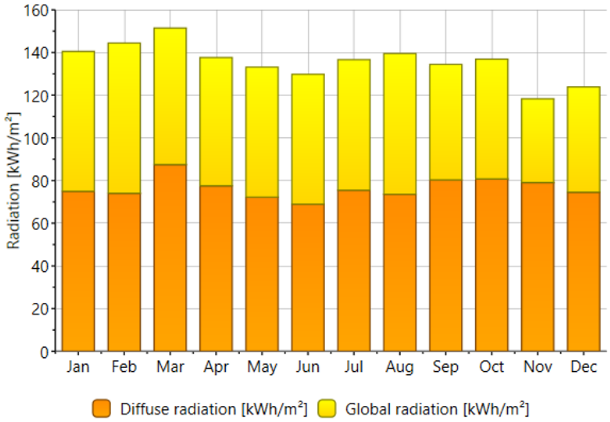

Fig 5. Diffuse and global radiation data

2.3 Data of solar PV component

To determine the total installed cost or total PV Rooftop investment, the data of solar PV component are calculated statistically as shown in table 1 below.

Table 1. Module, Inverter, and BOS (Balance of System) in USD/W$_p$ *(watt peak)*

	Module PV	**BOS**	**Inverter**
Min	0,44	0,015	0,03
Maks	0,86	1,7	0,17
Mean	0,62	1,00	0,087
Std Deviasi	0,074	0,34	0,025
Data Input SAM	0,6	1,05	0,1

2.4 Utility electricity tariff in industrial sector

The data of electricity tariff for Industrial Sector (case in Indonesia). The electricity generated from the solar PV Rooftop with net metering scheme, Solar PV Rooftop is not sold to the utility grid at a special price. The revenue generated from the installed Solar PV Rooftop comes from savings on electricity consumption payments to the utility grid company. Therefore, it is necessary to analyse the utility grid tariff applied to an industry to know the amount of savings.

2.5 Financial and macro economy data

The financial data required include the following:
a. The prime lending rate is around 12.5% per annum.
b. The rate of inflation since 2010-2016 is 5.5%.
c. Discount rate is circa 7.39%

2.6 Industrial load profile

It is very important parameter to run the simulation, the load curve is defined as a curve that describes the use of load (electricity consumption) in a time (annual, weekly, even daily). In this case the cement Industry data has been recorded in one week see Fig.6

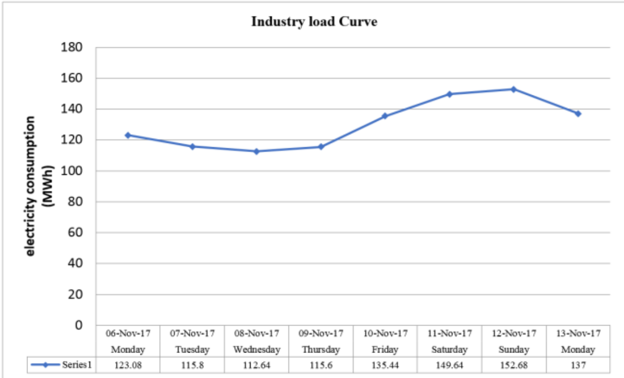

Fig 6. The Industry load curve

3. Result and Analysis

3.1 Validation data of PV system

To analyse the economic feasibility of the solar PV rooftop using SAM and Stochastic simulations. This model is expected to fulfil the principle of how to "produce electricity at the lowest possible cost" by finding the lowest LCOE values within some parameters such as maximum Net Present Value (NPV), Payback Period (PBP), and Internal Rate of Return (IRR). The analysis was performed on data that has been identified in the previous discussion. There are 100 samples of data collected and generated. then the data is tested normality with Minitab software. The validation of these data is required to look at the nature of the data (whether normal and no outlier) and obtain the statistical descriptions of each data.

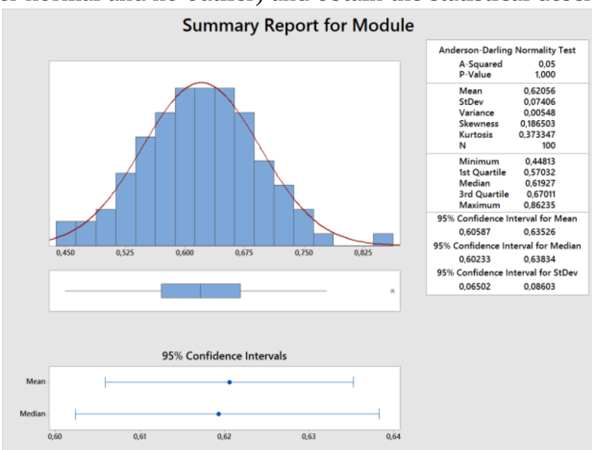

Fig 7. Normality test on PV module cost

Normality Test on Inverter Cost and BOS cost is also through the same process that is sourced from data collection as much as 6 (six) data come from local data which then generated with stochastic simulation and calculated minimum, maximum and average value statistically.

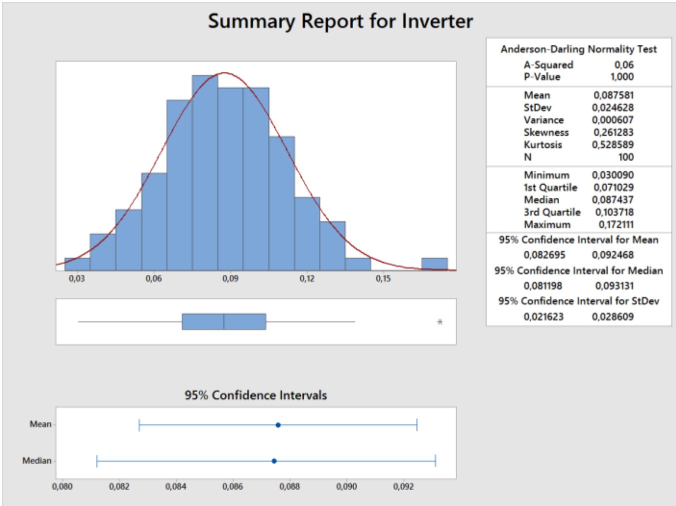

Fig 8. Normality test on inverter cost

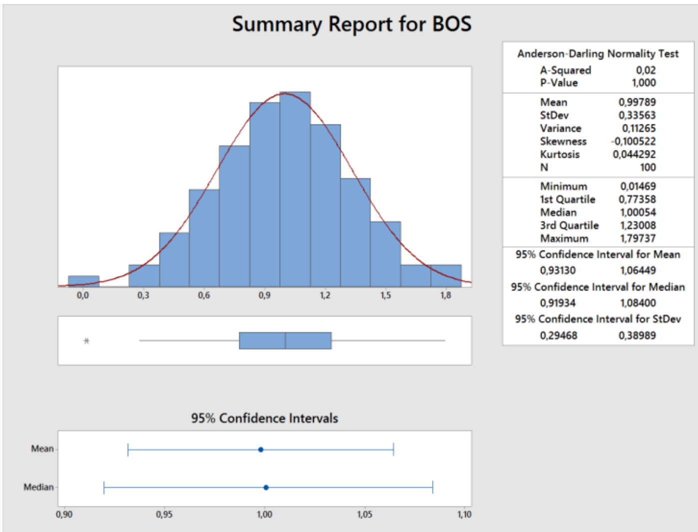

Fig 9. Normality test on BOS cost

The fig. 7-9 can be clearly described of statistics as follow:

1. The average module cost of USD 0.6/W_p, with a standard deviation of USD 0.074/W_p,
2. The average Inverter Cost of USD 0.087/W_p with standard deviation of USD 0.024/W_p
3. The average BOS cost of USD 0.997/W_p with standard deviation of USD 0.336/W_p

3.2 Trend analysis

Furthermore, the trend of decreasing total installed cost of PV systems has been carried out from 2010 until 2017, see fig. 10.

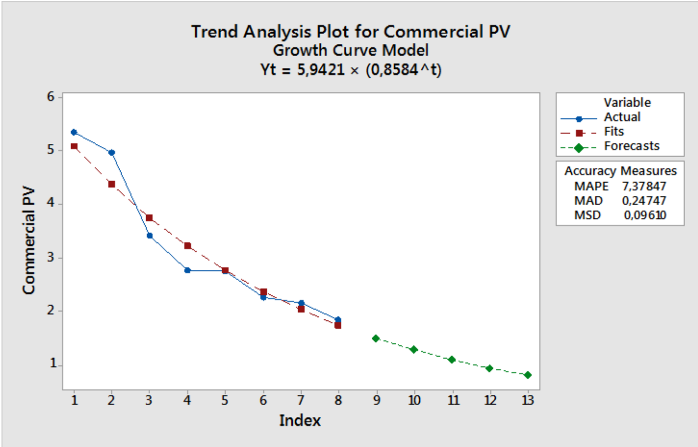

Fig 10. Trend of the total installed cost of PV system

Trend analysis of electricity tariffs is required to select the best forecasting model to see the magnitude of the trend of electricity tariff change from year to year as input electricity escalation in SAM software.

From the data of electricity tariff for 6 years (2010-2015), conducted trend analysis with Linear model, S-Curve, and Growth Curve Model. Measurement The best model accuracy is done by looking at the smallest MAPE, MAD and MSD values. Selected Model Growth Curve as the right model to predict the tendency of Electricity Tariff in the coming years. The rate graph of the trend in electricity rates as can be seen in fig. 11.

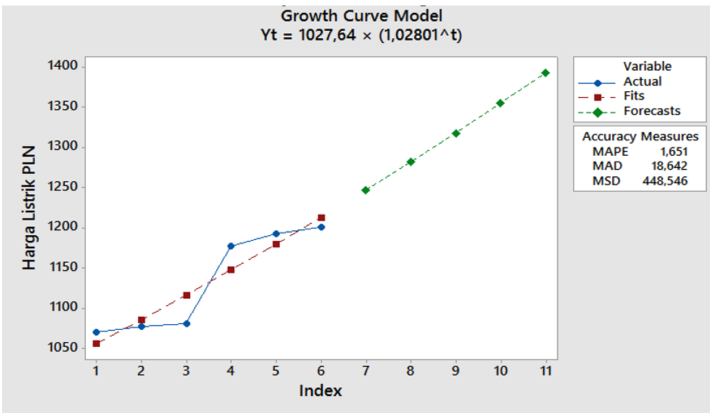

Fig 11. Trend of utility electricity tariff in industry sector

3.3 The Grid Parity

The grid parity happened from the intersection of two graphs between the LCOE graph of solar PV and the utility tariff of the industry. Fig. 12 shows the trend of PV costs continuing to decline year by year, and the tendency of increasing electricity tariffs, the intersection between the two graphs is reached in 2023. This means that PV Costs will be able to compete economically without any intervention in the form government incentives in 2023. Nevertheless, before the achievement of the grid parity PV systems can still compete economically without incentives with innovations in the business schemes described below.

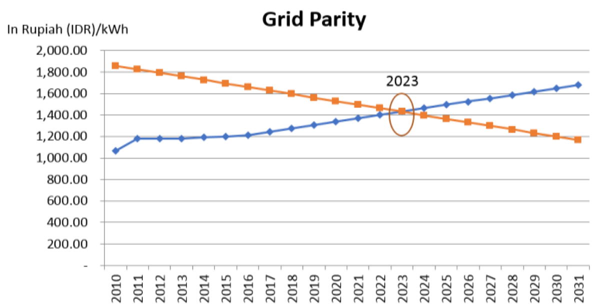

Fig 12. Grid parity

3.4 Developing Scenarios and SAM simulation

The simulation will be done in 3 (three) scenarios, namely: 1. Solar PV Roof-top 200 kW with Net Billing Scheme, where Solar PV roof top's price is higher than utility grid tariff.

2. Solar PV Roof-top 200 kW with Net Billing Scheme with lower Solar PV Rooftop Selling's price than Utility Tariff.

3. Solar PV Roof-top 200 kW with Net Metering Scheme.

Furthermore, as a basis for performing the initial simulation, the feasibility of investing solar PV rooftop with 200 kW capacity is used as a benchmark. The next analysis is the effect of changes on the solar PV rooftop's capacity on the economic value.

The simulation results obtained comparison of NPV values as the table below.

Table 2. Comparison result by three scenarios

Metric	NET BILING 1	NET BILING 2	NET METERING
Annual energy	215,754 kWh	215,754 kWh	215,754 kWh
Capacity factor	12.50%	12.50%	12.50%
First year kWhAC/kWDC	1,093 kWh/kW	1,093 kWh/kW	1,093 kWh/kW
Performance ratio	0.75	0.75	0.75
Battery efficiency	0.00%	0.00%	0.00%
Levelized COE (nominal)	25.52 ¢/kWh	25.52 ¢/kWh	25.52 ¢/kWh
Levelized COE (real)	17.26 ¢/kWh	17.26 ¢/kWh	17.26 ¢/kWh
Electricity cost without system	$238,048	$238,048	$238,048
Electricity cost with system	$218,630	$210,000	$200,252
Net savings with system	$19,418	$28,048	$37,796
Net present value	$-144,145	$-44,059	**$69,076**
Payback period	13.7 years	9.7 years	7.3 years
Net capital cost	$369,293	$369,293	$369,293
Equity	$369,293	$369,293	$369,293
Debt	$0	$0	$0

The simulation results show that the Net Metering scheme achieves positive value of NPV $ 69,076 with a payback period of 8 years. The value of this NPV shows the return value of the project during the analysis period of 20 year.

3.5 Sensitivity analysis of LCOE

This sensitivity analysis is conducted to see how far some input variables influence the change of LCOE value. The greater the LCOE changes to the change of input variables analyzed, it can be concluded that the LCOE value is sensitive to the change of the variable. The input variables include periods of project analysis, investment costs, bank interest rates, the proportion of debt as a source of investment funding, and operational costs.

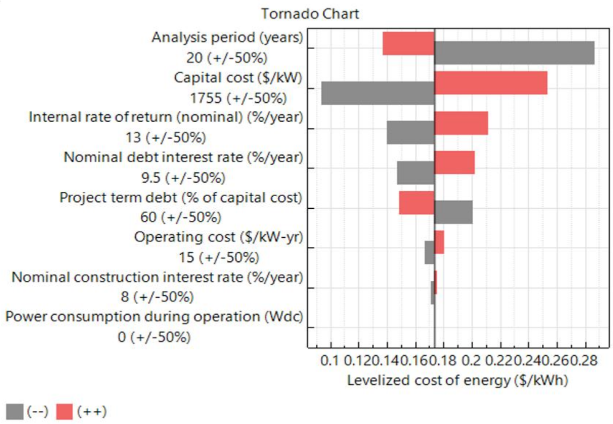

Fig 13. The Tornado Chart of LCOE sensitivity

The Fig. 13 shows the Tornado Chart for sensitivity test on variables consisting of project analysis period, investment cost, IRR, bank interest rate, and project financing percentage derived from loan. From the above sensitivity test, the result of significant variables affecting LCOE value is period of project analysis, and investment cost.

Table 3. Electricity Saving (in IDR – Indonesia Rupiah)

Year	Value of electricity savings (IDR)	Electricity Without System (IDR)	%
0	0	0	-
1	38.277.400	229.395.000	16,69%
2	41.324.276	248.894.000	16,60%
3	44.613.628	270.050.000	16,52%
4	48.164.848	293.004.000	16,44%
5	51.998.736	317.909.000	16,36%
6	56.137.840	344.931.000	16,28%
7	60.606.416	374.250.000	16,19%
8	65.430.680	406.062.000	16,11%
9	70.638.928	440.577.000	16,03%
10	76.261.792	478.026.000	15,95%
11	82.332.208	518.658.000	15,87%
12	88.885.920	562.744.000	15,80%
13	95.961.560	610.578.000	15,72%
14	103.600.128	662.477.000	15,64%
15	111.846.816	718.787.000	15,56%
16	120.749.864	779.884.000	15,48%
17	130.361.712	846.174.000	15,41%
18	140.738.592	918.099.000	15,33%
19	151.941.696	996.137.000	15,25%
20	164.036.480	1.080.810.000	15,18%

Table 3 above shows the energy savings generated by the solar PV rooftop. The saving can be achieved 16 %

4. Conclusion

The utilization of solar photovoltaic, particularly for PV rooftop system, bring a lot of benefits for industry players. The industrial sector has many advantages to implement the PV roof-top due to the electrical infrastructure, facility, security standard and roof wide area compared to residential sector. The result shows that significant variables affecting the LCOE value is period of project and the investment cost. Due to the declining of solar PV's LCOE and contrary the utility grid tariff is rising gradually, the "grid parity" will be occurred around the world, in Indonesia is around 2023. Based on the simulation, the saving potential is circa 16 percent for industries that use solar PV roof-top. This figure will get bigger in the next few years especially after grid parity and the smart-grid era.

Acknowledgment

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