Techno-economic analysis in application of glass solar cell on storey building: A case study of office building

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Abstract. Urban area populated by edifice and storey building can complicate process of electric energy distribution to the middle of city. Citizen reluctance if their settlement passed by transmission network or being built substation, and bigger cost of underground cable than overhead line increases such difficulty level. If there is problem in delivering electric energy, so the city will face electric energy crisis and disrupt society life. One of solution in overcoming that issue is by installation the glass solar cell (transparent solar cell) with thin film material (CdTe) on storey building, which located in the middle of city and its electric energy supplied by PLN. In this study, glass solar cell will be installed in existing building “W” with solar cell area about 6,916 m². Glass transparency level of study object building is 30%, so by installing same transparency level of solar cell can supply maximum electric energy 897,184 kWh/year or equal to 35% electric energy demand of building. Economic feasibility analysis applied in this study, where NPV is IDR 398,961,738, IRR is 7.47% and the payback period is 11 years, so this technology is feasible to be implemented economically. If considering the tilt and azimuth angle of solar cell installation, instalment in B and C side of building generates smaller electric energy than A and D side. This condition caused by bigger reduction on solar irradiation energy that accepted by B side and 67.22% for C side. The usage of glass solar cell contributes to deduct greenhouse gas emission, maximum 732,999 kg/year.

1. Introduction

Urban area develops rapidly and followed by increase of high-rise building construction. Escalation of building quantity intensifies level of electric energy demand. In 2017, it was founded that a hotel building in South Jakarta consumed electric energy about 7.8 million kWh each year and expensed around 9.4 billion Rupiah per year[1]. Since city become more developed, there is difficulty in delivering electric energy to the midst of it. Free space reduction, citizen reluctance in permitting their settlement passed by high voltage overhead line (HV) and extra high voltage overhead line (EHV) or being built substation enhance that adversity. Reluctance of some people towards HV or EHV is due to assume that health hazards exist if they live around it[2].

Metropolitan area tends to expend energy in big portion almost 60 percent of world energy consumption[3]. Dependence of fossil fuel encourages renewable energy implementation, one of them is utilization of solar energy that has abundant potency. There are various kinds of solar panel installation such as rooftop, façade, field, halt, bridge, and so on. In 2016, potential energy of rooftop solar cell in US was estimated 40% of national electric energy sale[4].
Location of solar cell assembly which enable to be connected directly to serviced load is very compatible with city condition that has obstacle in distributing electric energy to the middle of city. Geographically, Indonesia lies in equator line that owns huge solar energy. Average solar irradiation energy in Indonesia achieves 4.8 kWh/m² per day and approximately the value fluctuation is 9 percent in every month[5].

Several types of material are developed for maximizing energy that produced by solar cell. There are five groups of solar cell material, namely Crystalline Silicon, Thin Film, Organic/Polymer, Hybrid PV Cell and Dye-Sensitized[6]. Thin film solar cell is more preferable due to consume fewer production material. Thin film consists of three material categories, namely Amorphous Silicon (a-Si), Copper Indium Gallium Selenide (CIGS), and Cadmium Telluride (CdTe)[7]. CdTe possesses better efficiency rate rather than CIGS, in case it is assembled in high temperature and humidity[8].

Renewable energy applications, specifically for solar cell in building or Building Integration Photovoltaic (BIPV) start to grow increasingly in metropolitan city. This technology tries to perform green energy building by utilization of renewable energy so that it contributes to lessen GHG emission. Research regarding application of vertical solar PV on building façade 120 m and floor area 1296 m² had been undertaken as a part of BIPV concept in Malaysia. Solar PV assembly in west and east side generated larger electric energy, namely 800 MWh/year rather than north and south side, around 400 - 390 MWh/year. Economically, payback period for PV system was 12 years[9].

In 2018, R.K. Putri et al., got investigation result that BIPV on high rise building in Jakarta region was capable of lowering energy consumption of building about 5.97% of electric energy demand. Assembly method of solar cell was on rooftop and façade. The building height was 214.6 m and total area of installation 111,960 m²[10]. Y.U. Putra et al., obtained study result and analysis that by using the same rooftop area and saddle roof, the east and west side of roof acquired larger solar energy than north and south[11].

There is glass solar cell technology (transparent solar cell) that can be performed in BIPV system. This material still enables sunlight to come into building in accordance with its transparency level. It also maintains outside architecture of the building totally. The transparent solar cell is made of nine materials such as Thin Film Photovoltaic (TPV), Near-infrared transparent solar cell, Polymer Solar Cell (PSC), Transparent Luminescent Solar Concentrator (TLSC), Perovskite Solar Cell, Electrophoretic Deposition (EPD) and others. From all those materials, the most developed material is solar cell with thin film type[12]. Solar cell system on BIPV is able to apply on-grid system, where electric energy from network keeps to supply the building constantly. Conversely, it is also known as off-grid system. Certainly, each system has its self excellences.

In this study, it is analysed the integrated solar energy on a building by using on-grid system. Object study is an existing building, where the electric energy supplied by State-Owned Electric Company or PLN’s network normally. Technical analysis is performed, such as the calculation of maximum energy quantity that produced by solar cell. The applied material corresponds to transparency level of installed building glass. Economic analysis such as the net present value (NPV), internal rate of return (IRR) and the payback period are calculated for considering the economic feasibility. Besides, the reduction of greenhouse gas (GHG) emission is estimated to assess the contribution of renewable energy system in green building concept as well.

### 2. Materials and methods

Irradiation data of solar energy is obtained from official website of SOLARGIS. Based on the data, the lowest rate of solar irradiation energy or Global Horizontal Irradiation (GHI) is in February that is 3.816 kWh/m² per day. The highest rate is in September 5.530 kWh/m² per day as displayed in table 1. The location of study object lies in East Jakarta city and the coordinate is -6.242278, 106.876639. The average of GHI in a range of one year at this coordinate is approximately 4.563 kWh/m² per day. In the table 1, the rate of GHI begins to increase gradually from January and achieves the peak rate in September. After that, it declines moderately from October to January. Geographically, the position of study object is in south hemisphere.
Table 1. Solar energy irradiation

| Month       | Global Horizontal Irradiation (GHI) kWh/m² per Day |
|-------------|-----------------------------------------------------|
| January     | 3.931                                               |
| February    | 3.816                                               |
| March       | 4.553                                               |
| April       | 4.557                                               |
| May         | 4.466                                               |
| June        | 4.301                                               |
| July        | 4.606                                               |
| Augustus    | 5.234                                               |
| September   | 5.530                                               |
| October     | 5.180                                               |
| November    | 4.480                                               |
| December    | 4.101                                               |

In figure 1 shown GHI rate hourly in September, where in this month is the time that generates maximum solar irradiation energy in one year. The maximum rate is at 10 to 11 AM, namely 752 Wh/m². Meanwhile, the minimum rate of solar irradiation energy is at 5 PM, as much as 23 Wh/m². Solar irradiation energy starts from 6 AM, and it rises significantly to peak rate at 10 AM. Then, the energy decreases slowly until 1 PM and it drops sharply to 5 PM.

![Global Horizontal Irradiation Hourly](image)

Figure 1. Global horizontal irradiation

Solar cell is installed on the building “W” which is an existing building and it located in the middle of the big city. Installation on A side of building is at azimuth angle (orientation) 129°, and area of
Installation is 1271 m². On B side of the building is at azimuth angle 39°, area of installation is 2045 m². Then, on C side of building is at azimuth angle 309°, where installation area is 1584 m². The last, on D side which has azimuth angle 219° and installation area is 2016 m². The 0° of azimuth angle faces the North Pole orientation. The installation is adjusted to building side that already installed by glass.

Electricity system configuration of glass solar cell (transparent solar cell) as displayed in figure 2. The system is on-grid type. It applies hybrid inverter that equipped with power backup facility such as battery (optional), if it is needed in the future. However, in this study, the glass solar cell system does not include power backup battery on technical design or economic calculation.

There are some transparency levels of glass solar cell that available in the market. The range is 10% with power output 72W till 80% with power output 16W. Nevertheless, in this study, the applied transparency level is 30% with power output 56W per module. Energy produced by the glass solar cell can be calculated when the value of solar irradiation energy, the efficiency of solar cell module and the area of solar cell installment are provided. The value of solar cell energy (Eₘₜₐₜ) is linear towards array PV efficiency (η), global irradiation energy (E₉₉₉₉) and area of PV array (A_array)[13].

\[ E_{th} = \eta \times E_{glob} \times A_{array} \]  

(1)

Eₘₜₐₜ is in kWh, η is in decimal, E₉₉₉₉ is in kWh/m² and A_array is in m².

If taking into consideration of the azimuth angle (γ) orientation as well as tilt (β) of solar cell installation, so solar irradiation energy that generated by glass solar cell will change. The total value of irradiation energy on the tilt surface Hₜ calculated by using the formula 2.

\[ H_T = H_B + H_D + H_R \]  

(2)

H_B is direct irradiation, H_D is diffusion irradiation, whereas H_R is reflected irradiation or albedo[14]. Electric energy yielded by glass solar cell is linear to solar irradiation accepted by solar cell module.

Economic analysis is undertaken to ensure the investment feasibility of design from economic point of view. The analysis parameters are the net present value (NPV), internal rate of return (IRR) and payback period. NPV is method for counting net cash flow in the present time by implementing money equivalence concept. Investment is categorized to be feasible when NPV value will be greater than zero or positive. Otherwise, in case NPV is lower than zero or negative, then it is assumed to be unfeasible[15]. NPV value calculated by the formula 3. NPV is supposed as present value of income cash flow subtracted by present value of outcome cash flow or present value of all expected cash flow[16].

\[ NPV = \sum_{t=1}^{N} \frac{CF_t}{(1+r)^t} \]  

(3)
Where CF<sub>t</sub> is cash flow, ‘t’ is time period, N is time period number and ‘r’ is interest.

The internal rate of return (IRR) is method in evaluating the investment feasibility pertinent to cash flow capability level on return investment in percent per time per period[15]. It can be obtained by equation 4 as following.

\[
IRR = \frac{iNPV_+ + \frac{NPV_+}{NPV_+ + NPV_-}}{} (4)
\]

Where IRR is internal rate of return (%). iNPV<sub>+</sub> and iNPV<sub>-</sub> are interest rate for positive NPV and negative NPV respectively. Payback period is the analysis method in acquiring the return period of investment when turnover condition is satisfied. Payback period is obtained by equation 5.

\[
Payback \ period = n + \frac{a-b}{c-b} \times 1 \ year \quad (5)
\]

The ‘n’ is the last year when amount of cash flow does not satisfy initial investment yet. The ‘a’ is amount of initial investment. The ‘b’ is amount of investment cash flow in year-n and the ‘c’ is amount of investment cash flow in year n+1[17].In the table2, investment cost of glass solar cell system is presented.

### Table 2. Investment cost of glass solar cell

| No | Description                          | Cost         |
|----|--------------------------------------|--------------|
| A  | Material                             |              |
| 1. | Glass solar cell (transparent solar cell) | IDR 5,258,737,500 |
| 2. | Hybrid solar inverter                | IDR 583,941,600   |
| 3. | Distribution panel                   | IDR 513,024,000   |
| 4. | Cable                                | IDR 337,915,200   |
| 5. | PV combiner box                      | IDR 25,550,000    |
| 6. | Material support & accessories       | IDR 591,166,629   |
| B  | Installation of glass solar cell     | IDR 1,344,700,000 |
| C  | Dismantling of existing glass material | IDR 1,037,400,000 |
|    | Total                                | IDR 9,692,434,929 |

Table 2 shows that the biggest cost of glass solar cell system constitutes the material cost of glass solar cell. It is 54% of total investment cost. Afterwards, it also represents that investment costs consist of material cost, installation cost and dismantling of existing building glass.

The applied interest rate is 7%. It is based on the corporate interest rate of City Bank, issued in April 2020. The data is registered in official website of Financial Service Authority or “Otoritas Jasa Keuangan”[18].

Energy of glass solar cell also contributes to reduce greenhouse gas emission in urban area. Emission factor of GHG for electricity system of Java-Bali region is 0.817 kg/kWh. The usage of this value is due to the building electric energy is normally supplied by electric network of Java-Bali[19].
Reduction of GHG stipulated by comparing the amount of emission that possibly generated from conventional generator which supply electric energy to the building. Emission total of GHG calculated as formula 6[20].

\[ \text{Emission total of GHG} = \text{Electricity of Emission Factor (EF)} \times \text{Total amount of electricity generation}. \]  

(6)

3. Results and discussion

The calculation result of energy produced by glass solar cell based on formula 1 is as indicated in table 3.

| Month    | Energy Produced by Solar Cell (kWh) |
|----------|-----------------------------------|
| January  | 65,621                            |
| February | 57,553                            |
| March    | 75,841                            |
| April    | 73,690                            |
| May      | 74,227                            |
| June     | 69,387                            |
| July     | 76,917                            |
| August   | 87,137                            |
| September| 89,288                            |
| October  | 86,599                            |
| November | 72,076                            |
| December | 68,311                            |
| Yearly   | 897,184                           |

Table 3 displays the electric energy value that generated by glass solar cell in every month, namely from January till December. The electric energy value that obtained in one year duration is also represented. Electric energy is acquired by installing glass solar cell with transparency level 30% where each modul is able to produce power as much as 56W.

Based on the table 3, the lowest electric energy is yielded in February around 57,553 kWh, meanwhile the biggest value is in September, namely about 89,288 kWh. The glass solar cell can produce electric energy as much as 897,184 kWh in one year. In March until May, the generated electric energy does not fluctuate significantly.

If considering the azimuth angle (\( \gamma \)) orientation as well as tilt (\( \beta \)) of solar cell installation there is a degradation of total value of solar irradiation energy that received on each building side. It is namely 55.76% on A side, 66.35% on B side, whereas degradation on C side is 67.22%. The last, degradation on D side is 57.74%. Accordingly, the biggest degradation of received solar irradiation energy is when the installation of glass solar cell performed in B side and C side of building. In other words, the lowest electric energy will be produced if installation is on B side and C side of the building.

From economic analysis, the calculation results of NPV, IRR and payback period for glass solar cell is shown in table 4.

| Description | Value |
|-------------|-------|
| Design life (n) | 25 years |
Interest rate (i)  7%
Initial investment (II)  IDR 9,692,434,929
NPV  IDR 398,961,738
IRR  7.47%
Payback period  11 years

In the table 4, the design life is as long as 25 years. The calculation results of NPV is positive value, namely IDR 398,961,738. Based on the analysis with NPV method, so implementation of the glass solar cell is feasible.

From computation with IRR method, it is obtained that the IRR value is about 7.47 %. It is higher than applied interest rate 7%. Economically, by using this method, solar cell investment satisfies the feasibility. From payback period view, payback period is 11 years where it is shorter than investment period or design life (25 years), so that investment is also feasible.

Energy produced by glass solar cell is able to reduce the electric energy usage of building “W” that supplied by electric network of PLN. For transparency level of glass solar cell 30% (corresponding to transparency level of building glass), it generates the electric energy as much as 35% per year from the total of electric energy demand of building. In the Table 5 provided the electric energy cost in every month for building “W” as well as the saving that acquired by installing glass solar cell.

In table 5 presented Electric energy cost of building “W” and cost saving by using glass solar cell.

**Table 5.** Electric energy cost of building “W” and cost saving by using glass solar cell

| Month   | Total Cost of Building Electric Energy “W” | Transparency 30% |
|---------|-------------------------------------------|------------------|
|         |                                           | Cost Saving      | Saving Percentage |
| January | IDR 245,703,432                           | IDR 73,241,543   | 30%              |
| February| IDR 213,166,040                           | IDR 64,279,468   | 30%              |
| March   | IDR 231,093,105                           | IDR 84,619,306   | 37%              |
| April   | IDR 236,124,542                           | IDR 82,152,567   | 35%              |
| May     | IDR 245,912,032                           | IDR 82,445,441   | 34%              |
| June    | IDR 205,728,529                           | IDR 77,069,359   | 37%              |
| July    | IDR 238,053,746                           | IDR 85,746,661   | 36%              |
| Augustus| IDR 236,530,990                           | IDR 97,200,985   | 41%              |
| September| IDR 239,710,287                          | IDR 99,227,034   | 41%              |
| October | IDR 251,881,790                           | IDR 96,328,522   | 38%              |
| November| IDR 258,062,547                           | IDR 80,145,189   | 31%              |
| December| IDR 235,369,130                           | IDR 75,955,424   | 32%              |
| Total   | IDR 2,837,336,171                         | IDR 998,411,499  | 35%              |

Based on table 5, the total cost of electric energy for building “W” is 2.4 billion Rupiah per year. By using glass solar cell, the cost saving is almost 1 billion Rupiah for one year. The biggest
consumption of electric energy is in October and the smallest consumption is in June. The highest saving contribution of electric energy from glass solar cell is in September around 99.2 million Rupiah. It equals to 41% of electric energy cost in that month. Meanwhile, the lowest contribution is in February, approximately 64.3 million Rupiah. It is equivalent to 30% of electric energy in that month.

Energy of glass solar cell participates in reducing greenhouse gas emission in urban area. Based on formula 6, the GHG value enables to be lowered as much as 732,999 kg/year or almost 733 tons/year.

4. Conclusion
Application of glass solar cell (transparent solar cell) on the building can become one of solution alternative in overcoming the difficulty of distributing electric energy to the middle of the city. Technically, energy of glass solar cell supplies as much as 897,184 kWh/year or 35% of the electric energy demand of building that normally powered by electric network of PLN. If taking into consideration of the tilt angle and azimuth angle (orientation) in installing the glass solar cell, so electric energy generated in B and C building side is lower than A and D building side. It is caused by B and C side get higher degradation toward solar irradiation energy rather than received by A and D side. Economically, the glass solar cell with 30% transparency is feasible to be implemented. The NPV value is IDR 398,961,738, IRR is 7.47% and payback period is 11 years. The glass solar cell deducts GHG emission, maximum as much as 732,999 kg/year or almost 733 tons/year.

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