

# Optimum Renewable Fraction for Grid-connected Photovoltaic in Office Building Energy Systems in Indonesia

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## ABSTRACT

This paper analyzes influences of renewable fraction on grid-connected photovoltaic (PV) for office building energy systems. The fraction of renewable energy has important contributions on sizing the grid-connected PV systems and selling and buying electricity, and hence reducing net present cost (NPC) and carbon dioxide (CO<sub>2</sub>) emission. An optimum result with the lowest total NPC for serving an office building is achieved by employing the renewable fraction of 58%, in which 58% of electricity is supplied from the PV and the remaining 42% of electricity is purchased from the grid. The results have shown that the optimum grid-connected PV system with an appropriate renewable fraction value could greatly reduce the total NPC and CO<sub>2</sub> emission.

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## 1. INTRODUCTION

Exploitation and utilization of renewable energy resources for buildings are parts of Indonesia's energy conservation policies to provide and develop renewable energy in order to reduce fossil fuel consumption and hence, reducing CO<sub>2</sub> pollution. Renewable energy systems are capable of powering buildings without connection to a utility grid. However, connecting renewable energy to the utility grid offers more reliable electricity supply [1], [2].

In recent years, the PV technology prices tend to decline [3], [4], while the prices of conventional fossil fuel-based electricity have been gradually increased. Moreover, the growth rate of grid-connected PV electricity systems rises significantly every year and dominates the PV electricity market [5].

According to the report in [6], [7], office buildings in Indonesia spend 15.2 TWh of electricity and require electrical energy, on average, by 250 kWh/m<sup>2</sup>/year. The total electricity consumption is dominated by air conditioning and lighting equipments. These two components consume about 80% of the total electricity for the buildings. However, most of the electric power demands of the office buildings are still dependent to the utility grid.

From an economic standpoint, the difference between prices of electricity purchased and sold is a substantial determinant in designing a grid-connected PV system [8], [9]. In the grid-connected PV system, an office building is hooked up to both the utility grid and the PV system. The building is billed if the electric energy consumption is in excess of the amount generated by the PV. The building could be supplied by a portion of energy from the PV during sunny days, and powered from the utility grid during nights or on cloudy hours when the PV output is insufficient. If there is any surplus electricity from the PV, it will be sent to the utility grid. In such way, the grid-connected system could use real-time electricity pricing methods via net-metering mechanisms for the billing process [10], [11]. It gives customer benefits by reducing the monthly bill [12], if the size of the PV in the grid-connected PV system is properly estimated. The parameter

describing the portion of electricity produced by the PV in the grid-connected PV system is the renewable fraction.

There are many investigation reports about economic point of grid-connected PV systems for buildings. Davi et al. [13] investigated on different scenarios of investment costs, discount rates and electricity tariffs for buildings with grid-connected PV system. Ayadi et al. [14] reported their economic analysis on payback period and internal rate of return for university building with grid-connected PV system. Economical and environmental analysis on grid-connected PV system for institutional building was investigated by Allouhi et al. [15]. Kazem et al. and Omar et al. investigated economic feasibility of grid-connected PV system for home buildings [16], [17]. Other economic analysis of the paid incentives and selling the electricity for economic profit of PV grid-connected system on buildings was reported by Orioli et al. in ref [18].

However, they did not analyze the influences of renewable fraction in their works. This paper intends to fill the gaps observed in the literature concerning the analysis of the effects of renewable fraction values on the size of a grid-connected PV system for the office building in order to suppress the total NPC and CO<sub>2</sub> emission of the electricity production.

## 2. BACKGROUND INFORMATION

### 2.1. Load Profile

The load profile of a typical office building in Indonesia is presented in Figure 1. The load profile indicates that the peak load of the office building is about 849 kW with energy consumption of 9,165 MWh/day. The average annual electricity consumption is 250.96 kWh/m<sup>2</sup>/year.

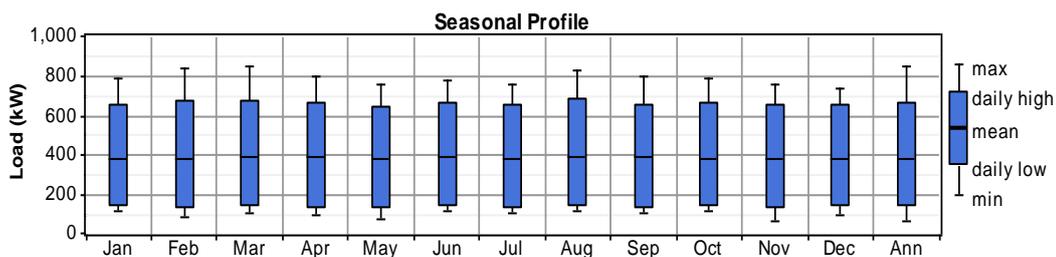


Figure 1. Monthly load profile of office building

The electricity demand in office building varies slightly each month, and this is dependent to the business activities, instead of the weather conditions. Office building in tropical climate region, such as Indonesia, has high cooling demands. Air conditioning is the major electricity consumers in the office building. Lighting and office equipments (laptop PCs, desktop PCs, printers, photocopiers) are other significant source of electricity use in the office building. The small amount of electricity is required by miscellaneous equipments such as: lifts, water pumps, and ventilation fans. Figure 2 shows the distribution of electricity usage in the office building.

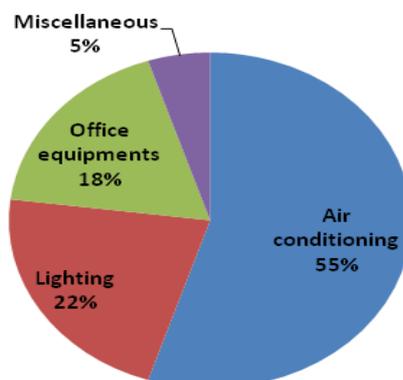


Figure 2. Electricity consumption distribution

## 2.2. Solar Radiation

In this work, HOMER [19] is employed for simulations. Solar radiation (in kWh/m<sup>2</sup>/day) and the clearness index (a dimensionless number between zero and one) are used as the input data as shown in Figure 3. The average solar radiation in Pontianak (Indonesia) is 5.12 kWh/m<sup>2</sup>/day according to data accessed from NASA [20]. Solar radiation is high during February through to September, while it is relative low in January, October, November and December.

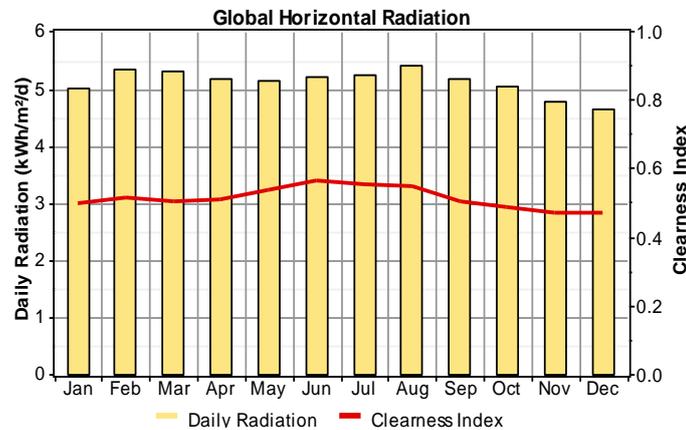


Figure 3. Solar radiation data

## 3. SYSTEM CONFIGURATION

The grid-connected PV system as seen in Figure 4 consists of PV array, inverter, grid, and load. The grid-connected PV system does not need batteries as the energy storage. The surplus electricity produced by the PV is sold to the grid. On the other hand, the grid will cover all electricity loads when the PV could not supply electricity at night or during cloudy hours

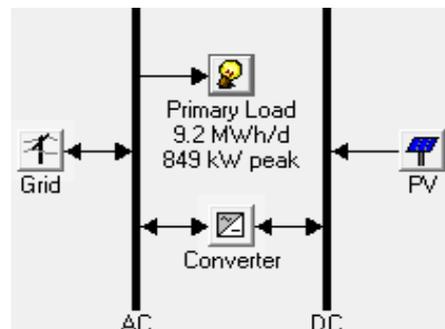


Figure 4. System configuration

### 3.1. PV Array

The PV array is sized dependent to the peak load demand and the renewable fraction required. The capital investment of PV arrays including construction and installation costs is set at \$ 2000/kW [21]. The estimated O&M cost is \$ 10/kW per year, while the PV array lifetime is 20 years. The PV cost data is provided in Table 1.

Table 1. PV and Inverter Data

	PV	Inverter
Lifetime	20 yr	15 yr
Efficiency	90%	98%
Capital cost per kW	\$ 2000	\$ 200
Replacement cost per kW	\$ 1500	\$ 150

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O & M cost per kW per year      \$ 10      \$ 15

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### 3.2. Inverter

A grid-connected PV system for commercial-scale applications (10kW-2MW) usually uses non module-level power electronics (MLPE) inverters as the DC-to-AC interfaces. Currently, the average price of the inverter is \$170/kW [22], and it becomes \$200/kW if the labor cost is included. Inverter O&M cost is estimated to be \$ 15 kW/yr and it is considered to last for 15 years [22], [23].

The inverter size depends on DC-to-AC ratio ( $R$ ). If the PV array's DC rating is higher than the inverter's AC rating, the DC-to-AC ratio will be larger than 1 ( $R > 1$ ). The DC-to-AC ratio for both residential and commercial PV systems is set to  $R=1.15$  as recommended by Fu et al. in NREL [22], in order to increase the inverter utilization during the sunniest periods. Over sizing inverter would increase costs to the system but also increase the amount of electricity generated. Although there are no batteries to store excess electricity generated by the PV, but no excess electricity would be dump, since all electricity is used by loads and sold to the grid. The inverter data is also summarized in Table 1.

### 3.3. Pricing

Electric price is regulated by the government via tariff adjusmant mechanisms which is based on nominal exchange rate, fossil fuel price, and inflation rate [24]. Non-subsidized electricity tariff at off-peak hours is \$ 0.113/kWh. The tariff is multiplied by a constant of  $k$  for shoulder and peak hours, where  $1.4 \leq k \leq 2.0$ . In this study, the price of electricity bought from the grid is set to \$ 0.113/kWh. The price becomes \$ 0.158/kWh and \$ 0.226/kWh at shoulder and peak hours, respectively. The demand rate (in \$/kW/month) for off-peak, soulder, and peak hours are also based on the regulation. The sellback rate for PV electricity is \$ 0.108/kWh as ruled in [25]. Selling and buying the electricity generated by the PV system is a part of Indonesia government policy in order to enhance utilization rate of renewable energy resources for electricity.

### 3.4. Total Net Present Cost

The total capital cost  $C_c$  for the grid-connected PV system is given by

$$C_c = C_{c,grid} + C_{c,PV} + C_{c,inv} + C_{c,f} \quad (1)$$

Where  $C_{c,grid}$ ,  $C_{c,PV}$ ,  $C_{c,inv}$  and  $C_{c,f}$  are the capital costs of grid, PV, inverter, and other system capital cost, respectively. The operating and maintenance cost  $C_o$  is the operating and maintenance costs of all components and the other system operating and maintenance cost, which is defined as follows:

$$C_o = C_{o,grid} + C_{o,PV} + C_{o,inv} + C_{o,f} \quad (2)$$

The total NPC is the present value of all the costs minus the present value of all the revenues over the project lifetime. The costs include capital costs, operating and maintenance costs, and the costs of buying electricity from the grid. Revenues include the revenues of selling electricity to the grid and the salvage value. The total NPC can be defined as

$$C_{NPC,tot} = C_{ann,tot} / CRF(i, R_{proj}) \quad (3)$$

Where  $C_{ann,tot}$  is the total annualized cost,  $i$  is the annual real interest rate (%),  $R_{proj}$  is the project lifetime (yr), and  $CRF()$  is a function of the capital recovery factor. The capital recovery factor is a ratio to obtain the present value of an annuity. The capital recovery factor is expressed by

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (4)$$

where  $N$  is number of years.

### 3.5. Renewable Fraction

The renewable fraction is the portion of total electricity production which is generated by renewable resources. The equation of renewable fraction is:

$$\text{Renewable Fraction} = \frac{\text{Renewable Electricity Production}}{\text{Total Electricity Production}} \quad (5)$$

#### 4. RESULT AND ANALYSIS

In this paper, the system performance is set at an unmet load of 0%. The office building's electrical load is served by both PV generator and electrical grid. The excess electricity produced by the PV is not dumped, but it is sold to the grid via the net-metering mechanism. The PV array parameters used in simulation are:  $T_{c,NOCT}=47^{\circ}\text{C}$ ,  $\alpha_p=-0.43\%/^{\circ}\text{C}$ ,  $\eta_{mp,STC}=15.67\%$ , and derating factor of the PV,  $f_{PV}=90\%$ . The environmental factors such as ground reflectance and ambient temperature are included into computation in order to obtain accurate results. The ground reflectance is 20% as measured on the location.

##### 4.1. PV Sizes

Figure 5 describes the effect of renewable fraction on the PV size. The renewable fraction of 0% means that all load demand is supplied by the grid without PV penetrations. The renewable fraction of 100% indicates the electrical load is served by a stand-alone PV. However, the stand-alone PV system without energy storage equipments could not be applied for 24-hour electricity service.

Increasing the renewable fraction would reduce the need for electricity from the grid. The higher renewable fraction requires the larger sizes of PV array and inverter in order to supply electricity from the PV to the building. The PV size increases significantly when the renewable fraction is higher than 70%, as shown in Figure 5. At the renewable fraction of 60%, the grid-connected PV system needs 1.7 MW of PV array. It requires 2.45 MW, 3.8 MW, and 7.75 MW of PV arrays for 70%, 80%, and 90% of renewable fraction, respectively. The PV size for renewable fraction of 90% is twice of it is for the renewable fraction of 80%

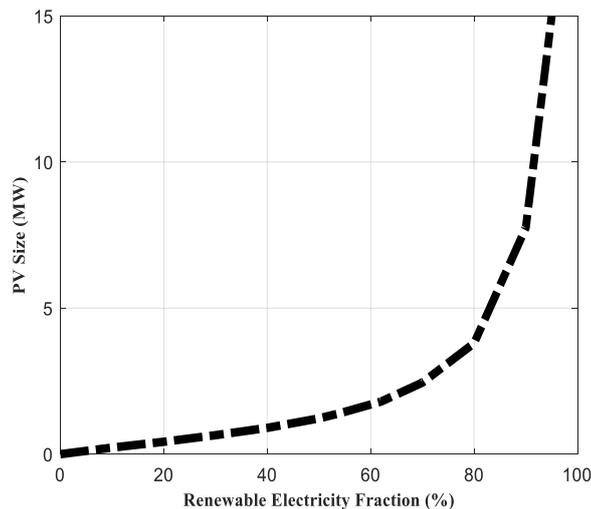


Figure 5. PV size vs. renewable fraction

##### 4.2. Net Purchases

Electricity purchased from and sold to the grid according to the renewable fraction is shown in Figure 6 and 7. The amount of electricity purchased from the grid decreases with increasing of the percentage of renewable fraction of the system. On the other hand, the system could sell more electricity to the grid when the renewable fraction is higher. The difference between the electricity sold and purchased prices is the net purchases. A negative value of the net purchases indicates that the system sells more electricity to the grid than it is purchased from the grid. As shown in Figure. 8, the net purchases value is negative after the renewable fraction becomes greater than 66%. At renewable fraction of 67%, the annually electricity purchased from the grid is 1,667,075 kWh/yr and the electricity sold to the grid is 1,701,991 kWh/yr. This results in the net purchases of -34,916 kWh/yr. However, the high grid sales earned does not mean that the NPC of the system becomes low. The NPC of the grid-connected PV system is indeed not only influenced by the net purchases, but also by the total costs of the PV array and inverter. Melodi et al. [26] observed costs of the PV as renewable energy sources for the grid-connected system. The PV array and inverter have the high initial capital costs. Therefore, the PV and inverter costs and the level of PV penetration contribute to the grid connected PV system costs.

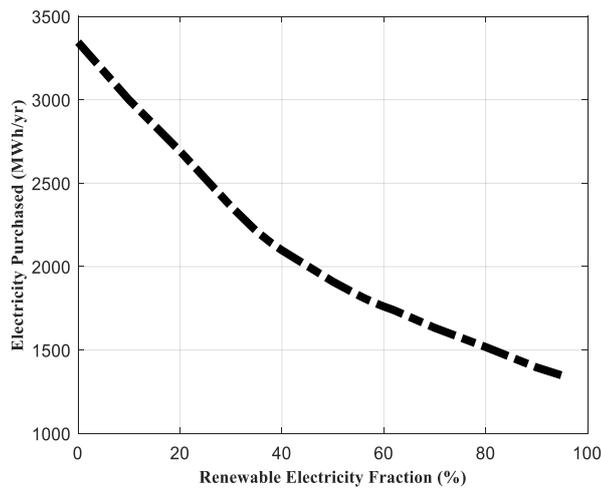


Figure 6. Electricity purchased vs. renewable fraction

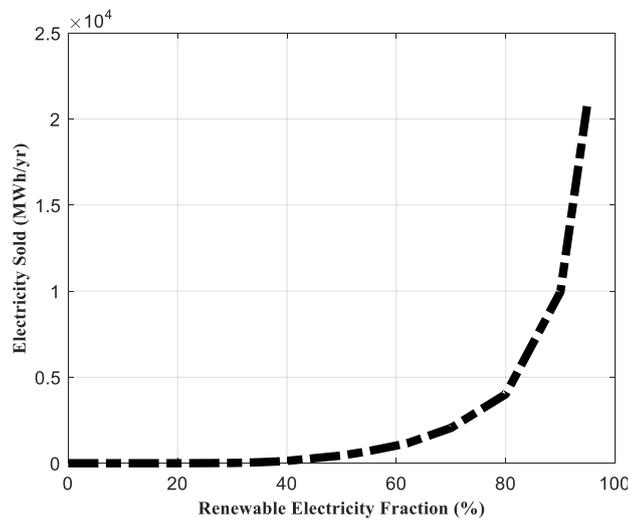


Figure 7. Electricity sold vs. renewable fraction

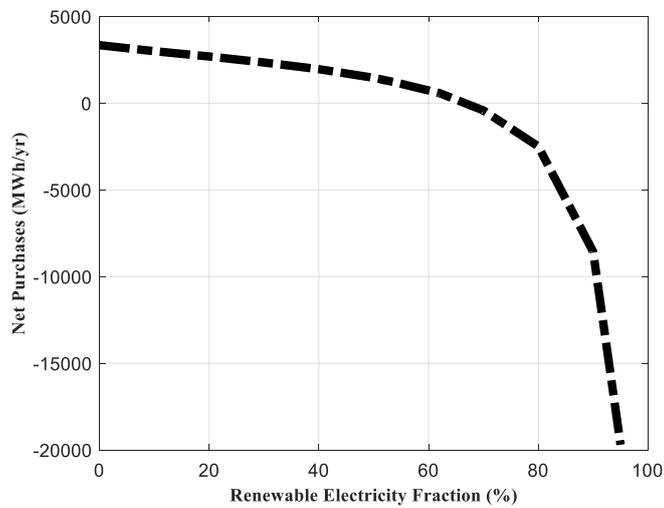


Figure 8. Net purchases vs. renewable fraction

### 4.3. Net Present Cost and Optimum Grid-Connected PV System

From Figure 9, it is observed that the NPC decreases with increasing of the PV energy penetrations until it is reached by the renewable fraction of 58%. The NPC rises dramatically after the renewable fraction of the system is greater than 58%. It has been mentioned that the revenues from selling electricity are very high when the renewable fraction is above 66%. However, the revenues from sales are not enough to cover the total costs of the PV system due to the large PV array and inverter sizes when the renewable fraction is increased.

The best NPC of grid-connected PV system is reached at the renewable fraction of 58%. In this condition, 58% of electricity is produced by PV arrays while the grid supplies the remaining 42% of production to meet the office building's load. The PV array of 1.6 MW produces 2,508,459 kWh/yr and contributes 58% of the total electricity, while the grid supplies the remaining 42% of demands. The surplus electricity from the PV is sold to the grid for revenues. At the renewable fraction of 58%, the electricity purchased from the grid is 1,785,646 kWh/yr, while the grid sales revenue is 898,703 kWh/yr. As the results, cost of the grid is \$ 3,335,497, and costs for both PV array and inverter are \$ 3,934,157, and hence the NPC of the grid-connected PV system becomes \$ 7,269,654. After all, the NPC of the grid-connected PV system is lower than the NPC of \$ 7,399,133, when the building buys all electricity from the grid (at renewable fraction of 0%), leading to save about \$ 129,276 as the result of selling and buying electricity via net-metering. Table 2 summarizes the optimization results for the optimum grid-connected PV system and the utility grid.

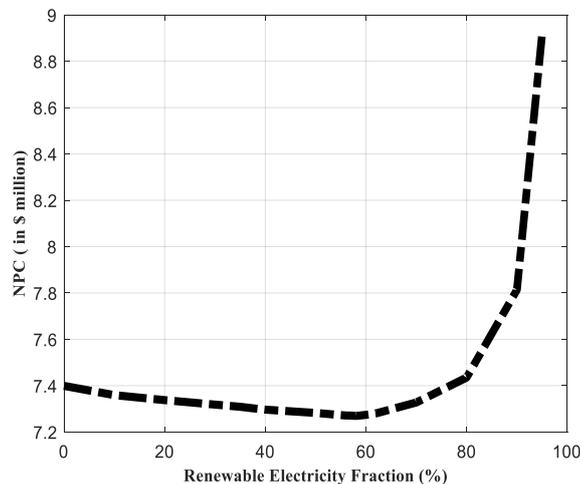


Figure 9. Total NPC vs. renewable fraction

Carbon dioxide emission also becomes an interesting environmental factor for a grid-connected PV system. For CO<sub>2</sub> emission factor of 721 g/kWh [27], the grid-connected PV system produces CO<sub>2</sub> emission of 677,129 kg/yr. This value is lower than the CO<sub>2</sub> emission of 2,411,911 kg/yr which is produced by the conventional utility grid. It is clear that the grid-connected PV system has an important contribution to reduce CO<sub>2</sub> emission. The grid-connected PV system will get more benefits if the government gives incentive for emitting low proportion of CO<sub>2</sub> pollutant.

Table 2. Optimization results

	Renewable fraction (%)	
	0	58
Primary load (kWh/yr)	3,345,227	3,345,227
PV size (kW)	0	1600
PV production (kWh/yr)	0	2,508,459
Grid purchases (kWh/yr)	3,345,227	1,785,646
Grid sales (kWh/yr)	0	898,703
PV costs (\$)	0	3,427,398
Inverter costs (\$)	0	506,759
Grid costs (\$)	7,399,133	3,335,497

## 5. CONCLUSION

The renewable fraction influences on PV array and inverter sizing, and also on cost and benefit from selling and buying electricity and the net purchase, the total NPC and CO<sub>2</sub> emissions in the grid-connected PV system. An optimum result, with the lowest NPC for serving the office building with a demand load of 3,345,227 kWh/yr, is obtained by implementing 1.6 MW PV size (with the ratio of  $R=1.15$ ) and renewable fraction of 58%. From an environmental standpoint, the rate of CO<sub>2</sub> emission is reduced by 72% in the case of the grid-connected PV system, compared to the conventional electricity grid. The grid-connected PV system offers the greater economic and environmental benefits than the utility grid without PV for the office building electricity

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