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# Model of Sustainable Electrical Power Management: Lamp Efficacy of the National Street Lighting in North Sumatera Province

Model of  
Sustainable  
Electrical  
Power

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Janter Napitupulu

*Study Program of Natural Resources Management and Environment,  
Postgraduate School, University of Sumatera Utara, Sumatera, Indonesia  
Faculty of Engineering, University of Darma Agung, Medan, Indonesia*

Herman Mawengkang

*Faculty of Mathematics and Natural Sciences, University of Sumatera Utara,  
Sumatera, Indonesia*

Usman Ba'afai

*Faculty of Engineering, University of Sumatera Utara, Sumatera, Indonesia*

Nasruddin M.N.

*Faculty of Mathematics and Natural Sciences, University of Sumatera Utara,  
Sumatera, Indonesia*

## Abstract

**Purpose** – The purpose of this study was to determine the efficacy value of national street lighting on energy conservation and *carbon dioxide* (CO<sub>2</sub>) emission reduction.

**Design/Methodology/Approach** – The methods used are the measurement of electrical parameters (low voltage network), the national road illumination level with SON lamp specification, 400 W, 180 W, and 110 Lumen/W, the simulation of energy conservation calculation, and the CO<sub>2</sub> emission reduction obtained by utilizing panel solar cells as a source of energy and LED lights for illumination.

**Finding** – The results show the efficacy of a 100-W light bulb at an altitude of 8 m for the following specification of light bulbs: LED, 130 Lumens/W, SON, 110 Lumen/W, and MBF, 53 Lumen/W gives the illumination level respectively 13,913 Lux, 11,773 Lux, and 5,672 Lux. By replacing the 180 W SON lamp with an LED, 100 W, of energy conservation by 3.171 GW h is obtained, which is equivalent to a CO<sub>2</sub> emission reduction of 3.641 kTon CO<sub>2</sub>.



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**Originality/Value** – This study is a continuation of a study of energy conservation with the utilization of solar cells as an electrical power source for an LED bulb that replaces low-voltage networks as a power source for the bulb type SON.

**Keywords** Electric power, energy conservation, solar cell, sunlight, light lamp

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## 1. Introduction

The provision of electrical energy for sectoral uses is generated using fossil-fueled natural resources such as oil and coal. Its use continues to increase, while the number of natural resources is limited.

In future, the lack of electrical energy can occur since the supply of electrical energy is limited when compared to the actual energy needs. In urban areas, the predicted rate of growth in electricity demand will tend to increase which, if not resolved, can cause the level of electricity supply to be disrupted.

For this purpose, the management of electrical energy considers conservation of energy as a solution that can be achieved with the consumption or supply of less energy but gives the same effect of lighting and illumination (Mohamed *et al.*, 2009). The energy conservation can be applied to industrial room lighting. The energy conservation can be obtained through solar cells as a source of energy illumination in buildings (Dhingra *et al.*, 2009).

To overcome the limitation of electric energy at night, especially for street lighting, energy from solar cell was utilized as energy source instead of LED lamps (Padmini, 2014).

Conservation efforts can be achieved through two aspects: (1) Aspect of technology and (2) aspect of human behavior change. In street lighting, electronic ballasts consume less energy than electromagnetic ballasts that can save energy up to 18% (Escolar *et al.*, 2015). In the case of electric energy crisis, Bangladesh is one of the developing countries that saved electricity consumption from 3% to 20% through changes in human behavior (Khan *et al.*, 2016).

There are two reasons for the usage of solar cells, namely, (1) limited fuel supplies used for electric power generation and (2) environmental hazards caused by the disposal of waste products during the conversion process.

## 2. Materials and methods

### 2.1. Material

The measurement of the electrical quantities was performed using the following multimeter measuring instruments: Heles YX-360 TRNB Reg.271-488, voltmeter, ammeter: Digital Multimeter CD772 Sanwa, tangmeter: Clampmeter 8 model 3908 VIP Electrical Instruments Works, Ltd., and luxmeter: Digital Luxmeter 1010 specification with a measurement range of 0.1–100×500 Lux.

### 2.2. Methods

**2.2.1. Carbon dioxide emission factor** The environmental hazard can be measured from the value of carbon dioxide (CO<sub>2</sub>) emission and determined by CO<sub>2</sub> emission factor determined as 1.14 kg CO<sub>2</sub>/kW h. Emission factor becomes the basis in the process of environmental pollution. Power generation with fossil fuels is a major source of greenhouse gas emissions, especially CO<sub>2</sub> gas. One way to reduce CO<sub>2</sub> in the air is to use a power plant that has a low CO<sub>2</sub> emission factor. CO<sub>2</sub> emission factor can be determined by using the following formula:

CO<sub>2</sub> emission factor = CO<sub>2</sub> emissions/energy generated, where, CO<sub>2</sub> emissions = fuel consumption × % C fuel × 44/12.

The emission time series model can be used to determine the accumulation of CO<sub>2</sub> concentration (Boykoff *et al.*, 2010).

**2.2.2. Sunlight and solar cells** Light is an electromagnetic wave that under certain conditions can behave like a particle. Electromagnetic waves are waves that do not require a medium to propagate, hence light can propagate without a medium. Therefore, sunlight can reach the earth and energize lives in it. Light travels very fast with a speed of  $3 \times 10^8$  m/s, meaning that within a second light can travel a distance of 300,000,000 m or 300,000 km, and has a radiation of 1,373 W/m<sup>2</sup> with 1–2% error. The source of light that is included in the natural light is the sun. Sunlight has a spectrum which can be seen from the division of energy regions comprising 8% in the ultra violet region, 44% in the visible region, and 48 % in the infra red region. Light has a constant known as a solar constant (*I<sub>o</sub>*) with a value of  $I_o = 1.37 \pm 0.02$  kW/m<sup>2</sup> (Mc.Veigh, 1983).

Theoretically, the potential of solar resources is the average solar energy on the earth's surface expressed in kW h/m<sup>2</sup>/year, which is the kilowatt hour on every square meter in the horizontal plane measured every day, month or year, and Bulgaria is a country in Europe which is divided into three solar regions ().

Indonesia, which is a tropical region, has the potential of solar energy where the average daily insolation is 4.5–4.8 kW h/m<sup>2</sup>/day.

Solar cells convert solar radiation in kW h/m<sup>2</sup>/ day into electric power as follows:

$$P = I_r \cdot A$$

where *I<sub>r</sub>* is the intensity of solar radiation and *A* is wide of solar cells (m<sup>2</sup>).

Sunlight on the surface of the earth is capable of providing power of 1,000 W/m<sup>2</sup> in bright weather, which in turn will produce current of about 30 mA/cm<sup>2</sup>.

If the solar cell module has an area of 1 m<sup>2</sup> with an efficiency of 10%, it is capable of generating 100 W electricity. The solar cell module can generate electricity depending on the level of sun exposure. The greater the level of sunlight exposure, the greater the electrical power that the solar cell modules can generate.

**2.2.3. Light efficacy** The efficacy of light is the ratio of the lumen output to the power consumption expressed in Lumen/W units.

$$K = \phi / P$$

where *K* is the light efficacy (Lm/W), *φ* is flux light (Lm), and *P* is the electric power (W).

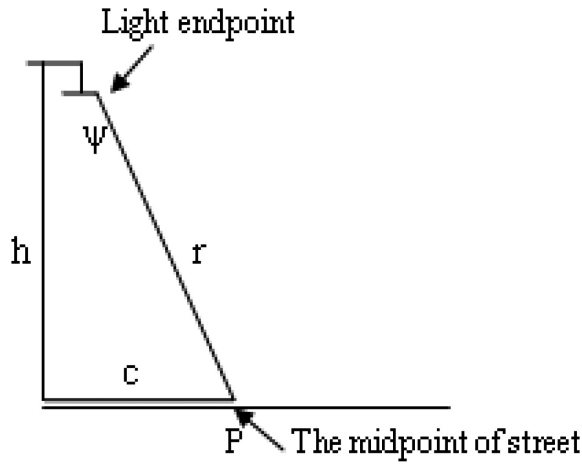
In street lighting, the height of the lamppost affects the spreading of light. The higher the pole is the wider the resulting light will be with a smaller level of illumination.

The angle of the tilt, the line connecting the endpoint of the lamp and the point in the middle of the path with a horizontal line as seen in Figure 1, can be determined using the following equation:

$$\begin{aligned} r &= \sqrt{h^2 + c^2} \\ \text{Cos}\psi &= h/r \end{aligned}$$

where *r* is the side of beveled line, the distance from the end of the lamp to the point in the middle of the road; *c* is the horizontal line, the distance from the projection point of the

**Figure 1.**  
Effect of lamppost  
height on  
illumination



lamp end to the point in the middle of the road;  $h$  is the pole height; and  $\psi$  is the angle between  $r$  and  $c$ .

The intensity of light ( $I$ ) in units of candela (cd) can be determined using the following equation:

$$I = \phi / \omega$$

$$\omega = 4\pi$$

$$K = \phi / P \text{ or } \phi = K \times P$$

Then,

$$I = K \times P / 4\pi$$

Illumination  $E_p$  in units of Lux at the point  $P$  in the middle of the street is

$$E_p = I \times \cos\psi / r^2$$

*2.2.4. Conservation approach model*  $P_{PJUN-SS}$   $P_{PJUN-SS}$  is a model approach with the utilization of solar cells as a source of energy for LED light in national street lighting. Energy conservation can be obtained as follows:

$$P_{PJUN-SS} = P_{PJUN-LED}$$

$$P_{Konsv-SS} = (P_{SUTR-SON} - P_{PJUN-SS}) \times n$$

$$W_{Konsv-SS} = P_{Konsv-SS} \times Oh$$

$$J_{Konsv-SS} = W_{Konsv-SS} \times J_E$$

where

- $J_{Konsv-SS}$  : energy conservation is converted to CO<sub>2</sub> emission (kg)
- $E_{Konsv-SS}$  : annual energy conservation (kW h/year)
- $P_{Konsv-SS}$  : conservation of electric power (kW)
- $P_{PJUN-SON}$  : the growing needs of electrical power for the lamp  $P_{PJUN-SON}$
- $P_{PJUN-LED}$  : power light for  $P_{PJUN-LED}$

$n$  : number of light  
 $Oh$  : operational hours  
 $J_E$  : CO<sub>2</sub> emission factor (kg/kW h).

### 2.2.5. Capacity of solar cell module

$Fk$  = multiplier factor due to losses and efficiency

LPM = duration of solar radiation

Energy generation ( $W_{SS}$ ) = load  $P_{PJU-LED}$

(Watt) × time (hour)

Solar cell module capacity ( $P_{SS}$ ) = ( $W_{ss} \times Fk$ )/LPM.

## 3. Results and discussion

### 3.1. The Effect of Height Variation of Light Pole on Illumination

The effect of the height variation of light poles on the illumination produced with certain light efficacy on the primary arterial road at the midpoint of the road is obtained by the using the following calculation:

(1) Lamp type: SON, 400 W, 110 lumens/W

Road width: 8 m

$$\begin{aligned} h &= 12 \text{ m} \\ c &= 2.95 \text{ m} \\ r &= \sqrt{12^2 + 2.95^2} \\ &= 12.35 \text{ m} \\ \text{Cos } \psi &= 12/12.35 \\ &= 0.97 \\ I &= 110 \times 400 / (4 \times 3.14) \\ &= 3,503.18 \text{ cd} \end{aligned}$$

Then,

$$\begin{aligned} E_p &= 3,503.18 \times 0.97 / 12.352 \\ &= 22.27 \text{ Lux} \end{aligned}$$

(2) Lamp type: MBF, 400 W, 53 lumens/W

Road width: 8 m

$$\begin{aligned} h &= 12 \text{ m} \\ c &= 2.95 \text{ m} \\ r &= \sqrt{12^2 + 2.95^2} \\ &= 12.35 \text{ m} \\ \text{Cos } \psi &= 12/12.35 \\ &= 0.97 \\ I &= 53 \times 400 / (4 \times 3.14) \\ &= 1,687.89 \text{ cd} \end{aligned}$$

Then,

$$\begin{aligned} E_p &= 1,687.89 \times 0.97 / 12.352 \\ &= 10.73 \text{ Lux} \end{aligned}$$

Height variation of lampposts against illumination with SON/MBF, 400 W, generated at the midpoint of the road width 8 m can be seen in Table 1.

*SON/MBF Lamp Specifications:*

- For lamp types: SON, 180 W, 110 lumens/W and MBF, 180 W, 53 lumens/W, the effect of variations on lamp height to illumination is presented in Table 2.
- For lamp types: SON, 100 W, 110 lumens/W and MBF, 100 W, 53 lumens/W, the effect of variations on lamp height to illumination is presented in Table 3.

*LED Lighting Specifications:*

- For lamp type: LED, 150 W, 130 lumens/W, the effect of variations on lamp height to illumination is presented in Table 4.
- For lamp type: LED, 100 W, 130 lumens/W, the effect of variations on lamp height to illumination is presented in Table 5.

**Table 1.**

Variation Height of lampposts against illumination SON/MBF, 400 Watt generated at the midpoint of the road road width 8 m

No.	Lamppost height (m)	Illumination (Lux)	
		SON	MBF
1	10	30,65	15,31
2	11	25,96	12,59
3	12	22,27	10,73

**Table 2.**

Variation Height of lampposts against illumination SON/MBF, 180 Watt generated at the midpoint of the road, road width 7 m

No.	Lamppost height (m)	Illumination (Lux)	
		SON	MBF/U
1	7	26,49	12,769
2	8	21,191	10,210
3	9	18,711	8,308

**Table 3.**

Variation Height of lampposts against illumination SON/MBF, 100 Watt generated at the midpoint of the road, road width 7 m

No.	Lamppost height (m)	Illumination (Lux)	
		SON	MBF/U
1	7	14,718	7,488
2	8	11,773	5,672
3	9	9,580	4,615

3.2. The Electrical Needs of National Road Segment

The electrical energy needs of the national road segment in 2019 are obtained by the following formulation:

(1) Load of SON on the length of primary arterial road:

The specified lighting quality of primary arterial road is 11–20 Lux. To obtain the lighting quality, SON lamp, 400 W, is used with lamp height 11 m, and distance between poles being 40 m. Then, the electrical energy consumption of primary arterial road along 1,142 km with the operation time 4,145 h in 1 year is as follows:

(a) The number of pole PJU is (the length of the road/40) + 1

(b) Electric power required on street lighting PJU

$$\begin{aligned} P_{\text{PJU-SUTR}} &= 400 \text{ W} \times \text{number of poles} \\ &= 400 \text{ W} \times 28,551 \\ &= 11.240 \text{ MW} \end{aligned}$$

(c) Electrical energy needs of street lighting for the length of national primary arterial road segment are as follows:

$$\begin{aligned} W_{\text{PJU-SUTR}} &= 400 \text{ W} \times \text{number of poles} \times 4,145 \text{ h} \\ &= 400 \text{ W} \times 28,551 \text{ poles} \times 4,145 \text{ h} \\ &= 47.337 \text{ GWh} \end{aligned}$$

(2) Load of SON on the length of national primary collector road:

The specified lighting quality of primary collector road is 3–7 Lux. To obtain the lighting quality, SON lamp, 180 W, is used with lamp height 8 m, and distance between poles being 40 m. Then, the electrical energy consumption of primary collector road along 1,490.22 km with the operation time 4,145 h in 1 year is as follows:

(a) The number of pole PJU is (the length of the road/40) + 1

(b) Electric power required on street lighting PJU

No.	Lamppost height (m)	Illumination (Lux)	
		Road width-7m	Road width-8m
1	7	26,091	24,215
2	8	20,870	19,660
3	9	16,983	16,195

**Table 4.** Variation Height of lampposts against illumination LED, 150 Watt generated at the midpoint of the road

No.	Lamppost height (m)	Illumination (Lux)	
		Road width-7m	Road width-8m
1	7	17,394	16,143
2	8	13,913	13,106
3	9	11,322	10,796

**Table 5.** Variation Height of lampposts against illumination LED, 100Watt generated at the midpoint of the road

$$\begin{aligned}P_{\text{PJU-SUT}} &= 180 \text{ W} \times \text{number of poles} \\ &= 180 \text{ W} \times 37,256 \\ &= 6.706 \text{ MW}\end{aligned}$$

- (c) Electrical energy needs of street lighting for the length of national primary collector road segment are as follows:

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$$\begin{aligned}W_{\text{PJU-SUTR}} &= 180 \text{ W} \times \text{number of poles} \times 4,145 \text{ h} \\ &= 180 \text{ W} \times 37,256 \text{ poles} \times 4,145 \text{ h} \\ &= 15.442 \text{ GW h}\end{aligned}$$

Thus, the total need of electrical energy for street lighting due to the increase in national roads is 15.442 GW h.

### 3.3. Potential use of solar cells

The energy needs of national public road lighting in North Sumatera province can be analyzed from the value of electrical energy generated by each solar cell module and the overall need of solar cell panels required to replace the energy generated by conventional power generation.

By using these solar cell modules, the need of electrical energy for public road lighting on national roads in 2019 and its increase can be obtained as follows:

- (1) Load of LED light on the total length of national road:

The specified lighting quality is 11–20 Lux. To obtain the lighting quality, LED lamp, 100 W, is used with lamp height 7 m, and distance between poles being 40 m. Then, the electrical energy consumption of primary arterial road and primary collector road along 2,632.22 km with the operation time 4,145 h in 1 year is as follows:

- (a) The number of pole PJU is (the length of the road/40) + 1  
(b) Electric power required on street lighting PJU

$$\begin{aligned}P_{\text{PJU-LED}} &= 100 \text{ W} \times \text{number of poles} \\ &= 100 \text{ W} \times 65,807 \\ &= 6.580 \text{ MW}\end{aligned}$$

- (c) Electrical energy needs of street lighting for the total length of national road segment are as follows:

$$\begin{aligned}W_{\text{PJU-LED}} &= 100 \text{ W} \times \text{number of poles} \times 4,145 \text{ h} \\ &= 100 \text{ W} \times 65,807 \text{ poles} \times 4,145 \text{ h} \\ &= 27.277 \text{ GWh}\end{aligned}$$

- (2) Load of LED light due to the increase of national road segment:

The increase in the length of the national roads is around 382.56 km. The electrical energy needs of street lighting along the length of national primary collector road segment are as follows

$$\begin{aligned}W_{\text{PJU-LED}} &= 100 \text{ W} \times \text{number of poles} \times 4,145 \text{ h} \\ &= 100 \text{ W} \times 9,565 \text{ poles} \times 4,145 \text{ h} \\ &= 3.964 \text{ GWh}\end{aligned}$$



Thus, the total need of electrical energy for street lighting due to the increase in national roads is 3.964 GW h.

(3) Capacity of solar cell module:

Sunlight can generate electrical energy of 1,000 W/m<sup>2</sup> at peak times. The solar panel efficiency of 15 % with an area of 1m<sup>2</sup> panel each, can produce output power of 150 Wp.

Solar cell module capacity to serve the load of national street lighting with PJU-LED, 100 W, for 12 h, 18.00–6.00, with 1.1 as multiplier factor, and 5.7 h as the duration of solar exposure, then

$$\text{Load } P_{\text{PJU-LED}} = 100 \text{ W}$$

The energy requirement to serve the load  $P_{\text{PJU-LED}} = 100 \text{ W}$  is as follows:

$$\begin{aligned} \text{Energy generation } (W_{\text{SS}}) &= 100 \text{ W} \times 12 \text{ h} \\ &= 1,200 \text{ W h} \\ &= 1.2 \text{ kW h} \end{aligned}$$

$$\begin{aligned} \text{Solar cell modul capacity } (P_{\text{SS}}) &= (120 \text{ W} \times 12 \text{ h} \times 1.1)/5.7 \text{ h} \\ &= 277 \text{ Wp} \end{aligned}$$

Thus, the need for solar cell modules to meet PJU-LED, 100 W, is two sets of solar cell modules each with a capacity of 130 Wp.

### 3.4. Effect of efficacy on illumination

Effect of height variation of lamppost on Illumination by using LED/SON/MBF can be seen in Table 6.

Light efficacy affects the energy consumption for the lamp. Hence, by using a high light efficacy lamp, maximum energy conservation is possible.

### 3.5. Energy Conservation

The growth of national roads in 2019 will be lengthy, around 382.56 km. This needs the growth of electric power also to fulfill the demand of lighting the entire length of the national roads.

When the SON lamp, 180 W, is changed to LED, 150 W, having the value of the illumination close to the same, energy conservation of 30 W per light bulb will be obtained:

$$\begin{aligned} W_{\text{Konsv-SS}} &= 30 \text{ W} \times \text{number of poles} \times 4,145\text{h} \\ &= 30 \text{ W} \times 9,565 \text{ poles} \times 4,145\text{h} \\ &= 1.189 \text{ GWh} \end{aligned}$$

No.	Lamppost height (m)	Illumination (Lux)		
		LED	SON	MBF
		Efficacy (lumen/watt)		
		130	110	53
1	7	17,394	14,718	7,488
2	8	13,913	11,773	5,672
3	9	11,322	9,580	4,615

**Table 6.**  
Effect of height variation of lamppost on Illumination LED/SON/MBF, 100 watts directed at midpoint of road, road width 7m

When the SON lamp, 180 W, is changed to an LED, 100 W, that has fulfilled the specified illumination level, energy conservation of 80 W per light bulb will be obtained:

$$\begin{aligned} W_{\text{Konsv-SS}} &= 80 \text{ W} \times \text{number of poles} \times 4, 145\text{h} \\ &= 80 \text{ W} \times 9, 565 \text{ poles} \times 4, 145\text{h} \\ &= 3.171 \text{ GWh} \end{aligned}$$

### 3.6. The effect of efficacy on CO<sub>2</sub> emission reduction

Effect of lamp efficacy on CO<sub>2</sub> emission is shown in Table 7.

**Table 7.**  
The effect of Efficacy  
on CO<sub>2</sub> emission  
reduction

Emission Factor (KgCO <sub>2</sub> /kWh)	Energy conservation (GWh)	CO <sub>2</sub> emission reduction (kTon CO <sub>2</sub> )
1.14	1.189	1.355
	3.171	3.614

## 4. Conclusion and recommendation

Energy conservation is the act of maintaining the energy by reducing energy consumption or replacing energy sources to obtain the same benefits. In this paper, energy conservation obtained by replacing conventional energy sources with solar cells for the increased length of national street lighting is 3.171 GW h in a year, and reduced carbon emission by 3.614 kTon CO<sub>2</sub> are studied.

Solar cell technology is a fast growing technology. However, for the utilization of solar cells, the investment cost required must be taken into account (Elaydi *et al.*, 2012).

In general, the public health can be viewed from a clean air environment. People living in rural areas tend to be healthier than people who live in urban areas. Air cleanliness is one of the important factors in human health (Fredrich *et al.*, 2010), which can be determined in the form of a health index.

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**Corresponding author**

Janter can be contacted at janter\_mh@yahoo.com