

ANALYSIS OF GREENHOUSE GAS MITIGATION IN ENERGY SECTOR / ELECTRICITY SUB-SECTOR ON STREET LIGHTING (CASE STUDY: PALEMBANG CITY)

***Abstract:*** *The greatest source of GHG emission from energy sector comes from fossil fuel combustion. According to PLN, 63.75% of electricity generation distributed in South Sumatra is derived from coal combustion. Coal is a non-renewable energy source and will deplete in a few decades. The research objective is solving problems related to energy efficiency and GHG emission reduction by reducing electricity consumption in street lighting sector. The research method was carried out through SPSS statistical analysis and LEAP analysis which had been justified based on observation on the survey results of 1,619 street lighting unit at four distribution areas of Palembang. The SPSS statistical analysis determines that 1,000-unit street lights require light intensity quality of 1,570 lux with correlation coefficient of 0.214. GHG mitigation was conducted in accordance with convenience and safety standards for road users. Based on secondary data, energy efficiency from the replacement of 3,741-unit energy-saving lamps can reduce GHG emissions by 1,650.9138 tons of CO2e with benefit economic 2,911,481,740 rupiahs. In addition, based on LEAP analysis, the more LED light installed to replace Son-T 250 W will reduce electricity energy consumption by 2030 with a consistent amount of energy efficiency.*

*Keywords: Street Lighting, Energy Efficiency, Emission Reduction, Green House Gas and LED*

***Abstrak:*** Sumber emisi terbesar sektor energi berasal dari pembakaran bahan bakar fosil. Berdasarkan data PLN, 63,75% pembangkitan listrik wilayah Sumbagsel berasal dari batubara. Bahan bakar batubara merupakan sumber energi tidak terbarukan dan akan habis dalam beberapa dekade selanjutnya. Tujuan penelitian merupakan penyelesaian masalah terkait efisiensi energi listrik dan pengurangan emisi GRK yang didasari pengurangan konsumsi energi listrik Sektor PJU. Metode penelitian yang digunakan adalah analisa menggunakan statistik SPSS dan LEAP yang telah dijustifikasi berdasarkan pengamatan hasil survey PJU sebanyak 1.619 unit di keempat rayon wilayah Kota Palembang. Penerapan efisiensi energi listrik Sektor PJU dilakukan dengan mengganti lampu Son T 250 W menjadi lampu LED dengan daya berbeda. Hasil analisa statisik SPSS bahwa 1.000 unit lampu PJU membutuhkan kualitas penerangan cahaya dengan intensitas cahaya sebesar 1.570 lux dengan koefisien relasi 0,214. Aksi mitigasi GRK Sektor PJU dilakukan sesuai dengan standar kenyamanan dan keselamatan. Berdasarkan data sekunder, efisiensi energi listrik PJU sebesar 9,603 % dengan pergantian lampu hemat energi sebanyak 3.741 unit mengurangi emisi GRK sebesar 1.650,9138 ton CO2e dengan biaya penghematan 2.911.481.740 rupiah. Maka berdasarkan analisa LEAP, semakin besar jumlah pemasangan LED menggantikan lampu Son T maka konsumsi energi listrik PJU di tahun 2030 akan mengalami penurunan dengan efisiensi energi yang konsisten.

*Kata kunci: Penerangan Jalan Umum, Efisiensi Energi, Emisi, Mitigasi GRK dan LED*

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# Introduction

* 1. **Background**

Electricity generation using coal fuel has become a problem in the energy sector and it requires a solution by reducing the use of this fuel [1]. In South Sumatra region, 95% of the electricity source is generated by private electricity generation [2]. The increase in electricity consumption increases the number of electricity generators and distribution to the four rayon in Palembang City. The distribution of electricity in Palembang City is divided into four districts consisting of Rivai, Kenten, Sukarami and Ampera Districts with an increase from 2015 to 2018 of 45,707,580 kWh and 52,845,036 kWh [3]. Total electrical energy in all sectors increases along with the increase in electrical energy in the Street Lighting sector [4]. To reduce the excessive use of electricity, it requires increasing the efficiency of electrical energy and taking GHG mitigation action [5].

Street lighting is an important aspect of city planning and is useful for making it easier for pedestrians and motorized vehicles [6]. Installation of Street Lighting also aims to facilitate the quality adjustment of the distance between vehicles. The profile of Street Lighting points in Palembang City is 42,770-unit lamps consisting of Son-T 250 W, 150 W, 70 W, LED, HPL 125 W and 80 W solar cell. Son-T lamp points 250 W, 150 W, 70 W, LED and HPL 125 W are 3,386 units, 11,074 units, 24,352 units, 3,741 units, 3,594 units and 10 units respectively which are installed on the protocol and collector roads of Palembang City. Street lighting supervision and operation are managed by Palembang City Public Housing and Settlement Service [7].

Based on secondary data for 2019, the Son-T 70 W lamps totaling 24,351 units have the largest power load of 1,704.57 kWh [8]. The biggest street lighting power consumption is Son-T 70 W followed by the Son-T 150 W with a percentage of 33.879% and 33.015%. The total consumption of electric energy for Street Lighting in 2019 is 22,037,225.4 kWh or the equivalent of 22,037.2 MWh [8]. Street lighting electricity consumption has increased every year. The increase in electricity consumption is due to the installation of the number of lamps that increases every year.

GHG mitigation actions are carried out by replacing Son-T 250 W with LED lamps on protocol road of Palembang City. The replacement of the LED lamps aims to reduce the electricity consumption of Palembang Street Lighting, improve electrical energy efficiency and reduce greenhouse gas emissions caused by the use of coal fuel. The results of indirect emission resulting from the use of street lighting electricity are calculated based on the emission factor and the amount of electrical energy consumption which is calculated for 1 (one) year [9]. The less electrical energy consumption, the greater the electricity savings for Street Lighting.

The target of achieving the reduction of GHG emissions in the energy sector is 11% in accordance with

the strategic guidelines for implementing the NDC document ratified by the Paris Agreement of 29% without foreign assistance and 41% with foreign assistance by 2030 [10] [11] [12]. The amount of electricity savings is multiplied by the emission factor which is equivalent to the reduction in GHG emissions. In calculating the energy balance calculated according to the Energy and Mineral Resources office, the reduction in GHG emissions should not exceed 29%. Thus, the achievement of emission reduction in the energy sector is maintained with the justification that the electricity consumption of Street Lighting will decrease in 2030 and the electricity consumption of LED lamps will increase [13].

**1.2. Research Problems**

Based on the above background, the following problems are formulated:

1. It is related to the Greenhouse Gas mitigation action activities carried out by Palembang City government in supporting efforts to achieve the energy sector emission reduction target of 11% from the national target of 29% in 2030 and support the energy mix target of 23% by 2050. The Greenhouse Gas mitigation action in the Street Lighting sector in Palembang City has not yet reached the energy saving target.
2. The consumption of electrical energy in Street Lighting sector of Palembang City has increased every year along with the construction of roads in Palembang City according to spatial planning and the community in inhabited road areas in Palembang City.
3. The source of GHG emissions in the energy sector has the potential to be the largest emission source compared to emission sources in other sectors.
	1. **Research Objectives**

Furthermore, the objectives of the research include:

1. Conducting an analysis of the GHG mitigation efforts of Palembang City Government in Street Lighting sector / electricity sub-sector in order to achieve an energy elasticity of less than 1 (one) percent by 2025
2. Conducting economic analysis related to GHG mitigation in Street Lighting sector in Palembang City so that the implementation of electricity savings can be increased in a sustainable manner.
3. Providing energy saving recommendations in Street Lighting sector based on the principle of energy efficiency and environmental conservation with the principle of sustainable development to realize the role of renewable energy of more than 5%.

# Research Material and Method

*Material and Instrument*

This research utilizes GPS (Global Positioning System), stationery, measuring equipment, fiber roll meter, spray paint, luxmeter, maps and camera.

*Collecting Data Method*

Primary data collection was carried out through direct interview. Primary data related to the light intensity of Street Lighting were taken directly at the location of collector and arterial roads in Palembang City. Secondary data were obtained from literature studies or related agencies.

The characteristics of the light intensity of street lighting depend on the values measured on the luxmeter. Light intensity is the light current emitted in every corner of the room in lumens [14]. The measured light intensity is taken perpendicular to the street surface.

*Sampling Method*

 Street lighting samples were calculated based on the Slovin formula. The use of the Slovin formula can be seen in equation 1.1 as follows [15] :

 n = $\frac{N}{1+ N.e^{2}}$ .........................................................(1)

Description:

n = number of samples

N = number of populations

e = error margin (error rate)

The number of street lighting samples was taken from arterial and collector roads of Palembang City from a total of 42,770 street lighting units with a total sample size of 397 units [8].

Survey and measurement of intensity using a luxmeter were carried out on each sample of the LED Street Lighting light points. In addition to measuring the electrical energy consumption of Street Lighting lamps, the measurement of light intensity also determines the feasibility of GHG mitigation actions based on the replacement of Son-T lamps into LED lamps.

*Electrical Energy Saving and Greenhouse Gas Emissions Calculation Method*

The calculation of electrical energy consumption used in each Street Lighting lamp in Palembang is calculated using the following formula [16] :

Ex =

$\frac{Power \left(kW\right)x lamp point of Street Lighting \left(unit\right)x 24 hours }{1.000.000} $[MWh] (2)

The total baseline electricity consumption of Street Lighting (MWh) lamps consists of Son-T 250 W, 150 W and 70 W, HPL 125 W and SOX lamps. The electricity consumption of LED lamp substitution is also calculated using the same formula. The substitution of LED lamps results in electricity savings that are calculated using the following formula [4]:

E = E1 – E2, where .....................................................(3)

E1 is the energy consumption before mitigation is carried out

E2 is the energy consumption after mitigation is carried out

The greater the E value, the mitigation activities will have a positive and significant impact in supporting energy savings in Palembang City.

The electricity consumption of Street Lighting lamps results in indirect GHG emissions. Emissions used in coal combustion for electricity generation produce electric power which is ultimately distributed to energy use in the Street Lighting sector. Thus, the resulting emissions are calculated using the multiplication of the emission factors.

The production of electricity from the power plant is integrated in one Sumbagsel (Southern Sumatra) interconnection network or outside the Java Madura Bali (JAMALI) interconnection system. [17].

Emission factors describe that the amount of coal used varies in an area. Thus, it results in different emission factors. The emission factors used in this research are based on secondary data from the Directorate General of Electricity and Department of Energy and Mineral Resources in 2016. The calculation of the GHG emission reduction formula is as follows [18] :

Emission reduction = Emission Mitigation Action - Emission without Mitigation Action [ton CO2e] [19]..............................................(4)

The amount of emission reduction can be seen every year according to the feasibility of mitigation action. Emission reduction is also an indicator of environmental impact and results in GHG mitigation action [20].

*Electrical Energy Efficiency Method in Street Lighting Sector*

Replacement of LED Street Lighting provides efficient use of electricity. The consumption of electrical energy in low-power lamps is smaller than that of high-power lamps. High power LED lamps consume less electrical energy than Son-T lamps of the same power. The calculation of the energy efficiency formula using LED lamps is as follows [4] [5] :

Ef = $\frac{E\_{1}- E\_{2}}{E\_{1}}$ x 100 %, where.........................................(5)

Ef=efficiency of electrical energy after mitigation action is carried out

E1=energy consumption before mitigation action is carried out

E2=energy consumption after mitigation action is carried out

The greater the E1 value, the smaller the efficiency of electrical energy. Therefore, to improve energy efficiency, reducing the waste of electrical energy consumption in Street Lighting is needed.

*Data Analysis Method*

This study applies the SPSS Kendall Tau and LEAP statistical analysis methods. The SPSS Kendall Tau method aims to analyze the correlation between light intensity of street lighting, the height of the lampposts and the street width. The results of the analysis provide safety and comfort standards for road users according to the SNI 7391 standard (2008) [21]. The LEAP method aims to analyze and justify that the installation of LED lamps can reduce the electricity consumption of Street Lighting until 2030 [22]. Based on the results of justification, saving electrical energy by replacing LED lamps can be continued and will provide economic savings every year. These savings can be used for repair and maintenance of street lamps as well as installing lamps in locations that require street lighting [23].

In addition to statistical analysis, it also analyzes the results of the Street Lighting point profile survey, the lamp flash survey, the Street Lighting electricity consumption analysis per year, the Baseline Street Lighting analysis per year, and the annual GHG emission reduction analysis.

1. **Results and Discussion**

The results of the study consisted of analysis of the Street Lighting point profile, Street Lighting electricity consumption, street light intensity, and GHG mitigation action analysis. The type of Street Lighting used in Palembang City is a high-pressure sodium lamp of the Son-T type with a maximum lifetime of 15,000 hours [14]. The efficiency of Son-T lamps has an average of 110 lumens/watt according to the brand and type of lamp [24]. The street lighting profile of Palembang City has a total number of lamp points of 42,770 units with the total power and the percentage of electricity consumption as presented in Table 3.1 [8].

 **Table 3.1.** Number and Power of Street Lighting Installed in 2004 to 2019

|  |  |  |  |
| --- | --- | --- | --- |
| Type of Lamp | Unit | Total Power (kW) | Power Consumption (%) |
| Son-T250 W |  3,486 | 871.5 | 17.28 |
| Son-T150 W | 11,074 | 1,661.1 | 32.95 |
| Son-T70 W | 24,351 | 1,704.57 | 33.81 |
| HPL 125 W | 3,594 | 449.25 | 8.912 |
| LED | 3,741 | 353.47 | 7.012 |
| SolarCell80W | 10 | 0.8 | 0.015 |
| Total | 42,770 | 5,040 | 100 |

*(Source: Department of Housing and Settlement Areas, 2019)*

Based on the data in Table 3.1, the number of lamp points of Street Lighting is 42,770 units with a total power of 5040.69 kW and different LED lamp power. Based on data from the Department of Housing and Settlement Areas, 3,408 LED lamps have replaced all of the Son-T 250 W lamps [7]. Due to limited data on LED lamps in 2011 to 2018, it is assumed that the total LED lamp power is 120 W which is used for the LEAP analysis study. In addition, the data on the specifications of LED lamps with different powers in 2019 are additional data. The specifications for the replacement and addition of types of LED lamps are presented in Table 3.2 below.

**Table 3.2.** Types of LED Lamps based on Secondary

Data in 2019

|  |  |  |  |
| --- | --- | --- | --- |
| Types of Street Lighting | Brand | Total (Unit) | Desc. |
| TL Lamps | - | - | TL 1 |
| LED 120 W | Brand 2 | 194 | LED 2 |
| LED 120 W  | Brand 1 | 1.723 | LED 1 |
| LED 120 W | Brand 7 | 22 | LED 7 |
| LED 90 W | Brand 3 | - | LED 3 |
| LED 90 W | Brand 4 | 73 | LED 4 |
| LED 55 W | Brand 5 | 1.306 | LED 5 |
| LED 27 W | Brand 6 | 90 | LED 6 |
| Solar Cell | - | 10 | SC 1 |
| Total | 3.418 |  |

 *(Source: Department of Housing and Settlement*

 *Areas, 2020)*

Based on Table 3.2, LED Street Lighting has different power and type (brand). A total of 3,418 units of LED and LED Solar Cell lamps have replaced all of the Son-T 250 W lamps. Meanwhile, a total of 333 LED lamps are assumed to have a power of 120 W. Based on the survey results, the LED lamps with a power of 55 W are retrofit lamps installed under the LRT bridge.

The highest number of Street Lighting units by type is the Son-T 70 W lamp. Each lamp has a different electrical energy consumption based on the number of lamps. The biggest Street Lighting power consumption is the Son-T 70 W lamp at 33.87% with a total power of 1,704.57 kW [8]. The percentage of electrical energy consumption in the Son-T 250 W lamp is 17.32%, which is greater than the LED lamp of 6.84%. The value (%) of electrical energy consumption will increase as the number of lamps increases.

The survey results related to Street Lighting's 12-hour run time represents the varying consumption of electrical energy per day and per year. The total electricity consumption of Street Lighting by type of lamp according to procurement for 2004 to 2019 is presented in Table 3.3.

**Table 3.3.** Total Electrical Energy Consumption of

Street Lighting Based on Lamp Procurement in

2004-2019

|  |  |  |  |
| --- | --- | --- | --- |
| Type of Street Lighting | P (kW) | Electrical Energy Consumption (kWh) | Electrical Power Consump-tion (%) |
| 1 Year |
|  Son-T 250W |  871.5 | 3,817,170 | 17.289 |
|  Son-T150W | 1,661.1 | 7,275,618 | 32.953 |
|  Son-T 70W | 1,704.5 | 7,466,016.6 | 33.816 |
|  HPL125W |  449.25 | 1,967,715 | 8.9124 |
|  LED\* |  353.47 | 1,548,199 | 7.0123 |
|  Solar Cell |  0.8 | 3,504 | 0.0158 |
|  Total | 5,040.69 | 22,078,222.2 | 100 |

*(\*LED consumption is calculated based on different power)*

 *(Source: Department of Housing and Settlement*

 *Areas, 2020)*

Based on Table 3.3, the total electricity consumption of Street Lighting in 1 year reaches 22,078,222 kWh which is equivalent to 22,078.2 MWh. The electrical energy consumption of 70 W Son-T lamps in 2019 shows the largest number with a total of 7,466,016.6 kWh. The largest percentage of electric energy consumption is the Son-T 70 W lamp, which is 33.816% of the total electricity consumption in 1 year. Meanwhile, the percentage of electricity consumption for LED lamps is 7.0123% and for LED solar cells is 0.00158%. Thus, the potential for even greater savings is in LED lamps and solar cells.

Electricity consumption profile of Street Lighting based on secondary data from PLN UP3, Palembang City area is divided into each district. The distribution of electricity in Palembang City is divided into Rivai District, Kenten District, Sukarami District and Ampera District. Rivai District has the highest level of electrical energy consumption of 16,182,968 kWh in 2019 [3].

The highest electricity consumption at Rivai District (P3 tariff) in 2015 to 2019 is due to the large number of office and hotel buildings as well as luxury housing clusters that require more street lighting. Based on PLN secondary data, an increase in the total electricity consumption of Street Lighting in Palembang City occurs annually from 45,707,580 kWh to 52,845,036 kWh in 2019 [3].

**3.1. Lamp Point Profile and Operational Maintenance for LED and Non-LED Street Lighting**

The installation of LED and non-LED Street Lighting points is mainly carried out on arterial and protocol roads of Palembang City. Arterial roads are roads that serve major transportation. Its characteristics

are that it is intended for long-distance travel, a high average speed, and the number of entrances is limited [25].

Installation of Son-T lamps is carried out on the left and right sides of arterial roads with a power of 250 W. The substitution of Son-T lamps into LED lamps is also carried out on the middle section of arterial roads (retrofitting) where the route passes through arterial and collector roads in Palembang City. [26]. Meanwhile, on the collector road, the installation of LED lamp points tends to be on the left and right side of the road (standalone) with a power of 120 W. The number of street lighting points along with the power specifications is presented in Table 3.4.

**Table 3.4.** Number of LED and Non-LED Lamp Points and Power per Year

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year | Total of Son-T | Total of LED | Total of HPL | Total of Street Lighting |
| 2004 |  7,799 |  0 |  3,594 | 11,393 |
| 2005 |  8,515 | 0 |  3,594 | 12,109 |
| 2006 | 10,036 | 0 |  3,594 | 13,630 |
| 2007 | 11,990 | 0 |  3,594 | 15,584 |
| 2008 |  13,997 | 0 |  3,594 | 17,591 |
| 2009 |  15,580 | 0 |  3,594 | 19,174 |
| 2010 |  15,821 | 0 |  3,594 | 19,415 |
| 2011 |  17,599 | 382 |  3,594 | 20,811 |
|  2012 |  19,013 | 484 |  3,594 | 22,123 |
| 2013  |  21,978 | 1,417 |  3,594 | 25,419 |
| 2014 |  23,840 | 1,651 |  3,594 | 27,311 |
| 2015 |  28,427 | 1,651 |  3,594 | 31,898 |
| 2016 |  32,915 | 1,831 |  3,594 | 36,386 |
| 2017 |  36,358 | 2,018 |  3,594 | 39,829 |
| 2018 |  39,036 | 2,236 |  3,594 | 42,507 |
| 2019 |  39,036 | 3,741 |  3,594 | 42,770 |

 *(Source: Department of Housing and Settlement*

 *Areas, 2019)*

Based on the data in Table 3.4 above, the total number of Son-T lamp points is 39,036 units [8]. The Son-T lamp is a yellow street lighting that uses an incandescent filament [16]. Son-T Street Lighting is installed on the collector road with a power of 150 W and secondary collector road with a power of 70 W and lamp power of 250 W which is installed on the arterial road of Palembang City.

Meanwhile, Son-T lamps with a power of 70 W are mostly installed in residential areas. Referring to Table 3.2, the number of LED Street Lighting points in the Palembang City area is 3,418 units. A number of LED light points entirely replaces the Son-T 250 W lamps. In addition, there is no increase in the number of Son-T 250 lamps in 2019 and the following years. Street Lighting SOx also did not experience additional units. It is the same with HPL lamps with a total of 3,594 units in 2019.

The initial installation of LED lights was prioritized at the Islamic Solidarity Games in 2013. The installation of LED lights on arterial roads and under the LRT (retrofit) bridge in Palembang City is also a policy of the Palembang City government in the success of the 2018 ASEAN Games.

The entire operational authority of Street Lighting belongs to the Public Housing and Residential Areas in carrying out the maintenance and management of Street Lighting and community services [23]. The city government of Palembang has made efforts to save operational costs for street lighting by replacing the Son-T 250 W lamps with LED lamps and solar cells.

Based on research conducted by Luqman Assafat (2015), the performance of Son-T lamps is better than HPL-N lamps because the light intensity is better than HPL-N lamps, the absorption of electric current is smaller and the efficiency is better [27]. The number of additions of Son-T lamps compared to HPL lamps in Palembang City also increases the efficiency of Street Lighting. Referring to research conducted by Asnal Effendi and Niko Razonta (2015), the efficient street lighting for collector roads with a width of 6 meters is the Son-T 150 W lamp and for environmental roads is the Son-T 70 W lamp [28].

The addition of 10 solar cell lights in 2019 is a pilot project whose plans will be developed in the following year [29]. The increase in the total number of Street Lighting in the Palembang City area occurred significantly from 2004 to 2019. The increase in the number of Street Lighting units increased the electricity consumption of Street Lighting every year. The total electricity consumption of Street Lighting reflects the increase in installed energy consumption in Palembang City and it is presented in Figure 3.1 below.



 **Figure 3.1.** Installation of Lamp Points and

 Energy Consumption from 2004 to 2019

Based on Figure 3.1, the electric energy consumption of the Son-T 250 W lamp has increased quite significantly from 2013 of 3,954,045 MWh which tends to be constant until 2019 [8]. The electric energy consumption of the Son-T 250 W lamp is the baseline for mitigation actions. The electric energy consumption of 70 W and 150 W Son-T lamps also increases every year. The increase in the electric energy consumption of Son-T 70 W lamps has increased from 2004 to 2019. Son-T, HPL and SOx lamps are the baseline for total mitigation.

Based on Graph 3.1, a significant increase from 2004 to 2019 has the potential to increase the consumption of electrical energy in Street Lighting in the following year. So, GHG mitigation actions are needed in order to save electrical energy of Street Lighting so that the waste of electricity does not occur and implement electrical energy efficiency to indirectly reduce GHG emissions.

**3.2. Lighting Quality of LED Street Lighting**

**3.2.1. LED Lighting Quality Based on the Height of the Lamppost**

The feasibility of GHG mitigation actions requires a level of safety and comfort in accordance with the standards [30] [31]. Safety and comfort standards are determined by the quality of street lighting according to Indonesian National Standard No. 7391 of 2008 [21]. The results of research related to the light quality of LED Street Lighting are aimed at the average light intensity, the light intensity based on the height of the Street Lighting lamppost and the light intensity of the LED lamps based on the street width.

Based on the height of the lamppost, the average light intensity means that the LED 2 lamps have nearly the same value range at the 12-m lamppost. The difference in the mean value is based on the location of different roads. The average light intensity of LED lamps with the 12-m lamppost has the greatest value of 53.42 lux on Jalan Demang Lebar Daun.

The value of light intensity which is quite large with the same height of the lamppost is also found on Jalan Srijaya Negara amounting to 51.53 lux. This value is also influenced by the lighting of billboards or spotlights installed on a bridge that is high enough to provide more guaranteed comfort and safety for road users.

The intensity of the light produced at Jalan Demang Lebar Daun (11 m wide) is higher than the SNI 7391 2008 standard regarding Street Lighting Specifications. The result of the greater light intensity of LED lamps uses smaller street lighting energy consumption than Son-T lamps. Thus, the replacement of Son-T lamps to LED lamps provides greater economic benefits and energy efficiency. It was found that the smallest light intensity at the 12-m lamppost was 26.19 lux which was calculated from the lamps installed on Jalan RE Martadinata. The average light intensity data acquisition corresponds to a smaller road width than Jalan Demang Lebar Daun.

The light intensity of the LED 1 lamp (120 W) has a range of average lamp values ​​of 22.19 lux to 37.7

lux based on different road locations. LED lamps 1 (120 W) at the 12-m lamppost are generally installed on arterial and collector roads that represent the area of ​​PLN distribution areas.

The light intensity of the LED lamp 3 (90 W) has an average value of 39.33 lux at the 12-m lamppost. The value of light intensity does not have a significant difference with the LED lamps 2 (120 W) and LED 4 (90 W) of 43.03 lux. However, the light intensity value is smaller at the power of the LED 6 (27 W) lamp of 15.91 lux. It is because the small power of the LED lamp consumes less electrical energy. The replacement of the LED lamps does not affect the quality of the LED lighting. The amount of average light intensity is in accordance with the SNI Standard regarding the Street Lighting Specification No. 7391 of 2008. Based on technical analysis, the conversion of Son-T lamps to LED lamps does not affect the feasibility standard of street lighting.

**3.2.3. Analysis of LED Light Intensity to Lamppost Height and Street Width**

Street light intensity is an important physical aspect that determines safety and comfort. This study conducted an SPSS analysis of street light intensity on the lamppost height and street width. The influence and magnitude of the correlation between the three variables were calculated based on the SPSS method. The survey results minus the number of lights that are not lit by 49 units. Thus, the total number of lamps analyzed is 1,619 units. The number of LED lamps based on the survey results is greater than the minimum sample size of 397 units. The results of the correlation of light intensity and other influencing variables are presented in Table 3.5.

**Table 3.5.** Correlation of Light Intensity to Street

Width and Lamppost Height Using Kendall Tau

|  |  |  |  |
| --- | --- | --- | --- |
|  | Street Width | Lamppost Height | Power (Watt) |
| Street Width | 1.000 | 0.669 | 0.214 |
| - | 0 | 0 |
|  | 1619 | 1619 | 1619 |
| Lamppost Height | 0.669 | 1 | 0.622 |
| 0 | - | 0 |
|  | 1619 | 1619 | 1619 |
| Watt | 0.214 | 0.622 | 1 |
|  | 0 | 0 | - |
|  | 1619 | 1619 | 1619 |
| Lux | 0.129 | 0.089 | 0.274 |
|  | 0 | 0 | 0 |
|  | 1570 | 1570 | 1570 |

 *(Source: The Researchers, 2020)*

Based on the results of calculations using the SPSS method in Table 3.5, each street length of 1,000 m requires a light intensity of 1,570 lux. Based on the effect of lamp power on street width, the correlation coefficient is 0.214. The power of one LED lamp required on a street

width of 9 m is 42.056 Watt with the same coefficient calculation. The effect of lamp power on the lamppost results in a correlation coefficient of 0.622. Thus, the power of one LED lamp for a lamppost of 7 m and 12 m is 11.25 Watt and 17.69 Watt.

The intensity of the LED lamps which affects the street width and the height of the lamppost results in calculations with a correlation coefficient of 0.129 and 0.089. The calculation results obtained based on the height of the LED lamppost of 7 m require a power of 11.25 Watt and a power of 19.29 Watt for the height of the 12-m lamppost. Thus, the higher the lamppost requires more lamp power to illuminate the street surface.

**3.3. GHG Mitigation Analysis in Street Lighting Sector**

Energy is power that can be used to carry out various process activities; for instance, the generation and consumption of electrical energy [32] [33]. According to the Directorate General of New, Renewable Energy and Energy Conservation, the current conditions illustrate that energy in Indonesia is still dominated by fossil energy, energy prices that must be suppressed, energy use is still not efficient, Indonesia is committed to implementing the Paris Agreement, energy distribution still needs to be improved, the potential for renewable energy is still not optimal [31].

GHG mitigation actions are part of energy conservation efforts aimed at sustainable national development, national energy security and reduction of GHG emissions [31]. Long-term steps to reduce greenhouse gas emissions with a target of reducing emissions in the energy sector are 1,335 Mton CO2 in the first scenario and 1,271 Mton CO2 in the second scenario [31] [36]. The reduction in CO2 emissions in the energy sector by 50.37 million tons of CO2 is the energy sector's mitigation contribution to 16% of the NDC target (until 2018) [31] [37].

The potential for energy saving LED street lighting savings of 90 W 54 GWh/year is IDR 79 billion per year and the HPS 250 W 150 GWh/year is IDR 220 billion per year assuming 8 hours running hours, electricity tariff (P3) IDR 1,467.28/kWh and 205,940 Street Lighting units in Indonesia [38] [39]. In this study, it is assumed that the savings of LED lamps is with a power of 120 W and a running hour of 12 hours and an electric power rate of IDR 1,467.28/kWh [38].

Street lighting sector savings also aim to reduce final energy consumption, energy intensity of 1% per year, and energy elasticity of less than 1% by

2025 according to the National Energy Policy. The reduction in electrical energy consumption and emissions in the Street Lighting sector is based on the components and indicators of mitigation actions which are presented in Table 3.6 below [20] [40] :

 **Table 3.6.** GHG Mitigation Action Components and

 Indicators in Street Lighting Sector

|  |  |  |  |
| --- | --- | --- | --- |
| Components | Criteria | Unit |  Indicators |
| Replacement of Son-T lamps into LED lamps (non-retrofit) | Operation of new LED lamps to replace incandescent lamps (Son-T lamps) |  MWh | 1. Reducing the electricity consumption of Street Lighting |
| Unit | 2. Increasing the number of installed LED lamps |
| Installation of LED lamps (retrofit) | The operation of LED lamps and LED retrofit (installed under the LRT bridge of Palembang City) |  MWh | 1. Lowering the electrical energy consumption of Street Lighting |
| Unit | 2. Increasing the number of installed LED lamps |
| 3. Increasing the total number of street lamps |
| Use of energy efficient solar cell (LED) lamps | The operation of the LED solar cell lamps in the area near Tugu Monpera |  MWh | 1. Increasing the power of the installed solar cell lamps |
| Unit | 2. Increasing the number of LED solar cell lamps |
| 3. Increasing the total number of street lamps |

 *(Source: Directorate General of Climate Change*

*Control, Ministry of Environment and Forestry, 2018)*

Based on Table 3.6, regarding the criteria for mitigation actions, a survey was conducted to determine indicators and collect data on the number of LED lamp points. Survey data regarding lamp points and analysis of electrical energy consumption of Street Lighting justify the installation of LED lamps, which can reduce the consumption of electrical energy of Street Lighting.

Referring to secondary data, a total of 3,741 LED lighting units have been installed throughout Palembang City [8]. LED retrofit lamps are installed under the LRT bridge and non-retrofit LED lights are installed on the left and right of the collector road.

The baseline electricity consumption of Street Lighting has increased every year. Baseline electrical energy consumption is the consumption of electrical energy without mitigation treatment which consists of the total electrical energy consumption of Son-T 70 W,

150 W, 250 W, SOX and HPL 125 W lamps. Increasing the number of LED lighting installations provides a reduction in baseline energy consumption. It results in ∆ or the difference in electrical energy consumption of Street Lighting as an indicator that the mitigation action has been successful. The graph of the baseline electricity consumption and mitigation is presented in Figure 3.2 below.



 **Figure 3.2.** Baseline Electrical Energy Consumption

 & Street Lighting Mitigation in 2011 – 2019

Electrical energy consumption is calculated based on the project baseline. Based on the graph in Figure 3.2, the increase in baseline energy consumption in 2011 to 2019 with a slope of 1,045.9 has decreased to 858.35. This is an indicator of the success of mitigation actions.

Total baseline electricity energy consumption in 2011 was 13,280,773 MWh, experiencing an increase in 2015 to 15,104,386 MWh and 20,663,394 MWh in 2019. The increase in total baseline consumption has affected the amount of energy savings. If the amount of baseline energy consumption increases sharply, the installation of LED lamp points will still provide a low energy efficiency value. The addition of a large enough number of LED lamp points provides greater savings in electrical energy. The efficiency of electrical energy in Street Lighting sector from 2011 to 2019 is presented in Table 3.7. [8].

 **Table 3.7.** Electrical Energy Efficiency (%)

|  |  |
| --- | --- |
| Year | Electrical Energy Efficiency (%) |
| 2011 | 1.638 |
| 2012 | 2.001 |
| 2013 | 6.233 |
| 2014 | 6.840 |
| 2015 | 6.215 |
| 2016 | 6.266 |
| 2017 | 6.470 |
| 2018 | 6.813 |
| 2019 | 9.603 |

 *(Source: Department of Housing and*

 *Settlement Areas, 2019)*

Referring to the data in Table 3.7, the electric energy efficiency in the Street Lighting sector in 2011 was 1.638% and increased to 6.233%. It is because the electrical energy consumption of LED lamps increases along with the reduction in electrical energy consumption from Son-T 250 W lamps. The result of electrical energy efficiency in the Street Lighting sector in 2019 is 9.603% with the addition of 10 solar cell lamp units.

Increasing the efficiency of electrical energy in Street Lighting also provides an indirect increase in emission reduction or reduction of GHG emissions. The reduction in GHG emissions has increased according to the increase in the number of LED lamp points which is presented in Table 3.8 below. [8] [20].

**Table 3.8.** Reduction of GHG Emissions in Street Lighting Sector in 2011 to 2019

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year | Baseline Emission | Mitigation Emission |  Emission after Mitigation | Emission Reduction (%) |
| A |  B |  C |  D = B-C |  E=D/B\*100 |
| 2011  |  11,049.60 | 10,868.6 | 180.968 |  1.64 |
| 2012 |  11,459.27 | 11,229.9 | 229.290 |  2.00 |
| 2013 |  12,566.84 | 11,783.5 | 783.348 |  6.23 |
| 2014 | 13,072.44 | 12,178.2 | 894.203 |  6.84 |
| 2015 |  14,388.01 | 13,493.8 | 894.203 |  6.21 |
| 2016 |  15,630.53  | 14,651.0 | 979.477 |  6.26 |
| 2017 |  16,508.81 | 15,440.7 | 1,068.06 |  6.46 |
| 2018 |  17,191.94 | 16,020.6 | 1,171.34 |  6.81 |
| 2019 | 17,191.94 | 15,541.0 | 1,650.91 |  9.60 |

*(Source: Department of Housing and Settlement Areas,*

 *2019)*

Based on the data in Table 3.8, the baseline emissions of Street Lighting have increased every year based on the calculation of the total electricity consumption of Son-T 70 W, 150 W, 250 W SOx and HPL 125 W lamps. This increase has the potential to continue in the next several years. In an effort to reduce GHG emissions, it requires mitigation actions in order to reduce GHG emissions so as to obtain a better environmental impact.

The results of GHG emission calculations based on the baseline project obtained 1,890.51 tons of CO2e with a total number of LED lamps of 3,741 units. The reduction of GHG emissions, based on data from a survey of lamp points classified according to the street name in Palembang City, obtained 4,281 units of LED lamps with a reduction of 1,881,662 tons. In addition, the 1,619 LED lamp units that have been surveyed are secondary data, so that the total number of LED lamps is 4,281 units in 2019. Additional LED lamp points are added annually according to the official budget. LED lamps and LED solar cells that are off are not taken into account in GHG mitigation actions.

The results of GHG emission reduction in this study can be seen in accordance with the reduction in the slope of the emission graph by 714.15, which is smaller than the slope of the baseline graph of 870.16. Emission reduction before and after mitigation action is presented in Figure 3.3 below.



 **Figure 3.3.** Emission Reduction of CO2 After

 Mitigation Action 2011 to 2019

Based on Figure 3.3, the slope reduction according to the graphic above shows the mitigation action indicator which is the replacement of the Son-T 250 W lamp into LED lamp. The percentage of GHG emission reduction, in this case CO2, has the same value as the percentage of electrical energy efficiency of 9.603% or 1,650.9 tons of CO2-e.

The increase in emission reduction every year needs to be maintained by adding or replacing Son-T lamps into LED lamps. Increased emission reduction also has positive environmental impacts [2] [41]. The addition of LED lamps affects the economy in GHG mitigation. The mitigation framework requires proper economic planning to achieve the GHG mitigation target of 29% by 2030 [36] [35].

The economics of GHG mitigation affect operational costs as well as the cost of procuring Street Lighting. The operating costs of LED lamps are cheaper than the operating costs of Son-T lamps. Meanwhile, the cost of installing Son-T lamps tends to be cheaper than the operational costs [42].

Son-T lamps of different power and type (brand) will also provide different economic costs. The more the number of LED lamps, the economic cost of the PJU will decrease because the savings in electricity consumption are increasing [43]. The increase in the cost of saving electrical energy is presented in Figure 3.4.



 **Figure 3.4.** Electricity Energy Saving Costs from

 Street Lighting in 2011 to 2019

The cost of electricity saving is calculated based on kWh, the amount of electricity saved per year, multiplied by rupiah per kWh. Based on the graph in Figure 3.4, street lighting electricity savings experienced a significant increase from 2012 to 2013 amounting to IDR 237,558,235 to IDR 811,594,378. An increase in the cost of electrical energy saving also occurred in 2018, amounting to IDR 1,883,559,005 to IDR 2,065,729,810. The increase in energy savings in electricity reduces the total cost burden of operating and installing street lighting. Thus, it requires planning to add LED lamps in order to obtain greater savings and the potential to achieve a 29% reduction in GHG emissions.

The results of other GHG mitigation analyzes are also based on light intensity data where GHG mitigation actions do not affect street lighting. The light intensity and correlation of street width and lamppost height are adjusted to the SNI 7391 Standard of 2008. In this case, the implementation of mitigation actions for the replacement of LED lamps does not reduce the quality of street lighting in Palembang City.

In order to improve the electrical energy efficiency of Street Lighting and achieve GHG emission reductions, the analysis of planning for installing Street Lighting for the following year is justified by LEAP method. The results of mitigation analysis using the LEAP method justify that the installation of LED lamps with a consistent number of increments will achieve energy efficiency and a significant reduction in GHG emissions by 2030. An analysis of the reduction in electrical energy consumption for Street Lighting Son-T lamps in 2030 can be projected based on the existing data presented in Figure 3.5 below.



**Figure 3.5.** Scenario of Projected Electric Energy

 Consumption for Son-T Lamps until 2030

Based on the graph (LEAP), the projected electrical energy consumption of Son-T 250 W, 150 W and 70 W lamps will experience a significant decrease in 2025. The electrical energy consumption of Son-T 250 W lamps of 3.8 thousand kWh has decreased continuously until 2019 by 0.5 thousand kWh. It is projected that the reduction in the electrical energy consumption of Son-T 250 W lamp in the following year is 0 kWh until 2030. The projection of electrical energy consumption of Son-T 150 W lamp of 5,690.3 thousand kWh in 2010 will decrease significantly by 5,155.4. thousand kWh in 2023 and 4,836.7 thousand kWh in 2030. The projected reduction in electricity consumption also occurs in Son-T 70 W lamps of 1,132.1 thousand kWh in 2010, 1,020.6 thousand kWh in 2023 and 957.5 thousand kWh in 2030.

The projection of decreasing the electric energy consumption of Son-T lamps is directly proportional to the reduction in the number of Son-T lamp points as a substitute form for LED lamps. The reduction in the number of Son-T lamp points is also projected using the LEAP method as justification for planning the implementation of sustainable mitigation. The results of the projection scenario for the reduction in the number of Son T 150 W and 70 W lamp points are presented in Figure 3.6.



 **Figure 3.6.** Scenario of Projected Number of Son-T

 Lamp Points until 2030

Based on the graph in Figure 3.6., the projected number of Son-T lamp points until 2030 will experience a decline. The projected number of Son-T 250 W lamp points will not be installed in 2020 and will be exhausted in 2021. It is estimated that the number of Son-T 150 W lamp points will decrease from 10.9 thousand units in 2020 to 10 thousand units in 2030. The number of Son-T 70 W lamp points is also projected to decrease from 24.3 thousand units in 2020 to 24 thousand units in 2030.

The projection of reducing the number of Son-T lamp points is a mitigation action that will be implemented in accordance with installation planning for LED lamps. The projection scenario of electricity consumption and LED lamp points until 2030 is presented in Figure 3.7.



**Figure 3.7.** Increase of Electrical Energy Consumption

 of LED Lamps

The electricity consumption of LED lamps is projected to increase until 2030. This is an indicator of the potential for electricity savings in Street Lighting in Palembang City. The increase in the electricity consumption of LED lamps by 2,005.6 thousand kWh increases continuously to 2,128.4 thousand kWh in 2023 and 2,444.8 thousand kWh in 2030. The increase in electricity savings in Street Lighting generally indicates a decrease in electricity consumption of Street Lighting. The decrease in the electricity consumption of Street Lighting is influenced by the reduction in the number of Son-T lamps 150 W and 70 W and the increase in the number of LED lamp points to be installed. The more the number of LED lamp points installed, the greater the chance of reducing energy consumption in Street Lighting. The increase in the number of LED lamp points installed until 2030 is presented in Figure 3.8.



 **Figure 3.8.** Projection of the Number of LED Lamp

 Points until 2030

Based on Figure 3.8, the projection of the number of LED lamp points (LEAP) has increased significantly in accordance with the increase in electricity consumption of LED lamps in Figure 3.7. The projected number of LED lamps in 2030 is 8,000 units.

Economy also determines the feasibility of mitigation actions. The electricity savings obtained from the replacement of Son-T 250 W lamps for LED lamps provide reduced costs that can reduce the cost burden of Street Lighting expenses.

The average electrical energy savings for Street Lighting are calculated based on the data per district. Secondary data on the average cost of electrical energy saving are presented in Table 3.9 based on Department of Housing and Settlement .

 **Table 3.9.** Energy and Electricity Cost Savings

 in Street Lighting Sector in 2020



*(Source: Department of Housing and Settlement*

 *Areas, 2020)*

Based on the data in Table 3.11, the calculation of the average cost savings per district refers to the data on electricity customers who are subject to the conversion of Son-T lamps into LED lamps, assuming that one panel has a total of 30 lamps. Referring to this data, it is found that 14 panels representing the Palembang City area with 420 LED lamps so that the calculation of the average cost savings for LED lamps is IDR 169,171.92 per lamp. Thus, the estimated average cost savings in 2030 is IDR 1,353,375,371 with 8,000 units of LED lamps. The estimated average cost of saving electricity in 2019 based on LEAP analysis is IDR 632,872,158 so that it will give a twofold increase in cost savings. Based on the increase in the percentage, Street Lighting savings cost calculated based on electricity consumption (kWh) in 2030 (project based) is IDR 6,226,103,694 with an electrical energy efficiency of 17.48%.

The greater the cost savings, the less the burden of operating and installing costs for Street Lighting. Thus, it is more profitable and simultaneously and indirectly reduces GHG emissions in Street Lighting sector [20] [44].

The GHG emission reduction target based on the NDC document in 2030 is 29%. Therefore, the achievement of the Street Lighting sector emission reduction target is maintained at 17.48% with the addition of LED lamp replacement in accordance with the Street Lighting Service’s budget. Referring to these data indicators, the GHG mitigation actions that have been carried out by the Palembang City government have met the criteria and standards for Street Lighting as presented in Table 3.8. The achievement of the overall GHG emission reduction target should not exceed 29% so as not to change the energy calculation [13].

Mitigation actions in Street Lighting sector in a sustainable manner require planning for the installation of LED lamps in the following year with a planned budget for the installation of LED lamps of IDR 30,134,060,000 in 2021 [45]. The current project cost of installing LED lamps in 2020 is IDR 9,560,000,000 [46].

The installation of LED lamp substitutions in 2020 has been delayed due to the Covid-19 pandemic. Part of the service budget has been allocated to financing the Covid-19 pandemic and the installation of LED lamps will be continued in the following year (2021) based on the 2021 budget planning.

The postponement of the Street Lighting solar cell lighting project and the rooftop project also occurred and has not been carried out further [47]. The delayed mitigation will result in a reduction in cost savings and a decrease in the electricity consumption of LED lamps by 2030. Thus, the estimated achievement of electricity savings in 2030 will be less than 17.48%.

Efforts to improve in reducing electrical energy consumption require the value of concern for the environment, especially energy consumption and greenhouse gas emissions, which are involved in the implementation of the construction and operation of Street Lighting [48]. Efforts to optimize GHG mitigation in the Street Lighting sector during the Covid-19 pandemic are by conducting energy audits in Street Lighting sector and making alternative Street Lighting (low cost) energy savings such as load substitution and reducing lamp hours. Another effort that can be carried out is by installing Street Lighting using solar cells, implementing a credit mechanism (JCM Indonesia) in the framework of low-carbon development to maintain the feasibility of the quality of Street Lighting as well as optimizing community services with minimal electrical energy Street Lighting according to the national energy policy. [49] [50] [51].

1. **Conclusions**

Conclusions for this research are as follows:

1. The GHG mitigation action in the Street Lighting sector provides a projection of Street Lighting savings below the electric energy efficiency target of 17.48% with projected electricity savings in 2030 due to the impact of the Covid-19 pandemic. There has been a decrease in the energy efficiency of Street Lighting with the projected energy consumption savings of Street Lighting (LEAP) of 1,911,000 kWh.
2. Efficiency of electrical energy for replacing LED lamps resulted in cost savings of IDR 2,911,841,740 in 2019 with a reduction in CO2 (indirect) emissions of 1,650.9 tons CO2-e. The scheme for the cost of saving electrical energy in 2030 is IDR 6,226,103,694 with an estimated additional number of lamps of 8,000 units and electricity consumption of 1,911,000 kWh.
3. Recommendations on the implementation of mitigation actions in Street Lighting sector:
* Replacing Son-T 150 W and 70 W lamps into LED lamps by 2030
* Implementing a low-carbon development-based credit mechanism within the Indonesian JCM framework
* Saving electrical energy by not turning on street lamps during the day or reducing Street Lighting hours
* Saving electrical energy optimally by using an electric meter and optimizing the implementation of SNI Street Lighting standards in all areas of Palembang City
* Saving electrical energy of street lighting based on the guidelines for implementing climate change GHG mitigation actions in order to achieve the emission reduction target according to the NDC document
* Conducting energy audits annually to obtain energy-efficient subsidies, thereby providing increased revenue and reducing Street Lighting technical maintenance operating costs and electricity consumption costs
* Replacing Son-T lamps into LED lamps up to 8,000 units to reduce street lighting electricity consumption and increase GHG emission reduction
* Carrying out mitigation efforts by prioritizing efficient activities to increase emission reduction
* Conducting a feasibility study for all street lighting (low cost) electricity saving activities carried out by Palembang City government
* Conducting an evaluation study of the Palembang City Regional Action Plan related to Greenhouse Gas by prioritizing the Street Lighting sector in order to reduce emissions below 17.48%
* Allocating the budget of Palembang City Regional Action Plan related to Greenhouse Gas during the Covid-19 pandemic to optimize the achievement of the 17.48% emission reduction target by 2030
* Conducting a research to evaluate funding for the planning of installing Street Lighting Solar Cells in order to increase the reduction of GHG emissions in Street Lighting sector

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