Analysis of Greenhouse Gas Mitigation

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Sriwijaya Journal of Environment
Article
ojs.pps.unsri.ac.id

Analysis of Greenhouse Gas Mitigation in Energy Sector/Electricity Sub-Sector on Street Lighting (Case Study: Palembang City)

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Article history

Received	Received in revised form	Accepted	Available online
18 November 2020	31 March 2021	26 April 2021	29 April 2021

Abstract: The greatest source of GHG emission from energy sector comes from fossil fuel combustion. According to PLN, 63.75% of electricity distribution 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 implementation of electrical energy efficiency is carried out by replacing Son T 250 W lamps into LED lamps with different power. The SPSS statistical analysis determines that 1,000-unit street lightstreet lighting 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 in which 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, if 8000 units of LED lamps replace Son T lamps, the electricity consumption of Street Lighting in 2030 will decrease with a projected efficiency of 17.48%.

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% distribusi 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 analisis menggunakan statistik SPSS dan LEAP yang telah dijustifikasi berdasarkan pengamatan hasil survey PJU sebanyak 1.619 unit di keempat rayon yang mewakili wilayah Kota Palembang. Penerapan efisiensi energi listrik Sektor PJU dilakukan dengan mengganti lampu Son T 250 W menjadi lampu LED dengan daya berbeda. Hasil analisis statistik 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 dengan efisiensi energi sebesar 9,603 % dengan pergantian LED sebanyak 3.741 unit mengurangi emisi GRK sebesar 1.650,9138 ton CO_2e dengan biaya penghematan 2.911.481.740 rupiah. Maka berdasarkan analisis LEAP, sebanyak lampu LED 8.000 unit menggantikan lampu Son T maka konsumsi energi listrik PJU di tahun 2030 akan mengalami penurunan dengan proyeksi efisiensi 17,48%.

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

1. Introduction

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]

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 CO_2 in the first scenario and 1,271 Mton CO_2 in the second scenario [31] [36]. The reduction in CO_2 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].

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

a. 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.
b. 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.
c. 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.

Furthermore, the objectives of the research include:

a. Conducting an analysis of the GHG mitigation efforts of Palembang City Government in Street Lighting sectorelectricity sub-sector in order to achieve an energy elasticity of less than 1 (one) percent by 2025.

b. 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.
c. 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%.

2. Research Material and Method

2.1. Material and Instrument

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

2.2. Methods

2.2.1. 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.

2.2.2. 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] :

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

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.

2.2.3. 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] :

$$E_x = \frac{Power\ (kW) x\ lamp\ point\ of\ Street\ Lighting\ (unit) x\ 12\ hours}{1.000.000} [MWh] \quad (2)$$

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 SO_X 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]:

$E = E_1 - E_2$, where ....(3)

E_1 is the energy consumption before mitigation is carried out
E_2 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. The electricity generation for street light supply in Palembang does not use coal. In addition, based on PLN WS2JB of Palembang, they have not used coal for a long time; for instance, PLTGU Keramasan, PLTG Borang, PLTG Jakabaring, PLTGU Indralaya, and PLTG Talang Duku use natural gas. However, there are many power plants outside Palembang that still use coal sources such as PTBA to supply the integrated power grid throughout South Sumatra Province.

Thus, the resulting emissions are calculated using the multiplication of the emission factors. The calculation of GHG Emission formula is as follows :

Emission = activity data x emission factors ....(4)

Activity data is the electrical energy consumption data from Son-T and LED lamps. Emission factors are data that follow the values given by the Ministry of Energy and Mineral Resources in 2016. 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 constantly 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 CO_2e] [19]...(5)

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].

2.3. 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] :

$$E_f = \frac{E_1 - E_2}{E_1} \times 100\ \%, \ldots\ldots(6)$$

E_f=efficiency of electrical energy after mitigation action is carried out
E_1=energy consumption before mitigation action is carried out
E_2=energy consumption after mitigation action is carried out

The greater the E_1 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.

2.4. 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]. LEAP method based on berdasarkan framework project scheme on Figure 1.

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.

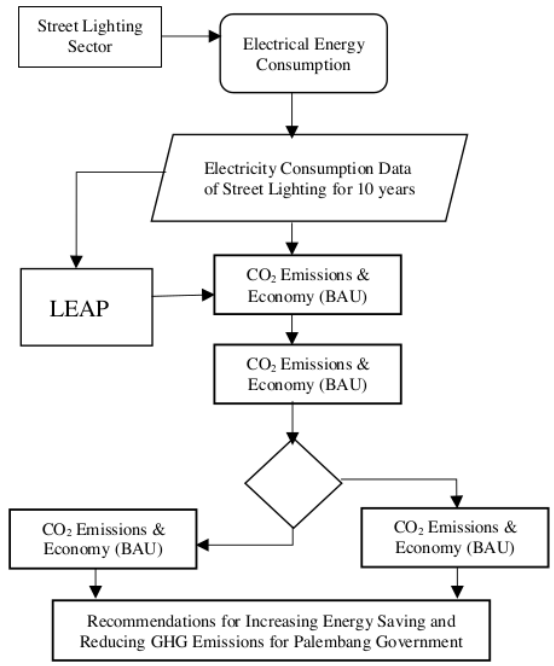

Figure 1. Project based mitigation framework street lighting sector

3. 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].

Based on the data in Table 1, the number of lamp points of Street Lighting is 42,770 units with a total power of 5,136.14 kW. 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. Based on the survey results, the LED lamps with a power of 120 W are retrofit lamps installed under the LRT bridge.

Table 1. Number and power of street lighting installed in 2004 to 2019

Type of Lamp	Unit	Total Power (kW)	Electrical Energy Consumption (kWh) Per 1 Year
Son-T250 W	3,486	871.5	3,817,170
Son-T150 W	11,074	1,661.1	7,275,618
Son-T70 W	24,351	1,704.5	7,466,016
HPL 125 W	3,594	449.25	1,967,715
LED	3,741	448.92	1,966,269
SolarCell80W	10	0.8	3,504
Total	42,770	5,136.14	22,496,293

Source: Department of Housing and Settlement Areas, 2019

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 2019 Table 1.

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 2.

Table 2. 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 2 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 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 8the 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 betterthan 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 2 below.

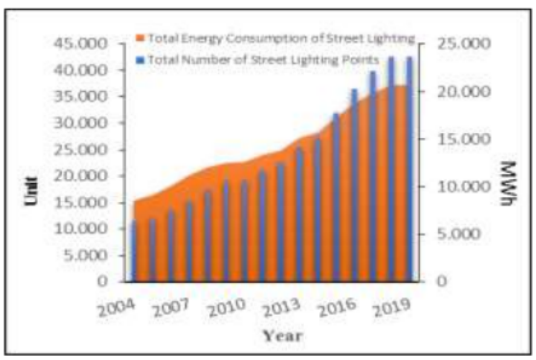

Figure 2. Installation of lamp points and energy consumption from 2004 to 2019

Based on Figure 2, 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 2, 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.

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.

Based on the results of calculations using the SPSS method in Table 3, 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.

Table 3. 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)

3.3. GHG Mitigation Analysis in Street Lighting Sector

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 4 below [20] [40] :

Table 4. GHG Mitigation Action Components an 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 4, 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 Δ or the difference in electrical energy consumption of Street Lighting as an indicator that the mitigation action has been successful. The table of the baseline electricity consumption and mitigation is presented in Table 5 below.

Table 5. Baseline Electrical Energy Consumption & Street Lighting Mitigation in 2011 – 2019

Total Baseline (MWh)	Mitigation Energy Consumption (MWh)	Electricity Energy Saving After Mitigation (MWh)	% Efficiency Energy
13,280.77	13,063.26	217.5108	1.638
13,773.17	13,497.58	275.5896	2.001
15,104.38	14,162.86	941.5248	6.233
15,712.06	14,637.30	1,074.764	6.840
17,293.29	16,218.52	1,074.764	6.215
18,786.69	17,609.43	1,177.256	6.266
19,842.31	18,558.58	1,283.734	6.470
20,663.39	19,255.53	1,407.863	6.813
20,663.39	18,679.12	1,984.271	9.603

(Sumber :ource Department of Housing and Settlement Area, 2019)

Electrical energy consumption is calculated based on the project baseline. Based on the graph in Table 5, 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 6. [8].

Table 6. 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 6, 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 7 below. [8] [20].

Table 7. Reduction of GHG Emissions in Street Lighting Sector in 2011 to 2019

Year	Baseline	Mitigation Emission	Emission after Mitigation	Emission Reduction (%)
A	B	C	D = B-C	E=D/B*10(
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 7, 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 CO_2e 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 below.

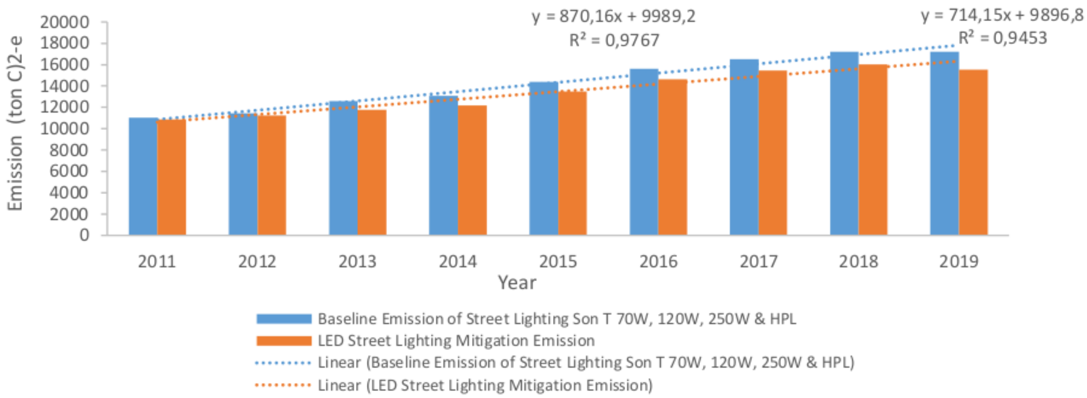

Figure 3. Emission reduction of CO_2 after mitigation action 2011 to 2019

Based on Figure 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 CO_2, has the same value as the percentage of electrical energy efficiency of 9.603% or 1,650.9 tons of CO_2-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 4.

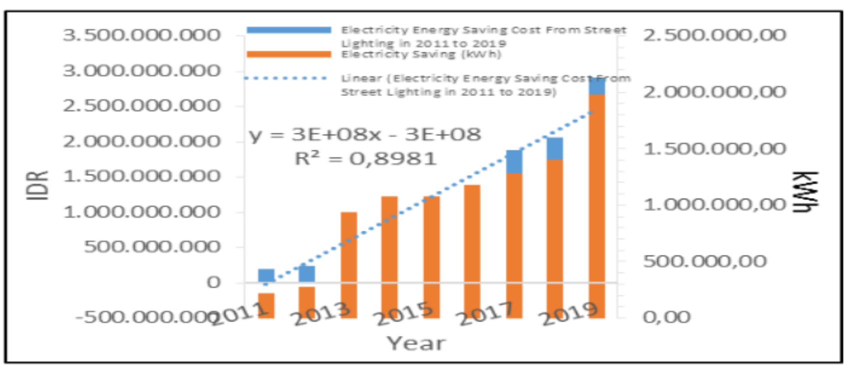

Figure 4. Electricity Energy Saving Costs from Street Lighting in 2011 to 2019

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 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.

LEAP analysis graphs are prepared by entering data on street lamps, baseline, data on lamp points before and after mitigation and a decrease in the amount of electricity consumption. It is assumed that there is a decrease in the energy consumption of Son T lamps and an increase in the electricity consumption of LED lamps. The demand for Street Lighting will continue to increase and the power sources that provide supply will not increase until 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 5 below.

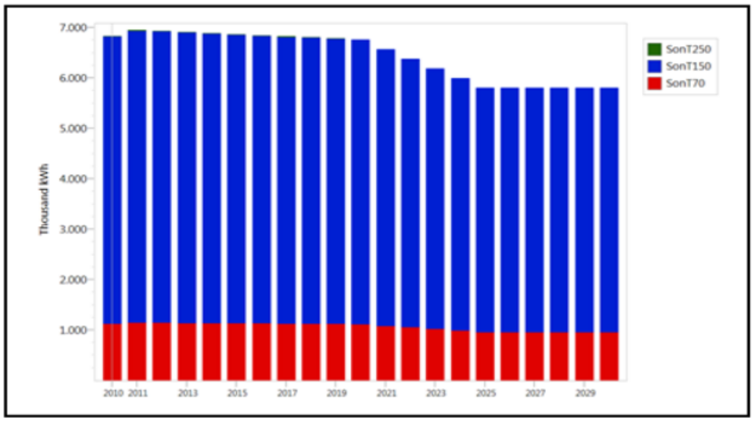

Figure 5. Scenario of Projected Electric Energy Consumption for Son-T Lamps until 2030

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 6

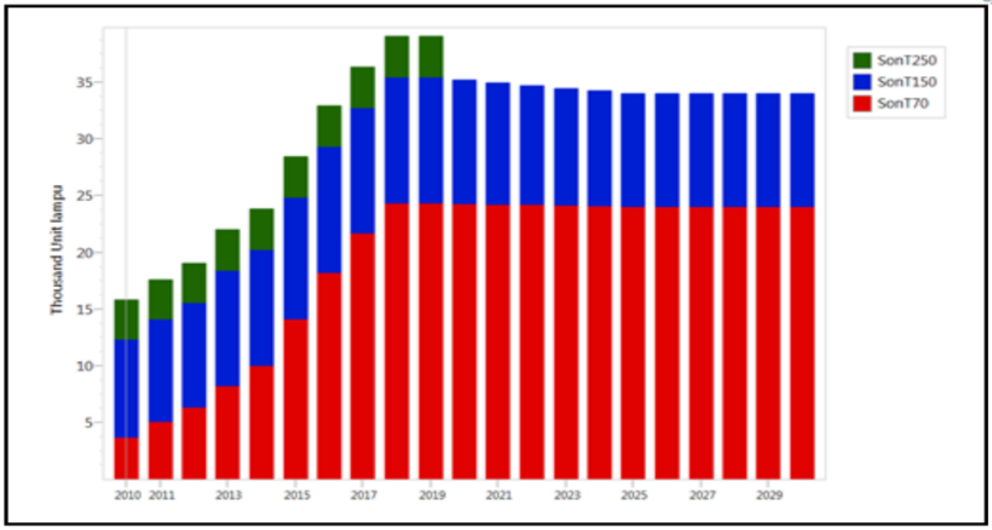

Figure 6. Scenario of Projected Number of Son-T Lamp Points until 2030

Based on the graph in Figure 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 7.

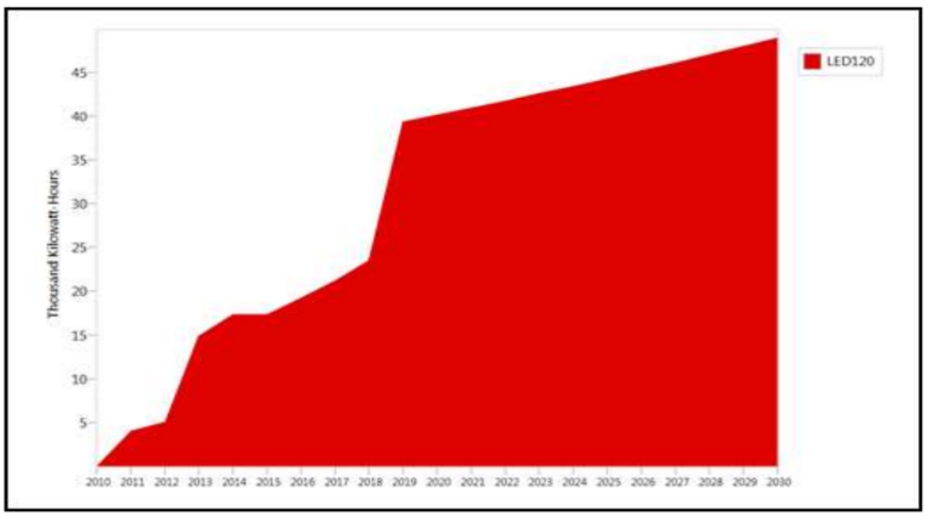

Figure 7. Increase of Electrical Energy Consumption of LED Lamps

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 8.

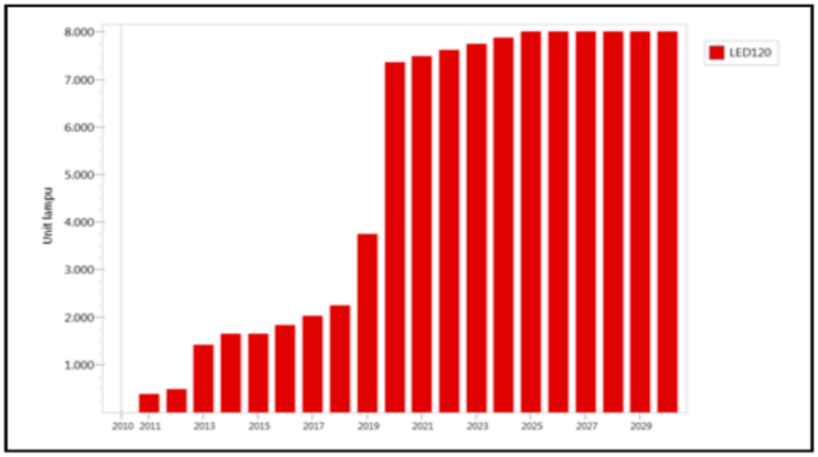

Figure 8. Projection of the Number of LED Lamp Points until 2030

Based on Figure 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 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 8 based on Department of Housing and Settlement.

Table 8. Energy and Electricity Cost Savings in Street Lighting Sector in 2020

Districts	Electricity Savings Per District				
	Customer IP	Street Name	Electrical Power	Cost (before)	Cost (after)
Kenten	2195323	R. Sukamto	5500	2,911,214	1,617,073
	2195311	Basuki Rahmat	7700	4,243,505	2,190,780
	14.100.219388.6	Sudirman	-	5,837,325	625,127
	14.100.219342.1	Sudirman	-	9,083,063	3,078,484
Rivai	14.100.240806.6	DLD	-	4,241,963	1,024,292
	14.100.220465.1	DLD	-	9,083,063	3,013,924
	14.100.220462.4	Mayor Salim BB	11000	6,462,032	1,969,221
Sukarami	14.120.258943.0	Soekarno Hatta	-	9,083,063	1,248,786
	2449707	Bypass AAL	10600	5,838,438	2,701,292
	2183612	Bypass AAL	23000	12,661,290	2,908,280
	2183636	Bypass AAL	23000	12,661,290	2,539,993
Ampera	1242109	Ahmad Yani	5500	3,032,999	1,093,254
	14.130.125161.9	Kertapati	-	5,837,325	1,433,663
	1247323	Ds. Palembang	13200	7,269,036	1,749,129
Total Number of Lamps (Assumption) =			420 units	98,245,606	27,193,399
Total Savings =			IDR 71,052,207		
Savings @1 unit LED =			IDR 169,171.92		

Source: Department of Housing and Settlement Areas, 2020

Based on the data in Table 8, 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 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 [44].

Based on the installed lamp points, the analysis of the investment cost between the Son T and LED lamps also determines the planning of further mitigation actions. Analysis of Son T and LED lamps, with electricity consumption costs paid, is compared to investment costs. The following is the total comparison data between operating and investment costs, which is presented in Table 9.

Table 9. Comparison of Total and Operating Costs

Year	Total Cost of Electricity Consumption Per Unit (IDR)	Total Investment Cost (IDR)	Comparison of Electric Energy Consumption Costs to Investment Costs
2010	2,137,002	75,967,150,646	0.675
2011	2,567,994	84,914,394,842	0.707
2012	2,699,525	89,830,891,254	0.743
2013	2,699,525	107,645,706,238	0.743
2014	3,457,397	115,206,184,266	0.952
2015	4,569,150	127,549,461,828	1.258
2016	4,234,058	141,587,856,036	1.166
2017	4,595,081	152,890,513,842	1.265
2018	4,524,367	162,472,430,302	1.246
2019	3,448,643	179,619,576,460	0.735

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

Based on Table 9, the cost of electricity consumption for Street Lighting before mitigation is IDR 27,818,465,924.6 to IDR 26,985,729,287 in 2019. In this case, there is a reduction or savings in electricity consumption costs after the mitigation action is carried out. This cost reduction is the basis and justification for the need to implement mitigation actions of changing LED lights in the following year.

During the 11 years of the LED lamp life, the total investment cost was greater than before the mitigation action was carried out, namely IDR 179,619,576,460. After the eleventh year, the LED lamps are replaced with new LED lamps. LED lights provide maintenance or management at low cost. However, the cost of saving will also continue to increase with a projection of 17.48% in 2030 and the energy consumption of LED electricity is lower than that of Son T lamps. Thus, the cost of electricity consumption is cheaper. The comparison of investment costs and electricity consumption refers to the data in the graph in Figure 9.

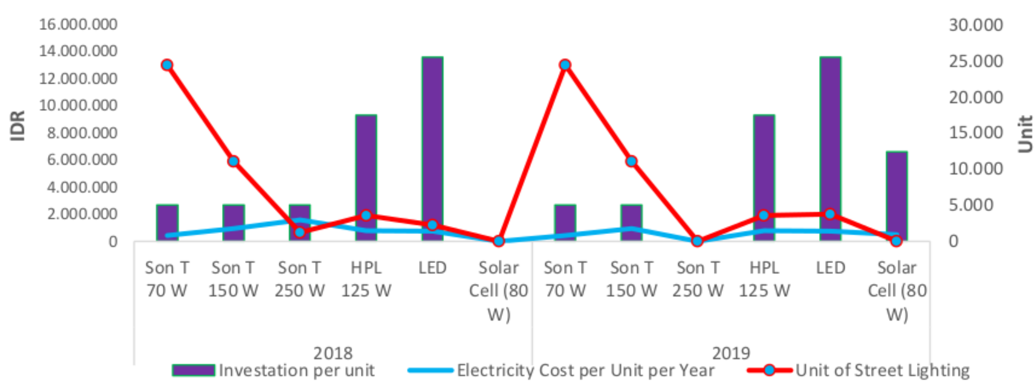

Figure 9. Comparison of Investment Costs and Electric Power Consumption

Based on Figure 9, the operational cost compared to the investment cost for Son T 250 W lamp is 58.78%. The number of points of the Son T 250 W lamps is small but consumes quite a lot of electricity costs compared to other lamps of Street Lighting. This value indicates that Son T 250 W lamps need to be replaced.

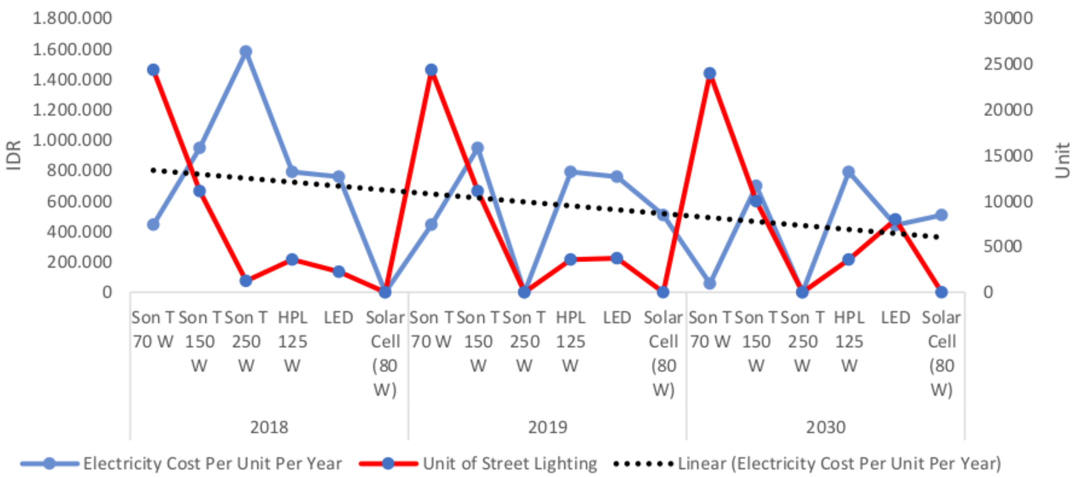

Figure 10 The comparation of street light unit projection and power consumption unit year 2030

Based on the projection of the graph in Figure 10, the cost of electricity consumption for Street Lighting has decreased and is an indicator of even greater savings, assuming that PLN electricity rates remain as in 2021. Cost savings per year are presented in Table 10.

Table 10. Cost of Electricity Saving Per Year

Year	Electrical Energy Saving		
	KWh	Cost in IDR	Percentage (%)
2011	217,510.80	178,358.856	1.638
2012	275,589.60	237,558.235	2.001
2013	941,524.80	811,594.378	6.233
2014	1,074,764.40	1,186,539.898	6.840
2015	1,074,764.40	1,568,081.260	6.215
2016	1,177,256.40	1,591,650.653	6.266
2017	1,283,734.20	1,883,597.517	6.470
2018	1,407,863.40	1,213,578.251	6.813
2019	1,984,271.40	2,866,676.892	9.603

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

The results of this research calculation refer to the data in Table 10, there are increases and decreases in cost savings in 2018 and 2019. The biggest cost savings occurred in 2019 amounting to IDR 2,866,676,892 due to the blackout of the lights under the LRT bridge by PLN and the replacement of Son T 250 W lamps becomes the LED lamps. The correlation of cost savings with investment costs and electricity consumption can be analyzed through investment costs and electricity consumption costs. The cost and power consumption per year is presented in Figure 11

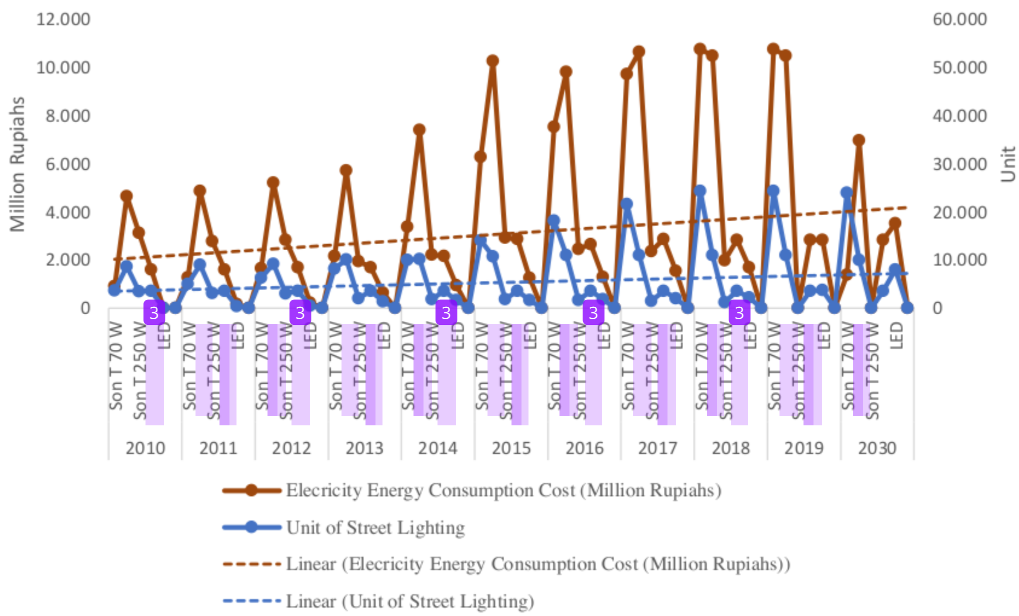

Figure 11. Cost and power consumption per year based on lamp type

Based on Figure 11, Street Lighting consumption costs increase according to the lamp power. Son T 150 W lamps have a higher electricity consumption cost and are increasing every year. Referring to the data in appendix 6, the cost of electricity consumption for Son T 150 W lamps in 2013 and 2014 is IDR 5,739,795,090 and IDR 7,427,358,720. Then, the cost of electricity for Son T 150 W lamps increased in 2016 and became IDR 10,675,368,779 in 2017. This cost decreased in 2018 and 2019, namely IDR 10,511,085,325 because there was no increase in the number of lamps.

In 2030, based on appendix data, the projected reduction in electricity cost consumption for Son T 70 W lamps will be IDR 1,383,300,250, Son T 150 W lamps IDR 6,987,580,490, HPL 125 W lamps IDR 2,842,757,861 and LEDs IDR 3,532,002,560 and solar cell IDR 5,062,229. This indicator of reducing the cost of electricity consumption provides greater savings if mitigation actions are carried out in a sustainable manner.

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 [46]. An alternative 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 [46] [47] [48].

4. Conclusions

Conclusions for this research are as follows:

1. Each road length of 1,000 m requires a light intensity of 1,570 lux with a correlation coefficient of 0.214. In this case, the required power of one LED lamp on a road width of 9 m is 42.056 watts with the same coefficient calculation. So, the taller the lamppost requires more lamp power to illuminate the road surface of Palembang City.
2. The GHG mitigation action in the Street Lighting sector provides projected savings below the electric energy efficiency target of 17.48%. Street Light energy efficiency with projected electricity consumption savings (LEAP) and a reduction of 1,911 MWh results in cost savings of IDR 2,911,841,740 in 2019 with a reduction in CO_2 (indirect) emissions of 1,650.9 tons CO_2-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 MWh. Recommendations on the implementation of mitigation actions in Street Lighting sector: a. Replacing Son-T 150 W and 70 W lamps into LED lamps by 2030; b. Implementing a low-carbon development-based credit mechanism within the

Indonesian JCM framework; c. Replacing Son-T lamps into LED lamps up to 8,000 units to reduce street lighting electricity consumption and increase GHG emission reduction

Acknowledgement

The author would like to thank Mr. Nanang Kristanto and Mr. Jamaludin Lastiko from the National Energy Council as the directors of LEAP program, Mr. Dedi Suprianto, Head of Street Lighting Sector at the Department of Housing and Settlement Areas of Palembang City, who gave permission for the research location, and Mr. Dicky Edwin Hindarto from JCM Indonesia for providing valuable opportunities and time to discuss about this research. Gratitude also goes to Sriwijaya University that had funded this study through Hibah Kompetitif 2017. The Head of Regional Development Planning Agency, Research and Development Agency of Palembang City, and the Central Statistics Agency of Palembang City which has granted research permits in Palembang City. The author also thanks the Ministry of Environment and Forestry, Mr. Rusdy Anwar, the Regional Mining and Energy Company, the Jakabaring Solar Power Plant, the Department of Energy, Resources and Minerals of South Sumatra Province for providing discussion opportunities and research permits, and Ms. Yossy Sunda Permatasari, State University of Malang for giving her valuable time to conduct discussions related to this research.

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