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Fostering Energy Efficiency Through Street Lighting System Improvement: A Case Study of City-Level in Indonesia

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Abstract

Street lighting can be considered the main energy consumer and greenhouse gas emitter at Indonesia's city level. In addition, public street lighting systems throughout Indonesia still use inefficient technologies, resulting in a significant portion of a municipality's operating expenditure. We conduct techno-economy analysis and formulate financing mechanisms to support energy efficiency improvements on street lighting systems. In doing so, a pilot case based on a survey in one of the provincial capitals in Kalimantan is performed. From the survey, it is found that around half of the street lighting systems in the observed city are unmetered, dominated by CFL (Compact Fluorescent Lamp) lamps. Efficiency through street lighting system improvement can be achieved through, among others, replacement with a highly efficient light-emitting diode (LED) lamp, power meters installation and the replacement of high-efficiency armatures. Our analysis shows that energy consumption reduction potential from street light system improvements can reach 69% from existing conditions. In the showcase, it can save 9,466,465 kWh, equal to energy costs of IDR 13,676,202,724 and a 7,667-ton emission reduction. From the analysis, we also delivered a financial scheme for the project that incorporated local government and special mission vehicles under the coordination of the Ministry of Finance. Having great potential, a financing support mechanism can become a reference to another local government with a limited budget constraint. These findings can also provide policymakers with important inputs while improving street lighting systems as a key service provided by local and municipal governments.

Keywords:

street lighting, energy efficiency, city-level energy consumption, techno-economy analysis, a light-emitting diode

1. Introduction

Public lighting accounts for the lion's share of municipal electricity consumption. It is estimated that at the global scope, public lighting consumes up to 80% of municipal electricity use, which is equal to 2.3% of global electricity consumption (Campisi et al., 2018). The global empirical studies found that conducting energy efficiency measures in public lighting can cut half of the electricity consumption that is financially feasible (Beccali et al., 2015).

Public street lighting is a vital service required by the community. It has multiple benefits, such as supporting navigation, increasing safety and comfort, supporting a conducive environment, minimizing crime and supporting economic activities during the night (Boyce, 2019; Herbert & Davidson, 1994;

Jiang et al., 2015; Lawson et al., 2018). As a key service the local government provides, street lighting has become a public service issue at the city level.

Indonesia has implemented regulations concerning minimal service provided by street lighting, such as by imposing Transportation Ministerial Decree No. 2/2013. Several Indonesian National Standard (Standar Nasional Indonesia/SNI) is also issued by the government. It defines minimum light levels based on different street classes covering the luminaires. Recently, Advancing Indonesia's Lighting Market to High Efficient Technologies (ADLIGHT) team conducted a survey related to street lighting conditions. In most surveyed cities, street lighting conditions are still below the minimum service standard (Rahim, 2022). Poor lighting conditions generated complaints from the community (The Jakarta Post, 2012). Even in certain city, it becomes the highest complaint among the services provided by the local government (Sander & Prathama, 2021).

Street lighting is considered one of the most expensive responsibilities of a municipality in Indonesia. In some cities, it can reach up to 38% of energy consumption (Asian Development Bank [ADB], 2017). In 2020, street lighting energy consumption reached 3635 GWh, equal to 1.49% of national electricity demand during the period (PLN, 2021). According to the source, the local government paid IDR 5.306.701 million for street lighting demand. In some cities, there are disputes with the utility company, especially for unmetered streetlighting and the maintenance cost is higher compared to the available local government budget allocation (Rahim, 2022).

Therefore, public street lighting systems throughout Indonesia still use inefficient technologies (ADB, 2017). It contributes to increasing emission since power plant in the country is still dominated by fossil fuel, especially coal fuel power plant generation (Kurniawan et al., 2020). The electricity bill is fixed based on capacity contracts with a significant proportion of unmetered street lighting systems. These contracts potentially become unfair due to a markup estimation compared to actual electricity consumption (al Irsyad & Nepal, 2016). This matter associates local governments' financial burden and thus leaves less budget allocation for other development.

In the last decades, technology related to the street lighting system has been growing significantly. There are several lamp technology utilized widely in public street lighting, such as LED, CFL, fluorescent tubes incandescane. From a techno-economic perspective, it is found that operational costs of LED technology were found 1.21, 1.62, 1.69 and 6.46 times lesser than fluorescent tubes, CFL, EEFL, incandescent bulbs, respectively (Khan & Abas, 2011). Furthermore, the experimental results of LED technology showed that it has a superior advantage. It includes energy saving, lower carbon emission, light quality, as well as life cycle costs (Abdullah et al., 2019). The empirical project also shows LED utilization in street lighting has a lower operating expense and higher efficiency (Lindawati et al., 2019). This experimental project also proves that several indicators, such as street lighting luminance and illumination, follow the standard. This technology has also been recommended in developed countries (see for instance Campisi et al., (2018)). Having such advantages, energy-efficiency improvements in street lighting systems can be achieved by utilizing the technology.

Local governments have encountered several obstacles in adopting and implementing improved technology for street lighting. The success of such technology implementation, such as LED, depends on their economic impact and the effectiveness of the technological intervention (Campisi et al., 2018). Although the street lighting project is economically feasible, it could not be implemented due to various barriers, such as limited budget, capital constraints, limited technology and awareness (ADB, 2017; al Irsyad & Nepal, 2016; Anggono et al., 2021).

Having such significance, existing literature concerning energy efficiency in the Indonesian context mainly focuses on industry, building and the household sector (see for instance Kurniawan & Feinnudin, (2021); Rosita et al., (2021); Surahman et al., (2022)). Studies highlighting street lighting efficiency in Indonesia generally focus on a particular area, such as offering new technologies for street lighting. It covers certain technology such as solar energy (Sutopo et al., 2020), LED lamps (Sudarmono et al., 2018) and smart street lighting system control (Adriansyah, 2020). Anggono et al. (2021) specifically

discuss energy service companies for financing streetlighting improvement in the country. Previous studies are also mainly located in Java islands, such as Batang and Semarang city (ADB, 2017), Surabaya (Sander & Prathama, 2021) and Jakarta (Sudarmono et al., 2018). Against this backdrop, this paper aims to fill the gap and add new viewpoints by providing a comprehensive analysis of street lighting improvement, capturing both technology and financing aspects for LED deployment in streetlighting. We also conducted the study in one of the provincial capitals in Kalimantan, which was rarely addressed in the previous literature.

The objective of this study is thus to investigate the existing condition of street lighting by observing the specific city, capturing the metering system and technology used, and recommending both technical and financial action. In doing so, we perform a pilot case based on a survey in one of the provincial capitals in Kalimantan. Then, we conduct a techno-economy analysis and formulate financing mechanisms to support energy efficiency improvements in the street lighting systems.

This study contributes to both empirical research and policymaking concerning public street lighting systems improvement. First, we are conducting a comprehensive study that addresses technical and financial issues of providing a better street lighting service. Second, understanding the best practice of street lighting improvement is necessary for stakeholders, such as local government, municipalities, funding agencies and a research community. It can also provide relevant policymakers with important inputs while improving street lighting systems as a key service provided by local and municipal governments. Third, our study focuses on a city outside Java that is still underrepresented in the literature. It will improve our understanding of the existing condition of the region as well as suitable measures.

2. Methods

Figure 1 presents the methodology of this research. The study is based on a survey of street lighting systems in one of the provincial capitals in Kalimantan conducted in 2021. It covers all of the public street lighting utilized, including their lamp type (LED, CFL and SON-T) and their metering system. Doing so, this study consists of several primary steps. In the beginning, preparation is being made by coordinating with several stakeholders, such as the local government and regional PLN. After that, a field survey is conducted. Field activity mainly consists of checking the system, investigating the type of lamp, and measuring electricity and illuminance parameters. The particular step is necessary to compare the existing condition with the standard, to obtain actual daily energy consumption, and to observe the actual physical condition of the systems, such as lamp condition and its specification. The last three months of electricity bill analysis are performed to classify the bill for each system. The step must confirm whether PLN has used a suitable tariff and accurately reported the electricity consumption. Field survey measurements are then compared to electricity bills to calculate the deviation, including unmeasured systems. We could estimate the energy savings achieved from the improved options by identifying their energy consumption. Those actions and energy efficiency potential are then further investigated by using techno-economic analysis to obtain a detailed estimation of the costs and benefits. The output of this step will become one of the considerations in formulating a suitable financing mechanism. In doing this, we also consider other aspects, including local government capacity and available financing options.

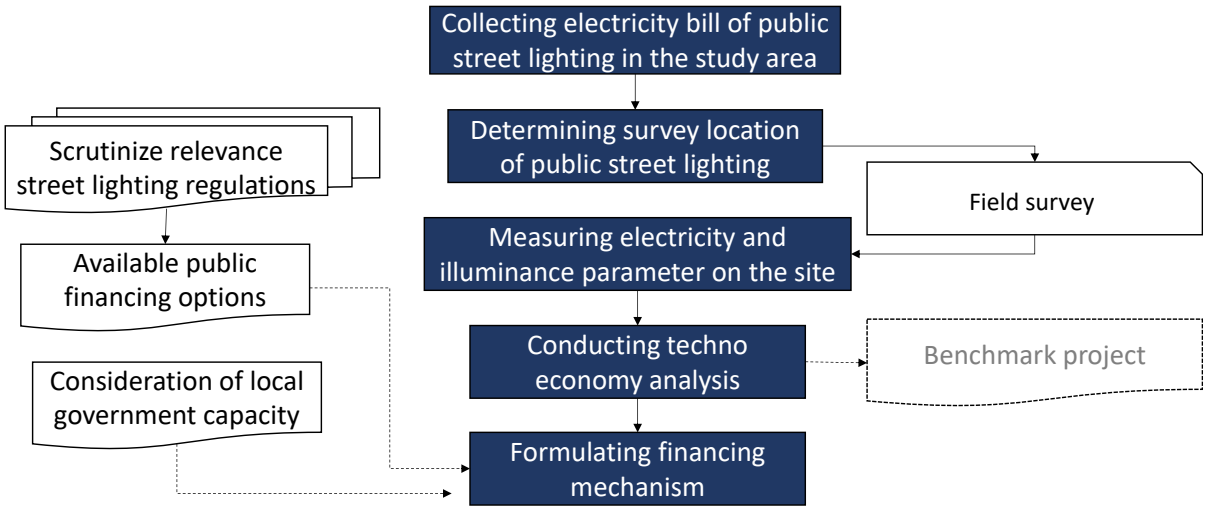

Figure 1. Methodology.

3. Result and Discussion

The results of the survey, as presented in Figure 2, show that more than half of the street lighting systems in the observed city are unmetered (17400 unmetered points compared to 16231 metered points). CFL lamp dominates with 11304 points, followed by LED (4711 points), TL (796 points), SON T/mercury (708 points) and incandescent (151 points) in the unmetered system of the observed city. The utility company and the local government agree on a fixed lump-sum payment in this unmetered system. This amount is based on the streetlights' estimated operating hours and total wattage consumed. Accordingly, the local government subsequently pays the lump sum. In the observed city's unmetered system, PLN estimates each point's electricity bill as 67 watts, running for 24 hours.

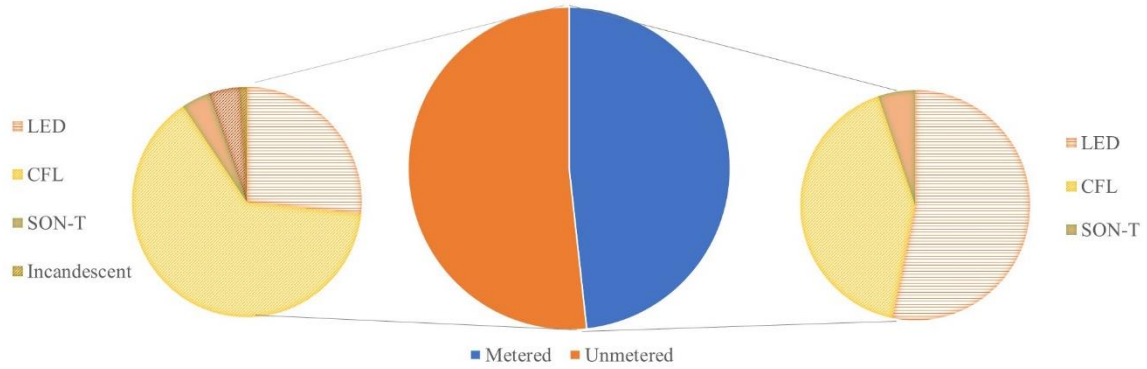

Figure 2. Street lighting system and its composition in observed city.

Meanwhile, metered streetlighting system in the observed city consists of LED (8.635 points), CFL (6.749 points), and SON-T (847 points) lamp types. In this metered system, the payment is based on the usage read by the utility company meters. All streetlights must be properly inventoried and metered to obtain such financing for a street lighting improvement project. It will ensure that the municipalities will realize the savings.

From the survey, it is known that the average street illumination is smaller than the standard lighting quality as determined by SNI as categorized by the type or classification of road functions. Thus, this condition requires improvement so that the criteria are fulfilled, and energy consumption can be reduced. Even though some street lighting had already utilized LED technology, from the survey, it is found that there is room for improvement, such as by using lower watt LED with eligible standards.

Based on the data, the capital expenditure for retrofitting can be estimated as presented in Table 1. Construction cost components can be agglomerated into three categories. The first category is material which includes LED lamps for the system. The second category is related to pole and armature installation, which also covers the cost of equipment, material and labor. The third cost category is network installation to the PLN system. The local market prices estimate the cost based on the amount of replaced lamp, wattage and supporting material. Non-construction costs consist of power up guarantee deposit, seal, electrical panel normalization cost and operation certification power up components. We also consider the tax of this project in this cost estimation. In aggregate, the estimated initial investment is IDR 49,228,423,827.

Table 1. Capital expenditure.

Item	Budget allocation
Retrofitting Materials (Assets) (IDR)	30,125,366,300
Pole and armature installation (IDR)	8,478,669,500
Network installation (IDR)	3,184,386,770
Non-Construction Costs	2,964,690,000
Tax (IDR)	4,475,311,257
Sub Total (IDR)	49,228,423,827

Several financing options can be considered by local governments/municipalities to fund street lighting improvement programs. The financing can be grouped based on the source of funding and payment mechanism, in this case, government budgets, public-private partnerships (PPPs), loans and local government bonds. Particular options are based on existing regulations as follows:

- Government Regulation No. 56 of 2018 on Regional Loan
- Government Regulation No. 2 of 2012 on Regional Grants
- Presidential Regulation No. 12 of 2021 on Government Procurement of Goods and Services
- Presidential Regulation No. 38 of 2015 on Cooperation between Government and Business Entities in Procurement of Infrastructure

The first option financing program is based on government budgets. Two other primary government budget mechanisms currently available for municipalities are the general allocation fund (DAU) and the specific allocation fund (DAK). DAU is a fund from the government budget allocated with the objective of financial capacity equity among regions to finance the regional needs in the context of decentralization. On the other hand, a specific allocation fund is a fund from the government budget allocated to certain regions with the objective to help to finance a special activity of a regional affair and in accordance with national priority. The most common and simplest mechanism for local governments to fund infrastructure projects, including street lighting, is the local budget. This option is through the existing local budget that is theoretically available to all municipalities. Therefore, in many cases of local government in Indonesia, the budget is not sufficient for large-scale retrofits. Furthermore, the mechanism copes with large programs' internal capacity challenges and procurement complexities.

The second option that can be considered for supporting streetlighting improvement is through public-private partnerships (PPPs) under President Regulation No. 38 years 2015 on Public Private Partnership. Dealing with the street lighting, the scheme allows payments to the private sector through a tariff or “availability payment” mechanism during the agreement period. Therefore, it is quite a complicated and time-consuming process for a relatively small project such as street lighting.

The third option for streetlighting financing is through loans. There are several primary loan options for municipalities to finance street lighting projects, including through regional public bank and PT Sarana Multi Infrastruktur under Ministry of Finance Regulation No. 175 years 2016, special mission vehicles under the coordination of the Ministry of Finance. The primary challenge for local governments to get

public loans, such as from banking, is the inability to use their local assets as collateral. Furthermore, it also requires a long-term financial commitment from a local government. Therefore, in a certain case, it must be approved by its locals to guarantee repayment beyond the political tenure of the elected officials.

Another option for securing financing for the street lighting project is through local government bonds. In the national scope, Indonesia has implemented several national bonds. Issuance of local government bonds can be a promising alternative source to fulfill street lighting improvement projects. Therefore, the bond mechanism requires a relatively large pipeline of projects developed.

Table 2. Loan assumption.

Item	Assumption	
Equity	30%	13,425,933,771
Loan	70%	32,173,888,568
Loan Repayment Period	3	Years
Loan Rate	6.70%	percent per year
Annual Payment	12,192,773,908	IDR/Year
Loan Provision	1.00%	upfront

In this study, we utilized a loan option for streetlighting financing. Using this scheme, this study tries to assess the project's financial feasibility. It also examines private involvement in such a green project. Using the capital expenditure presented in Table 1, loan estimation is performed based on specific assumptions as presented in Table 2.

Table 3. Existing and estimated retrofitted lamp and technology comparison.

Component	Existing Condition	Retrofitted
For Non-Meter Electricity Payment		
Number of lights	17,400	17,400
Average wattage of lights (watt)	66.63	26.31
Type of lights	Incandescence, CFL, Mercury, TL, LED	LED
Total power consumption per year (watt)	10,155,294	1,838,069
Annual energy cost (IDR)	14,671,288,230	2,655,433,794
Technology	None	Automatic Meter Reading, Smart Monitoring System
For Metering Electricity Payment		
Number of lights	16,231	16,231
Average wattage of lights (watt)	46	38
Type of lights	LED, CFL, HPS	LED
Total power consumption per year (watt)	3,623,689	2,977,455
Annual energy cost (IDR)	5,234,998,582	4,301,528,865
Technology	None	Automatic Meter Reading, Smart Monitoring System

The repayment using the loan assumption and the capital expenditure, the comparison between existing conditions with estimated improved street lighting after retrofitting project is indicated in Table 3.

Table 4. Existing and estimated retrofitted streetlighting comparison.

Component	Before Investment (IDR)	After Investment (IDR)
Current Electricity Bill/ year	19,906,286,812	6,230,084,087.00
Electricity Tariff (kWh)	1,444	1,444.00
Total kWh/year	13,778,837	4,312,372.18
Total tCO2e/year	11,160	3,493.00

It is found that the retrofitting project potentially reduces energy consumption significantly in Table 4. Based on the estimation, the post-retrofit condition shows energy savings of up to IDR 13,676,202,724 (69% saving), as presented in the table. The retrofitting project also can reduce emissions by 7,667 tCO2e as obtained from the reduction of streetlighting electricity consumption through street lighting improvement. We also calculate some financial indicators of the project. It is found that the project has a 15.49% Internal Rate of Return, IDR 25,962,092,217.28 Net Present Value, and a 1.51 Profitability Index.

4. Conclusion and Policy Recommendations

4.1 Key Findings

Street lighting systems in Indonesia have contributed to the undesirable local government budget, public service complaints, inefficient energy consumption and greenhouse gas emission. Having significance, we conducted a techno-economy analysis and formulated financing mechanisms to support energy efficiency improvements on street lighting systems. This study is based on an actual survey of a pilot case based in one of the provincial capital in Kalimantan.

It is found that more than half of street lighting systems in the observed city are in unmetered condition. Furthermore, inefficient lighting is also observed in the existing condition. Several actions are proposed to improve the streetlighting condition. This primary measure consists of replacing a highly efficient light-emitting diode lamp, installing power meters and replacing high-efficiency armatures. Utilizing the recommendations, energy consumption reduction potential from street light system improvements can reach 69% from existing conditions. From the local government's perspective, it can reduce annual energy costs of IDR 13,676,202,724. It is derived from 9,466,465 kWh electricity consumption, which equals a 7,667-ton emission reduction.

From the analysis, we also delivered a financial scheme for the project that incorporated local government and special mission vehicles under the coordination of the Ministry of Finance. Having great potential, a financing support mechanism can become a reference to another local government with a limited budget constraint. These findings can also provide policymakers with important inputs while improving street lighting systems as a key service provided by local and municipal governments.

4.2 Policy Recommendations

The first set of policy recommendations related to the finding that the street lighting system in the observed area still uses inefficient technologies and is mostly unequipped with the metering system. It is suggested to replace the system with a highly efficient light-emitting diode lamp equipped with a power meters system. By doing so, local governments can accelerate the implementation of LED technologies, acting as regulators that can issue construction permits with high-efficiency criteria. These best practices can also provide policymakers, such as local governments, with important inputs while improving street lighting systems as one of their key public service. This initiative will also improve sustainability in the Kalimantan region. Even the project implementation can be part of post-pandemic recovery in the region. As highlighted by Halimatussadiah et al. (2020), energy efficiency programs should be prioritized in terms of sustainable recovery over the short and long-term framework.

The second set of policy recommendations stems from the finding that there is very limited knowledge and capacity concerning street lighting improvement. This limited knowledge and capacity create an unwillingness to retrofit city streetlights. At a national level, it is recommended to develop and publish a national standard that incorporates the best practices and lessons learned in streetlighting improvement. It is also suggested to implement multiple demonstrations of retrofitting projects with different financing schemes as well as provide a nationwide capacity-building program to local government. As public infrastructure owners, local governments can conduct energy efficiency programs by developing innovative initiatives and street lighting improvements in this case.

The third set of policy recommendations is related to the limited budget capacity of the local government. Delivered financing support mechanisms can become a reference to another local government with a limited budget constraint. Another financing scheme, such as project-based financing, is needed to enable financial institutions and ESCOs (Energy Services Company) to finance the retrofit programs. ESCOs are principally one of the key solutions for generating green jobs and managing finance. ESCO offers guaranteed energy savings, implementation, maintenance for a client, also absorb capital and technology risk with an extension of the beneficiary of reducing greenhouse gas as their advantage. In doing so, the government should adjust multiyear contract duration to at least ten years respectively to be able to grow the ESCO environment that originally received repayment from energy-saving performance.

Abbreviation

ADLIGHT	: Advancing Indonesia's Lighting Market to High Efficient Technologies
LED	: Light-Emitting Diode
SNI	: Standard Nasional Indonesia
CFL	: Compact Fluorescent Lamp
EEFL	: Electrode Less Fluorescent Lamps
PPPs	: Public-Private Partnerships
DAU	: General Allocation Fund
DAK	: Specific Allocation Fund
ESCOs	: Energy Services Company

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