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*Original Article*

# Households' electricity consumption for lighting in Indonesia and its saving potentials

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**Abstract**

A survey conducted between Nov. 2011 and Jan. 2012 investigated electrical energy consumption of lighting in urban households in Indonesia. Data was collected from 600 respondents living in seven major cities in Indonesia, of which 474 (79%) of the respondents were considered to be valid. Results show that compact fluorescent lamps (CFLs) are widely used in Indonesian households. The results of the survey were then used to initiate energy saving programs that would work to reduce the need of new power plants. It was found that if an energy efficiency improvement program is implemented by replacing the conventional lamps with the efficient ones from 2012 to 2030, then the costs of saved energy (CSE) of the program are found only a small fraction of the long range average cost (LRAC) of electricity generation expansion, ranging from 6.2% to 1.6% of LRAC.

**Keywords:** household, electricity consumption, lighting, energy saving

## 1. Introduction

Indonesian electricity demand has experienced a relatively high growth rate for the past few years. Total electricity demand was 107.03 TWh in 2005 and 157.99 TWh in 2011 or an increase of 6.7% per year (Ministry of Energy and Mineral Resources [MEMR], 2012). In order to meet this high demand, the Government of Indonesia (GOI) directs the National Electricity Company (*Perusahaan Listrik Negara*, PLN) to develop a medium-term power development plan covering a 10-year time horizon period officially called the 'Electrical Power Supply Business Plan' (*Rencana Umum Penyediaan Tenaga Listrik*, RUPTL). This plan specifies the number and type of power plants for its expansion plan, but does not embrace any demand side management (DSM) measures to reduce electricity demands in the long term (PLN, 2012). DSM refers to any systematic utility and government activities designed to change the amount and/or timing of the customer's use of energy for the overall benefit of the society (Bhattacharyya, 2011). It includes the load management option through energy conservation programs.

The lack of DSM in the RUPTL is probably caused by the absence of data in details and understanding of the characteristics of electrical energy consumption of end users, which are necessary for assessing energy saving potentials and economic feasibility. This study was initiated and conducted a primary survey to investigate characteristics of lighting electrical energy consumption of the household sector in urban areas in Indonesia. Its results were then used to identify the potential of electrical energy savings for lighting and to evaluate their economic viability. Energy consumption for lighting is important in Indonesia since it

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coincide with the peak demand of electricity which is occurs between 17:00-22:00 p.m. (Manoppo, 2011). In this study, the energy saving for lighting is conducted by proposing high efficiency lamps such as light emitting diode (LED) to replace the conventional one.

The objectives of this study are to delineate the lighting electrical energy consumption characteristics of household sector in urban areas in Indonesia and to assess it saving potential. The assessment of the electrical energy saving potential is done for the period of 2012-2030. The results were then adopted to assess its investment costs of energy conservation approach and compare with the option of new power plants' construction. We applied a methodology documented by (Swisher *et al.*, 1997) in determining cost of energy saving programs. Although nearly two decades have passed since Swisher's paper was released, it presents a conventional method that is still relevant in most of developing countries including Indonesia which has no prior well documented experiences on implementing DSM programs.

The overview of contents is as follow: Section 2 of this paper provides the entire methods of this study which covers the data collection method and the methods for calculating household's electrical energy consumption for lighting and its saving potentials. Section 3 presents results and discussion of this study. Finally, Section 4 provides the conclusion and policy recommendations.

## 2. Methods

### 2.1 Data collection

#### 2.1.1 Selection of survey sites

Since more than 80% of Indonesian population live in Java, Sumatra, and Bali Island (Statistics Indonesia [BPS], 2008), we decided to conduct a survey of electrical energy consumption by urban households on these islands. Denpasar, Surabaya, Yogyakarta, Jakarta, Bandung, Bandar Lampung, and Palembang, were selected for the survey. Figure 1 depicts the location of the surveyed cities.

#### 2.1.2 Pilot survey and sample size

Since the questionnaire of this survey comprises both discrete (categorical variables such as income classes, types of equipment, etc.) and continuous random variable, a calculation of sampling size for those mentioned variables need to be performed. Sampling size for discrete random variables can be represented by Equation 1 (Cochran, 1977),

$$n_{categorical} = \frac{Z^2 pq}{e^2} \quad (1)$$

while, for or continuous random variables, can be given by Equation 2

$$n_{continous} = \frac{Z^2 s^2}{[(\mu + \mu \cdot e) - \mu)^2} = \frac{Z^2 s^2}{[\mu \cdot e]^2} \quad (2)$$

where $Z$ is a standard normalized value which corresponds to the selected confidence level. The estimated proportion of an attributed variable's presence in the population is denoted $p$ and $q$ is $1-p$. The specified level of precision of the estimated true mean value of population ($\mu$) which is normally specified as a percentage of $\mu$ is denoted $e$, while $s$ is the estimated standard deviation of population.

Generally, the variance ($s^2$) of a variable of interest is unknown. Dealing with this problem, we took sampling in two rounds. The variance of the first samplings (the pilot survey) is used to determine a sample size for the second round of samplings (the actual survey) in order to obtain a more accurate and more reliable result. In order to estimate the variance ($s^2$) of a variable of interest, a pilot survey of 29 households was conducted in Java and Sumatra. The expenditure on electrical energy consumption[1] was chosen as a reference variable for calculating sample size because its mean ($\mu$) and standard deviation ($s$) give the largest sample size as compared to other continuous variables[1]. The mean

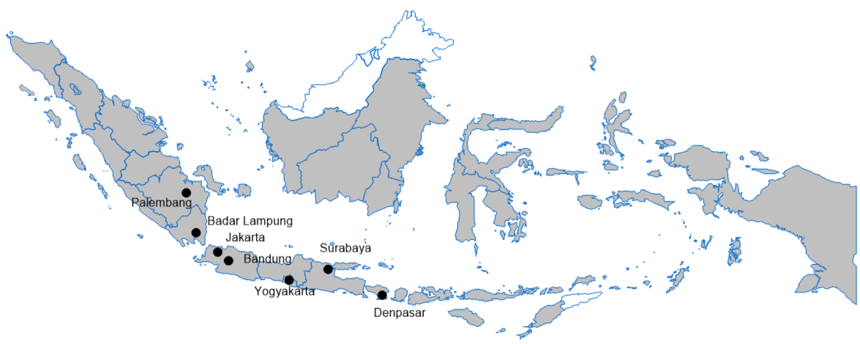


Figure 1. Survey sites

[1] Other variables were expenditure for: transportation; food drinks, and tobacco; personal care; dressing and foot wear; housing; health; and education.

and standard deviation of this variable were found to be 162,758 IDR or USD 17.13 and 134,984 IDR or USD 14.21 (1 USD = 9,500 IDR, 2012 currency exchange rate), respectively. This standard deviation was then assumed to be the estimated standard deviation of populations, *s*. By using Equation 2, the sample size for 95% confidence level (Z = 1.96) and the level of precision 10% ($e = 0.10$) is

$$n_{continous} = \frac{Z^2 s^2}{[(\mu + \mu \cdot e) - \mu)^2} = \frac{Z^2 s^2}{[\mu \cdot e]^2} = \frac{1.96^2 \cdot 134,984^2}{(162,758 \cdot 0.1)^2} \approx 264$$

Because of some random variables are discrete, a check of sample size by using Equation 1 is needed, the sample size for the discrete random variable at the same level of confidence and precision and assuming that maximum variability exists in the population (i.e. $p = 0.5$), is

$$n_{categorical} = \frac{Z^2 pq}{e^2} = \frac{1.96^2 \cdot 0.5 \cdot 0.5}{0.05^2} = 384$$

Since the sample size for categorical (discrete) variables is larger than the sample size of continuous variables, 384 is adopted as the minimum suggested sample size in this study.

#### 2.1.3 Actual survey

The actual survey was conducted between November, 2011 and January, 2012. The number of sample size calculated in the previous section (384 households) is the suggested minimum number of respondents needed to meet the above mentioned level of confidence and precision. Due to the potential of invalid response, a larger number of respondents are needed. We decided to collect 600 respondents to make allowance for that mentioned error. The numbers of respondent samplings were proportionally allocated for each surveyed city in accordance with the number of population in each city. Out of 600 respondents, only 474 of them, or 79% of respondents, were considered to be acceptable.

#### 2.1.4 Income class determination

The distribution of the log of incomes per capita was assumed to be a normal distribution. Incomes of respondents were then categorized into four classes of income groups. Each class was segregated by one standard deviation. Figure 2 illustrates the method to classify households in each income group.

### 2.2 Households' electricity consumption for lighting

A total electrical energy consumption for lighting of all households, *EL*, is defined as (Swisher *et al.*, 1997)

$$EL = \sum_{i=1}^{n} \sum_{j=1}^{m} N_{i,j} \cdot P_{i,j} \cdot M_{i,j} \cdot I_{i,j}, \quad (3)$$

where *N* is a number of households, *P* is a number of lamps per household (unit/household), M is a length of time in using an appliance (h), and *I* is a rated power of lamp (W), *i* is a type of lamp, and *j* is an income class.

### 2.3 Projection of households' electricity consumption for lighting under the business as usual case

The number of households (*N*) in Equation 3 was projected for each year. Electric rated power per lamp (*I*) and number of lamps per household (*P*) were assumed to be constant. Then, the total electricity consumption for lighting of all households under the business as usual (BAU) case was calculated. This study adopted 1.3% population growth rate and 0.58% declining rate of household size to project a number of households in each year (MEMR, 2005, 2009). The official data of the percent share of households in urban areas was obtained from Statistics Indonesia (BPS, 2008). Table 1 shows the projected population, household sizes, numbers of households, and percent shares of households in urban areas from 2011 to 2030.

### 2.4 Urban household's electricity consumption for lighting under energy efficiency improvement case

This study proposed the adoption of high efficiency technology for lighting to replace the conventional one. We assumed that the number of appliances per household (*P*) for each type in Equation 3 are constant throughout the planning horizons. The comparisons between conventional and high efficiency lamps are presented in Table 2.

Percent share of accumulated high efficiency lamps in annual total stock varies as a function of time (year), assumed

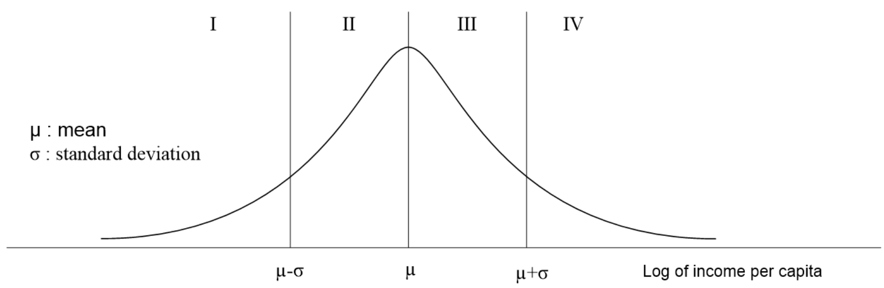


Figure 2. Classification of income groups in this study.

Table 1. Projection of population, household size, number of household, and percentage of households in urban areas.

| Year | Population (Thousand) | Household size (Person/hh) | Household (Thousand) | Household in urban areas (%) | Urban households (Thousand) | Rural Households (Thousand) |
|---|---|---|---|---|---|---|
| 2011 | 240,730 | 4.00 | 60,182 | 55 | 33,013 | 27,169 |
| 2012 | 243,860 | 3.98 | 61,321 | 56 | 34,226 | 27,095 |
| 2014 | 250,241 | 3.93 | 63,662 | 58 | 36,746 | 26,916 |
| 2016 | 256,790 | 3.89 | 66,092 | 59 | 39,287 | 26,805 |
| 2018 | 263,510 | 3.84 | 68,615 | 61 | 41,954 | 26,662 |
| 2020 | 270,406 | 3.80 | 71,235 | 63 | 44,698 | 26,536 |
| 2022 | 277,482 | 3.75 | 73,954 | 64 | 47,521 | 26,433 |
| 2024 | 284,743 | 3.71 | 76,778 | 66 | 50,474 | 26,304 |
| 2026 | 292,195 | 3.67 | 79,709 | 67 | 53,461 | 26,248 |
| 2028 | 299,841 | 3.62 | 82,752 | 68 | 56,581 | 26,171 |
| 2030 | 307,688 | 3.58 | 85,911 | 70 | 59,837 | 26,074 |

Table 2. Comparison between conventional and high efficiency lighting technologies (McKinsey & Company 2012, The climate group 2012, LEDinside 2013).

| Measures | Initial investment cost (USD) | | Life time (hours) | |
|---|---|---|---|---|
| | con | eff | con | eff |
| Replace Incandescent 25 by CFL 8 W | 0.47 | 2.74 | 1,500 | 8,000 |
| Replace Incandescent 40 W by CFL 11 W | 0.58 | 2.84 | 1,500 | 8,000 |
| Replace Incandescent 60W by CFL 18 W | 0.63 | 3.47 | 1,500 | 8,000 |
| Replace T9 FL 18 W by T5 FL 14 W | 1.37 | 3.49 | 10,000 | 25,000 |
| Replace T12 FL 20 W by T5 FL 14 W | 1.37 | 3.49 | 10,000 | 25,000 |
| Replace T9 FL 36 W by T5 FL 24 W | 1.68 | 4.05 | 10,000 | 25,000 |
| Replace T12 FL 40 by T5 FL 24 W | 1.68 | 4.05 | 10,000 | 25,000 |
| Replace CFL 8 W by LED 3 W | 2.74 | 4.58* | 8,000 | 50,000 |
| Replace CFL 11 W by LED 5 W | 2.84 | 7.33* | 8,000 | 50,000 |
| Replace CFL 18 W by LED 7 W | 3.47 | 11.00* | 8,000 | 50,000 |

Remark: con : conventional, eff : efficient
* Initial investment cost for Light Emitting Diode (LED) lamps is a forecasted price in 2020

to follow S-curve, and denoted by *PH (t)* as shown in Equation 4. It was also assumed that a single *PH (t)* is applied for all income class. Since Indonesia has no prior experiences in implementing any kinds of new high efficiency appliance household replacement programs, the penetration rate is unknown. This study adopted Thailand's experience for the penetration rate of new high efficiency appliances substituting for traditional inefficient appliances in residential sector for the rate of *PH (t)* (Batih *et al.*, 2016). A logistic function, *PH (t)* in Equation 4, was fitted to actual data of the penetration rate of high efficiency appliances for energy saving programs implemented in Thailand's residential sector.

$$PH\left(t\right)=\frac{1}{1+a\cdot e^{b\cdot t}} \quad (4)$$

where *t* is time(years), while *a* and *b* are constant parameters representing the characteristics of logistics function. We fit the parameters to data by maximizing the coefficient of determination ($r^2$) using the built-in solver in Microsoft Excel™. We chose to use the generalized reduced gradient (GRG) nonlinear solver because it is appropriate for smooth nonlinear functions like the logistic. It was found that a=46.51 and b = 0.31. Stocks of conventional and high efficiency lamps during the planning period and its share in the selected years are illustrated in Figure 3.

## 2.5 Energy saving potential of EE programs for lighting

The energy saving potential of the EE program for lighting, *ELSAV* can be expressed as:

$$ELSAV = EL_{BAU} - EL_{EE} = \sum_{i=1}^{n}\sum_{j=1}^{m} N_{i,j}\cdot P_{i,j}\cdot M_{i,j}\cdot R_{i,j}\cdot PE_{i,i}(\varepsilon_{BAU_{i,j}} - \varepsilon_{EE_{i,j}}) \quad (5)$$

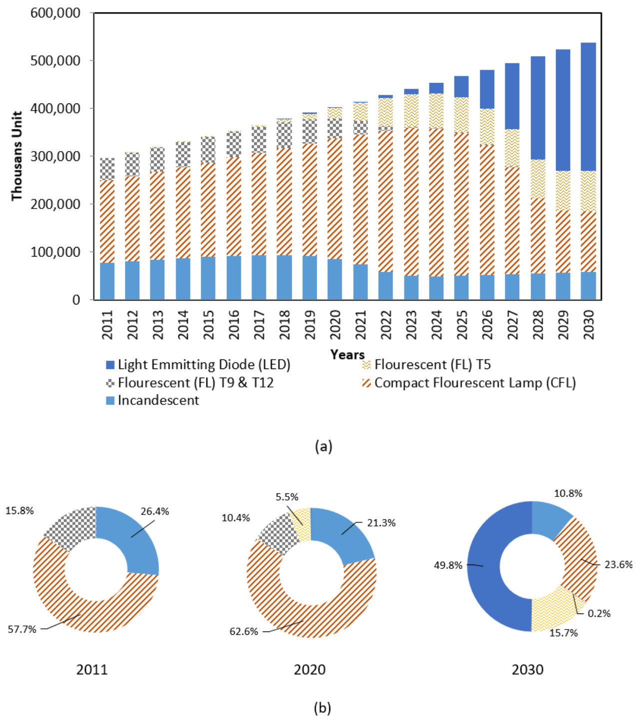


Figure 3. (a) Stock of lamps by types, and (b) percent share of lamps by types to the total stock of lamps in selected years

where *PE* is the percent share of accumulative high efficiency lamps in households, $\varepsilon_{BAU}$ and $\varepsilon_{EE}$ are the rates of electricity power consumption for conventional and high efficiency lamp, respectively.

### 2.6 Economic savings potential of EE programs for lighting

An annual investment cost for each energy saving program can be determined by a term of cost of saved energy (*CSE*) (Swisher *et al.*, 1997) given in Equation 6.

$$CSE = \frac{ALCC_{EE} - ALCC_{BAU}}{ELSAV}, \quad (6)$$

where *ALCC* is the annualized initial investment cost of appliances (USD/year), subscript EE and *BAU* denoted the energy conservation program and business as usual scheme, respectively. In determining *ALCC*, a discount rate of 12% was used in this study. On other hand, *ELSAV* is the annual amount of electrical energy savings (kWh/year), thus the unit of *CSE* is USD/kWh. *CSE* is then compared to the estimated cost of electricity generation expansion. In this study the long run average cost (*LRAC*) is adopted to represent the cost of electricity generation expansion (Shresta *et al.*, 1998). *LRAC* is given by Equation (7),

$$LRAC = \frac{TC}{\sum_{t=1}^{t=T} (E_t)/(1+r)^t}, \quad (7)$$

where *TC* is the present value of a total power generation cost of new power plants for the planning horizon, $E_t$ is generated electrical energy in year *t*, *r* is the discount rate, and *T* is the year of planning horizon. In this study, *LRAC* is calculated under the assumption of constant fuel price based on PLN's price assumption. Data for *LRAC* calculation were obtained from references (PLN, 2005, 2012; MEMR, 2009). A discount rate of 12% was used in this study (about 2% greater than the long term average of the Indonesian government treasury bond's interest rate) (Indonesian Central Securities Depository, 2013, The Central Bank of Republic of Indonesia, 2013).

If the value of *CSE* is lower than that of *LRAC*, then the EE program is more cost-effective than the supply-side option. Alternatively, if the value of *CSE* is higher than that of *LRAC*, then the conventional supply-side option is more cost-effective. We show below that the EE program is considerably less expensive.

## 3. Results and Discussion

### 3.1 Household's electricity consumption for lighting

Out of 600 respondents, only 474 or 79% of respondents were considered to be valid. Data of respondent's income is then classified by the technique shown in Figure 3, and the result is shown in Table 3.

Table 4 presents the result of survey covering the data of electric power consumption (*I*), number of lamps per household (*P*), and length time of use (*M*) for each income class. Table 4 also shows that the ownership of lamps in household is dominated by the compact fluorescent lamp (CFL) with relatively high length time of use. This emphasizes the importance of energy efficiency improvement program by replacing CFL by LED since this program has high energy saving potential.

Households' electricity consumption for lighting by each income class was calculated by Equation 4 and the

Table 3. Classification of income classes.

| Income class | Monthly income per capita (IDR) | Percentage of household under each income class (%) |
|---|---|---|
| I | < 467,230 | 18.3 |
| II | 467,230-831,605 | 27.0 |
| III | 831,606-1,480,142 | 42.2 |
| IV | > 1,480,142 | 12.6 |

Table 4. Result of survey on characteristics of electricity consumption for lighting in Indonesian household

| Type of lamp | | Income class I | | Income class II | | Income class III | | Income class IV | |
|---|---|---|---|---|---|---|---|---|---|
| | I (W) | P (unit/household) | M (h/day) | P (unit/household) | M (h/day) | P (unit/household) | M (h/day) | P (unit/household) | M (h/day) |
| INC | 5 | 0.73 | 6.8 | 0.79 | 6.11 | 0.38 | 7.52 | 0.67 | 6.86 |
| INC | 10 | 0.64 | 6.4 | 0.40 | 6.77 | 0.16 | 5.59 | 0.82 | 6.65 |
| INC | 15 | 0.45 | 6.4 | 0.51 | 5.02 | 0.67 | 6.50 | 0.88 | 6.90 |
| INC | 25 | 0.45 | 8.9 | 0.52 | 5.39 | 0.48 | 6.03 | 0.80 | 4.40 |
| INC | 40 | 0.13 | 5.1 | 0.25 | 5.65 | 0.31 | 4.78 | 0.27 | 6.00 |
| INC | 60 | 0.01 | 1.5 | 0.04 | 3.00 | 0.02 | 1.50 | 0.00 | 0.00 |
| FL | 10 | 0.02 | 8.3 | 0.01 | 6.00 | 0.02 | 8.25 | 0.00 | 0.00 |
| FL | 18 | 0.79 | 5.3 | 0.63 | 4.97 | 0.61 | 6.61 | 1.41 | 7.36 |
| FL | 20 | 0.38 | 5.3 | 0.63 | 7.44 | 0.42 | 6.60 | 0.75 | 6.49 |
| FL | 36 | 0.04 | 4.0 | 0.04 | 5.70 | 0.06 | 4.69 | 0.16 | 7.88 |
| FL | 40 | 0.02 | 6.0 | 0.22 | 4.91 | 0.09 | 8.38 | 0.08 | 7.50 |
| CFL | 5 | 0.10 | 7.5 | 0.09 | 9.69 | 0.01 | 13.50 | 0.00 | 0.00 |
| CFL | 8 | 1.14 | 7.4 | 1.10 | 5.87 | 1.52 | 7.34 | 0.90 | 7.44 |
| CFL | 11 | 1.67 | 7.6 | 1.16 | 7.37 | 1.51 | 6.95 | 2.25 | 7.35 |
| CFL | 18 | 0.67 | 4.9 | 1.57 | 6.74 | 1.85 | 6.05 | 3.14 | 8.54 |
| CFL | 25 | 0.38 | 4.2 | 0.85 | 6.50 | 0.63 | 7.57 | 0.82 | 7.72 |

Note: INC: Incandescent FL: Fluorescent Lamp CFL: Compact Fluorescent

results are presented in Figure 4. As expected, average monthly electricity consumption for lighting was found to be higher for a higher income group.

### 3.2 Energy saving potential of EE program for lighting

Table 5 shows the total amount of electrical energy saving potential (kWh) and the saving per household (kWh/hh) due to the implementation of high efficiency lamps for each income class in 2020 and in 2030.

Clearly, as shown in Table 4, the electrical energy saving potential for lighting becomes higher as the accumulated units of new high-efficiency lamps in the stock are larger in later years. Since those higher income classes generally possess more units of equipment per household, and they normally install higher rated power of lamps, this leads to higher potentials of electricity saving per household for the higher income groups than the lower one. In 2030, the total amount of electrical energy savings from lighting (lamps) is expected to be 9.2 TWh. This is equivalent to a 2 x 1,000 MW plant operating at 75% capacity in a year.

### 3.3 Economic saving potential of EE programs

Figure 5 shows that, the implementation of electrical energy saving programs to reduce the electrical energy demand is more cost effective than the supply-side expansion, because its *CSE* is much lower than *LRAC* of the supply-side electrical energy expansion.

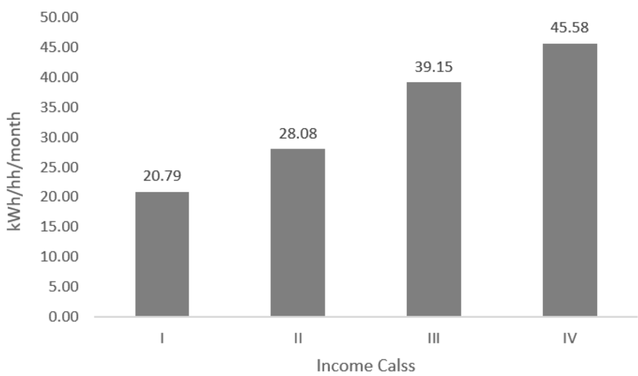


Figure 4. Monthly averages of households' electrical energy consumption for lighting by different income classes.

Table 5. Annual electrical energy saving potential (per household) by implementing EE programs in 2020 and 2030.

| Income class | GWh (kWh/hh) | |
|---|---|---|
| | 2020 | 2030 |
| I | 179.7(22.0) | 1212.8(110.8) |
| II | 290.6(24.1) | 2235.0(138.3) |
| III | 457.4(24.3) | 3940.0(156.0) |
| IV | 110.9(23.0) | 1902.0(252.3) |
| Total | 1038.6(23.6) | 9289.9(158.1) |

*CSE* of the EE program ranges from 0.007 USD/kWh equal to 6.3% of *LRAC*, at the beginning of the implementation program, to 0.002 USD/kWh, at the end of the implementation program. As the shares of accumulated stock of high efficiency lamps increase, both the investment cost and the accumulated saving of electrical energy resulted from the EE programs also increase. In this case, the rate of electrical energy savings grows faster than the rate of increasing investment cost in each year. As a result, the *CSE* will gradually drop after year 2018, this is because of the introduction of LED lamps at that time.

Despite a high initial investment cost of LED lamps, when comparing to the conventional incandescent and CFL lamps, the combination effect of low electricity power consumption and its long expected life span, LED lamps allow ones to save more energy for lighting than CFL types of lamps. In the near future, it is expected that the implementation of LED lamps will be more cost effective because of a declining trend of LED prices.

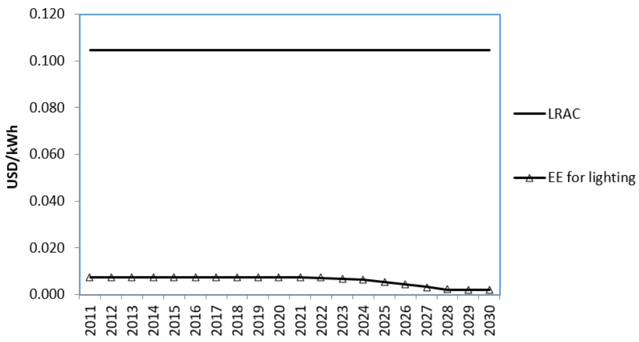


Figure 5. Comparisons between CSE of energy saving programs and LRAC of power plant expansions.

## 4. Conclusions and Recommendations

This study reveals that incandescent (INC), fluorescent lamp (FL), compact fluorescent lamp (CFL) are types of lamps commonly found in Indonesian urban household. Among those types CFL is currently dominate the lighting technology in Indonesian urban household. Energy efficiency program by replacing lamps with more efficient one especially replacing CFL with LED will help in reducing both electricity power and energy consumption.

Energy efficiency improvement programs for lighting were found to be more cost-effective than supply side capacity expansion by construction of new power plants. Data analysis from this study showed that the investment cost of saving programs is much lower than the cost of *LRAC* for the expansion of the power supply. Government of Indonesia (GOI) should prioritize EE program for lighting to replace CFL lamps by LED.

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