SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index

ISSN: 2462-1943

A Benefit-Loss Analysis of Electricity Generation in Indonesia: Life Cycle Assessment and Economic Input-Output Analysis Application

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ARTICLE INFO

Article history:
Received 3 March 2024
Received in revised form 12 June 2024
Accepted 21 June 2024
Available online 20 August 2024

Keywords:

Electricity; health; Indonesia

ABSTRACT

This paper presents a benefit-loss analysis of Indonesia's electricity generation from 2014 to 2018. The loss and benefits are expressed as Disability-Adjusted Life Years (DALY) per capita. In this paper, the benefit is the contribution of value-added triggered by electricity demand to GDP per capita. The value-added is calculated using the economic input-output model. The relationship between GDP per capita with DALY per capita is derived to estimate the reduction in the value of DALY per capita. The loss is the health damage of pollutants produced by electricity generation and is calculated using Life Cycle Assessment. The rise in DALY caused by the pollutants is quantified using Eco-Indicator 99. The results show that the average benefit-loss ratio is 1.257. In Indonesia, the average rate of change of the benefit with respect to electricity consumption per capita is lower than the rate of change of the loss. The analysis also shows a positive relationship between the rate of change of the benefit with the rate of change of electricity price. Promoting renewable energy and improving efficiency are ways to increase the benefit-loss ratio. The results also suggest that increasing the price is a lucrative alternative to increasing the benefit-loss ratio.

1. Introduction

Energy is one of the critical components of economic growth [1]. It powers the industries, industrializes the economy, and affects almost all aspects of life [2]. Literature also suggests that there is a positive correlation between electricity consumption and the economy of a country [3-8].

The need for electricity is a function of population size, living standards, and the level of industrialization [1]. Electricity production also depends on the ability of the natural environment to support humans' demand for electricity [1]. Therefore, balancing economic growth and the extraction of natural resources is required [9]. Trade-off among energy provision, economic, and environmental aspects has been a matter of interest for years [10].

Indonesia is an island country in Asia with the population of 275.5 million people. The Indonesia's electricity requirement continues to increase because of the economic growth, urbanization, and

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https://doi.org/10.37934/araset.50.2.208227

industrialization [11,12]. According to the Ministry of Energy and Mineral Resources of the Republic of Indonesia (ESDM) [13,14], Indonesia's installed capacity for electricity generation was 53,063 MW. Almost 50% of the installed capacity was from steam power plants, followed by the combined cycle (19%) and diesel (12%). Other sources of energy, such as hydro, gas, geothermal, wind, solar, coal gasification, and waste contributed about 20% (combined) to the installed capacity.

Same with other technologies and economic activities, electricity production and consumption have benefit and loss [15]. The benefit is from the economic growth trigger by electricity production and consumption. The loss is from the pollutants emitted by electricity production and they affect human health [15]. The objective is to get a higher benefit. However, there is not much research about the economic, environmental, and health effects of Indonesia's electricity production and consumption.

In Indonesia, CO_2 production was closely related to energy consumption [16]. About 23% of Indonesia's total greenhouse production was due to energy production activities [17]. Additionally, about forty percent of GHG emissions in the energy production activities came from electricity production. The use of coal as the primary energy source had a significant contribution to GHG emission.

From an economic side, the causal association between economic development and electricity demand was only one direction in Indonesia [18,19]. There was a causal relationship between economic growth and electricity consumption, but no cause and effect run from the demand for electricity to economic development. This phenomenon implied that the use of electricity was mostly to fulfil basic human needs.

Electricity demand in Indonesia was forecasted to rise [12]. The use of air conditioning and lighting cause the increase and will have a greater environmental effect. However, from an economic perspective, the increase would not have a significant effect on Indonesia's economic growth [18,19].

Based on previous studies, it is known that the increase in electricity production and consumption in Indonesia had negative environmental impacts and did not have a causal relationship with the country's economic growth. However, previous research assessed the impacts from the economic or environmental perspective only. There are limited studies assessing the economic benefit and environmental loss of Indonesia's electricity production and generation simultaneously.

The levels of the benefit and loss of electricity generation and consumption in Indonesia remains unknown. No studies have yet explored this area. If known, policy makers may be able to formulate better policies and recommendations to increase the benefit-loss ratio of electricity production and consumption. The challenge is how to express the benefit and loss in the same unit.

The objective of this paper is to perform a benefit-loss analysis of electricity generation in Indonesia. Like other economic activities, electricity production and consumption will change the levels of economic outputs in the supply chain network [15]. The changes will have effects on the level of pollution emissions, employment and wages, and the amount of taxes paid.

The exposure of the population to pollutants worsens the population health outcome. The increase in the levels of employment and income will reduce poverty. Moreover, public sector expenditures rise when more money received from taxes. As a consequence, the mortality and morbidity rates of the population decreases.

Using the theory presented by Norris [15], the health gain and loss triggered by the demand for electricity can be compared. Since income and tax contribute to Gross Domestic Product (GDP), the positive health effect can be estimated by modelling the relationship between Disability Disability-Adjusted Life Year (DALY) and GDP of the population. DALY is a metric used by WHO to measure the number of years lost to specific causes, disability, and premature death. The loss, which is the increase in DALY caused by the exposure of the population to the pollutants, can be estimated by using the endpoint impact assessment method of the Life Cycle Assessment (LCA). This paper does not consider the effect of the change in employment level triggered by electricity demand to the health outcome of the population in Indonesia.

The method used in this paper is an alternative or a new approach to performing benefit-cost analysis. Usually, the benefit-cost analysis is done based on monetary value. The proposed method is based on DALY and does not involve subjective judgment. Furthermore, the results of the proposed method can be used to plan and develop policies for electricity generation and implementation, such as price determination, subsidy policy, and the policy of using renewable energy sources. Finally, the proposed method can be applied to any technology or economic activity, not only electricity generation.

2. Methodology

Figure 1 presents the step-by-step process for performing the benefit-loss analysis. The figure shows four parts of the analysis: electricity demand calculation, benefit calculation, loss calculation, benefit-loss ratio calculation, and sensitivity analysis. The benefit calculation consists of three steps: value-added per capita calculation, regression analysis, and benefit calculation in terms of the reduction in DALY per capita. The inputs to this part are electricity demand, price, economic input-output table, population size, DALY data, and GDP data. The loss calculation consists of two steps: Life Cycle Inventory (LCI) analysis and the Life Cycle Impact Assessment (LCIA) used to quantify the loss in terms of the increase in DALY per capita. The input to this part is the life cycle inventory data.

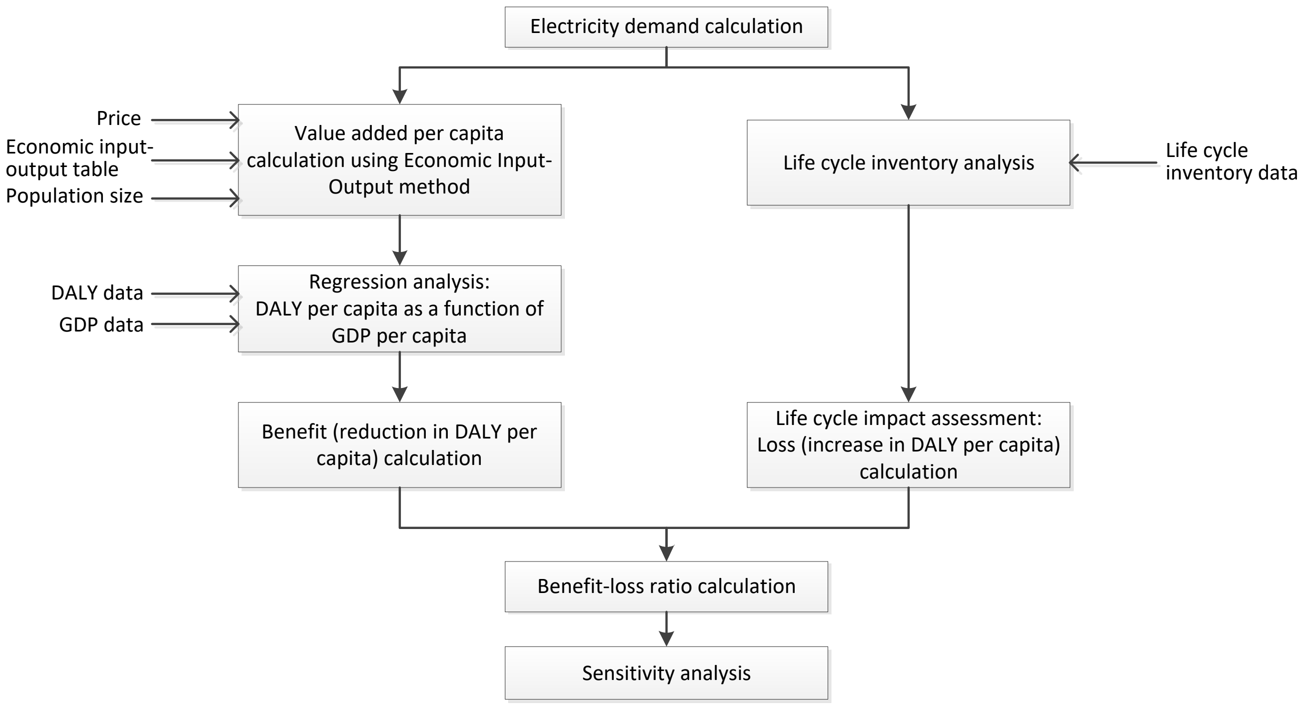

Fig. 1. Step-by-step process in performing the benefit-loss analysis

2.1 Benefit, Loss and Benefit-Loss Ratio

This paper calculated the impact of electricity demand on income and tax by using the economic input-output (EIO) method [20]. It is a method that represents the interdependencies among the industrial sectors. Wassily Leontief developed the technique and won the Nobel Prize in Economics for it.

Quantifying the negative health outcome due to electricity generation was straightforward. The Life Cycle Assessment (LCA) method, in this case, the endpoint impact assessment method was applied. In the Eco-Indicator 99, which uses the endpoint impact assessment method, DALY is the measure of human health damage caused by pollutants [21]. When the positive and negative impacts were in DALY, the benefit-loss ratio was calculated.

Figure 2 is an EIO table common presentation [20]. There are three main parts of the table. The first part is the *n* by *n* elements recording the transaction between the industries in the economy, known as the intermediate input. In the intermediate input part, the rows record sales from sector *i* to *j*, and the columns present purchases. The next part, called as the final demand, consists of consumptions by the government and community, investment, and export. The last component, namely the primary input, is the value-added and imports. Total value added is the Gross Domestic Product (GDP). The last column is the total output (supply), and the final row at the bottom is the total input (use) by the industry sectors. In equilibrium, total input equals total output in the monetary unit.

From the intermediate input part [20],

$$\left(\sum_{j=1}^{n} x_{ij}\right) + F_j = X_j \quad (1)$$

$$a_{ij} = \frac{x_{ij}}{X_j} \quad (2)$$

where,
x_{ij} = The amount of *i*th industrial sector commodity used by the *j*th industrial sector (US$)
X_j = Total commodity used as an input by the *j*th industrial sector (US$)
F_j = The final demand to the *j*th industrial sector (US$)
a_{ij} = The ratio between the output of the *i*th industrial sector used by the *j*th industrial sector and the total output of the *j*th industrial sector

Intermediate output from sectors	**Intermediate input to sectors**				**Final demand**	**Output**
	1	2	…	n		
1	x_{11}	x_{12}	…	x_{1n}	F_1	X_1
2	x_{21}	x_{22}	…	x_{2n}	F_2	X_2
…	…	…	…	…	…	…
n	x_{n1}	x_{n2}	…	x_{nn}	F_n	X_n
Value added	V_1	V_2	…	V_n	*GDP*	
Wage	W_1	W_2	…	W_n		
Operating surplus	S_1	S_2	…	S_n		
Tax	T_1	T_2	…	T_n		
Imports	I_1	I_2	…	I_n		
Input	X_1	X_2	…	X_n		

Fig. 2. Economic input-output table [20]

Substituting Eq. (2) into Eq. (1), it was found that,

$$\left(\sum_{j=1}^{n} a_{ij}X_j\right) + F_j = X_j$$

The above equation was translated into matrix notation [20]

$$\mathbf{AX} + \mathbf{F} = \mathbf{X}$$

Solving for **X**,

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}\mathbf{F} \tag{3}$$

$\mathbf{X}$ denotes the amount of input-output that must be provided by the industry sectors in the economy to satisfy the final demand [20]. The *n* by *n* matrix **A**, Eq. (4), was known as the economic input-output matrix and $(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ was the output multiplier matrix [20]. They were essential in the input-output computation. **I** is an *n* by *n* identity matrix.

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \tag{4}$$

From the value-added part of the table, the employee compensation and tax coefficient per total input was computed. They are denoted as employee compensation w_j and tax coefficient t_j and given by Eq. (5) and Eq. (6) [22],

$$w_j = \frac{W_j}{X_j} \tag{5}$$

$$t_j = \frac{T_j}{X_j} \tag{6}$$

Thus, *n* by *n* diagonal matrixes whose elements are w_j and t_j , denoted as wage $\mathbf{W}$ and tax $\mathbf{T}$ matrixes, was formed, Eq. (7) and Eq. (8) [22].

$$\mathbf{W} = \begin{pmatrix} w_1 & 0 & 0 & \cdots & 0 \\ 0 & w_2 & 0 & \cdots & 0 \\ 0 & \cdots & w_3 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 & w_n \end{pmatrix} \tag{7}$$

$$\mathbf{T} = \begin{pmatrix} t_1 & 0 & 0 & \cdots & 0 \\ 0 & t_2 & 0 & \cdots & 0 \\ 0 & \cdots & t_3 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 0 & t_n \end{pmatrix} \tag{8}$$

The added-value in the form of wages (**Y**) and taxes (**Z**) was then estimated using Eq. (9) and Eq. (10).

$$\mathbf{Y} = \mathbf{W}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} \tag{9}$$

$$\mathbf{Z} = \mathbf{T}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} \tag{10}$$

Assume that there are N types of electricity consumers, the demand from the ith consumer is e_i (kWh), and the average price for the ith consumer is p_i (US$/kWh), Eq. (11) gives total electricity demand f (US$) [22]. In the column vector **F**, $F_{j=j'} = f$, where j' = sector number for electricity generation in Indonesia EIO table, otherwise $F_{j\neq j'} = 0$.

$$f = \sum_{i=1}^{N} e_i p_i \tag{11}$$

The overall added value is the sum of **Y** and **Z**. Dividing the total with the population size P (people), the overall contribution of employee compensation and tax to GDP per capita ΔG (US$ per capita), due to the economic activity triggered by electricity demand, was obtained. Eq. (12) was utilized to calculate ΔG.

$$\Delta G = \frac{\mathbf{1}(\mathbf{Y} + \mathbf{Z})}{P} \tag{12}$$

where,

ΔG = Increase in GDP per capita (US$ per capita)
1 = A row vector with all entries is 1
P = Population size (people)

A regression analysis was conducted to approximate the consequence of the increase in GDP per capita on DALYs. In the regression model, GDP per capita G (US$ per capita) is the independent variable, and DALY per capita H is the dependent variable. H is a function of G, $H = f(G)$. The benefit (B) is the decrease in DALY per capita or the difference between $f(G)$ and $f(G + \Delta G)$, Eq. (13).

$$B = f(G) - f(G + \Delta G) \tag{13}$$

The LCA approach was followed to determine the negative health outcomes of electricity generation. The life cycle inventory data to produce 1 kWh of electricity was obtained from the literature. In this case, the life cycle inventory data were the direct emissions from the energy-generating process. Multiplying each inventory flow with the total electricity generated in a particular year resulted in the total inventory flow for that specific year.

The end-point impact assessment method was applied for the Life Cycle Impact Assessment (LCIA). The selected damage category was the damage to human health. In this paper, the damage to human health acts as health loss. The damage factors for each inventory flow were obtained from Eco-indicator 99 [21]. The basic formula to characterize damage in the LCIA step is [22],

$$\begin{pmatrix}\text{Characterized}\\ \text{damage to human health}\end{pmatrix} = \begin{pmatrix}\text{Health}\\ \text{loss}\end{pmatrix} = \sum_{k=1}^{K}\left[\begin{pmatrix}\text{The } k\text{th}\\ \text{inventory flow}\end{pmatrix} \times \begin{pmatrix}\text{Damage factor for}\\ \text{the } k\text{th inventory flow}\end{pmatrix}\right]$$

The *k*th inventory flow is the total electricity demand for a particular year, denoted as *E* (in kWh), times amount (kg) of the *k*th substance per kWh, denoted as m_k. The total electricity demand is the total demand from all customers, $E = \sum_{i=1}^{N} e_i$. Since there is loss η in electricity transmission and distribution, then the kth inventory flow is the following [22].

$$\begin{pmatrix}\text{The } k\text{th}\\ \text{inventory flow}\end{pmatrix} = \frac{\begin{pmatrix}\text{Total electricity}\\ \text{demand}\end{pmatrix} \times \begin{pmatrix}\text{Mass of the}\\ k\text{th pollutant}\end{pmatrix}}{1 - (\text{Electricity loss})} = \frac{Em_k}{1-\eta}$$

If h_k is the damage factor per kg of the *k*th pollutant and *P* is the population size in that particular year, then the health loss per capita *L* is given by Eq. (14) [22].

$$\begin{pmatrix}\text{Health}\\ \text{loss per capita}\end{pmatrix} = L = \frac{E}{(1-\eta)P} \sum_{k=1}^{K} m_k h_k \tag{14}$$

Finally, the benefit-loss ratio *r*, is the quotient between *B* and *L*, Eq. (15).

$$r = \frac{B}{L} \tag{15}$$

2.2 Sensitivity Analysis

The objective of sensitivity analysis is to analyse the effect of change in electricity demand per capita *c* and electricity average price *p* to the benefit *B*, loss *L*, and benefit-loss ratio *r.* Income and tax multipliers matrices ($\mathbf{M_W}$ and $\mathbf{M_T}$) are formulated to calculate the consequence of the increase in demand per capita to the benefit. Eq. (16) and Eq. (17) give the multiplier matrices [22].

$$\mathbf{M_W} = \mathbf{W}(\mathbf{I} - \mathbf{A})^{-1} \tag{16}$$

$$\mathbf{M_T} = \mathbf{T}(\mathbf{I} - \mathbf{A})^{-1} \tag{17}$$

Based on $\mathbf{M_W}$ and $\mathbf{M_T}$, income and tax multiplier, denoted as *v*, was calculated, Eq. (18) [22]. *v* shows the amount of added value (wage and tax) if there is a rise in electricity consumption by one dollar. The product between *v*, *p*, and *c* results in (ΔG), Eq. (19) [22].

$$v = \mathbf{1}(M_W(1, M\,;\, j') + M_T(1, M\,;\, j')) \tag{18}$$

where,

$M_W(1, M\,;\, j')$ = the intersection between the first row and column *j'* of $\mathbf{M_W}$
$M_T(1, M\,;\, j')$ = the intersection between the first row and column *j'* of $\mathbf{M_T}$
j' = column in EIO table denoted electricity production

$$\Delta G = v\,p\,c \tag{19}$$

Substituting Eq. (19) into Eq. (13) resulted in Eq. (20). The first derivatives of Eq. (20) with respect to *c* and *p* give the rates of change in the benefit when electricity consumption per capita and price change, Eq. (21) and Eq. (22).

$$B = f(G) - f(G + v\,p\,c) \tag{20}$$

$$\frac{\partial B}{\partial c} = -\frac{\partial f(G + v\,p\,c)}{\partial c} v\,p \tag{21}$$

$$\frac{\partial B}{\partial p} = -\frac{\partial f(G + v\,p\,c)}{\partial p} v\,c \tag{22}$$

Estimating the effect of change in *c* to *L* was straightforward. In Eq. (14), *E*/*P* = electricity demand per capita = *c*. Therefore, the rate of change of *L* with respect to the change in *c* is the following.

$$\frac{\partial L}{\partial c} = \frac{1}{1-\eta}\sum_{k=1}^{K} m_k h_k \tag{23}$$

L is not a function of *p*, therefore ∂*L*/∂*p* = 0.

It was easy to get the effect of change in the electricity consumption per capita and price to the benefit-loss ratio, Eq. (24) and Eq. (25).

$$\frac{\partial r}{\partial c} = \frac{\frac{\partial B}{\partial c} L - B \frac{\partial L}{\partial c}}{L^2} \tag{24}$$

$$\frac{\partial r}{\partial p} = \frac{1}{L}\frac{\partial B}{\partial p} \tag{25}$$

3. Results

This research utilized data from the Indonesian National Electricity Company, called as PLN, to compute Indonesia's electricity final demand. There are six types of PLN's customers, see Table 1. Indonesia's electricity consumption (GWh) and its selling price (2010 US$/kWh) from 2014 to 2018 in are presented in Table 1. Using Eq. (11) and data shown in Table 1, Table 2 gives electricity final demand in Indonesia from 2014 to 2018.

In this paper, the impact of electricity demand on the overall value-added (wage and tax) was calculated using the EIO method. The latest published Indonesia's EIO table was for the year of 2010. As a consequence, all monetary values in this paper are in 2010 US$. In the EIO table released by the bureau, there are 185 products, and electricity is the 145th product [29]. Therefore, the column vector **F** have 185 rows with $F_{145} = f > 0$ and $F_{j\neq 145} = 0$. Using the year of 2014 as an example, F_{145} = 17,209.794 million 2010 US$, $F_{j\neq 145} = 0$, and the column vector **F** is the following.

$$\mathbf{F} = \begin{pmatrix} 0 \\ \vdots \\ 17{,}209.794 \\ \vdots \\ 0 \end{pmatrix}$$

In this paper, the EIO matrix **A** has 185 rows and columns. Eq. (2) and Eq. (4) give a_{ij} and matrix **A**. The latest Indonesia's EIO table supplied x_{ij} and X_j. In this paper, the matrix **A** was obtained from [22].

$$\mathbf{A} = \begin{pmatrix} 0.067 & 0 & \cdots & 0 \\ 0 & 0.082 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0.001 & 0.001 & \vdots & 0.322 \end{pmatrix}$$

W and **T** have the same size as A. Wage (w_j) and tax (t_j) quantities were obtained using Eq. (5) and Eq. (6). w_j and t_j are the non-zeros entries [22].

$$\mathbf{W} = \begin{pmatrix} 0.183 & 0 & \cdots & 0 \\ 0 & 0.135 & \cdots & 0 \\ \cdots & \cdots & \ddots & 0 \\ 0 & 0 & 0 & 0.303 \end{pmatrix}, \quad \mathbf{T} = \begin{pmatrix} 0.006 & 0 & \cdots & 0 \\ 0 & 0.008 & \cdots & 0 \\ \cdots & \cdots & \ddots & 0 \\ 0 & 0 & 0 & 0.003 \end{pmatrix}$$

Table 1
Electricity demand and selling price in Indonesia according to customer types from 2014 to 2018 in Indonesia [24-28]

Year	Demand (GWh) & Average Selling Price (2010 US$/kWh)	Consumer Type					
		Household	Industry	Business	Social	Gov. office building	Public street lighting
2014	Demand	88,682.130	65,908.680	36,282.420	5,446.460	3,483.990	3,393.760
	Average Selling Price	0.068	0.088	0.114	0.073	0.113	0.099
2015	Demand	88,682.130	64,079.390	36,978.050	5,940.980	3,717.160	3,448.110
	Average Selling Price	0.073	0.099	0.111	0.070	0.115	0.130
2016	Demand	93,634.630	68,145.320	40,074.380	6,630.790	4,021.610	3,497.590
	Average Selling Price	0.071	0.089	0.102	0.069	0.104	0.120
2017	Demand	94,457.380	72,238.370	41,694.790	7,095.370	4,121.260	3,526.550
	Average Selling Price	0.086	0.088	0.101	0.067	0.104	0.119
2018	Demand	97,832.280	76,946.500	44,027.400	7,781.340	4,403.280	3,627.070
	Average Selling Price	0.086	0.085	0.097	0.064	0.100	0.114

Table 2
Total electricity final demand in Indonesia (million 2010 US$) [24-28]

Customer type	Year				
	2014	2015	2016	2017	2018
Household	6,059.638	6,433.772	6,684.497	8,093.820	8,428.647
Industry	5,808.033	6,346.833	6,064.728	6,382.191	6,526.245
Business	4,139.378	4,115.906	4,072.880	4,214.258	4,280.205
Social	397.593	418.358	457.792	472.881	500.599
Government office building	394.444	426.742	420.148	427.561	440.502
Public street lighting	335.519	446.826	418.846	418.215	414.306
Total	17,209.794	18,188.440	18,118.911	20,008.958	20,590.619

Utilizing Eq. (9) and Eq. (10), **Y** and **Z** were computed. As an illustration, the following equations are **Y** and **Z** for the year of 2014. In the **Y** and **Z** vectors, Y_{145} = 1,704.635 and Z_{145} = 56.238 million 2010 US$.

$$\mathbf{Y}=\begin{pmatrix}0.183 & 0 & \cdots & 0\\ 0 & 0.135 & \cdots & 0\\ \cdots & \cdots & \ddots & 0\\ 0 & 0 & 0 & 0.303\end{pmatrix}\begin{pmatrix}0.933 & 0 & \cdots & 0\\ 0 & 0.918 & \cdots & 0\\ \cdots & \cdots & \ddots & 0\\ 0 & 0 & 0 & 0.678\end{pmatrix}^{-1}\begin{pmatrix}0\\ \vdots\\ 17{,}209.794\\ \vdots\\ 0\end{pmatrix}=\begin{pmatrix}1.048\\ \vdots\\ 1{,}704.635\\ \vdots\\ 1.789\end{pmatrix}$$

$$\mathbf{Z}=\begin{pmatrix}0.006 & 0 & \cdots & 0\\ 0 & 0.008 & \cdots & 0\\ \cdots & \cdots & \ddots & 0\\ 0 & 0 & 0 & 0.003\end{pmatrix}\begin{pmatrix}0.933 & 0 & \cdots & 0\\ 0 & 0.918 & \cdots & 0\\ \cdots & \cdots & \ddots & 0\\ 0 & 0 & 0 & 0.678\end{pmatrix}^{-1}\begin{pmatrix}0\\ \vdots\\ 17{,}209.794\\ \vdots\\ 0\end{pmatrix}=\begin{pmatrix}0.033\\ \vdots\\ 56.238\\ \vdots\\ 0.018\end{pmatrix}$$

The change in GDP per capita (US$ per capita) ΔG due to the demand for electricity is the ratio between total value-added (employee compensation and tax) and the population size, Eq. (12). The following equation gives ΔG in 2014 due to the demand on electricity power.

$$\Delta G=\frac{\begin{pmatrix}1 & 1 & \cdots & 1\end{pmatrix}\left(\begin{pmatrix}1.048\\ \vdots\\ 1{,}704.635\\ \vdots\\ 1.789\end{pmatrix}+\begin{pmatrix}0.033\\ \vdots\\ 56.238\\ \vdots\\ 0.018\end{pmatrix}\right)}{255.129}=15.451\,\text{US\$ per capita}$$

Note that the population of Indonesia in 2014 was 255.129 million people [30], value-added in the forms of wage and tax are in million 2010 US$, and therefore ΔG is in 2010 US$ per capita. Table 3 summarizes ΔG from 2014 to 2018.

Indonesia's GDP and DALYs per capita [30,31] were utilized to calculate the effect of the increase in GDP per capita on DALYs. Based on the data, a regression analysis was performed.

Table 3
Total value-added and change in GDP per capita

	Year				
	2014	2015	2016	2017	2018
Total value added (million 2010 US$)	3,941.898	4,166.057	4,150.131	4,583.046	4,716.275
Population (people)	255,129,004	258,383,256	261,554,226	264,645,886	267,663,435
Change in GDP per capita (2010 US$ per capita)	15.451	16.124	15.867	17.318	17.620
Benefit *B* (DALY per capita)	4.253E-04	4.240E-04	3.976E-04	4.131E-04	3.993E-04

Figure 3 presents the plot of DALY per capita versus GDP per capita in Indonesia. From the graph, it was concluded that there was an inverse relationship between DALY per capita and GDP per capita in Indonesia. Eq. (26) gives the regression equation.

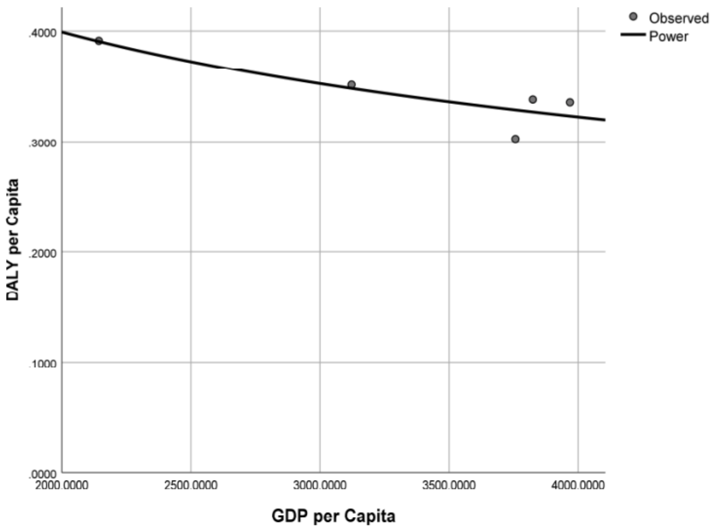

Fig. 3. DALY per capita vs GDP per capita

From Table 4, it is concluded that the formula is good enough because the coefficient determination of the regression curve is more than 70% and the variation explained by the model is not due to chance at 10% significance level. Eq. (26) gives the regression equation.

Table 4
Regression model

Response Variable: DALYs per Capita							
	Model Summary					Parameter Estimates	
Equation	*R* Square	*F*	df_1	df_2	Sig.	Constant	b_1
Power	0.727	8.007	1	3	0.066	4.168	-0.309

The explanatory variable is GDP per Capita (2010 US$).

$$H = f(G) = 4.168G^{-0.309} \quad (26)$$

$$B = 4.168G^{-0.309} - 4.168(G + \Delta G)^{-0.309} \quad (27)$$

Substituting Eq. (26) into Eq. (13), Eq. (27) was obtained. Using Eq. (27) and data on Indonesia GDP per capita, the benefit *B* was calculated. The last row of Table 6 presents the benefit *B* in Indonesia from 2014 to 2018.

From the equation, it was inferred that a higher GDP per capita led to a lower health benefit. However, one way to keep the level of the benefit was by increasing added value. This could be done by increasing annual electric power demand per capita and price.

Now let's start estimating the loss (*L*). Table 5 presents the amount of electricity generated from 2014 to 2018. PLN data from 2014 to 2018 were used to calculate the amount of energy produced [24-28].

Table 5
Amount of electricity generation from 2014 to 2018 [24-28]

	Year				
	2014	2015	2016	2017	2018
Percentage of because of distribution (%)	9.71	9.77	9.48	8.75	9.51
Demand (GWh)	203,197.44	202,845.82	216,004.32	223,133.72	234,617.87
Electricity Generated (GWh)	225,049.77	224,809.73	238,626.07	244,530.10	259,274.91

The life cycle inventory data (the amount of pollutants produced per 1 kWh of electricity generation, m_k) and the damage factors (h_k) presented in Table 6 were based on Eco-indicator 99 [21] and Widiyanto *et al.*, [23]. By using Eq. (14), the health loss *L* (increase in DALY per capita) due to the demand for electricity in Indonesia from 2014 to 2018 was estimated. Note that in [23], there are other pollutants other than the pollutants that listed in Table 6. They are not presented in Table 6 because their damage factors for human health damage category are not available in Eco-Indicator 99.

Table 6
Direct pollutants produced per kWh of electricity generation and damage factors [21,22]

Pollutant	Amount (kg/kWh)	Health Impact (DALY/kg)
CO_2	7.000E-01	2.100E-07
SO_2	2.300E-03	5.460E-05
CH_4	1.500E-05	4.413E-06
NMHC	3.000E-05	1.280E-06
N_2O	1.900E-05	6.900E-05
SPM	2.300E-04	3.750E-04

From the equation, it was inferred that the health loss depended only on the level of electricity consumption per capita, the number of pollutants produced per kWh generated, and the efficiency of electricity transmission and distribution process. A higher electricity demand per capita caused a higher health loss. The loss could be reduced by using environmentally friendly electricity generation technology, and increasing the efficiency of electricity transmission and distribution. Table 7 presents the health loss triggered by electricity demand in Indonesia from 2014 to 2018.

Table 7
Health loss (L) triggered by electricity demand in Indonesia (DALY per capita)

Pollutant	Year				
	2014	2015	2016	2017	2018
CO_2	1.297E-04	1.279E-04	1.341E-04	1.358E-04	1.424E-04
SO_2	1.108E-04	1.093E-04	1.146E-04	1.160E-04	1.216E-04
CH_4	5.839E-08	5.759E-08	6.039E-08	6.116E-08	6.412E-08
NMHC	3.387E-08	3.341E-08	3.503E-08	3.548E-08	3.720E-08
N_2O	1.156E-06	1.141E-06	1.196E-06	1.211E-06	1.270E-06
SPM	7.608E-05	7.504E-05	7.869E-05	7.969E-05	8.355E-05
Total = Loss (L)	3.178E-04	3.134E-04	3.287E-04	3.329E-04	3.490E-04

Based on the results presented in Table 3, Table 7, and by using Eq. (10), the benefit-loss ratios r of electricity generation in Indonesia from 2014 to 2018 were calculated. Table 8 presents the benefit-loss ratios. On average, the benefit-loss ratio was 1.257, which means that the health gain is about 25.7% higher than the health loss.

Table 8
Benefit-loss ratio

	Year					Average
	2014	2015	2016	2017	2018	
Benefit-loss ratio	1.338	1.353	1.210	1.241	1.144	1.257

3.1 Effects of Changes in Electricity Demand Per Capita and Price

In this paper, the $\mathbf{M_W}$ and $\mathbf{M_T}$ matrices were obtained from [22].

$$\mathbf{M_W} = \begin{pmatrix} 1.958\text{E-01} & \cdots & 6.008\text{E-05} & \cdots & 2.497\text{E-04} \\ 2.042\text{E-05} & \cdots & 3.935\text{E-05} & \cdots & 3.109\text{E-05} \\ 8.848\text{E-07} & \cdots & 2.041\text{E-06} & \cdots & 3.734\text{E-06} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 5.586\text{E-04} & \cdots & 1.039\text{E-04} & \cdots & 4.468\text{E-01} \end{pmatrix}$$

$$\mathbf{M_T} = \begin{pmatrix} 6.230\text{E-03} & \cdots & 1.937\text{E-06} & \cdots & 7.946\text{E-06} \\ 1.246\text{E-06} & \cdots & 2.402\text{E-06} & \cdots & 1.897\text{E-06} \\ 3.341\text{E-08} & \cdots & 7.706\text{E-08} & \cdots & 1.410\text{E-07} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 5.691\text{E-06} & \cdots & 1.059\text{E-06} & \cdots & 4.551\text{E-03} \end{pmatrix}$$

In Indonesia's EIO table, electricity sector number is 145. Thus j' is 145. According to Afrinaldi [22], $v = 0.229$ (0.221 from wage and 0.008 from tax). The value was obtained by adding all entries in the 145th column of $\mathbf{M_W}$ and $\mathbf{M_T}$. This value has the meaning that the overall increase in income and tax is 0.229 for every one US$ increase in electricity demand.

Using Eq. (19) and the above result, an alternative equation to calculate change in GDP per capita (ΔG) was formulated. Eq. (28) gives the alternative equation.

$$\Delta G = 0.229\, p\, c \tag{28}$$

Based on Eq. (21), Eq. (22) and Eq. (28), the rates of change of *B* with respect to the change in *c* and *p* are the following.

$$\frac{\partial B}{\partial c} = 1.286(G + v\, p\, c)^{-1.309}\, v\, p \tag{29}$$

$$\frac{\partial B}{\partial p} = 1.286(G + v\, p\, c)^{-1.309}\, v\, c \tag{30}$$

In Eq. (23), the sigma notation gives the sum-product of the mass of the pollutants and their damage factors. In this case study, the sum-product equals to 3.602E-07 DALY/kWh. Substituting this value into Eq. (23) resulted in the rate of change of the health loss with respect to change in electricity demand per capita, Eq. (31).

$$\frac{\partial L}{\partial c} = \frac{3.602\text{E}-07}{1-\eta} \tag{31}$$

In Eq. (29) and Eq. (31), $\partial B/\partial c$ and $\partial L/\partial c$ are in DALY/kWh. In Eq. (30), $\partial B/\partial p$ is in DALY per capita/(US$ · kWh).

If the rate of change of the benefit and loss was analysed, it was seen that rate of change of the benefit and loss increased with respect to the change in electricity demand per capita and price. Eq. (27) is non-linear. Therefore, Eq. (29) gives the instantaneous rate of change of benefit with respect to the change in electricity demand per capita. On the opposite, Eq. (14) is linear. Thus Eq. (31) gives the rate of change of loss with respect to the change in electricity demand per capita (a constant rate of change). Using the data of Indonesia in 2018, it was found that $\partial B/\partial c$ and $\partial L/\partial c$ were 4.544E-07 and 3.981E-07 DALY/kWh, respectively. $\partial B/\partial p$ = 4.538E-03 DALY per capita/(US$ · kWh) in 2018, and it gives the instantaneous rate of change of benefit with respect to the change in price. Since $\partial L/\partial p$ = 0, the change in price did not affect the loss.

Using the data of Indonesia in 2018, Figure 4 presents how the benefit and loss changed when electricity demand per capita and price increased simultaneously. In the figure, *p* = 0.03, 0.09 (price in 2018), and 0.15 US$/kWh were used. At *p* = 0.09 US$/kWh, the benefit was higher than loss when the value of electricity demand per capita *c* was less than 4.89E+04 kWh, but when *c* was higher than 4.89E+04 kWh, the loss was higher than benefit. The figure also suggests that the average rate of change of loss was higher than the average rate of change of benefit with respect to the electricity demand per capita at *p* = 0.09 US$/kWh (price in 2018).

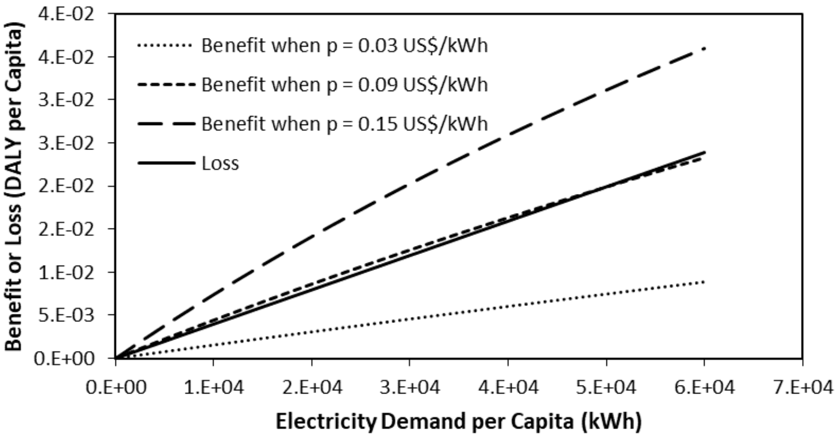

Fig. 4. Benefit and loss versus electricity demand per capita and electricity price

Furthermore, Figure 5 presents that the benefit-loss ratio decreased exponentially when electricity consumption per capita increased. The figure also shows that a higher price led to a higher benefit-loss ratio. In 2018, to be at the break-even point ($B = L$ or $r = 1$), the price should be $p = 0.077$ US$/kWh, given that the other parameters stay the same. When $p < 0.077$ US$/kWh, then $B < L$ (loss region); and when $p > 0.077$ US$/kWh, then $B > L$ (benefit region). This result shows that rising the price seems to be an easy alternative to increasing loss-benefit ratio.

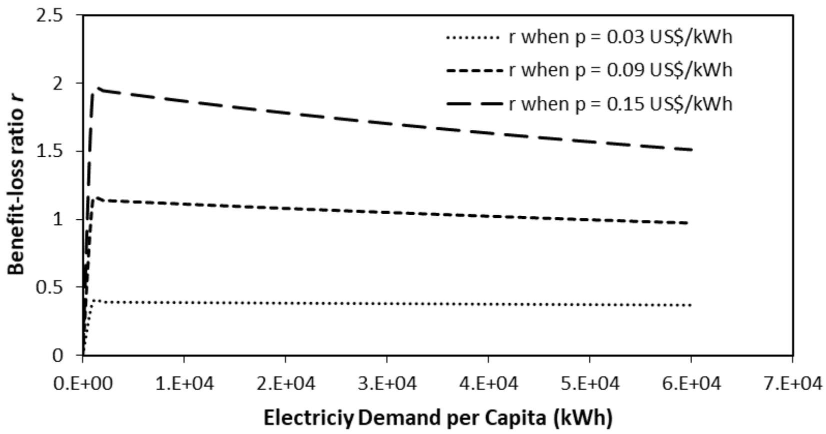

Fig. 5. Benefit-loss ratio versus electricity demand per capita and electricity price

4. Discussion

It can be inferred from Eq. (26) and Eq. (27) that a higher GDP per capita will result in a lower benefit. Afrinaldi *et al.*, [32], Norris [15], and Klöpffer [33] support the finding. The result may also be the reason why developing economies prioritize economic development and developed economies put more attention on reducing the environmental impacts of economic activities [32,33].

It is also noteworthy that the input-output analysis with Indonesia's electrical energy consumption acting as the final demand was also carried out by Afrinaldi [22]. Therefore, some of the matrices and coefficients used in this article were obtained from Afrinaldi [22]. The main difference between this paper and Afrinaldi [22] is in the calculation of benefit and loss. This paper used DALY per capita while Afrinaldi [22] used monetary value. Afrinaldi *et al.*, [34] also performed a regression analysis where DALY per capita as the dependent variable and GDP per capita as the independent variable. Using their results, it was found that the benefit from electricity generation in Indonesia in 2018 equalled to 2.553E-04 DALY per capita. That number is about 36% lower than the benefit presented in this paper. The set of data used to perform the regression analysis causes the difference. Afrinaldi *et al.*, [34] used global data. This research used Indonesian data only.

Using global data means that data from the low-income (lower GDP per capita) and high-income (higher GDP per capita) countries were utilized. Since Indonesia GDP per capita was about 39% of world GDP per capita in 2018 [35], and Indonesia is classified as a lower-middle-income country, it is reasonable that when using global data, a lower benefit was obtained. In other words, the average of the benefit is lower because countries with higher GDP per capita pull the regression line to produce a lower health benefit. This finding is consistent with the results presented earlier, saying that there is a lower health benefit due to the economic activities in the higher-income countries than in the lower-income countries.

The results in estimating the health loss show that the magnitude of the loss depends on the energy sources used to generate the electricity and distribute it. If Indonesia is compared with Japan, about 37% of the Japanese grid system composition ratio was from nuclear power plants [23]. In Indonesia, the composition ratios were about 19% (oil), 30% (coal), 35% (natural gas), 13% (hydro), and 3% (geothermal) [23]. This caused the Indonesian grid system to produce more pollutants [23]. If Indonesia had the same composition ratio as Japan, on average, Indonesia would have a 57% decrease in health loss or a 57% increase in benefit-loss ratio (assuming the other parameters are the same as what this paper presents). This finding reveals that using renewable energy and cleaner technologies is the key to reduce health damage to the population caused by electricity generation.

The basis of this paper in estimating benefit is the EIO table. The advantage of using the EIO model is that it is comprehensive and based on the stable flow of goods among the industries [20]. In this paper, the 2010 EIO table of Indonesia was utilized. The table was developed based historical data and might not reflect the current situation. As a consequence, the estimate on the benefit might not be very accurate. Furthermore, the EIO table usually presents the flow of commodities among the industrial sectors. The inputs and outputs are aggregate values. The use of aggregate values may also affect the accuracy of the estimated health benefit.

Another aspect that may affect the accuracy of the estimated benefit is the use of regression analysis in modelling the relationship between GDP per capita and DALY per capita. Although the R^2 of the model is high, the regression model was developed based on a small sample size. If more data is available, the accuracy of the model will be better.

In the Eco-indicator 99 [21], not all pollutants have damage factor to human health. For example, Widiyanto *et al.*, [23] presented that Ni, V, As, Cd, Cr, and other pollutants are parts of Indonesia's electricity generation LCI. Since Eco-indicator 99 does not list their damage factors to human health, this paper does not consider their effect on human health.

Norris [15] presented that the economic activities such as electricity generation may affect three aspects, wages, taxes, and employment levels. This paper only considers two of the three, wages and taxes. Therefore, it is expected to have a higher health benefit when all three aspects are combined.

Finally, although the model presented in this paper has limitations, it can still be used to estimate health benefits and loss caused by electricity demand and generation. The accuracy of the model improves when more and recent data are available. Moreover, the same approach can also be used to evaluate other technologies.

5. Policy Implication

There are two approaches to increase the benefit-loss ratio, decreasing the loss and increasing the benefit. It seems that reducing the loss is a better way for Indonesia. The reason is that the average rate of change of the loss is higher than the average rate of change of the benefit with respect to electricity consumption per capita. The results show that, from 2014 to 2018, the highest electricity demand per capita in Indonesia occurred in 2018. However, the level of the benefit in 2018 was not the highest. Moreover, the results show that, from 2014 to 2018, the benefit-loss ratio in 2018 was the lowest.

The above reason is consistent with Yoo [18] and Yoo and Kimb [19]. Their conclusions stated there is no meaningful causality from electricity consumption to economic development in Indonesia, but there is a considerable causality in the opposite direction. Since the increase in economic growth due to electricity consumption is not significant, the decrease in DALY per capita is low. On the other hand, an increase in electricity consumption per capita will increase emissions and raise the level of loss. The increase in loss is higher because the loss has a higher rate of change.

Therefore, promoting the use of renewable energy sources is a better choice for Indonesia. It will have a significant impact on reducing CO_2 emissions [16]. Our finding shows that a 1% reduction in CO_2 emission will reduce the loss by 1% because of their proportionality relationship. Furthermore, Indonesia has the potential to use forest biomass (bio-methanol or fuel cells) for electricity generation. Research shows that generating electricity using bio-methanol, Indonesia can avoid 9% – 38% current carbon emissions per year [36].

Indonesia has a national energy policy, and clean energy is one of the priorities. The policy was established in 2006 and revised in 2014. However, there are challenges in the development of renewable energy in Indonesia. The biggest one is the large subsidies on fossil fuel [37].

Burke and Kurniawati [38] proposed electricity subsidy reform for Indonesia. They estimated that the full reduction of electricity subsidies would produce savings of around 6%. According to the authors, the reform will have an indirect effect on reducing emissions from the on-grid electricity sector. It is an indication that price influence electricity demand in Indonesia. Attracting the private sector to invest in electricity generation in remote areas of the country is also one of the alternatives [39,40]. The private sectors are considered to be able to address challenges in implementing renewable energy-based village grids in Indonesia [40].

McNeil *et al.*, [12] presented that Indonesia’s electricity demand will increase three times between 2010 and 2030. The main factor causing the increase is the use of air conditioning, lighting, and refrigerators. Therefore, Indonesia needs energy-efficiency improvement. The improvement can be achieved by promoting pro-environmental behaviour and wise electricity use [41]. As a consequence, there will be monetary savings, reductions in greenhouse gasses and other pollutants emissions, and finally a decrease in the level of the loss.

6. Conclusions and Future Work

This paper has successfully determined the benefit-loss ratio of Indonesia's electricity generation. The benefit and loss are expressed in DALY, a metric used by the WHO for health assessment. The basis of estimating benefit was the value-added (wage and tax) triggered by the demand for electricity. The EIO was applied to calculate the value-added. Then, the effect of the change in the value-added to the GDP per capita was calculated. To approximate the benefit, the relationship between GDP per capita and DALY per capita was modelled by using historical data.

To estimate the loss, the health effects caused by the exposure of the people to the pollutants emitted by the power plants were calculated. The endpoint impact assessment methodology of the LCA was applied. For this purpose, the life cycle inventory and damage factors were obtained from the literature.

The result shows that the average of benefit-loss ratio in Indonesia is 1.257, meaning that the estimated benefit is more than the loss. This paper also concludes that, in Indonesia, the average rate of change of the benefit with respect to electricity consumption per capita is lower than the rate of change of the loss. Both have positive values. Thus, the benefit-loss ratio decreases as electricity consumption per capita increases. The analysis also shows a positive relationship between the rate of change of the benefit with the rate of change of electricity price per kWh. However, electricity price per kWh does not affect loss. As a result, the benefit-loss ratio increases as the price of electricity per kWh increases.

Using the 2018 data of Indonesia, the level of the benefit equals the loss when the electricity price was set to be 0.077 US$/kWh (the price in 2018 was 0.09 US$/kWh). When the price was less than 0.077 US$/kWh, then the benefit was less than the loss (loss region); and when price was more than 0.077 US$/kWh, then benefit was more than the loss (benefit region). This result suggests that that rising the price is an easier option to increasing loss-benefit ratio. Based on the findings and the literature, suggestions for the policymakers in Indonesia to increase the benefit-loss ratio of electricity generation include, promoting the use of renewable energy sources; electricity subsidy reform; attracting the private sectors investing in electricity generation, especially in the remote area of the country; and energy efficiency improvement.

Using the most recent EIO table of an economy is important for future research. Also, it is essential to use a larger sample in determining the empirical relationship between GDP per capita and DALY per capita of an economy. The above improvement will increase the accuracy of the model. Furthermore, this paper only considers the effects of electricity generation on income and taxes. Theoretically, the impact of economic activities on employment level can also be quantified using the EIO method. Note that the model presented in this paper does not consider electricity price as one of the variables affecting loss. The literature indicated that price might affect the electricity consumption level in Indonesia. Therefore, it might affect the value of the loss. Thus, for future research, employment level and price should be incorporated into the model. Finally, the social aspects also need to be included as part of the benefit or loss. The social impacts of economic activities can be estimated using the Social Life Cycle Assessment (S-LCA). Thus, the sustainability impact of an economic activity can be determined.

Acknowledgement
This research was not funded by any grant.

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