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Estimation of health impacts and externality costs with the robust uniform world model in the Muara Karang generation units

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Abstract: To encourage national economic growth, efforts are made to maintain electricity availability in Indonesia. Until now, the need for electrical energy in Indonesia is still supplied by fossil fuel power plants, especially Steam Power Plants and Gas Steam Power Plants. One of the negative impacts arising from electricity generation activities is air pollution. Air pollution is produced in the form of waste gases such as PM_{10}, SO_2, NO_2, and these gases causes global warming and impact of human health. In this study, the magnitude of the negative impact calculated based on the impact on public health, which will then be limited to economic value (cost of externalities). Cost of externalities are conditions when the effect of the production of goods or services imposes costs or benefits on other parties, and these costs are not reflected in the price charged for the goods or services produced. The estimation of public health impacts and externality costs calculated in this study comes from power plants operating at the Muara Karang Generation Unit using Robust Uniform World Model (RUWM). The research results show that the amount of health and externality costs obtained for each power plant are different because each power plant has different operating conditions. In PLTGU Block 1, the resulting externality cost was 18,51 cents USD/kWh, PLTGU Block 2 was 3,05 cents USD/kWh, and PLTGU Block 3 was 1,75 cents USD/kWh. The two Unit of PLTU Muara Karang generate different externality costs, namely 1,52 cents USD/kWh for PLTU Unit 4 and PLTU Unit 5 of 1,10 cents USD/kWh.

Keywords: Energy; Health impacts; Externality costs; Robust uniform world model; Air pollution

1. Introduction

The increase energy consumption in Indonesia has increased every year and occurs in all sectors, including the industrial, transportation, household, commercial, and other sectors. The increase in energy shows that energy plays an essential role in national economic growth. In terms of encouraging economic growth, the government is trying to maintain the availability of electricity in Indonesia (Ministry of Energy and Mineral Resources of the Republic of Indonesia, 2022). The availability of electricity in Indonesia, seen from the total installed capacity, is still dominated by fossil fuel-fired power plant such as coal, natural gas, and oil because it is supported by energy reserves which are still relatively abundant, and the price is low when compared to renewable energy technologies.

Fossil fuel power plants are closely related to environmental problems. Air pollution is one of the negative impacts of exhaust emissions from burning power plants. The amount of emissions from power plant is directly proportional to fuel consumption, resulting in waste gases, including CO_2, SO_2, NO_x, and PM, which can cause global warming and impact human health. Air pollution, from construction power plants, fuel transportation, and production processes to transmission and distribution processes, is included in externalities (Sugiyono, n.d.). Externalities or costs of externalities are benefits or costs generated as an unwanted by-product of an economic activity not obtained by the parties involved, and no compensation is issued (Owen, 2004). The cost of the power plant's externality is not considered in calculating the price of electricity, and those who bear the cost of the externality are the people affected by the power plant activity.

Calculating the cost of externalities aims to empirically measure the impact of damage to the economic value arising from electricity production activites. In general, what can be done to measure the relationship between the emissions generated from power plants and the damage they cause (Szpunar & Gillette, 1992), among other things; first, the relationship between the number of emissions from power plants, precisely, and the amount of concentration of environmental pollution is produced. Second, is the relationship between environmental pollution concentration and health or the surrounding environment. Third, the relationship between physical and biological impact on economic valuation.

Research related to the calculation of externality costs has also been carried out in several power plants in Indonesia, although this still needs to be improved. Therefore, in this study, externality cost calculations were carried out based on estimates of public health impacts at one of the power plants located in the center of Jakarta, namely the Muara Karang Generation Unit, which operates a Gas Steam Power Plant (PLTGU) and a Steam Power Plant (PLTU) with a total installed capacity of 1979 MW. Estimating public health impacts (cases/year) was carried out using the Robust Uniform World Model, a type of modeling in the SIMPACTS software, the AIRPACTS module. RUWM measures health impacts by considering local areas, regional areas, population density, power plant stack, to exposure to pollutans produced by power plants (Büke & Köne, 2011).

2. Methods

The research method used in this study is a descriptive research method based on a case study at the Muara Karang Generation Unit. The calculation of externality costs in this study was carried out using Bottom-Up approach, which is an approach that estimates externality costs based on atmospheric dispersion and requires some data, including power plant operating data, meteorological data, and population data (receptor). The calculation process uses the Robust Uniform World Model (RUWM) modeling because this modeling can provide more accurate calculation results and can be done manually.

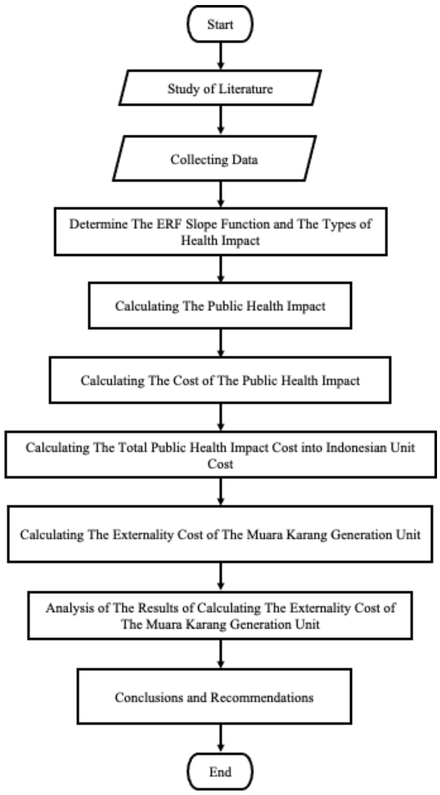

Figure 1. Flowchart of estimating public health impacts and costs of externalities

Determining the ERF slope function and types of health impact

The value of the ERF Slope function (number of cases per year) on human health is calculated using equation (1) (Büke & Köne, 2011). IRR is the Increased Risk Ration, Incidence is incident rate in annual cases per receptor, and f_{pop} is the fraction of the population. The magnitude of the value of the equation is obtained from the AIRPACTS module or based on the availability of data at the research location.

$$\text{ERF Slope} = \text{IRR x Incidence x } f_{pop} \quad (1)$$

Due to data limitations in Indonesia and this study, it was also calculated manually; the ERF Slope function used was obtained from the results of studies on the European Unions's ExternE project. The ERF Slope function for each type of impact and type pollutant has a different value, and the receptors are divided based on population size, occupation, age, to community-borne diseases. The function of the ERF Slope summarizes several health impacts, including mortality (chronic, acute, infant) and morbidity (chronic bronchitis, bronchodilator usage, lower respiratory symptoms, restricted activity days, hospital admissions) and some health impacts in full in Table 1 (Jorli et al., 2017).

Calculating public health impacts

The public health impacts in this study are divided into local health impacts and regional health impacts, the difference in the distance from the emission source. Local health impacts are within 0-50 km of emission sources (local areas), while regional impacts are 500-1000 km (regional areas). Local health impacts only calculated impacts due to primary pollutans, while regional impacts include impacts due to primary and secondary pollutans. The magnitude of the impact is calculated using equation (2) (Casas-Ledon et al., 2014). Where D is the magnitude of the impact (cases/year), ρ is the regional population density (person/km^2), ERF is Exposure Response Function (case/year.person.μg/m^3), Q is the annual emission rate (ton/year), R is the impact radius (km), and k is the depletion velocity (cm/s).

$$D = \frac{\rho_{Regional} ERF\ Q\ R}{k} \tag{2}$$

In RUWM modeling, it has different R values for primary pollutans (PM_{10}, SO_2, NO_2) and secondary pollutans (Sulfate, Nitrate) (Mayasari, 2013). The R value of primary pollutants is calculated by considering local population density, stack parameters, and atmospheric conditions as in equation (3), while the R value for secondary pollutans is around 1(Liun, 2012).

$$R = \left(\frac{\rho_{Local}}{\rho_{Regional}}\right)\left(\frac{\sqrt{2}\,k}{\sqrt{\pi}\,u}\right)\int_0^{Ro}\frac{1}{\sigma_z}\exp\left(-\frac{{H_e}^2}{2{\sigma_z}^2}\right)dr + \exp\left(-\frac{k\,Ro}{u\,H_{mix}}\right) \tag{3}$$

From the equation for the R value above, if it is substituted into equation (2), two equations can be obtained that can be used to calculate the size of the local health impact and regional health impact. (Mayasari, 2013). Local health impacts for each primary pollutant.

$$D_{Lokal} = \frac{\sqrt{2}\,\rho_{Lokal}\,ERF\ Q}{\sqrt{\pi}\,u} \times \int_0^{Ro}\frac{1}{\sigma_z}\exp\left(-\frac{{H_e}^2}{2{\sigma_z}^2}\right)dr \tag{4}$$

Regional health impact for each primary pollutant and secondary pollutant (R = 1)

$$D_{Regional} = \frac{\rho_{Regional}\,ERF\ Q}{k}\exp\left(-\frac{k\,Ro}{u\,H_{mix}}\right) \tag{5}$$

Where ρ is the local and regional population density (person/km^2), u is the average wind speed (m/s), R_o is the local domain radius (50 km), H_e is the effective stack height, H_{mix} is the emission mix layer height (1000 km) and σ_z is the vertical dispersion coefficient.

Because local and regional health impacts will be calculated using the RUWM modeling, it requires population density and meteorological data. The local population density is calculated from 9 areas including DKI Jakarta, Bogor Regency, Depok, Tangerang Regency, Tangerang City, South Tangerang City, Serang Regency, Bekasi City, and Bekasi Regency is 5824,31 person/km^2. Meanwhile, the regional population density which covers several areas outside Java with a total of 16 areas is 355,37 person/km^2, where the data is obtained from the Central Bureau of Statistics for 2021. Meteorological data in this study are obtained from Nasa for every hour in one year or 8760 hours consisting of wind speed (m/s), wind direction (^{o}), ambient temperature (K), anemometer height, and mixing layer height. These data are the processed again to determine the percentage of the distribution for each type of Pasquill stability class.

Table 1. Muara karang generation unit pollutant data

Pollutant	**Emission Coefficint (g/kWh)**	**Emission Rate (ton/year)**
PLTGU Block 1		
PM_{10}	0,140595353	323,14
SO_2	0,220813107	507,51

NO_2	5,400438311	12412,2
PLTGU Block 2		
PM_{10}	0,102404562	231,19
SO_2	0,166379176	375,62
NO_2	1,510452897	3410,02
PLTGU Block 3		
PM_{10}	0,461116625	972,74
SO_2	0,033083177	69,79
NO_2	0,044621284	94,13
PLTU Unit 4		
PM_{10}	1,060903525	381,83
SO_2	0,099580395	35,84
NO_2	0,096440723	34,71
PLTU Unit 5		
PM_{10}	0,657879715	282,36
SO_2	0,037605109	16,14
NO_2	0,037605109	16,14

Table 2. Depletion velocity

Pollutant	Depletion velocity (cm/s)
PM_{10}	1,2
SO_2	0,75
NO_2	1,5
Sulfate	1,5
Nitrate	1,4

Table 3. Muara Karang generation unit meteorological data

Parameters	Units	Values
Pasquill Distribution Class A (%)	%	8
Pasquill Distribution Class B (%)	%	15
Pasquill Distribution Class C (%)	%	11
Pasquill Distribution Class D (%)	%	4
Pasquill Distribution Class E (%)	%	22
Pasquill Distribution Class F (%)	%	40
Anemometer Height	m	10
Ambient Temperature	K	300,3
Wind Speed (u)	m/s	3,01
Mixing Layer Height (Hmix)	km	1000

Calculating the cost of public health impacts

The public health impact cost is obtained by multiplying the health impact by the unit cost. Unit cost values in Indonesia are currently not available. Therefore the unit cost values used are also taken from ExternE research result in USD_{2000}. (Zyśk et al., 2021).

Table 4. Health impact, ERF Slope, and unit cost

Health Impact & Receptor	ERF Slope (case/year.person.$\mu g/m^3$)	Unit Cost (USD_{2000})
PM_{10}		
Chronic Mortality (entire population)	4×10^{-4}	45872
Acute Mortality (entire population)	$2{,}88 \times 10^{-6}$	68807
Infant Mortality (children under 12 months)	$1{,}8 \times 10^{-7}$	917431
Chronic Bronchitis (adults aged 27+)	$1{,}81944 \times 10^{-5}$	183486
Lower Respiratory Symptoms		35

(adults with chronic respiratory symptoms)	$3,0756 \times 10^{-2}$	
(children aged 5-14)	$2,057 \times 10^{-2}$	
Bronchodilator Usage		1
(asthmatic adults aged 20+)	$3,15 \times 10^{-3}$	
(asthmatic children 5-14)	$3,663 \times 10^{-4}$	
Cardiac Hospital Admissions (entire population)	$4,2 \times 10^{-6}$	1848
Respiratory Hospital Admissions (entire population)	$6,82 \times 10^{-6}$	1848
Restricted Activity Days		119
(working adults aged 15-64)	$2,36379 \times 10^{-2}$	
(non-working adults aged 15-64)	$2,67786 \times 10^{-3}$	42
SO_2		
Acute Mortality (entire population)	$7,85 \times 10^{-6}$	68807
Respiratory Hospital Admissions (entire population)	$2,04 \times 10^{-6}$	1848
NO_2		
Chronic Mortality (adults 15+)	$3,91 \times 10^{-4}$	45872
Sulfate		
Chronic Mortality (entire population)	4×10^{-4}	45872
Acute Mortality (entire population)	$2,88 \times 10^{-6}$	68807
Infant Mortality (children under 12 months)	$1,8 \times 10^{-7}$	917431
Chronic Bronchitis (adults aged 27+)	$1,81944 \times 10^{-5}$	183486
Lower Respiratory Symptoms		35
(adults with chronic respiratory symptoms)	$3,0756 \times 10^{-2}$	
(children aged 5-14)	$2,057 \times 10^{-2}$	
Bronchodilator Usage		1
(asthmatic adults aged 20+)	$3,15 \times 10^{-3}$	
(asthmatic children aged 5-14)	$3,663 \times 10^{-4}$	
Cardiac Hospital Admissions (entire population)	$4,2 \times 10^{-6}$	1848
Respiratory Hospital Admissions (entire population)	$6,82 \times 10^{-6}$	1848
Restricted Activity Days		119
(working adults aged 15-64)	$2,36379 \times 10^{-2}$	
(non-working adults aged 15-64)	$2,67786 \times 10^{-3}$	42
Nitrate		
Chronic Mortality (entire population)	2×10^{-4}	45872
Acute Mortality (entire population)	$1,44 \times 10^{-6}$	68807
Infant Mortality (children under 12 months)	9×10^{-8}	917431
Chronic Bronchitis (adults aged 27+)	$9,0972 \times 10^{-6}$	183486
Lower Respiratory Symptoms		35
(adults with chronic respiratory symptoms)	$1,51217 \times 10^{-2}$	
(children aged 5-14)	$1,0285 \times 10^{-2}$	
Bronchodilator Usage		1
(asthmatic adults aged 20+)	$1,575 \times 10^{-3}$	
(asthmatic children aged 5-14)	$1,7908 \times 10^{-4}$	
Cardiac Hospital Admissions (entire population)	$2,1 \times 10^{-6}$	1848
Respiratory Hospital Admissions (entire population)	$3,534 \times 10^{-6}$	1848
Restricted Activity Days		119
(working adults aged 15-64)	$1,14114 \times 10^{-2}$	
(non-working adults aged 15-64)	$1,29276 \times 10^{-3}$	42

Calculating the cost of public health impacts in indonesia's unit cost

Before determining the cost of health impacts in Indonesia unit cost, a change in health impacts cost in European unit costs for 2021 is first carried out using equation (6) (Kusumawati et al., 2010). After obtaining the cost of public health impacts in European unit costs in 2021 is converted into Indonesia unit costs using equation (7) (Rokhmawati et al., 2023).

$$\text{Health Impact Costs } (USD_{2021}) = \text{Health Impacts Costs } (USD_{2000}) \times \frac{\text{USD Deflator}_{2021}}{\text{USD Deflator}_{2000}} \tag{6}$$

$$\text{Unit Cost in Indonesia } = \text{Unit Cost in Uni Eropa} \times \left(\frac{PPPGNI_{Indonesia}}{PPPGNI_{Uni\ Eropa}}\right)^{\gamma} \tag{7}$$

Where, the European Union deflator in 2021 and 2000 is 110,048 and 100. PPP (Purchasing Power Parity) GNI (Gross National Income) Indonesia's in 2021 is 12680 USD, European Union PPPGNI is 48791 USD, and γ is *Income Elasticity Coefficient* (0,3-1). The value of the deflator and PPPGNI is obtained from World Bank data.

Calculating the externality cost of the muara karang generation unit

The cost of externalities in this study is defined as the cost of public health impacts resulting from electricity production per year. To determine the externality cost per kWh is necessary to know the total electricity production for each power plant operating at the Muara Karang Generation Unit in one year for 2021. The equation for finding the externality cost of a power plant as follows.

$$\text{Externality Costs} = \frac{\text{Total Cost of Health Impact } (\text{USD}_{2021})}{\text{Electricity Production}_{2021}} \quad (8)$$

3. Results and discussion

In this study, the public health and externality costs were calculate based on the power plants operating in the Muara Karang Generation Unit, namely PLTGU, with and istalled capacity of each Block 1,2,3, is 404 MW, 680 MW, 495 MW, and also two unist of PLTU 4 and PLTU 5 with a total installed capacity of 400 MW. By knowing the installed capacity of each power plant and its operating time, the electricity production is 3539040 MWh/year for PLTGU Block 1, Block 2 is 5956800 MWh/year, and PLTGU Block 3 is 4336200 MWh/year. Electricity production for PLTU Unit 4 and Unit 5 is 1752000 MWh/year, respectively. Based on the data above, the result of calculating the public health impact for each power plant in the Muara Karang Generation Unit show in table 5.

Figure 2. Muara Karang Generation Unit Location

Table 5. Results of the calculation of the public health impact of the Muara Karang generation unit

Health Impact & Receptor	Public Health Impact (cases/year)				
	PLTGU Block 1	PLTGU Block 2	PLTGU Block 3	PLTU Unit 4	PLTU Unit 5
PM_{10}					
Chronic Mortality (entire population)	1221,726721	823,9555809	3683,634536	1295,505525	3,0151904
Acute Mortality (entire population)	8,796432393	5,932480182	26,52216866	9,327639783	397709371
Infant Mortality (children under 12 months)	0,549777025	0,370780011	1,657635541	0,582977486	-31106836
Chronic Bronchitis (adults aged 27+)	55,57146164	37,47844355	167,5538005	58,92736433	,57627895
Lower Respiratory Symptoms (adults with chronic respiratory symptoms)	93938,5676	63353,94461	283234,6595	99611,41985	561,78799
(children aged 5-14)	62827,29664	42371,91575	189430,906	66621,37164	265,93117
Bronchodilator Usage	9621,09793	6488,650199	29008,62197	10202,10601	44,369624

(asthmatic adults aged 20+) (asthmatic children 5-14)	1118,796245	754,5373232	3373,288327	1186,359185	7,3024106
Cardiac Hospital Admissions (entire population)	12,82813057	8,651533599	38,67816263	13,60280802	,0591595
Respiratory Hospital Admissions (entire population)	20,8304406	14,04844265	62,80596885	22,08836921	16,334159
Restricted Activity Days (working adults aged 15-64)	72197,63516	48691,44906	217683,462	76557,57515	13,66817
(non-working adults aged 15-64)	8179,032794	5516,094229	24660,64395	8672,956066	13,576394
SO_2					
Acute Mortality (entire population)	39,90099851	27,93335487	5,495277386	2,544939225	46074751
Respiratory Hospital Admissions (entire population)	10,36917668	7,259113877	1,428072085	0,661360002	97833439
NO_2					
Chronic Mortality (adults 15+)	44960,64486	11629,36851	341,5248752	112,5683932	,34381638
Sulfate					
Chronic Mortality (entire population)	152,5061971	112,8733971	20,97181828	10,7698806	50052258
Acute Mortality (entire population)	1,098044619	0,812688459	0,150997092	0,07754314	34920376
Infant Mortality (children under 12 months)	0,068627789	0,050793029	0,009437318	0,004846446	02182524
Chronic Bronchitis (adults aged 27+)	6,936896882	5,13415934	0,953924126	0,489878789	20609477
Lower Respiratory Symptoms (adults with chronic respiratory symptoms)	11726,2015	8678,835502	1612,523108	828,0961195	2,9205181
(children aged 5-14)	7842,631186	5804,514445	1078,475755	553,84111	9,4139374
Bronchodilator Usage (asthmatic adults aged 20+)	1200,986302	888,8780021	165,153069	84,81280974	,19416153
(asthmatic children 5-14)	139,65755	103,3638134	19,20494259	9,862518161	41435355
Cardiac Hospital Admissions (entire population)	1,60131507	1,185170669	0,220204092	0,113083746	50925549
Respiratory Hospital Admissions (entire population)	2,600230661	1,92449142	0,357569502	0,183626464	82693391
Restricted Activity Days (working adults aged 15-64)	9012,315592	6670,225183	1239,324358	636,4434017	,6126257
(non-working adults aged 15-64)	1020,975612	755,6478878	140,3989833	72,10058117	,46940235
Nitrate					
Chronic Mortality (entire population)	1998,135244	548,9503186	15,15319367	5,587669738	98242281
Acute Mortality (entire population)	14,38657376	3,952442294	0,109102994	0,040231222	18707344
Infant Mortality (children under 12 months)	0,89916086	0,247027643	0,006818937	0,002514451	01169209
Chronic Bronchitis (adults aged 27+)	90,88717971	24,96955419	0,689258167	0,254160746	18183648
Lower Respiratory Symptoms (adults with chronic respiratory symptoms)	151076,0086	41505,31017	1145,710244	422,4753274	,4492015
(children aged 5-14)	102754,1049	28229,77014	779,2529847	287,3459163	,6146093
Bronchodilator Usage (asthmatic adults aged 20+)	15735,31505	4322,983759	119,3314002	44,00289919	,46115796
(asthmatic children 5-14)	1789,130298	491,5301153	13,56816962	5,003199483	26466138
Cardiac Hospital Admissions (entire population)	20,98042006	5,763978346	0,159108534	0,058670532	27281544
Respiratory Hospital Admissions (entire population)	35,30704976	9,69995213	0,267756932	0,098734124	45910941
Restricted Activity Days (working adults aged 15-64)	114007,6026	31321,45833	864,5957715	318,8156722	,2479098
(non-working adults aged 15-64)	12915,54659	3548,30507	97,94721327	36,11757965	,79451846
Total Public Health Impact	**725760**	**312768**	**759035**	**267684**	**196976**

From the results of the calculation of the public health impact (cases/year) obtained, the calculate public health impact costs by multiplying the result in Table 5 with the unit cost in Table 4. An example of calculating the public health impact costs for PM_{10} pollutants at PLTGU Block 1 as follows.

$$\text{Chronic Mortality Costs} = 1221{,}726721\,\frac{\text{case}}{\text{year}} \times 45872\ \text{USD}_{2000} = 56043048{,}16\ \text{USD}_{2000}/\text{year}$$

Table 6. Results of the calculation of public health impact costs of the Muara Karang generation unit

Health Impact & Receptor	Health Impact Costs (USD2000/year)				
	PLTGU Block 1	PLTGU Block 2	PLTGU Block 3	PLTU Unit 4	PLTU Unit 5
PM_{10}					
Chronic mortality (entire population)	56043048,16	37796490,41	168975683,5	59427429,46	43946072,81
Acute mortality (entire population)	605256,1237	408196,1639	1824910,859	641806,9105	474610,6887
Infant mortality (children under 12 months)	504382,4854	340165,0766	1520766,232	534841,6184	395510,7754
Chronic bronchitis (adults aged 27+)	10196585,21	6876769,693	30743776,64	10812346,37	7995637,12
Lower respiratory symptoms (adults with chronic respiratory symptoms)	3287849,866	2217388,061	9913213,083	3486399,695	2578162,58
(children aged 5-14)	2198955,382	1483017,051	6630081,711	2331748,008	1724307,591
Bronchodilator usage (asthmatic adults aged 20+)	9621,09793	6488,650199	29008,62197	10202,10601	7544,369624
(asthmatic children 5-14)	1118,796245	754,5373232	3373,288327	1186,359185	877,3024106
Cardiac hospital admissions (entire population)	23706,3853	15988,03409	71477,24454	25137,98922	18589,32675
Respiratory hospital admissions (entire population)	38494,65422	25961,52202	116065,4304	40819,3063	30185,52583
Restricted activity days (working adults aged 15-64)	8591518,584	5794282,438	25904331,98	9110351,443	6737026,513
(non-working adults aged 15-64)	343519,3774	231675,9576	1035747,046	364264,1548	269370,2086
SO_2					
Acute mortality (entire population)	2745468,004	1922010,349	378113,5511	175109,6332	78857,96541
Respiratory hospital admissions (entire population)	19162,23851	13414,84245	2639,077213	1222,193284	550,3961944
NO_2					
Chronic mortality (adults 15+)	2062434701	533462392,1	15666429,07	5163737,334	2401115,545
Sulfate					
Chronic mortality (entire population)	6995764,274	5177728,471	962019,2482	494035,963	222481,5972
Acute mortality (entire population)	75553,15611	55918,6548	10389,65688	5335,510857	2402,766329
Infant mortality (children under 12 months)	62961,26081	46599,09911	8658,088298	4446,280049	2002,314732
Chronic Bronchitis (adults aged 27+)	1272823,461	942046,3607	175031,7222	89885,89949	40478,7505
Lower respiratory symptoms (adults with chronic respiratory symptoms)	410417,0523	303759,2426	56438,30877	28983,36418	13052,21813
(children aged 5-14)	274492,0915	203158,0056	37746,65143	19384,43885	8729,487807
Bronchodilator usage (asthmatic adults aged 20+)	1200,986302	888,8780021	165,153069	84,81280974	38,19416153
(asthmatic children 5-14)	139,65755	103,3638134	19,20494259	9,862518161	4,441435355

Cardiac hospital admissions (entire population)	2959,230249	2190,195397	406,9371619	208,9787632	94,11041401
Respiratory hospital admissions (entire population)	4805,226261	3556,460145	660,7884391	339,341706	152,8173866
Restricted activity days (working adults aged 15-64) (non-working adults aged 15-64)	1072465,555	793756,7967	147479,5987	75736,7648	34106,90245
	42880,97572	31737,21129	5896,757297	3028,224409	1363,714899
Nitrate					
Chronic mortality (entire population)	91658459,92	25181449,02	695107,3002	256317,5862	119186,5699
Acute mortality (entire population)	989896,9805	271955,6969	7507,049739	2768,1897	1287,196248
Infant mortality (children under 12 months)	824918,0468	226630,8179	6255,904332	2306,835646	1072,668606
Chronic Bronchitis (adults aged 27+)	16676525,06	4581563,621	126469,2241	46634,93859	21685,04491
Lower respiratory symptoms (adults with chronic respiratory symptoms) (children aged 5-14)	5287660,301	1452685,856	40099,85854	14786,63646	6875,722052
	3596393,672	988041,9548	27273,85446	10057,10707	4676,511325
Bronchodilator usage (asthmatic adults aged 20+) (asthmatic children 5-14)	15735,31505	4322,983759	119,3314002	44,00289919	20,46115796
	1789,130298	491,5301153	13,56816962	5,003199483	2,326466138
Cardiac hospital admissions (entire population)	38771,81628	10651,83198	294,0325701	108,4231436	50,41629322
Respiratory hospital admissions (entire population)	65247,42796	17925,51154	494,8148108	182,4606617	84,84341916
Restricted activity days (working adults aged 15-64) (non-working adults aged 15-64)	13566904,71	3727253,541	102886,8968	37939,065	17641,50127
	542452,9568	149028,8129	4113,782957	1516,938345	705,3697751
Total cost of health impac	**2.290.524.606**	**634.768.439**	**265.231.165**	**93.220.749**	**67.156.615**

The amount of the cost of health impacts in the European Union unit cost in 2021 and the Indonesian unit cost as follows.

Table 7. Public health impact costs by 2021

Health Impact Costs (USD_{2021}/year)				
PLTGU Block 1	**PLTGU Block 2**	**PLTGU Block 3**	**PLTU Unit 4**	**PLTU Unit 5**
2.520.676.518	698.549.972	291.881.592	102.587.570	73.904.511

Table 8. Public health impact costs in indonesia unit cost

Health Impact Costs (USD/year)				
PLTGU Block 1	**PLTGU Block 2**	**PLTGU Block 3**	**PLTU Unit 4**	**PLTU Unit 5**
655.083.484	181.541.957	75.855.354	26.660.868	19.206.600

The externality costs for each power plant at the Muara Karang Generation Unit in 2021 are as follows.

Table 9. Muara karang generation unit externality costs

Externality costs	**Muara Karang Generation Unit**				
	PLTGU block 1	**PLTGU block 2**	**PLTGU block 3**	**PLTU unit 4**	**PLTU unit 5**
USD/kWh	0,1851	0,0305	0,0175	0,0152	0,0110
cent USD/kWh	18,51	3,05	1,75	1,52	1,10

The results of the research that has been carried out, it is obtained the results of significant estimates of public health impacts and externality costs that are different for each type of power plant operating in the Muara Karang Generation Unit. At PLTGU Block 1, the number of health cases per year is 725760 cases/year with an externality cost of 0,1851 USD/kWh or 18,51 cents USD/kWh. The externality costs obtained are huge compared to other power plants operating in the exact location. In PLTGU Block 2, 312768 cases/year were obtained for health impacts, and the externality costs were 0,0305 USD/kWh or 3,05 cents USD/kWh. Furthermore, for Block 3 PLTGU, which is still classified as a new power plant among the power plants operating in the Muara Karang Generation Unit, the health impacts that occur are 759035 cases/year, and the externality costs are only 0,0175 USD/kWh or 1,75 cents USD/kWh. The two Muara Karang Steam Power Plant units generate smaller externality costs than PLTGU, namely 1,52 cents USD/kWh for PLTU Unit 4 and 1,10 cents USD/kWh for PLTU Unit 5. The difference in the estimated value of the health impact and the cost of resulting externality strengthens the opinion of previous research that applying different calculation methods will produce different results, and the assumptions used can also affect the results of the accuracy of the calculation. (Rokhmawati et al., 2023).

4. Conclusion

Based on the data analysis and calculation results in this study, it can be concluded that the performance of the power plant, especially when viewed from the emission rate produced for each pollutant, dramatically influences the magnitude of the estimated results of public health impacts and externality costs. The higher the emission rate, the greater the externality costs, and vice versa. Not only based on plant characteristics, receptor conditions, and meteorological conditions, the use of assumptions such as the type of health impact and the type of pollutant being analyzed also influences the results of calculating public health impacts and externality costs. It is hoped that future research will determine externality cost estimates for other power plants in Indonesia, both fossil-fuel power plants and renewable energy, and also develop other calculation methods that can provide better results.

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