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## EXTERNALITY ASSESSMENT OF CONTROL COST AND DAMAGE COST OF ELECTRICAL STEAM GENERATION STUDY CASE : PLTU PAITON

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**Abstract** – Externality or External Cost in energy field is a negatif externality due to the impact to others and causing the external cost that should be spend by particular party. Nevertheless, the cost is not considered by this party.

Externality has two concept based on the compensation given, externality to the investment of abatement technology, known as control cost and externality to the damage cost.

The assessment using AIRPACTS module, has given the external cost of PLTU Paiton (damage cost) is 0.468 cent USD/kWh or 97,9 Million USD/yr.

Whereas the using of abatement technology, there are several scenario can be assessed, with Selective Catalytic Reduction (SCR), with Flue Gas Desulphurization (FGD) and with both FGD and SCR. The Total cost (included capital cost, operation and maintenance cost and external cost) of the scenario are 91.5, 86.4 and 96.9 Million USD/yr respectively. These indicate, the damage cost of PLTU Paiton is cost more than the control cost and the most effective scenario for abatement technology of PLTU Paiton is the installation of FGD since it has the lowest total cost an the generation producer could save 11 million USD/yr for enviroment and social sectors, comparing with damage cost.

**Keywords**- Externality, Control Cost, Damage Cost, AIRPACTS, Selective Catalytic Reduction, Flue Gas Desulphurization.

### I. INTRODUCTION

Electrical generation takes the biggest portion of the entire energy utilities and most of these energy using fuel fossil. These will give negative impacts to the enviroment, mostly because of the emission such as NOx, SO2, CO2 and PM, is widely spread to the atmosphere.

On the power system designed, components of designing are investment cost, operation and maintenance cost. Afterward the analysis is done to determine the electricity tariff and government subsidy. However, the external cost due to the enviromental impact is not included. Whereas the enviromental issues and human health are the important factor and should be considered by the party involved.

The options are to equip emission control technologies to directly decrease the impact of emission or without these technonologies but will provide compensation because of the impacts.

Analysis of the difference of the external cost before and after new technologies attached and amount of the new technologies investment cost, is needed to give an option to the decision maker which of them is the most effective and efficient methods.

### II. LITERATURE VIEW

Externality or External Cost is categorized into 2 concepts, based on the compensation chosen by the activity party to the party affected. The concept are : (1) Externality to the investment of abatement technology, called *control cost*, is a concept that adds investment of emission controlled technologies to control and mitigate the negative impacts of generation activity and prevent the further damages. (2) Externality to the *damage cost*, is externality concept that calculate the impact and the cost because of the generation activity without trying to limited the emission.

The abatement emission controlled technology is one of effort of electrical producer to push the emisson rate produced by generation unit. The effort is directly diminished the external cost. Common emission controlled technologies used are abatement to PM, SO2 and NOx emission.

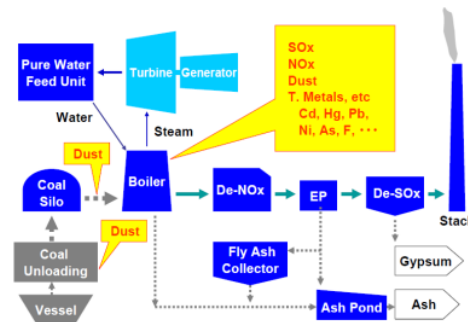


Figure1. Emission Controlled of Electrical Steam Generator

Emission controlled technology to particular pollutant use a separate technology and methods. A Steam Generator could have one, two or aggregate those technologies. It depends on the financial availability of investment.

#### Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR) is one of technology to reduce NOx Emission. The principle of SCR

is adding Amonia (NH3) to a catalyst, grid or plate shaped, installed in reactor and reacted with flue gases from combusted process. The catalyst is mixed from titanium and vanadium or other materials.

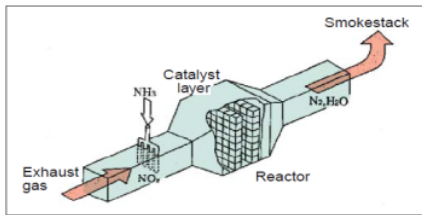


Figure 2. SCR Denitration Process

At 350° C temperature, the optimum catalyst temperature, NH3 will react with NOx (NO or NO2) and transform it into H2O and N2. It is shown on the following reaction :



At lower temperature, the amonia will react with SO3 in flue gas and produce Amonium Hydrogen Sulfate (NH4HSO4). It will cover the catalyst surface and will reduce the catalyst ability to diminish NOx. While at higher temperatur (above 400° C), NH3 will be oxidized and decresed its volume, thus will reduce its ability to daminish NOx as well.

The technology has 80 – 90 % (about 90 %) efficiency with relatively low temperature , therefore SCR is the most effective methods to reduce NOx emission.

Due to lower temperature and higher efficiency, the investment and operational cost of the equipmet is high. It is also caused by the wider catalyst volume.

**Capital Cost of SCR<sup>[1]</sup>**

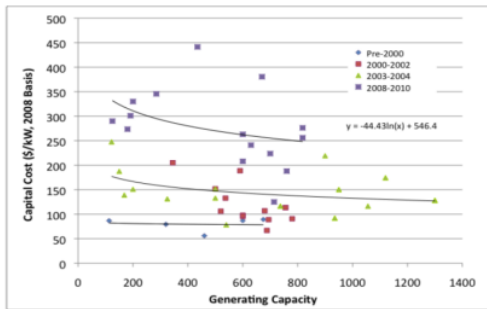


Figure 3 Capital Cost of SCR Process Equipment vs. Generating Capacity

Figure 3 reports cost incurred over four discrete time periods. These include the time periods for the years (a) pre-2000, reflecting the most early projects, (b) 2000-2002, reflecting the initial class of units installed prior to broad SIP-Call compliance, (c) 2003-2004, reflecting units installed during the height of the SIP-Call compliance, and (d) 2008-2010, reflecting units recently installed or presently under construction.

The equation represented the line from the chart is connecting the capital cost as the y axes and the generating capacity as the x axes  
y = -44,43 ln (x) + 546,4 [USD/kW].....(1)

**Operation and Maintenance Cost of SCR<sup>[1]</sup>**

The following figure shows the NOx removal cost based on its capital cost of SCR installation.

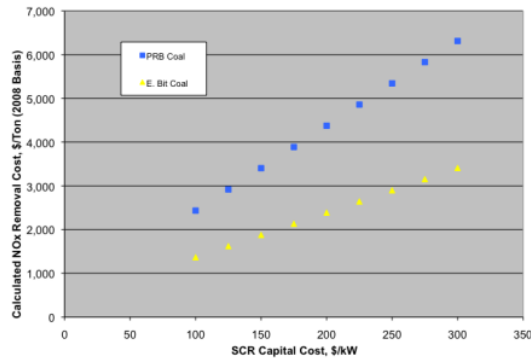


Figure 4. NOx Removal Cost, USD per Ton

**Flue Gas Desulphurization (FGD)**

Flue Gas Desulphurization (FGD), known as Scrubber, is a method to reduce SO2 emission on flue gas from combustion process. Flue Gas Desulphurization is categorized into 2 types, based on the reaction product of sulfurdioxide and reagent, a chemical added. There are Wet Scrubber and Dry Scrubber.

On generation industry, Wet Scrubber is the most common FGD used, because of its higher efficiency and it produces high quality sythesis Gypsum.

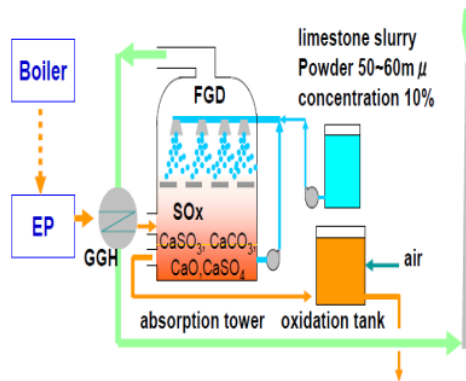


Figure 5. FGD of Wet Lime dan Gypsum Type

Flue gas will enter the absorption tower and will react with lime stone in the tank. The lime stone is injected after being processed from 10% concentration of limestone slurry powder . The chemical reaction process of FGD in the tank is illustrated on the following figure.

**FGD Process Chemical Reaction**

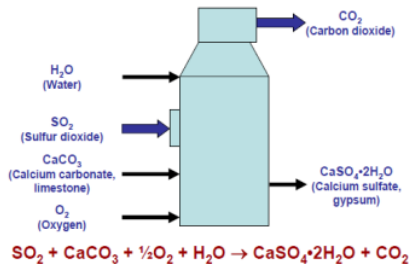


Figure 6. FGD Process Chemical Reaction

Flue gas enters the tank, while O<sub>2</sub> is injected into the tank. SO<sub>2</sub> will be oxidized into SO<sub>3</sub>. The mixed between SO<sub>3</sub> and water will perform Sulfate (H<sub>2</sub>SO<sub>4</sub>) and reacts with Ca(OH)<sub>2</sub>. The reaction of H<sub>2</sub>SO<sub>4</sub> and Ca(OH)<sub>2</sub> produces Gypsum.

The advantages of this type of FGD are the higher efficiency (more than 90 %, or about 97 %) with the higher ability of scrubber absorption and the production of high quality gypsum, which is similar with the natural one.

**Capital Cost of FGD<sup>[1]</sup>**

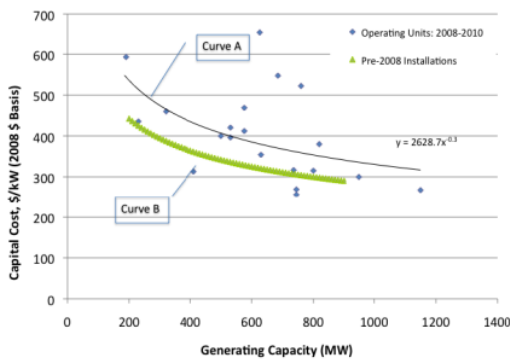


Figure 7. Wet FGD Process Equipment Cost

Figure 7 depicts two curves, based on when the FGD process started commercial service. All costs are reported on a 2008-dollar basis. One curve (Curve A) represents units starting commercial operation after January 2008, and includes several units scheduled for a 2010 startup. This curve, based on 20 data points for the 2008-2010 startup dates, suggests a modest economy of scale with larger generating capacities, enabling lower unit cost. Figure 5-1 also shows a cost curve (Curve B) similarly based on 20 data points (not shown for simplicity) for units that began commercial operation between 2004-2007, relating capital cost and generating capacity.

The equation that represents the line is :  
 $y = 2628,7 x^{-0,3} \dots\dots\dots (2)$

**Operation and Maintenance Cost of FGD<sup>[1]</sup>**

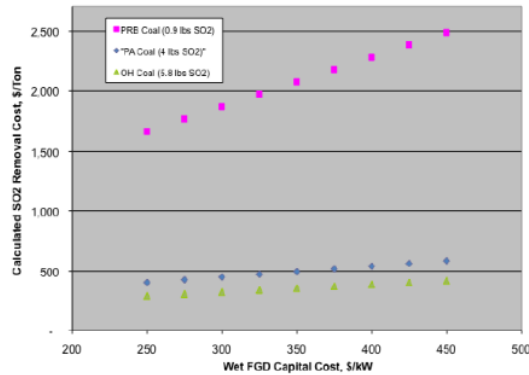


Figure 8. SO<sub>2</sub> Removal Cost per Ton (\$/Ton)

**III. EXTERNAL COST OF PLTU PAITON**

PLTU Paiton is a coal steam generation, located at 142 km Eastern Surabaya and along the North beach of East Java Province, Indonesia. PLTU Paiton has several units, but in this paper, the unit with 400 MW capacity will be analyzed. The annual energy production is 2.754.090 MWh/year and built in the year 2006. The unit is equipped with ElectroStatic Precipitator (ESP) Technology. ESP is a Particulate Matter emission controlled, used to control the emission of particulate pollutant (PM10) or dust.

The external cost assessment of PLTU Paiton is using AIRPACTS Module on SIMPACTS Software. The software is issued by IAEA (International Atomic Energy Agency). The AIRPACTS Modul needs some input parameters, such as source location, stack parameters, statistical or time series meteorological data, receptor data for local (50 km radius) and regional (500 km radius) areas, generation emission data, Exposure Response Function to link the impact and polutan concentration, and particular unit cost.

Table 1  
Emission Rate of PLTU Paiton

Polutant	Emission Coefficient	Emission Rate
	(g/kWh)	(ton/tahun)
PM10	0,67	1.834,22
SO2	4,43	11.952,75
NOx	4,56	12.558,65

**Exposure Response Function**

ERF is used to determine the impact of particular pollutant to human health. Table 2 gives the various ERF on AIRPACTS Module and justified to Indonesian condition. The value of the table is represented sensitivity and various factor at each generation units.

**The Result of Assessment**

Table 2  
Assessment result of PLTU Paiton Externality using AIRPACTS

ERF Function	Local USD <sub>2000</sub> / yr	Regional USD <sub>2000</sub> / yr	Total USD <sub>2000</sub> / yr
<b>Polutan : PM10</b>			
Chronic Mortality, YOLL, entire population	4,81E+06	8,98E+06	1,38E+07
Infant Mortality (YOLL), Infants < 1	4,33E+04	8,08E+04	1,24E+05
Acute Mortality, YOLL, entire populatin	5,20E+04	9,70E+04	1,49E+05
Cardiac Hospital Admission, entire population	2,04E+03	3,80E+03	5,83E+03
Resporatory Hospital Admission, ALL	3,41E+03	6,36E+03	9,77E+03
Chonic Bronchitis, Cases (Adult, 27+)	8,71E+05	1,63E+06	2,50E+06
<b>Polutan : Nitrate</b>			
Chronic Mortality, YOLL, entire population	n/a	2,96E+07	2,96E+07
Infant Mortality (YOLL), Infant < 12 months	n/a	2,66E+05	2,66E+05
Acute Mortality (YOLL), entire population	n/a	3,19E+05	3,19E+05
Cardiac Hospital Admission, entire population	n/a	1,25E+04	1,25E+04
Resporatory Hospital Admission, ALL	n/a	1,26E+05	1,26E+05
Chonic Bronchitis, Cases (Adult, 27+)	n/a	5,35E+06	5,35E+06
<b>Polutan : Sulfate</b>			
Chronic Mortality, YOLL, entire population	n/a	2,35E+07	2,35E+07
Infant Mortality (YOLL), Infant < 12 months	n/a	2,12E+05	2,12E+05
Acute Mortality (YOLL), entire population	n/a	2,54E+05	2,54E+05
Cardiac Hospital Admission, entire population	n/a	9,95E+03	9,95E+03
Resporatory Hospital Admission, ALL	n/a	1,67E+04	1,67E+04
Chonic Bronchitis, Cases (Adult, 27+)	n/a	4,26E+06	4,26E+06
Total	4,0E+06	7,6E+07	8,00E+07
Total USD2008		9,79 E+07	
<b>External Cost</b>	<b>0,0046 USD/kWh</b>		

The total cost is based on European unit year 2000, whereas the external cost has been converted to year 2010 in Indonesia unit. Because the capital cost analysis of abatement technology scenario is using European unit in the 2008 as a based year, therefore, total cost should be converted into particular year.

**IV. ABATEMENT TECHNOLOGY SCENARIOS**

**PLTU Paiton With SCR**

Table 3  
Emission Rate with and without SCR

Polutant	Emission Rate Without SCR (ton/year)	Emission Rate With SCR (ton/year)
PM10	1.834,22	1.834,22
SO2	11.952,75	11.952,75
NOx	12.558,65	1.255,86

Table 4  
Assessment result of PLTU Paiton Externality with SCR

ERF Function	Local USD <sub>2000</sub> / yr	Regional USD <sub>2000</sub> / yr	Total USD <sub>2000</sub> / yr
<b>Polutan : PM10</b>			
Chronic Mortality, YOLL, entire population	4,81E+06	8,98E+06	1,38E+07
Infant Mortality (YOLL), Infants < 1	4,33E+04	8,08E+04	1,24E+05
Acute Mortality, YOLL, entire populatin	5,20E+04	9,70E+04	1,49E+05
Cardiac Hospital Admission, entire population	2,04E+03	3,80E+03	5,83E+03
Resporatory Hospital Admission, ALL	3,41E+03	6,36E+03	9,77E+03
Chonic Bronchitis, Cases (Adult, 27+)	8,71E+05	1,63E+06	2,50E+06
<b>Polutan : Nitrate</b>			
Chronic Mortality, YOLL, entire population	n/a	2,96E+06	2,96E+06
Infant Mortality (YOLL), Infant < 12 months	n/a	2,66E+04	2,66E+04
Acute Mortality (YOLL), entire population	n/a	3,19E+04	3,19E+04
Cardiac Hospital Admission, entire population	n/a	1,25E+03	1,25E+03
Resporatory Hospital Admission, ALL	n/a	1,26E+04	1,26E+04
Chonic Bronchitis, Cases (Adult, 27+)	n/a	5,35E+05	5,35E+05
<b>Polutan : Sulfate</b>			
Chronic Mortality, YOLL, entire population	n/a	2,35E+07	2,35E+07
Infant Mortality (YOLL), Infant < 12 months	n/a	2,12E+05	2,12E+05
Acute Mortality (YOLL), entire population	n/a	2,54E+05	2,54E+05
Cardiac Hospital Admission, entire population	n/a	9,95E+03	9,95E+03
Resporatory Hospital Admission, ALL	n/a	1,67E+04	1,67E+04
Chonic Bronchitis, Cases (Adult, 27+)	n/a	4,26E+06	4,26E+06
Total	4,0E+06	4,4E+07	4,8E+07
<b>External Cost</b>	<b>0,0027 USD/kWh</b>		

**PLTU Paiton with FGD**

Table 5  
Emission Rate with and without FGD

Polutant	Emission Rate Without FGD (ton/year)	Emission Rate With FGD (ton/year)
PM10	1.834,22	1.834,22
SO2	11.952,75	358,58
NOx	12.558,65	12.558,65

Table 6  
Assessment result of PLTU Paiton Externality with FGD

ERF Function	Local USD <sub>2000</sub> / yr	Regional USD <sub>2000</sub> / yr	Total USD <sub>2000</sub> / yr
<b>Polutan : PM10</b>			
Chronic Mortality, YOLL, entire population	4,81E+06	8,98E+06	1,38E+07
Infant Mortality (YOLL), Infants < 1	4,33E+04	8,08E+04	1,24E+05
Acute Mortality, YOLL, entire populatin	5,20E+04	9,70E+04	1,49E+05
Cardiac Hospital Admission, entire population	2,04E+03	3,80E+03	5,83E+03
Resporatory Hospital Admission, ALL	3,41E+03	6,36E+03	9,77E+03
Chonic Bronchitis, Cases (Adult, 27+)	8,71E+05	1,63E+06	2,50E+06
<b>Polutan : Nitrate</b>			
Chronic Mortality, YOLL, entire population	n/a	2,96E+07	2,96E+07
Infant Mortality (YOLL), Infant < 12 months	n/a	2,66E+05	2,66E+05
Acute Mortality (YOLL), entire population	n/a	3,19E+05	3,19E+05
Cardiac Hospital Admission, entire population	n/a	1,25E+04	1,25E+04
Resporatory Hospital Admission, ALL	n/a	1,26E+05	1,26E+05
Chonic Bronchitis, Cases (Adult, 27+)	n/a	5,35E+06	5,35E+06
<b>Polutan : Sulfate</b>			
Chronic Mortality, YOLL, entire population	n/a	705.347	705.347
Infant Mortality (YOLL), Infant < 12 months	n/a	6.348	6.348
Acute Mortality (YOLL), entire population	n/a	7.405	7.405
Cardiac Hospital Admission, entire population	n/a	298	298
Resporatory Hospital Admission, ALL	n/a	499	499
Chonic Bronchitis, Cases (Adult, 27+)	n/a	127.666	127.666
Total	4,0E+06	4,9E+07	5,3E+07
<b>External Cost</b>	<b>0,0030 USD/kWh</b>		

**PLTU Paiton with SCR and FGD**

Table 7  
Emission Rate with and without FGD and SCR

Polutant	Emission Rate Without FGD&SCR (ton/year)	Emission Rate With FGD&SCR (ton/year)
PM10	1.834,22	1.834,22
SO2	11.952,75	358,58
NOx	12.558,65	1.255,86

Table 8  
Assessment result of PLTU Paiton Externality with FGD  
and SCR

ERF Function	Local USD <sub>2000</sub> / yr	Regional USD <sub>2000</sub> / yr	Total USD <sub>2000</sub> / yr
<b>Polutan : PM10</b>			
Chronic Mortality, YOLL, entire population	4,81E+06	8,98E+06	1,38E+07
Infant Mortality (YOLL), Infants < 1	4,33E+04	8,08E+04	1,24E+05
Acute Mortality, YOLL, entire populatin	5,20E+04	9,70E+04	1,49E+05
Cardiac Hospital Admission, entire population	2,04E+03	3,80E+03	5,83E+03
Resporatory Hospital Admission, ALL	3,41E+03	6,36E+03	9,77E+03
Chonic Bronchitis, Cases (Adult, 27+)	8,71E+05	1,63E+06	2,50E+06
<b>Polutan : Nitrate</b>			
Chronic Mortality, YOLL, entire population	n/a	2,96E+06	2,96E+06
Infant Mortality (YOLL), Infant < 12 months	n/a	2,66E+04	2,66E+04
Acute Mortality (YOLL), entire population	n/a	3,19E+04	3,19E+04
Cardiac Hospital Admission, entire population	n/a	1,25E+03	1,25E+03
Resporatory Hospital Admission, ALL	n/a	1,26E+04	1,26E+04
Chonic Bronchitis, Cases (Adult, 27+)	n/a	5,35E+05	5,35E+05
<b>Polutan : Sulfate</b>			
Chronic Mortality, YOLL, entire population	n/a	705.347	705.347
Infant Mortality (YOLL), Infant < 12 months	n/a	6.348	6.348
Acute Mortality (YOLL), entire population	n/a	7.405	7.405
Cardiac Hospital Admission, entire population	n/a	298	298
Resporatory Hospital Admission, ALL	n/a	499	499
Chonic Bronchitis, Cases (Adult, 27+)	n/a	127.666	127.666
Total	4,0E+06	1,6E+07	2,0E+07
<b>External Cost</b>	<b>0,00119 USD/kWh</b>		

Comparing with investment and operation cost of SCR and FGD, it can be achieved from the previous figure of capital and operation cost. Table 10 gives the calculation of capital and operation cost of those scenarios.

Table 9  
Capital and Operation Cost of SCR and FGD for 400 MW Generation Unit

	Capital Cost (USD/15yr)	Operation Cost (USD/yr)	Total Capital - Operation Cost (USD/yr)
SCR	1,12E+08	3,61E+07	4,35E+07
FGD	1,74E+08	2,78E+07	3,34E+07
FGD and SCR	1,86E+08	6,39E+07	7,69E+07

Table 10  
Total Cost of several scenarios of PLTU Paiton

	External Cost (USD/yr)	Total Capital & Operation Cost (USD/yr)	Total Cost (USD/yr)
Without SCR & FGD (Damage Cost)	9,79E+07	0	9,79E+07
With SCR	4,8E+07	4,35E+07	9,15E+07
With FGD	5,3E+07	3,34E+07	8,64E+07
With FGD & SCR	2,0E+07	7,69E+07	9,69E+07

The table indicates that the control cost (using abatement technology) in PLTU Paiton is cost less than the damage cost whatever the scenario chosen. But the most effective scenario is the installation of Flue Gas Sulphurization (FGD). Thus the generation producer could save 11,5 millions USD/yr for the environment-social cost.

## V. CONCLUSION

Externality has two concepts, known as control cost vs damage cost. Control cost is the concept using abatement technology such as SCR and FGD to reduce particular emission.

The assessment using AIRPACTS module has given the external cost of PLTU Paiton is 0.46 cent USD/kWh or 97,7 Million USD/yr. this would be the damage cost of PLTU Paiton.

When using abatement technology, there are several scenarios can be assessed, with SCR, with FGD and with FGD and SCR, the result are 91.5, 86.4 and 96.9 Million USD/yr respectively.

These indicate, for PLTU Paiton, the damage cost is cost more than the control cost and the most effective scenario for abatement technology of PLTU Paiton is the

installation of FGD since it has the lowest total cost and the generation producer could save 11 million USD/yr for environment and social sectors, comparing with damage cost.

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