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Life Cycle Assessment of Producing Electricity in Thailand: A Case Study of Natural Gas Power Plant

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Abstract. Environmental impacts from natural gas power plant in Thailand was investigated in this study. The objective was to identify the hotspot of environmental impact from electricity production and the allocation of emissions from power plant was studied. All stressors to environment were collected for annual natural gas power plant operation. The allocation of environmental load between electricity and steam was done by WRI/WBCSD method. Based on the annual power plant operation, the highest of environmental impact was fuel combustion, followed by natural gas extraction, and chemical reagent. After allocation, the result found that 1 kWh of electricity generated 0.425 kgCO_2eq and 1 ton of steam generated 225 kgCO_2eq. When compared based on 1GJ of energy product, the result showed that the environmental impact of electricity is higher than steam product. To improve the environmental performance, it should be focused on the fuel combustion, for example, increasing the efficiency of gas turbine, and using low sulphur content of natural gas. This result can be used as guideline for stakeholder who engage with the environmental impact from power plant; furthermore, it can be useful for policy maker to understand the allocation method between electricity and steam products.

1 Introduction

Electricity is an important energy which help us to facilitate our daily life. To produce electricity, however, it consisted of various processes and required a fuel source to produce power. At present, the electric power industry can be mainly divided into two main types such as renewable energy power plant (solar, wind, biomass) and fossil fuel power plant

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(natural gas, coal, heavy oil). Main fuel for electricity production in Thailand was natural gas (69.22%), followed by coal (19.10%), hydro (8.65%), renewable energy (2.24%), and others (0.79%) [1]. Natural gas is fuel type that has high efficiency of combustion which can result in reducing environmental burden. Thailand, as one of the countries that has own natural gas resources, therefore selected natural gas as main fuel for country's development. In Thailand, Electricity Generating Authority of Thailand (EGAT) is a main operator in producing, supplying, and distributing electricity to every part of the country. EGAT is presently 43 power plants with capacity of 16,376 MW, which comprised of 3 thermal, 6 combined cycle, 22 hydro, 8 renewable, and 4 diesel power plants [2]. In addition to the electricity that produced by EGAT, EGAT has purchased the electricity from 11 of Independent Power Producers (IPP) with total capacity of 13,166 MW, and from Small Power Producers (SPP) with total capacity of 3,726.6 MW. Furthermore, Thailand also purchased electricity from neighbouring countries (Laos, and Malaysia) with total capacity of 2,404 MW. IPP and SPP are private companies and play an important role for electricity production in Thailand with 32% of total capacity production. Most of IPP and SPP used natural gas as main fuel for producing electricity with strict regulation on emissions to the environment. However, there are no evidence about life cycle inventory from IPP and SPP in Thailand to assess the environmental impact.

Life Cycle Assessment (LCA) can be used as a tool for identifying the environmental impact through cradle-to-grave (i.e. from raw material acquisition through material processing, distribution, use, and disposal). Energy policy makers can use this tool for supporting the decision making in the national level. There are some studies that apply LCA with power plant and compared the environmental impact of electricity production between combined-cycle and thermal technology in Thailand. They suggested that, in addition to natural gas feedstock, the other feedstocks and power production technologies should be further investigated for helping in decision making. Other studies also investigate the environmental impact from power plant but most of them concerns only carbon dioxide [3, 4].

Therefore, the objective of this study was to identify the hotspot of environmental impact from SPP power plants. In addition, this study evaluates the allocation of environmental burden between products from power plant (i.e. electricity and steam), not only carbon dioxide but also in every pollutant that emitted from power plant. The result of this study was expected to be beneficial for power plant in case of supporting data of environmental load in each product.

2 Materials and Methods

In this study, the framework of life cycle assessment was operated according to ISO 14040:2006 standard [5]. The step of normalization and weighting score were not considered in this study. Detail in each step can be described as follows.

2.1 Goal and scope of the study

The objective of this study was to evaluate the environmental impact of SPP power plant producing electricity and steam. The scope of this study was to provide the life cycle inventory of natural gas power plant in both material balances and heat balance to allocate the environmental impact in each of the product **(**electricity and steam**).**

2.1.1 System boundaries

The scope of determining the environmental impact was started from the cradle-to-gate of electricity production. The stage of natural gas production, natural gas transmission, gas separation plant, and power generation at case-study site were included in this study, as shown in Fig. 1. A Combined Heat and Power (CHP) Plant was selected as a case study. In this process, the multiple forms of energy (i.e. electricity and steam) were generated at the same time from the same input energy supply. To produce the electricity, natural gas was combusted in the gas turbine-powered generator. An exhaust gas (as a result of the combustion of natural gas) was sent to Heat Recovery Steam Generator (HRSG) unit to make high-pressure steam and fed to steam turbine to produce electricity. From steam turbine, there are low-pressure steam left over which can feed to an industrial process.

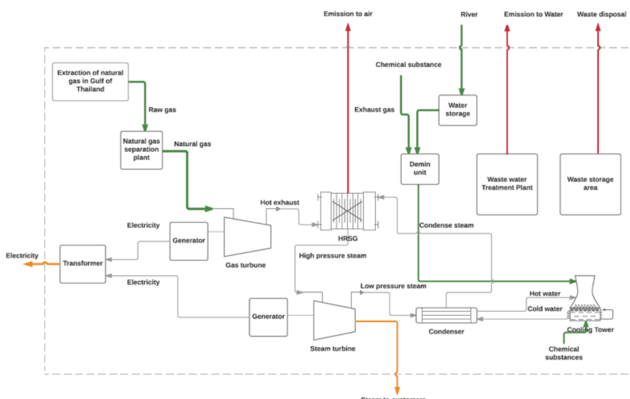


Fig. 1. The boundary system of life cycle assessment for producing electricity and steam production

2.1.2 Functional unit

This study, all energy and material used and environmental impacts were collected in the period of one year operation of natural gas power plant. The environmental impact will be allocated to1 kWh of electricity and 1 ton of steam production.

2.1.3 Allocation method

In this study, the multi-input of material and multi-output of product were determined which was required to allocation. The direct and indirect emissions those generated from raw material acquisition and at natural gas power plant were combined and allocated to the electricity and steam by using the Efficiency method as shown in Equation 1 and 2 [6].

$$E_H = \frac{\frac{H}{e_H}}{\frac{H}{e_H} + \frac{P}{e_P}} x E_T \tag{1}$$

$$E_P = E_T - E_H \tag{2}$$

where E_H is the emission allocated to steam production, H is the steam output (energy), e_H is the assumed efficiency of steam production, P is the delivered electricity generation (energy), e_P is the assumed efficiency of electricity generation, E_T is the total direct emissions of the CHP system, and E_P is the emission allocated to electricity production. With this method, the emissions generated from CHP plant were allocated based on the separate efficiencies of electricity and steam products.

2.2 Life cycle inventory

The data collected in each stage of the cradle-to-gate are as follows ;

(a) Raw material acquisition of natural gas: The data of natural gas extraction, separation, and transmission were based on the work [7].

(b) Direct emission at natural gas power plant : The data were collected from power plant case study. Emission data on SO_2, NO_x, and Particulate Matter (PM) were collected from the CEM database in the period of January 2014 to December 2016. The data from CEM were obtained as on hourly average records. CO_2 from natural gas combustion were calculated based on the composition according to the methodology that suggested by American Petroleum Institute 2009 [8].

Based on the composition of natural gas, CO_2 was estimated by using Equation 3,

$$E_{CO_2} = FC\ x\ \frac{1}{molar\ vol.\ conversion} x MW_{mixture}\ x\ Wt\%C_{mixture}\ x\ \frac{44}{12} \tag{3}$$

where E_{CO2} refers to mass emissions of CO_2, FC is the fuel consumed (scf), molar volume conversion is the conversion from molar volume to mass (379.3 scf/lbmole or 23.685 m^3/kgmole), $MW_{mixture}$ refers to molecular weight of mixture, and 44/12 is the stoichiometric conversion of C to CO_2. All data related with the quantity of raw material, energy, electricity and steam products, waste generation, were collected by using questionnaire form. The result of LCI was shown in Table 1.

Table 1. Overall LCI data collected from power plant case study

Mass/Energy Category	Total input	Unit	Reference
Natural gas	5,615,021	MMBTU	at site
Water	1,098,153	m^3	
Auxiliary process			
Diesel for system backup generator	1,200	liter	
Diesel for fire pump	400	liter	
Diesel for forklift	125	liter	
Chemicals input			
SF_6	1.00E-04	kg	at site
H_2SO_4	240	tons	EIA report (2555)
NaOH	144	tons	
NaOCl	35	tons	
Cooling water corrosion inhibitor	5	tons	
Oxygen scavenger	1.5	tons	
Na_3PO_4	5	tons	
Feed water corrosion inhibitor	1	tons	
Cooling water dispersent	6	tons	
Cooling water biocide	1.5	tons	
Scale inhibitor	1.5	tons	
Sodium bisulfate	6	tons	
Closed cooling water circuit corrosion inhibitor	1	tons	
Output			
Emission into air			
SO_2	21,030	$kgSO_2$	EIA report (2555)
NO_x	15,1361	$kgNO_x$	
CO_2	324,686,938	$kgCO_2$	
Particular Matter	40,460	kgPM	EIA report (2555)
Emission into water			
BOD	6.09	mg/l	at site
COD	52	mg/l	
Suspended solid	25	mg/l	
Dissolved solid	1,646	mg/l	
Waste			
Municipal waste	7,850	kg	at site
Non-hazardous waste	1,650	kg	
Hazardous waste	480	kg	

2.3 Life Cycle Impact Assessment (LCIA)

The environmental impact from life cycle inventory was calculated using The International Reference Life Cycle Data System (ILCD) method. ILCD method supports the analysis of emission into air, water, and soil; in addition, it also determines the impact of natural resources consumed in terms of their effect to different impacts **[9].** This method determines sixteen impacts such as climate change, ozone depletion, human toxicity (non-cancer effects), human toxicity (cancer effects), particulate matter (PM), ionizing radiation (HH), ionizing radiation E (interim), photochemical ozone formation (POF), acidification, terrestrial eutrophication, freshwater ecotoxicity, land use, water resource depletion, and mineral, fossil & resource depletion**.** However, the impacts of land use and water resource depletion were not included in this study.

2.4 Interpretation

The results of impact assessment were interpreted to identify the hotspot of environmental impact from life cycle of electricity production. Measures to reduce environmental impact were suggested and also discussed on the allocation methodology.

3 Result and discussion

3.1 Characterization impacts

Fig. 2 shows the result of 14 impact characterizations for one year of operation of the natural gas power plant. Each impact category was affected by different stages of producing electricity. It can be seen that the emission of exhaust gas was a hotspot of climate change, particular matter, photochemical ozone formation, acidification, terrestrial and marine eutrophication.

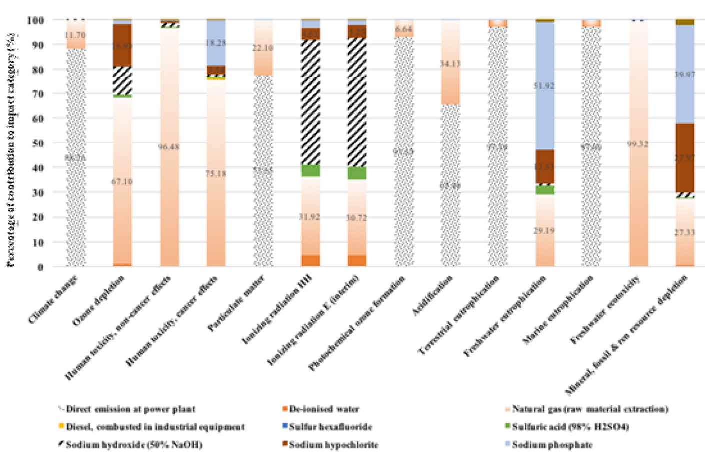


Fig. 2. The characterised result of 14 impacts for annual natural gas power plant

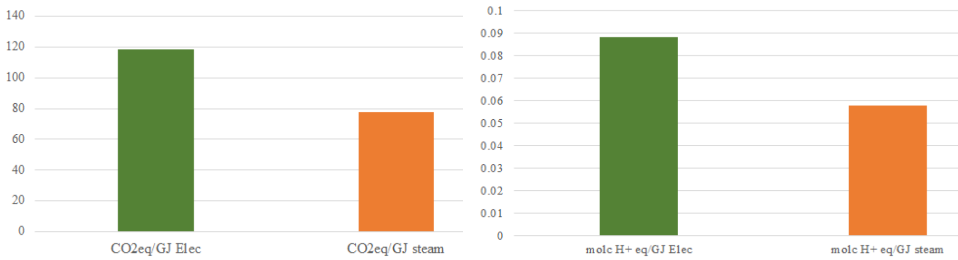
The main air pollutants was generated from natural gas combustion which depended on the composition of natural gas. CO_2 from fuel combustion was the major cause in climate change, while high sulfur content in natural gas will more affect to acidification impact. In case of POF, the major cause was generated from NO_x emission by fuel combustion. Although the power plant installed Dry Low NO_x Combustion Technology, NO_x is still dominant in this impact. The major of ozone depletion effect was generated from the refrigerant used in the natural gas extraction and separation. Also, the heavy metal was largely emitted in this section which was effect to the human toxicity category.

3.2 Allocation of Emissions

Due to the products from power plant consisted of more than one product (i.e. electricity and steam), it is therefore necessary allocating the environmental impact to reflect the environmental burden in each of product. The calculation of emission allocation in each category was done by using equation 1 and 2. The efficiency of electricity generation and steam production were 53% and 80%, respectively. With the total of 727,696 MWh and 259,200 tons-steam, the result of allocation was shown in Table 2. To determine the effect of allocation, this study compares the environmental impact in each product based on 1 GJ of energy product as shown in Fig. 3. After allocation, the environmental impact of electricity will be higher than steam product. This is because the efficiency of producing electricity has lower than steam production; it means that electricity used energy to produce more than steam. In this case study, the efficiency of producing electricity was about 50% which mainly based on the efficiency of turbine. Compared with steam production, the efficiency will be based on the HRSG performance which is normally about 80 - 85% of energy input [10].

Table 2. Allocation of environmental impact from electricity production

Impact category	Unit	Impact/kWh	Impact/ton steam
Climate change	kg CO_2 eq	4.25E-01	2.25E+02
Ozone depletion	kg CFC-11 eq	1.04E-10	5.50E-08
Human toxicity, non-cancer effects	CTUh	5.89E-10	3.11E-07
Human toxicity, cancer effects	CTUh	1.22E-11	6.43E-09
Particulate matter	kg PM2.5 eq	2.23E-05	1.18E-02
Ionizing radiation HH	kBq U235 eq	2.95E-05	1.56E-02
Ionizing radiation E (interim)	CTUe	2.82E-10	1.49E-07
Photochemical ozone formation	kg NMVOC eq	2.45E-04	1.29E-01
Acidification	molc H^+ eq	3.17E-04	1.68E-01
Terrestrial eutrophication	molc N eq	9.88E-04	5.22E-01
Freshwater eutrophication	kg P eq	1.59E-08	8.39E-06
Marine eutrophication	kg N eq	9.03E-05	4.78E-02
Freshwater ecotoxicity	CTUe	1.28E-02	6.76E+00
Mineral, fossil & resource depletion	kg Sb eq	1.10E-08	5.83E-06



(a) Climate change (b) Acidification

Fig. 3. The comparison of allocating climate change (a) and acidification (b) impacts between electricity and steam product from power plant.

4 Conclusion

This study investigated the environmental impact of electricity production from natural gas power plant in Thailand. The boundary of assessment was cradle to gate. From the result, it can be concluded that the hotspot of environmental impact was fuel combustion. To improve the environmental performance, it should be suggested that low sulphur-content of natural gas could be playing an important role for the reduction of environmental impact. After allocated the emissions, the environmental impact of electricity is higher than steam, approximately 50% of every impact. For future investigation, it should be further study about the comparison of the environmental impact between different fuel types of power plant. The results presented in this study is expected to serve as a guideline for stakeholder who engage with the environmental impact from power plant, and for helping policy maker to understand the allocation method between electricity and steam products.

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