ANALYSIS OF ELECTRICITY GENERATION AND CLEAN COAL TECHNOLOGY DEVELOPMENT AS GREENHOUSE GAS CONTROL STRATEGY IN INDONESIA

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ABSTRACT

As Indonesian economic grow, electrical energy demand increased significantly over the last years. It is known that electrical industry is one of the largest sectors who contributed to the global CO_2 emission besides transportation. Highly dependent in coal, fuel oil and diesel are the main causes of this problem. In the 20 years vision of Indonesian government, the country plans to construct coal fired power plant in the near future due to the abundance of coal reserves in the country and increase the share of renewable energy to meet the electricity demand as well as to cut the reliance in fuel oil.

A clear view of 23 years trend of Indonesia's electricity generation from 1987 to 2009 has been reviewed to show a pattern of electricity generation and emission of the country. In addition, Indonesian future power plant composition is investigated to predict fuel consumption and emission production of electricity generation until 2025. The result shows that most of CO_2 emission is coming from steam turbine which uses coal as a fuel. Moreover, by increase the share of renewable energy do not gives any effect in CO_2 emission reduction as the government intended to increase the supply of coal for electricity generation. However, there are some other policies and technology to control the emissions.

In order to answer the energy demand, the government cannot avoid developing new coal-fired power plant to secure energy security of the country in the future. Besides encouraging energy efficiency, the only way to minimize negative impact of coal-fired power plant is by applying clean coal technology. To investigate the impact of clean coal technology on emission reduction, the simple mathematical model was selected as a method. The result showed clean coal technology could reduce CO_2 emission up to 39% compare to conventional coal burning.

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In conclusion, by constructing more coal-fired power plant will give rise to the level of emissions that are dangerous to human health and will not resolve the energy sustainability problems. However, it may be able to sustain the energy security for a little longer until the development of new and renewable energy reach its best potential.

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ABSTRAK

Memandangkan pertumbuhan ekonomi Indonesia, permintaan tenaga elektrik meningkat dengan ketara sejak beberapa tahun lalu. Ia dikenali bahawa industri elektrik adalah salah satu sektor terbesar yang menyumbang kepada pelepasan CO_2 global selain pengangkutan. Sangat bergantung pada arang batu, minyak bahan api dan diesel adalah punca utama masalah ini. Pada tahun-tahun penglihatan 20 daripada kerajaan Indonesia, negara itu merancang untuk membina loji janakuasa arang batu pada masa akan datang kerana banyak rizab arang batu di negara ini dan meningkatkan bahagian tenaga boleh diperbaharui untuk memenuhi permintaan elektrik serta untuk mengurangkan pergantungan pada minyak.

Satu pandangan yang jelas 23 tahun trend penjanaan elektrik Indonesia 1987-2009 telah dikaji semula untuk menunjukkan corak penjanaan elektrik dan pengeluaran negara. Di samping itu, Indonesia elektrik pada masa hadapan komposisi tumbuhan disiasat untuk meramalkan penggunaan bahan api dan pengeluaran pelepasan penjanaan elektrik sehingga 2025. Hasil kajian menunjukkan bahawa kebanyakan pelepasan CO_2 yang datang dari turbin stim yang menggunakan arang batu sebagai bahan api. Selain itu, dengan meningkatkan bahagian tenaga boleh diperbaharui tidak memberikan apa-apa kesan di dalam pengurangan pelepasan CO_2 sebagai kerajaan bertujuan untuk meningkatkan bekalan arang batu untuk penjanaan elektrik. Walau bagaimanapun, terdapat beberapa polisi dan teknologi lain untuk mengawal pelepasan.

Untuk menjawab permintaan tenaga, kerajaan tidak boleh mengelakkan membangunkan loji janakuasa arang batu baru untuk menjamin keselamatan tenaga negara pada masa hadapan. Selain menggalakkan kecekapan tenaga, satu-satunya cara untuk minimalize kesan negatif loji janakuasa arang batu adalah dengan menggunakan teknologi arang batu bersih. Untuk menyiasat kesan teknologi arang batu bersih kepada

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pengurangan pelepasan, model matematik yang mudah telah dipilih sebagai kaedah. Hasilnya menunjukkan teknologi arang batu bersih boleh mengurangkan pelepasan CO_2 sehingga 39% berbanding dengan pembakaran arang batu konvensional.

Kesimpulannya, dengan membina loji kuasa lebih arang batu akan menimbulkan tahap pengeluaran yang berbahaya kepada kesihatan manusia dan tidak akan menyelesaikan masalah kemampanan tenaga. Walau bagaimanapun, ia mungkin dapat mengekalkan keselamatan tenaga untuk lebih lama sehingga pembangunan tenaga baru dan boleh diperbaharui mencapai potensi terbaik.

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University of Malaya

TABLE OF CONTENTS

University of Malaya

University of Malaya

University of Malaya

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

REFERENCES

Appendices A – Related publications

University of Malaya

LIST OF FIGURES

University of Malaya

University of Malaya

LIST OF TABLES

University of Malaya

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NOMENCLATURES

CV	Calorific value (kcal/m^3, kcal/l, kcal/kg)
CF	Power plant capacity factor (%)
EF	Emission factor in power plant (kg/Mm3)
EG	Electricity generation in power plants (GWh)
EM	Power plant emission (ton)
EP	Emission per unit electricity generation (kg/GWh)
FC	Power plant fuel consumption (Mm^3)
FE	Share of fuel consumption (%)
k, C	Constant values
NC	Power plant nominal capacity (%)
NP	Share of nominal capacity (%)
P	Population
PC	Per capita electricity consumption (kWh)
PE	Share of electricity generation (%)
PF	Share of thermal energy (%)
PN	Per capita nominal capacity (W)

Subscripts

f	Fuel type consumed in power plant
i	In the year *i*
j	Range of selected years

Superscripts

n	Power plant type
p	Emission type

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LIST OF APPENDICES

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CHAPTER 1

INTRODUCTION

1.1 Background

The level of energy demand plays a fundamental role in today's society. It is a vital input in supporting the physical and social development of a country, as well as national economic growth. Electricity as one of the most dependable source of energy that drives most of human activity generated from the burning of non-renewable energy which leads to some negative impacts on our environment. Burning more fossil fuel for thermal electricity generation will increase the greenhouse emissions which subsequently cause rapid depletion of non-renewable energy source (Mazandarani, Mahlia, Chong, & Moghavvemi, 2010, 2011).

Based on the long-term energy plans, Indonesia introduced a diversification program called the "Blueprint for National Energy Management 2005-2025" that underlines the utilization of more renewable energy in a more reasonable and sustainable way while increasing public accessibility to electricity and maintaining it at reasonable price rates (Minister of Energy and Mineral Resource, 2006). After Indonesia planned to construct 10,000 MW of Steam Turbine Power Plants (STPPs) in project phase I, the country has announced that 93 more power plants will be built 10,000 MW electricity project phase II by the year 2014 (The Jakarta Post, 2011). Although the project aims to promote the use of clean and renewable energy, the utilization of coal are significantly increased to replace the oil share as much as possible and will contribute up to 33% of the overall expected energy mixed under this scheme in 2025 (Sutrisna & Rahardjo, 2011).

However, the concern about environmental impact causes some difficulties as Indonesia committee to reduce CO_2 emission in Kyoto Protocol. In this respect, the

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country should develop clean coal technology to minimalize negative impact of coal-fired power plant.

1.2 Objective of the study

- To study the pattern of electricity generation and emission in Indonesian power generation sector in the past decades.
- To predict the future fossil fuel consumption and emission in power sector.
- To predict CO_2 reduction using clean coal technology in Indonesian coal-fired power plant.

1.3 Contribution of the study

There is a necessity to predict the electricity supply and demand for the future in order for making a scenario and prevent electricity crisis. This study will help the government to conserve the limited non-renewable energy sources and control the emission of electricity generation. In addition, by understanding this study, the government can make a right decision and optimize the related policies to sustain energy supply of the country in the future. The result also can be used for the country to consider the implementation of clean coal technology including the impact in environmental aspect.

1.4 Related publications

While conducting the research, a number of papers have been published in the international journals. The list of published papers is presented in below.

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- M.H. Hasan, T.M.I. Mahlia, Hadi Nur. A review on energy scenario and sustainable energy in Indonesia. Renewable and Sustainable Energy Reviews, Volume 16, Issue 4, May 2012, Pages 2316-2328. (ISI/Scopus cited publication)

- M.H. Hasan, W.K. Muzammil, T.M.I. Mahlia, A. Jannifar, I. Hasanuddin. A review on the pattern of electricity generation and emission in Indonesia from 1987 to 2009. Renewable and Sustainable Energy Reviews, Volume 16, Issue 5, June 2012, Pages 3206-3219. (ISI/Scopus cited publication)

1.5 Limitation of the study

The increasing in electricity demand are depends on several aspect such as population and economic growth, political condition, technology development, and life style of the country. In this study it has been assumed the electricity demand of the country in the future generated by mathematical model and not considered the other aspects.

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CHAPTER 2

LITERATURE REVIEW

2.1 Energy in Indonesia

Indonesia is an ASEAN country stretches from 6°08' N latitude to 11°15' S latitude, and from 94°45' E to 141°05' E longitude (Geography of Indonesia, 2011). Indonesia is the fourth most populous nation with 230 million people and rank 13th in the primary energy use which is about 893 Mboe. The country is an archipelago nation consisting of more than 17,000 islands covered area about 9,822,570 km^2. The GDP grew at an average economic rate of 6.1% per year from 1971 to 2008 with GDP per capita about of US$ 2,850 in 2010 (Ibrahim & Wahid, 2010). Like many developing countries, development and economic growth continue to effect the growing of energy consumption demand. Total primary energy supply had increased steadily over the past 19 years. It is estimated to reach about 1,270.9 Mboe in 2009 which is more than 200% increase from 1990 as shown in Figure 2.1 and it is considered high among developing countries (Ministry of energy and mineral resources, 2010a).

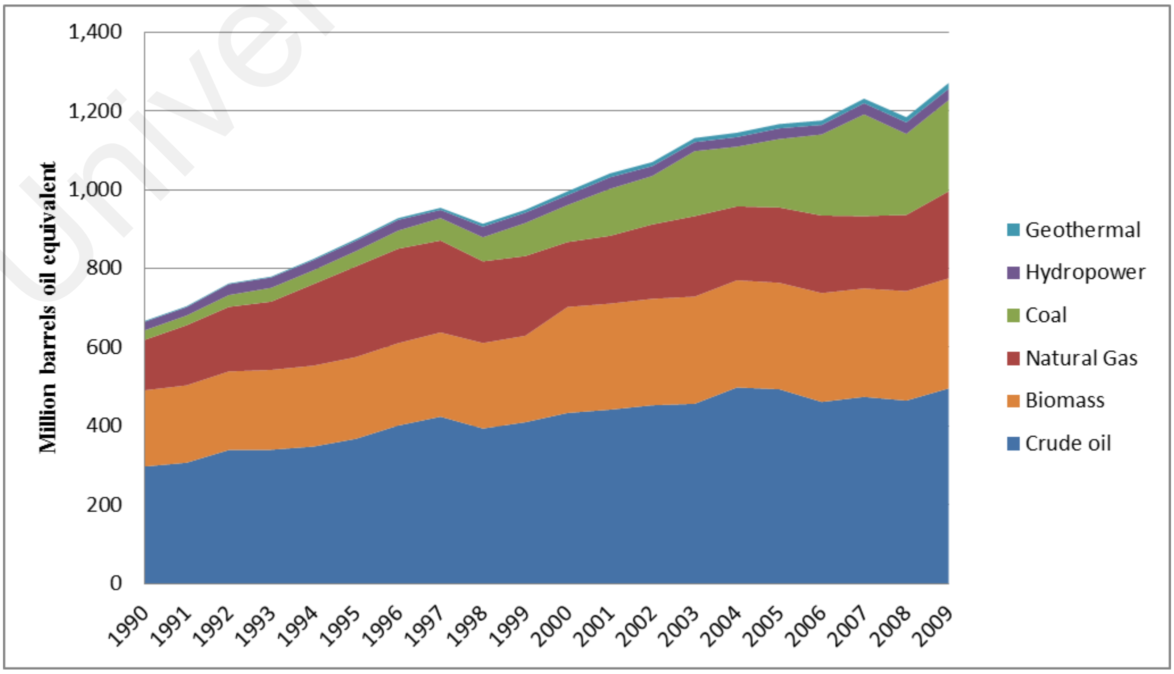

Figure 2.1: Primary energy supply by fuel type in Indonesia

Industrial sectors dominate energy consumption in Indonesia with its consumption is about 296 Mboe (41%) from total consumption of national energy in 2009 and followed closely by transportation sector which consume 226.6 Mboe (37%). Residential and commercial sector also increased steadily. The final energy consumption by sector in Indonesia is shown in Figure 2.2 (Ministry of energy and mineral resources, 2010a).

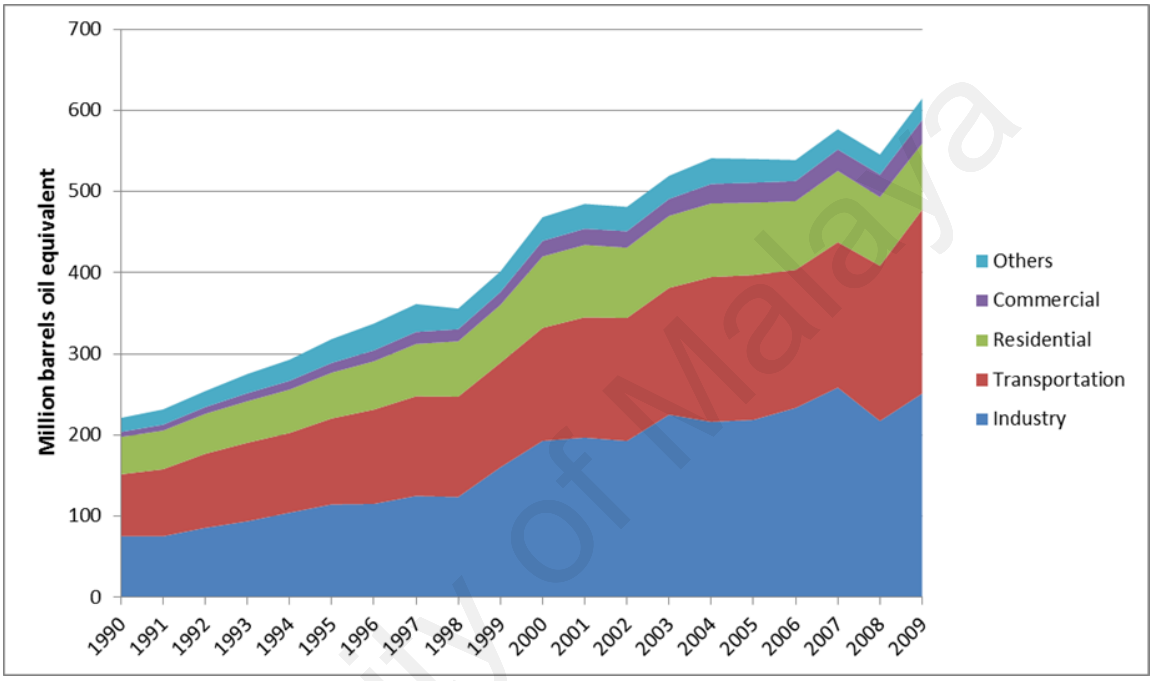

Figure 2.2: Final energy consumption by sector in Indonesia

Indonesia has an abundance of natural resources suitable for electricity generation including coal, natural gas, oil, geothermal and hydropower. Currently the final energy supply is dominated by non-renewable energy resources such as oil, gas and coal which contributed for 75% of the final energy consumption. This situation worrying the government and the energy society as the fossil energy resources and supply will be diminished in the near future. On the other hand, the utilization of new and renewable energy resources has not been optimized due to its high production cost and worsens by the subsidy policy on fossil energy where LPG is used cooking and fuel oil for the transportation sector. The contribution of crude oil in energy supply in Indonesia has decreased from 45% in 1990 to 39% in 2009. On the other hand, the contribution of coal in energy supply has accelerating from 4% in 1990 to 18% in 2009 which is mainly used in power generation and the cement industry. The primary energy supply share in Indonesia is presented in Table 2.1 (Ministry of energy and mineral resources, 2010a).

Table 2.1: Primary energy supply share in Indonesia

Primary energy supply	Amount (kboe)		Share (%)	
	1990	2009	1990	2009
Crude oil	297,435	495,710	45	39
Biomass	193,191	279,251	29	22
Natural gas	127,604	220,930	29	18
Coal	24,390	231,351	4	18
Hydropower	21,678	28,688	3	2
Geothermal	2,185	14,973	0	1

With increasing environmental issues, the use of natural gas also expected to grow at a steadily increasing pace. The contribution of the other energy resource such as hydropower, geothermal, wind, and solar is only 3% in 2009, which is very low in comparison to other countries.

2.2 Electricity generation sector in Indonesia

The electricity demand in Indonesia has increased tremendously in 23 years of time (1987 to 2009). In 2009, Indonesia's electricity production reached 155,334GWh, which is 620% more than the production of electricity in 1987 (21,559.29 GWh) (Ministry of energy and mineral resources, 2006, 2010a; PT. PLN, 2010). Nominal capacity of Indonesian power plants is 31,375.04MW, in which 83% of the total nominal capacity or 26,041.28 MW was contributed by the National Electricity Company (PLN). The rest of the energy supplied was contributed by Independent Power Plant (IPP) that reaches up to 4,392.50 MW of energy or 14%, and finally 920 MW (or 3%) of energy was contributed by PPU (Private Power Utility). Currently, the national electrification ratio is 66% (Ministry of Energy and Mineral Resources, 2010b). This is due to electricity demand growth that are not able being pursued by the growth of power supply.

2.2.1 Fossil fuel based power plants

At present, most of Indonesian power plants are using non-renewable sources such as natural gas, fuel oil, coal and diesel to generate electricity. These power plants operate using steam turbine, combined cycle, gas turbine and diesel engine. Recently, the development of power plants in Indonesia has been focused on improving the national power supply to its islands around the archipelago. Some types of power generation in Indonesia are discussed below:

Steam turbine power plants

Steam power plants rely on high pressure steam to generate electrical energy. Steam power plant uses a variety of fuels, especially coal while fuel oil used for startup. Currently steam power plant in the country has 39.23% of total nominal capacities and produce 48.19% of the total electricity generation of the country in 2009 (Ministry of energy and mineral resources, 2010a). Due to the abundance of coal and its cheap price, Indonesian government planning to construct more steam turbine power plant (STTP) in the future to meet the electricity demand (Minister of Energy and Mineral Resource, 2006). The capacity of STPPs increases from 2,816.95 MW in 1987 to 12,309.00 MW

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in 2009 with an increase rate of 6.9% annually (Ministry of energy and mineral resources, 2006, 2010a; PT. PLN, 2010). It is expected this trend will continue to rise in the coming years and will be reaching 35,798.60 MW by the year 2025. The conventional steam power plants in Indonesia have thermal efficiency which varies from 30% to 35% (Rosyid et al., 2010).

Combined cycle power plants

Combined cycle power plant is a type of power plant that uses a combination between the Brayton cycles of gas turbine with Rankine cycle of HRSG (Heat Recovery Steam Generator) which is channeled directly into the steam turbine, where the exhaust gas from gas turbine is used as working fluid to produce steam in HRSG (Akram, Hidayat, & Salam, 2011). The nominal capacity of the power plant increases to 8,076.97 MW with an annual increase rate of 8.6% from 1987 to 2009 (Ministry of energy and mineral resources, 2010a). The trend is expected to rise continuously and reaches a nominal capacity of 30,236.09 MW by the year 2025. Commonly, commercial combine cycle power plants available in the market have thermal efficiency in range 50-55% depend on lower heating value (Chase, 2000).

Gas turbine power plants

Gas turbine power plants are sometimes used as emergency power generator or in situations where there is an extra demand for energy that primary power plants may not be able to cope at peak hours. The current capacity of this type of power plant is 3,365.59 MW with an increase rate of 5.1% annually from 1987 to 2009 (Ministry of energy and mineral resources, 2010a). It is expected that this rising trend will continue in the coming years and reaches 7,459.41 MW in 2025. Gas turbine power plants in Indonesia have thermal efficiency between 25% and 30% (Almanda, 1999).

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Diesel power plants

Three decades ago, power generation using reciprocating engines was very common, unlike today. Currently, power production utilizing engines only represent 10-15% of the total installed capacity across the world (Kanogˇlu, Işık, & Abuşogˇlu, 2005). The current installed capacity of this type of power plant in Indonesian power distribution network is 2,980.63 MW in 2009 (Ministry of energy and mineral resources, 2010a). Due to fuel prices and environmental issues, Diesel engines are only used for specific tasks such as to provide electricity in rural areas and backup generators for industry, hospital, airports and hotels that require a constant, uninterrupted power supply. In this study, the capacity of diesel engine in 2025 is considered to remain at 2,980.63 MW, which is the same in the year 2009. This type of power plant in Indonesia has thermal efficiency around 30% (Almanda, 1999).

Power plant fuel consumption

Economic, political and technical parameters influence the type of fuel selected for power plants in a country. Technical parameters that needed to be considered as a main reason for the development of a power plant include the type of fuel available, cost of fuels, geographical location of the power plant, environmental concerns and medium to long term policies of the energy sector of the country. Most of Indonesian power generation comes from thermal power plants that consume fossil fuels such as coal, natural gas, diesel and petroleum fuel. Coal, natural gas and fuel oil are widely used for steam turbines; whereas gas turbine and combined cycles power plants utilize natural gas and diesel as fuels. Diesel engine utilize diesel as a fuel without any additional fuel. The types of fuel consumed in Indonesian power plants are summarized and presented in Table 2.2.

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Table 2.2: Fuel types consumption in all of Indonesian thermal power plants

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Coal	x	-	-	-
Natural gas	x	x	x	-
Fuel oil	x	-	-	-
Diesel	-	x	x	x

(x), fuel is consumed in power plant and (-), fuel is not consumed in power plant.

2.2.2 Renewable energy power plants

Renewable energy is the energy derived from natural processes that do not involve exhaustible resources such as fossil fuels and uranium. Indonesia has an abundance of potential renewable energy resources such as hydro-power, geothermal, wind energy, solar energy and biomass. Today's global trend of renewable energy sources represents only a small fraction of the total energy generated. Despite the high growth rates, renewable energy is still not fully utilized yet. This is due to expensive technologies, high investment costs and low awareness that generally plague most of the developing countries around the world today. Indonesia is currently using renewable energy sources such as hydro and geothermal for electricity generation. Biomass sector particularly for electricity generation has also been recently exploited due to the abundance of oil palm trees in the country.

Hydro-power plants

Hydro-power is a type of renewable energy technology that is commercially viable on large scale in Indonesia. It is not only producing zero emissions, but also produce large amount of sustainable electricity, although the startup cost is expensive. The country has a huge amount of hydropower resources. The potential hydropower

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energy is estimated to be about 75,000 MW, however, only 3,500 MW out of 75,000 MW is exploitable, which only produces approximately 11.22% of nominal capacity and 7.33% of electricity generation in 2009 (Ministry of energy and mineral resources, 2010a). Based on the country's 20 years vision plan (2006-2025), hydropower plants with capacity up to 2,846 MW will be built by investing USD 2,678 million and expected to reach 6,366.35 MW of electrical power by 2025 (Minister of Energy and Mineral Resource, 2006).

Wind turbines

Wind energy can be converted into useful energy such as electricity. Utilization of wind power as an energy source in the country is being seen as good potentials for electricity production, especially in coastal areas where wind is abundant. With the wind speeds between 2 to 6 ms^{-1}, the suitable wind power generators to develop in Indonesia are small (10 kW) to medium scale power generations (10 kW to 100 kW) (University of Indonesia, 2001). The nominal capacity of this type of power plant is 1.06 MW of total electricity generation in 2009 (Ministry of energy and mineral resources, 2010a). The country is planning to construct wind generators to generate 200 MW electrical powers by investing about USD 824 million by 2025 (Minister of Energy and Mineral Resource, 2006).

Solar energy

Being located in the equator line, the potential of solar energy in Indonesia is relatively good with the daily average radiation approximated between 4.0-5.1 kWh/m^2. Due to its potential, PLN is planning to construct 870 MW of solar power plants by investing USD 2,795 million to provide electricity specifically in rural areas (Minister of Energy and Mineral Resource, 2006).

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Geothermal energy

Indonesia is estimated to have about 40% of the world's geothermal reserves which is equivalent to a total of 27,140 MW of power due to its location in the "Ring of Fire" volcano belt (Aurora, 2005). Geothermal power plants have already been running in the country with nominal capacity of about 1,122.50 MW (Ministry of energy and mineral resources, 2010a). The country is planning to expand the capacity of geothermal power plants up to 16,170 MW by 2025 with investment amounting to USD 17.97 million (Minister of Energy and Mineral Resource, 2006).

Biomass energy

Indonesia's large agricultural sector has the potential to be used in biomass energy sector as a source of energy for power plants. Furthermore, oil palm empty fruit bunches; rice husks, bagasse, and wood pieces are very abundant but often regarded as waste. Traditionally, biomass is often utilized through direct burning. New technology and technique can be used to convert the energy contained in biomass waste through pyrolysis or gasification. The country is currently planning to construct 180 MW of biomass power plant in their 20 year vision by investing USD 300 million (Minister of Energy and Mineral Resource, 2006).

2.3 Clean Coal technology

Being the cheapest and most abundant available fossil fuel, coal will always have a role in energy mix in Indonesia. The estimated of coal reserve in this country is about 21.13 billion short tons (approximately 85% consist of lignite and sub-bituminous), of which most of the reserves are located in Sumatra and Kalimantan, with

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the balance in West Java, and Sulawesi as presented in Figure 2.3 (EIA, 2007; Ministry of energy and mineral resources, 2010a; Mulyono, 2009).

In 2009, Indonesia produced 256 million short tons (MMst) of coal, up about 232% more than in 2000 and 95% of the coal produced from surface mining operation. This is because of largely amount of Indonesian coal are close to surface (University of Indonesia, 2001).

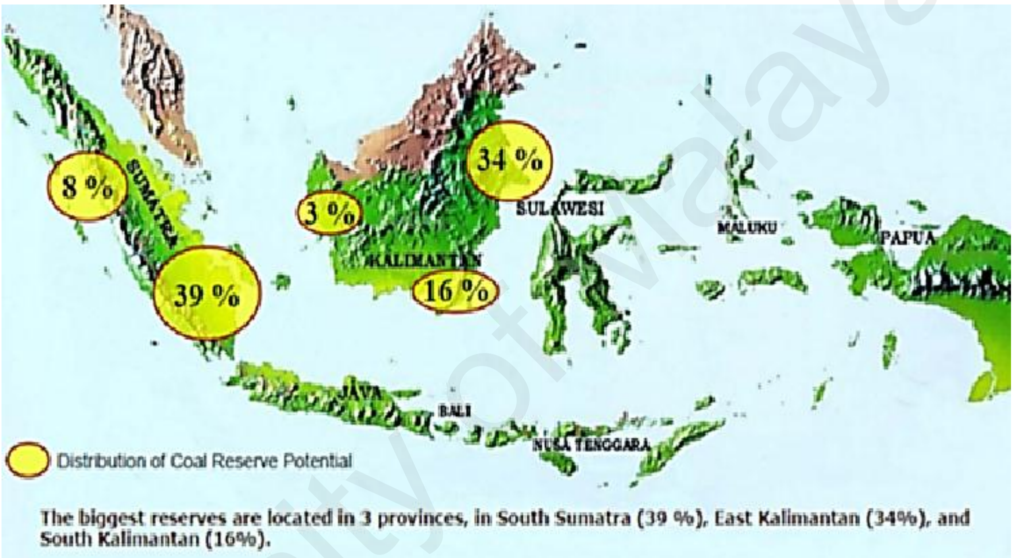

Figure 2.3: Indonesia’s distribution coal reserve potential

The country export 198 million tons which represented 77% of total coal production to Japan, Taiwan, China, India, South Korea, Hong Kong, Malaysia, Thailand, and Filipina. The remaining 58 MMst of coal which is relatively small compared to its production, mainly used for power generation and industrial sector like cement production, iron and steel plants as presented in Figure 2.4 (Ministry of energy and mineral resources, 2010a).

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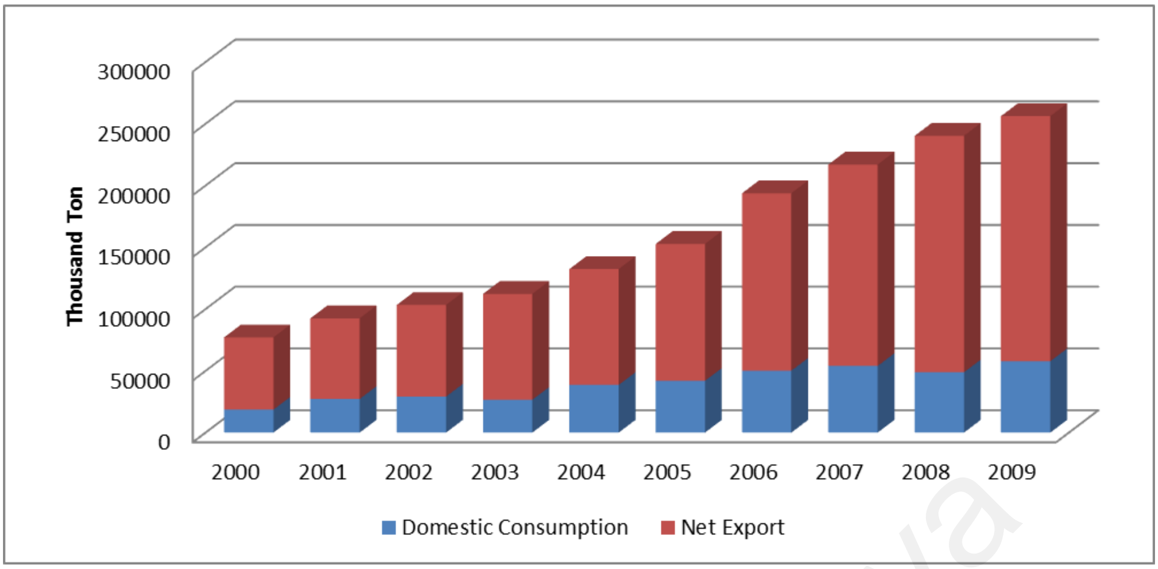

Figure 2.4: Indonesia's production, domestic consumption and net exporter

Considered as replacement fossil fuel for fuel oil and diesel in power generation sector, domestic coal consumption is predicted to increase tremendously in near future. High CO_2 emission is the main problems to utilize coal as main fuel for power generation. According to Haug, there are three potential ways to reduce CO_2 emission without hampering economic growth namely by using energy more efficiently, by changing the source into renewable energy and final option is by burning fossil fuels and capture the CO_2 instead releasing it into environment (Haug, 2004). Clean coal technology is one of the choices to utilize fossil fuel to support economic growth as well as to counter the negative impact of coal for power generation. Several technologies that represent clean coal technology are Supercritical (SC), Ultra-super critical (USC), Integrated gasification combined cycle (IGCC) and Pressured fluidized bed combustion (PFBC).

Supercritical (SC) and Ultra-Super Critical (USC) Coal Fired Power Plant

The super (ultra-super) critical power plants which technically mature will be the preferred choice clean coal technology to control coal fire power plant pollution. The efficiency of supercritical and ultra-supercritical is approximately 44% and 40%, respectively. Compared to other CCT technology, super (ultra-super) critical power plant can be more easily commercialized as it is already exist around the world. This technology also provides quite low risk for investors and producers (Wang & Nakata, 2009).

Integrated Gasification Combined Cycle (IGCC) Coal Fired Power Plant

IGCC coal gasification technology is considered one of the best clean coal technologies which high efficiency, lower emissions, well adoption to all types of coal as well as more easily to couple with carbon capture systems and water demand is lower. In addition, IGCC can work together in the production of other commercial products through the coal–gas process along with the production of electricity. Due to the reality most of the Indonesian high quality coal is being exported, low quality coal is used as fuel for coal fired power generation in the country. In the condition of low quality coal as a fuel and limited water source, IGCC is the right choice. IGCC barriers are the high capital costs and its low reliability. According to China's State Development Planning Commission (SDPC), at least 20% of capital cost need to be reduces for IGCC to be competitive (Wang & Nakata, 2009).

Pressured Fluidized Bed Combustion (PFBC) Coal Fired Power Plant

Potential PFBC plant efficiency can reach as high as 45% through the use of fluidized bed combustion technology. Furthermore, PFBC capable to burn low-quality fuels and the cost of capital are lower than the IGCC. However, due to limitations of boiler material, it is difficult to improve the efficiency of the power plant. In addition, the process requires a large of energy to increase the pressure (Wang & Nakata, 2009).

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2.4. Greenhouse gases emission

It has been recognized in 1827 by Jean-Baptiste Fourier that gases in the environment trapping heat inside the earth's atmosphere. This phenomenon was observed for the first time, and using quantitative spectral prove John Tyndall. In 1896, the idea put forward by the Swedish chemist, carbon dioxide emissions from the burning of coal can increase the disastrous consequences of the greenhouse effect that causes global warming caused by adverse (McGinness, 2001; Othman, Zakaria, & Fernando, 2009; Yantovski, Gorski, Smyth, & ten Elshof, 2004).

In 1997, 158 countries reached a landmark agreement to limit greenhouse gas emissions to face of global climate change (Othman, et al., 2009). As reported, the global GHGs emissions in 2008 composed of 85%, 7%, 6% and 2% of CO_2, CH_4, N_2O, and F-gas, respectively (UNFCCC, 2008b). Indonesia officially participated in worldwide emission reduction on December 3rd 2004 (Othman, et al., 2009). Although Indonesia is not subjected to a commitment to reduce greenhouse gas emissions, Indonesia still show the responsibility to reduce GHGs and demonstrate its commitment to the environment, especially since Indonesia include in 20 highest carbon emitter in the world. (Bournay, 2008).

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CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the outline of the methodology in the study is presented. The mathematical model to analyze the power sector composition statistics are presented including power plant capacity, generation, fuel consumption and emission in the last 23 years. Furthermore, the mathematical model to predict the future power plant composition using different scenario and the effect of clean coal technology in order to reduce power plant emission especially from coal based power plant is also given. The entire mathematical model used in this study is adopted from Refs (Mazandarani, et al., 2010, 2011; Shekarchian, Moghavvemi, Mahlia, & Mazandarani, 2011).

3.2 Electricity generation statistics

3.2.1 Method of data estimation

There are several methods for estimating data; the one that widely used is polynomial curve fitting. This method tries to describe the relationship between a variable X as the function of available data and a response Y that seeks to find a smooth curve for the best fit of the data. Mathematically, a polynomial of order k in X can be expressed in the following equation form (Klienbaum, 1998):

$$Y = C_0 + C_1X + C_2X^2 + \cdots + C_kX^k \tag{3.1}$$

Another method used to estimate the predicted data is the single compound amount. This method may be used to determine the single future amount of a single

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present amount for an interest rate d for n period. Mathematically this equation can be expressed in the following form:

$$F = P \times (1 + d)^n \tag{3.2}$$

3.2.2 Per capita nominal capacity

The per capita nominal capacity for each year is the total nominal capacities divided by the population in that particular year. The per capita nominal capacity in the year i can be calculated by the following equation:

$$PN_i = \frac{NC_i}{P_i} \tag{3.3}$$

3.2.3 Per capita electricity consumption

The per capita electricity consumption in the year i is electricity production divided by population in particular year, which can be calculated by the following equation:

$$PC_i = \frac{EG_i}{P_i} \tag{3.4}$$

3.2.4 Percentage of electricity generation and nominal capacity

To understand the changes in pattern of electricity generation and nominal capacity, the share of each type of power plants should be identified. Share of electricity generation and share of nominal capacity can be calculated by the following equations:

$$PE_i^n = \frac{EG_i^n}{EG_i} \times 100 \tag{3.5}$$

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$$\mathrm{NP}_i^n = \frac{\mathrm{NC}_i^n}{\mathrm{NC}_i} \times 100 \qquad (3.6)$$

3.2.5 Capacity Factor

The capacity factor of a power plant can be taken as the ratio of generated electricity of a power plant and its nominal capacity over a period of time. The ratio for each year is calculated by taking a timeframe of 1 year which is equivalent to 8,766 hrs. This equation is essential in order to estimate the potential electrical power generation of the thermal power plants. The capacity factor of a power plant is thus calculated by the following equation:

$$\mathrm{CF}_i^n = \frac{\mathrm{EG}_i^n}{\mathrm{NC}_i^n \times 8.766} \times 100 \qquad (3.7)$$

3.2.6 Potential fuel consumption per unit electricity generation

The potential fuel, f consumption per unit electricity generation in thermal power plant type, n in the year i can be calculated by the following equation:

$$\mathrm{FE}_{if}^n = \frac{\mathrm{FC}_{if}^n}{\mathrm{EG}_i^n} \qquad (3.8)$$

3.2.7 Emission

Due to the lack of any time series emissions measurements or frequent stack measurements, emission factors have been used to calculate an emission. The data of CO_2, SO_2, NO_X and CO emissions from fossil fuel for a unit of electricity generation are determined. The emission data are based on emission factors for each fuel type and the types of power plants.

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As mentioned early, all power plants (except diesel engines) use more than one type of fossil fuel. This means that emission factor of a fuel will be different based on the power plant type.

3.2.8 Emission production

Emission production is equal to emission factor multiplied by the amount of fuel consumed. Therefore, the emission p due to use fuel f in power plant type n in year i, can be calculated by the following equation:

$$\mathrm{EM}_{\mathrm{if}}^{\mathrm{np}} = \mathrm{EF}_{\mathrm{f}}^{\mathrm{pn}} \times \mathrm{FC}_{\mathrm{if}}^{\mathrm{n}} \tag{3.9}$$

To assess the impact of each type of fuel in total emission of each power plant, contribution of each fuel in total emission should be calculated by the following equation:

$$\mathrm{FE}_{\mathrm{if}}^{\mathrm{np}} = \frac{\mathrm{EM}_{\mathrm{if}}^{\mathrm{np}}}{\sum_{\mathrm{f}} \mathrm{EM}_{\mathrm{if}}^{\mathrm{np}}} \times 100 \tag{3.10}$$

The annual emission is the summation of emission for all types of power plants by all types of fuel used. This can be calculated by the following equation:

$$\mathrm{EM}_{\mathrm{i}}^{\mathrm{p}} = \sum\nolimits_{\mathrm{n}} \sum\nolimits_{\mathrm{f}} \mathrm{EM}_{\mathrm{if}}^{\mathrm{np}} \tag{3.11}$$

Thermal energy released due to combustion of each type of fuel depends on fuel's calorific values. The share of each type of fuel in total thermal energy consumed in power plants can be calculated by the following equation:

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$$PF_{if}^{n} = \frac{CV_f \times FC_{if}^{n}}{\sum_f CV_f \times FC_{if}^{n}} \times 100 \qquad (3.12)$$

3.2.9 Emission per unit electricity generation

The emission per unit electricity generation for each year is a function of annual emission divided by total electricity generated by power plants. This can be calculated by the following equation:

$$EP_{i}^{p} = \frac{EM_{i}^{p}}{EG_{i}^{t}} \qquad (3.13)$$

3.2.10 Emission per unit electricity generation for each type of power plant

The emission per unit electricity generation for each type of power plant is a function of emission factor, fuel consumption in each type of power plant and electricity generation from that particular power plant. The emission p per unit electricity generation in a power plant type n in the year i, can be calculated by the following equation:

$$EP_{i}^{np} = \frac{\sum_f EF_{f}^{np} \times FC_{if}^{n}}{EG_{i}^{n}} \qquad (3.14)$$

To estimate each type of emission for a unit electricity production in each type of power plants used, only the values related to certain years are applied. The average emission for certain years considered as a selected value, calculated by the following equation:

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$$EP^{np} = \frac{EP_i^n + EP_{i+1}^n + \cdots + EP_{i+j-1}^n}{j} \quad (3.15)$$

3.3 Power plant composition prediction

3.3.1 Indonesia power generation scenarios

In order to estimate the production of emissions in the future, a pattern on the development of power plants need to be identified. Focus of this study touches on the composition of new power plants that are announced by the government. Furthermore, other alternatives will be described and discussed to draw a better understanding and prediction on the utilization of fuel and its emissions in the upcoming years. These scenarios are means to sort out other alternative insights into the future that may or may not be an accurate prediction of tomorrow's world. Furthermore, these scenarios may be used as instruments for analysts, policy makers or researchers to evaluate possibilities and consequences of the decisions made in regards to the choice of fuels and investments on the type of power plants.

Consequently, this study focuses on two different scenarios that will be analyzed and discussed in the following sections.

Scenario 1: New composition

In this scenario, it assumed that the type of power plant with the plan that has been presented in Section 2. It is consist of 35,798.60 MW of steam turbine, 2,980.63 MW of diesel engine, 7,459.41 MW of gas turbine, 30,236.09 MW of combined cycle, 6,366 MW of hydropower, 200 MW of wind energy, 870 MW of solar energy and 16,170 MW of geothermal energy by 2025.

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Scenario 2: Business as usual

It is assumed that the fuel types and number (percentage) of power plants in 2025 is similar to year 2009. Additionally, there are no technological advancements implemented, no changes in the composition of the power plants, fuel consumptions are unchanged; in short the data are constant throughout the years. This scenario is applied due to its simplicity and also used as a benchmark to the other scenario.

3.3.2 Nominal capacity prediction

Throughout the study, mathematical models are used to calculate statistical input data that are presented in Tables 3.1. Estimation of fuel consumption and emission from power plants can be generated by this method. There are a few types of mathematical calculations that can be employed to generate the needed data. For this particular study, single amount compound that are presented in Eq. (3.2) is used as a method to calculate the projected data.

3.3.3 Power plants nominal capacities

For the case in the second scenario, nominal capacity of each type of power plants can be determined by means of multiplying its contribution with the total nominal capacity of the country in the same year.

3.3.4 Potential electricity generation

The potential electricity generation by thermal power plants according to types, n and in the year i can be calculated by using the following equation:

$$EG_i^n = \frac{CF^n \times NC_i^n \times 8.766}{100} \quad (3.16)$$

3.3.5 Potential fuel consumption

The total of potential fuel consumption in power plants can be predicted by multiplying the potential fuel consumption per unit electricity of a power plant type, n with the potential electricity generated of a given year, i.

$$\mathrm{FC}_{\mathrm{if}}^{\mathrm{n}} = \mathrm{FE}_{\mathrm{f}}^{\mathrm{n}} \times \mathrm{EG}_{\mathrm{i}}^{\mathrm{n}} \qquad (3.17)$$

3.3.6 Potential emissions

The total annual emission is calculated by multiplying the summation of emission per unit electricity generation with the total electricity generated by the power plant in year i.

$$\mathrm{EM}_{\mathrm{i}}^{\mathrm{p}} = \sum_{\mathrm{n}} \mathrm{EP}^{\mathrm{np}} \times \mathrm{EG}_{\mathrm{i}}^{\mathrm{n}} \qquad (3.18)$$

3.4 Clean coal technology application

To date, coal has been used in plenty to generate electricity from steam turbines due to its abundance and availability. However, this type of solid fuel produces very high carbon emissions when it is burned to generate steam in power plants. For any power plants, the selection of fuel types have been very critical on the pricing of fuel and its availability, site of the plant, environmental issues and policies of a country. Due to recent environmental apprehension and the worrying impact of high carbon footprint, applying clean coal technology can help to reduce the emission of greenhouse gases. Hence, this scenario is used to predict the outcome of using different clean coal technology to the fullest by eliminating the conventional coal fired steam turbine.

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3.5 Data collection

The data used for this study are based on electricity generation, fossil fuel used and the population of Indonesia in selected years. These data are collected and extracted from Refs. (Central Statistics Agency, 2010; DGEEU, 2010; Ministry of energy and mineral resources, 2006, 2010a; PT. PLN, 2010) and shown in Tables 3.1-3.5. Due to the lack of time series data, therefore some of the data were interpolated based on available data. The emission factors for all types of fuel were mostly obtained from Refs. (EPA, 1998, 2002; Wang & Nakata, 2009) and given in Table 3.6 - 3.8.

The characteristics of fuel used in Indonesian power plant are important to assess the contribution of each fuel emission. Calorific value is essentials to calculate thermal energy available for types of fuel. Fuel oil calorific value is 9370 kcal/L, diesel calorific value is 9070 kcal/L, natural gas calorific value is 8904 kcal/m^3 and coal calorific value is between 4200 kcal/kg and 5100 kcal/kg (PLN, 2010). To calculate the amount of SO_2, the sulfur content for diesel assumed to be 5000 ppm (equivalent to 0.5%), 3% for fuel oil and 0.057% of natural gas.

Table 3.1**:** Nominal Capacity (MW) for various type of Indonesian power plant from 1987 to 2009

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power	Total
1987	2,816.95	1,116.68	-	140.00	1,651.86	1,512.06	7,237.55
1988	3,416.95	1,233.68	-	140.00	1,769.02	1,969.57	8,529.22
1989	3,946.95	1,233.68	-	140.00	1,794.89	1,972.95	9,088.47
1990	3,940.60	1,230.09	-	140.00	1,869.60	2,928.65	10,108.94
1991	3,940.60	1,213.86	-	140.00	1,945.96	3,091.54	10,331.96
1992	3,940.60	1,222.76	1,312.05	140.00	2,059.56	3,299.98	11,974.95
1993	4,690.60	974.61	3,411.31	195.00	2,118.74	3,355.38	14,745.64
1994	4,755.60	1,168.51	3,942.11	305.00	2,164.12	3,356.43	15,691.77
1995	4,821.00	1,020.00	4,413.00	308.00	2,228.00	3,363.99	16,153.99
1996	5,020.60	1,093.31	5,203.31	308.75	2,448.84	3,366.01	17,440.82
1997	6,770.60	1,431.12	5,738.89	527.50	2,416.39	3,620.38	20,504.88

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1998	7,970.60	1,407.41	6,845.97	525.00	2,535.02	4,190.64	23,474.64
1999	9,170.00	1,576.11	6,566.70	525.00	2,649.94	4,196.13	24,683.88
2000	9,170.00	1,263.37	7,148.22	705.00	2,549.85	4,199.28	25,035.72
2001	9,300.00	1,284.72	7,148.22	705.00	2,585.12	4,289.80	25,312.86
2002	9,300.00	1,284.72	7,148.22	785.00	2,589.12	4,339.21	25,446.27
2003	9,300.00	1,284.72	7,148.22	807.00	2,670.62	4,351.77	25,562.33
2004	10,865.00	1,541.57	6,845.97	852.00	3,276.93	4,383.48	27,764.95
2005	10,865.00	2,783.63	6,655.97	855.50	3,325.62	4,405.00	28,890.72
2006	11,670.00	3,396.22	7,318.39	820.00	3,001.49	3,532.47	29,738.57
2007	12,014.00	3,452.63	7,318.27	932.50	3,069.77	3,512.90	30,300.07
2008	12,309.00	3,165.69	7,738.11	1,002.50	3,134.40	3,515.89	30,865.59
2009	12,309.00	3,365.59	8,076.97	1,122.50	2,980.63	3,520.35	31,375.04

Table 3.2: Electricity generation (GWh) for various types of power plant from 1987 to 2009

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power	Total
1987	12,221.83	1,374.67	-	719,39	2,785.99	4,457.41	21,559.29
1988	14,218.38	1,581.98	-	1,011.96	2,900.87	5,226.86	24,940.05
1989	16,468.19	1,454.41	-	1,006.87	3,157.04	6,629.66	28,716.17
1990	19,713.78	2,174.96	-	1,125.42	3,609.13	6,492.44	33,115.73
1991	23,242.27	2,640.01	-	1,049.46	3,761.72	7,409.17	38,102.63
1992	22,888.69	2,688.91	-	1,083.74	3,977.53	9,645.48	40,284.35
1993	21,983.60	1,572.85	1,775.27	1,089.97	4,331.26	8,891.08	39,644.03
1994	21,585.71	1,013.21	8,830.35	1,601.76	4,601.05	7,982.94	45,615.02
1995	22,738.92	1,219.07	14,228.36	2,210.03	4,930.51	8,293.14	53,620.03
1996	25,492.24	1,299.06	14,875.25	2,340.37	5,414.27	8,824.37	58,245.56
1997	30,109.79	1,731.49	23,043.91	2,725.88	6,303.03	5,865.62	69,779.72
1998	30,517.37	1,395.51	24,980.78	3,284.00	5,331.85	10,363.50	75,873.01
1999	34,004.54	1,555.04	27,045.52	3,938.23	5,371.46	10,379.78	82,294.57
2000	43,661.00	1,252.00	27,079.00	4,869.00	6,449.00	10,016.00	93,326.00
2001	47,767.00	1,459.00	28,139.00	6,031.00	6,608.00	11,655.00	101,659.00
2002	52,659.00	2,229.00	29,728.00	6,238.00	7,430.00	9,933.00	108,217.00
2003	62,370.00	2,486.00	29,920.00	6,294.00	8,260.00	9,099.00	118,429.00
2004	59,083.00	3,179.00	32,647.00	6,656.00	8,924.00	9,674.00	120,163.00
2005	60,832.00	6,039.00	34,211.00	6,604.00	8,959.00	10,725.00	127,370.00
2006	68,066.00	5,031.00	34,521.00	6,658.00	9,209.00	9,623.00	133,108.00
2007	74,184.00	5,148.00	35,634.00	7,021.00	9,166.00	11,286.00	142,439.00
2008	72,570.00	5,621.00	40,663.00	8,309.00	10,746.00	11,528.00	149,437.00
2009	74,861.00	8,674.00	40,165.00	9,295.00	10,958.00	11,381.00	155,334.00

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Table 3.3: Population of Indonesian for selected years between 1971 and 2010

Year	Population
1971	119,208,229
1980	147,490,298
1990	179,378,946
1995	194,754,808
2000	206,264,595
2010	237,641,326

Table 3.4: Total fossil fuel consumption (kL, Mm^3 and kton) for power plants from 1987 to 1996

Year	Coal (kton)	Fuel Oil (kL)	Diesel (kL)	Natural Gas (Mm^3)
1987	2,084.15	1,996,592	1,329,755	195.72
1988	2,746.01	2,101,324	1,340,086	281.22
1989	3,970.56	1,890,516	1,274,572	334.36
1990	4,421.87	2,585,585	1,621,648	365.90
1991	5,000.55	3,109,515	1,900,092	365.53
1992	5,005.16	3,252,033	2,409,000	420.16
1993	4,789.28	1,043,675	3,130,299	1,346.70
1994	5,530.07	1,865,637	1,927,903	4,547.95
1995	5,593.40	1,157,591	1,825,836	6,226.91
1996	7,966.66	1,111,006	2,236,289	7,051.17

Table 3.5**:** Composition of fuel consumption in Indonesian power plants from 1997 to 2009

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
1997	Coal	9961.96	0.00	0.00	0.00	9961.96
	Natural gas	1052.48	25.01	5382.49	0.00	6459.98
	Fuel oil	1554360.94	0.00	0.00	0.00	1554360.94
	Diesel	0.00	440380.50	977533.11	1633801.44	3051715.05
1998	Coal	10643.49	0.00	0.00	0.00	10643.49
	Natural gas	1023.83	24.33	5235.99	0.00	6284.15
	Fuel oil	1395728.64	0.00	0.00	0.00	1395728.64
	Diesel	0.00	395436.90	877769.71	1467061.74	2740268.35
1999	Coal	11414.10	0.00	0.00	0.00	11414.10
	Natural gas	1090.95	25.92	5579.24	0.00	6696.11
	Fuel oil	1587124.15	0.00	0.00	0.00	1587124.15
	Diesel	0.00	449662.95	998137.79	1668239.11	3116039.85
2000	Coal	13135.58	0.00	0.00	0.00	13135.58

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	Natural gas	1055.11	25.07	5395.93	0.00	6476.11
	Fuel oil	1695268.52	0.00	0.00	0.00	1695268.52
	Diesel	0.00	480302.34	1066149.48	1781910.54	3328362.36
2001	Coal	14027.71	0.00	0.00	0.00	14027.71
	Natural gas	997.26	79.02	5218.23	0.00	6294.51
	Fuel oil	1789626.93	0.00	0.00	0.00	1789626.93
	Diesel	0.00	554638.14	1244474.04	1810349.07	3609461.25
2002	Coal	14054.34	0.00	0.00	0.00	14054.34
	Natural gas	690.55	130.29	4934.28	0.00	5755.13
	Fuel oil	2166224.32	0.00	0.00	0.00	2166224.32
	Diesel	0.00	731217.79	1716280.89	1892561.51	4340060.19
2003	Coal	15260.30	0.00	0.00	0.00	15260.30
	Natural gas	383.91	181.57	4650.34	0.00	5215.82
	Fuel oil	2542821.71	0.00	0.00	0.00	2542821.71
	Diesel	0.00	907797.44	2188087.71	1974773.96	5070659.11
2004	Coal	15412.74	0.00	0.00	0.00	15412.74
	Natural gas	395.46	359.93	4237.75	0.00	4993.14
	Fuel oil	2642689.12	0.00	0.00	0.00	2642689.12
	Diesel	0.00	843656.34	3047392.90	1990679.28	5881728.52
2005	Coal	16900.97	0.00	0.00	0.00	16900.97
	Natural gas	260.25	438.47	3349.60	0.00	4048.32
	Fuel oil	2226522.55	0.00	0.00	0.00	2226522.55
	Diesel	0.00	1750112.04	3843320.20	2067968.25	7661400.49
2006	Coal	19084.44	0.00	0.00	0.00	19084.44
	Natural gas	275.03	579.34	3607.50	0.00	4461.88
	Fuel oil	2359120.02	0.00	0.00	0.00	2359120.02
	Diesel	0.00	1582632.24	3904159.16	1847868.75	7334660.15
2007	Coal	21466.35	0.00	0.00	0.00	21466.35
	Natural gas	558.98	543.13	3912.75	0.00	5014.86
	Fuel oil	2702130.71	0.00	0.00	0.00	2702130.71
	Diesel	0.00	1582632.24	3904159.16	2292992.58	7779783.98
2008	Coal	20999.52	0.00	0.00	0.00	20999.52
	Natural gas	259.52	556.02	4257.54	0.00	5073.08
	Fuel oil	2827173.13	0.00	0.00	0.00	2827173.13
	Diesel	0.00	1705134.99	4273990.53	2514190.64	8493316.16
2009	Coal	21604.46	0.00	0.00	0.00	21604.46
	Natural gas	242.32	2022.71	5231.96	0.00	7496.98
	Fuel oil	2588586.13	0.00	0.00	0.00	2588586.13
	Diesel	0.00	1115367.00	2950343.90	2754607.45	6820318.35

Note: Natural gas in Mm^3, fuel oil and Diesel in kL and coal in kton.

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Table 3.6: Emission factor (kg/KWh) used for estimating emission in power plants

Fuels	Emission (kg/kWh)			
	CO_2	NO_X	SO_2	CO
Coal	1.18	0.0052	0.0139	0.0002
Natural gas	0.53	0.0009	0.0005	0.0005
Fuel oil	0.85	0.0025	0.0164	0.0002
Diesel	0.85	0.0025	0.0164	0.0002

Table 3.7: Emission factors used for estimating emissions in power plants

Fuel type	Power plant	CO_2	NO_X	SO_2	CO	unit
Fuel oil	Steam turbine	2.93	5.64×10^{-3}	$0.0188 \times S\%$	6×10^{-4}	kg/l
Diesel	Gas turbine or combine cycle	2.61	1.46×10^{-2}	$0.0168 \times S\%$	5.48×10^{-5}	kg/l
	Diesel engine	2.73	7.33×10^{-2}	4.82×10^{-3}	1.58×10^{-2}	kg/l
Natural gas	Steam turbine	1.86	4.35×10^{-3}	9.32×10^{-6}	1.31×10^{-3}	kg/m^3
	Gas turbine	1.74	5.07×10^{-3}	$0.0149 \times S\%$	1.30×10^{-3}	kg/m^3

S% indicates percentage of sulfur in the respective fuel, by weight.

Table 3.8: CO_2 emission per unit electricity generation of Clean Coal fired power plant

SC (kg/KWh)	USC (kg/KWh)	PBFC (kg/KWh)	IGCC (kg/KWh)
0.913	0.715	0.790	0.718

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Indonesian power sector composition

4.1.1 Power generation growth

The nominal capacity and electricity production growth by type of power plant in Indonesia are shown in Figures 4.1 and 4.2. The annual electricity production growth in the country was 10.76% and the annual nominal capacity growth was 6.89%. This is equivalent to the annual growth of 6,080.66 GWh of electricity production that needs to create 1,097.15 MW of new power generation capacity annually.

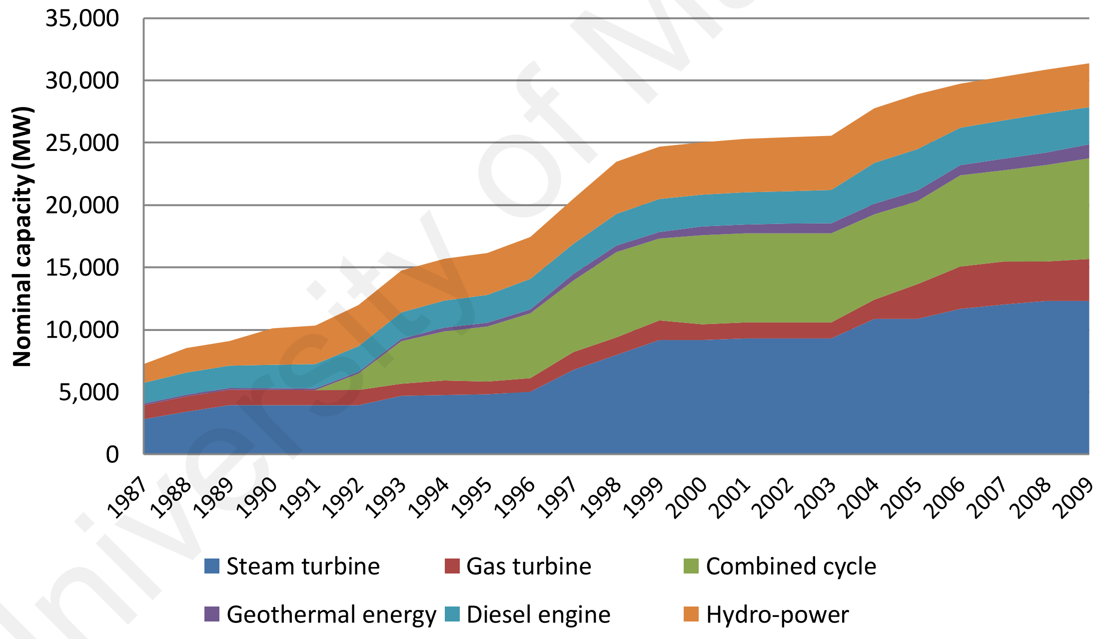

Figure 4.1.Nominal capacity (MW) of Indonesian power plants by type of power plant from 1987 to 2009

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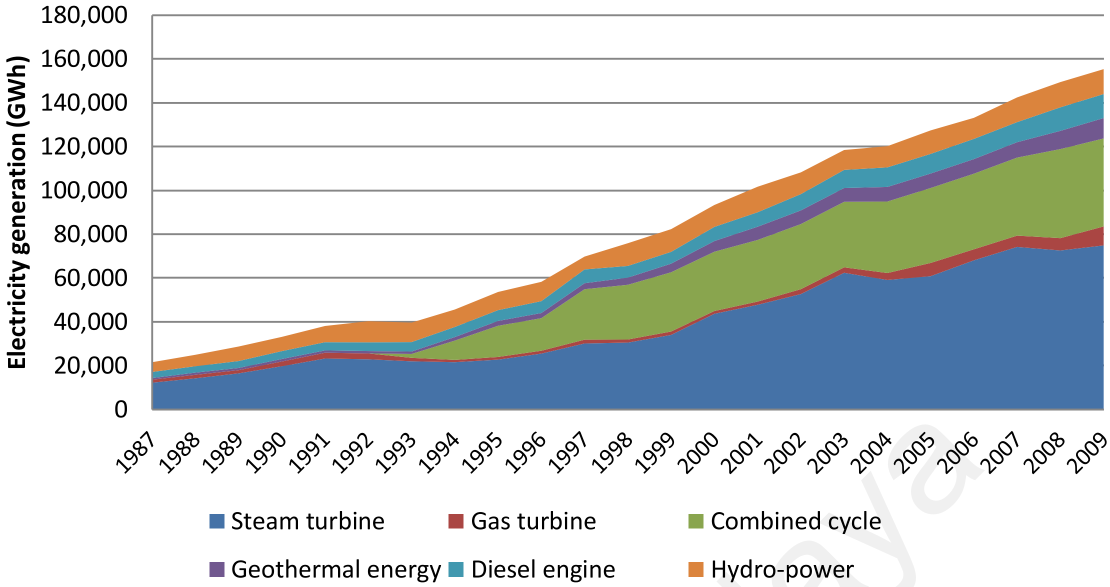

Figure 4.2.Electricity generation (GWh) of Indonesian power plants by type of power plant from 1987 to 2009

4.1.2 Per capita capacities

The annual population growth is estimated using the data in Table 3.3 and Eq. (3.1). The nominal capacity and electricity consumption per person have been calculated using Eqs. (3.3) and (3.4) which are based on the statistical data in Tables 3.1 and 3.2. From 1987 to 2009, there is no exchange of electricity between Indonesia and its neighboring countries, therefore per capita rate of electricity generation and consumption should remain the same. The results are tabulated in Table 4.1 and graphically illustrated in Figure 4.3.

Table 4.1: Per capita nominal capacity and per capita electricity consumption in Indonesia

Year	Population	Per Capita Nominal Capacity (Watt)	Per Capita Electricity Consumption (kWh)
1987	169,487,458	43	127
1988	172,539,978	49	145
1989	175,582,143	52	164
1990	179,378,946	56	185

1991	181,635,406	57	210
1992	184,646,504	65	218
1993	187,647,246	79	211
1994	190,637,633	82	239
1995	194,754,808	83	275
1996	196,587,341	89	296
1997	199,546,661	103	350
1998	202,495,626	116	375
1999	205,434,235	120	401
2000	206,264,595	121	452
2001	211,280,387	120	481
2002	214,187,929	119	505
2003	217,085,116	118	546
2004	219,971,947	126	546
2005	222,848,423	130	572
2006	225,714,544	132	590
2007	228,570,308	133	623
2008	231,415,717	133	646
2009	234,250,771	134	663

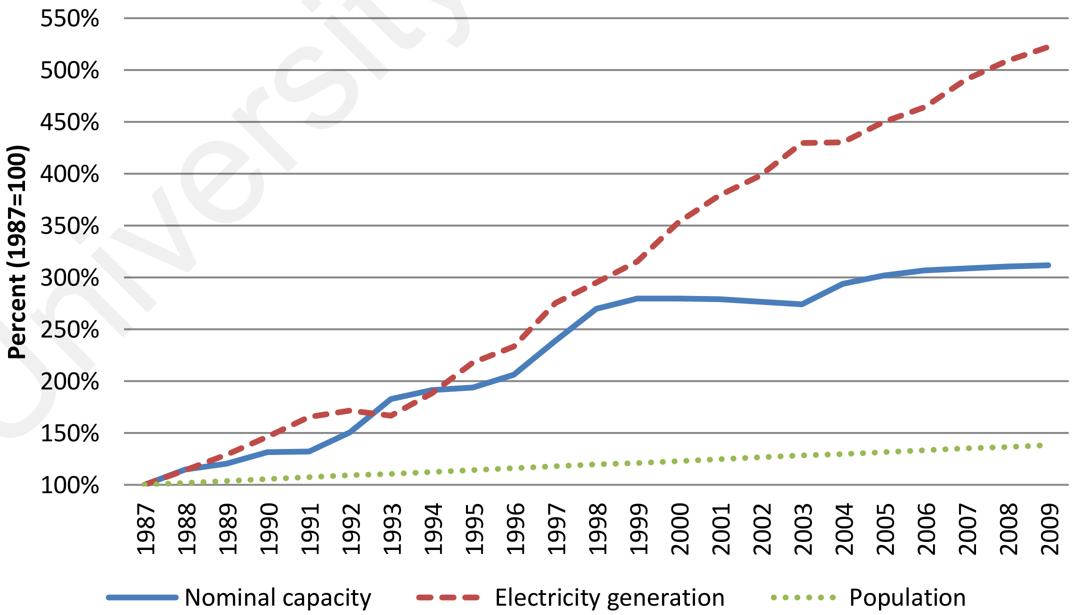

Figure 4.3.Per capita nominal capacity and per capita electricity consumption and population growth between 1987 and 2009

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For 23 years, from 1987 to 2009, the average population growth in Indonesia was 1.48%. Whereas, the per capita electricity consumption saw an increase from 127 kWh in 1987 to 663 kWh in 2009 with an average annual growth rate of 7.8%. This increase in energy consumption is due to the economic growth of the country that caused the rate of electricity production was much higher than the population growth.

4.1.3 Pattern of electricity generation

The pattern of electricity generation and nominal capacity which are based on the type of power plant are calculated using the data in Tables 3.3 and 3.4 and Eqs. (3.5) and (3.6). The results are tabulated in Tables 4.2 and 4.3, and illustrated in Figures 4.4 and 4.5. Figure 4.5 show that fossil fuel dominates most of the share of electrical power generation, much higher than the renewable sources of geothermal and hydro-power energy. This can be said is due to the tendency of using fossil fuel power plants to meet the high demand for electricity. Additionally, the abundance of fossil fuel resources, lack of proper energy management and low investments in renewable energy sources contribute to the high usage of fossil fuel power plants. However, starting from the year 1992, combined cycle power plants that utilize both natural gas and diesel fuel were introduced and has since became the second largest contributor of electrical energy amongst the other types of power plants, while diesel engine power plants are slowly being phased out. From 1987 to 2009, the share of nominal capacity of electrical power generation of diesel engine power plants has shrunk from 22.82% to 9.50%. Additionally, the policy of using coal to generate electricity due to its low price had also contributed to the decrease of diesel engine power plant's share of power generation.

On the other hand, hydro-power plant's contribution for power generation has been steadily decreasing from 21% in 1987 to 11.2% in 2009. Furthermore, from time to time the share of electricity production from the hydro-power plants was less than its nominal capacity due to extreme weather that causes draught and limited water

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resources. Other than hydro-power, geothermal energy is another renewable resource that has been utilized by the country. Although this source contributes the lowest share of electrical energy supply, the geothermal energy saw a steady increase in nominal capacity and power generation contribution since 1987.

Table 4.2: Power plants nominal capacity contribution (%) from 1987 to 2009

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power
1987	38.92	15.43	0.00	1.93	22.82	20.89
1988	40.06	14.46	0.00	1.64	20.74	23.09
1989	43.43	13.57	0.00	1.54	19.75	21.71
1990	38.98	12.17	0.00	1.38	18.49	28.97
1991	38.14	11.75	0.00	1.36	18.83	29.92
1992	32.91	10.21	10.96	1.17	17.20	27.56
1993	31.81	6.61	23.13	1.32	14.37	22.76
1994	30.31	7.45	25.12	1.94	13.79	21.39
1995	29.84	6.31	27.32	1.91	13.79	20.82
1996	28.79	6.27	29.83	1.77	14.04	19.30
1997	33.02	6.98	27.99	2.57	11.78	17.66
1998	33.95	6.00	29.16	2.24	10.80	17.85
1999	37.15	6.39	26.60	2.13	10.74	17.00
2000	36.63	5.05	28.55	2.82	10.18	16.77
2001	36.74	5.08	28.24	2.79	10.21	16.95
2002	36.55	5.05	28.09	3.08	10.17	17.05
2003	36.38	5.03	27.96	3.16	10.45	17.02
2004	39.13	5.55	24.66	3.07	11.80	15.79
2005	37.61	9.64	23.04	2.96	11.51	15.25
2006	39.24	11.42	24.61	2.76	10.09	11.88
2007	39.65	11.39	24.15	3.08	10.13	11.59
2008	39.88	10.26	25.07	3.25	10.15	11.39
2009	39.23	10.73	25.74	3.58	9.50	11.22

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Table 4.3: Power plants electricity generation contribution (%) from 1990 to 2009

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power
1987	56.69	6.38	0.00	3.34	12.92	20.68
1988	57.01	6.34	0.00	4.06	11.63	20.96
1989	57.35	5.06	0.00	3.51	10.99	23.09
1990	59.53	6.57	0.00	3.40	10.90	19.61
1991	61.00	6.93	0.00	2.75	9.87	19.45
1992	56.82	6.67	0.00	2.69	9.87	23.94
1993	55.45	3.97	4.48	2.75	10.93	22.43
1994	47.32	2.22	19.36	3.51	10.09	17.50
1995	42.41	2.27	26.54	4.12	9.20	15.47
1996	43.77	2.23	25.54	4.02	9.30	15.15
1997	43.15	2.48	33.02	3.91	9.03	8.41
1998	40.22	1.84	32.92	4.33	7.03	13.66
1999	41.32	1.89	32.86	4.79	6.53	12.61
2000	46.78	1.34	29.02	5.22	6.91	10.73
2001	46.99	1.44	27.68	5.93	6.50	11.46
2002	48.66	2.06	27.47	5.76	6.87	9.18
2003	52.66	2.10	25.26	5.31	6.97	7.68
2004	49.17	2.65	27.17	5.54	7.43	8.05
2005	47.76	4.74	26.86	5.18	7.03	8.42
2006	51.14	3.78	25.93	5.00	6.92	7.23
2007	52.08	3.61	25.02	4.93	6.44	7.92
2008	48.56	3.76	27.21	5.56	7.19	7.71
2009	48.19	5.58	25.86	5.98	7.05	7.33

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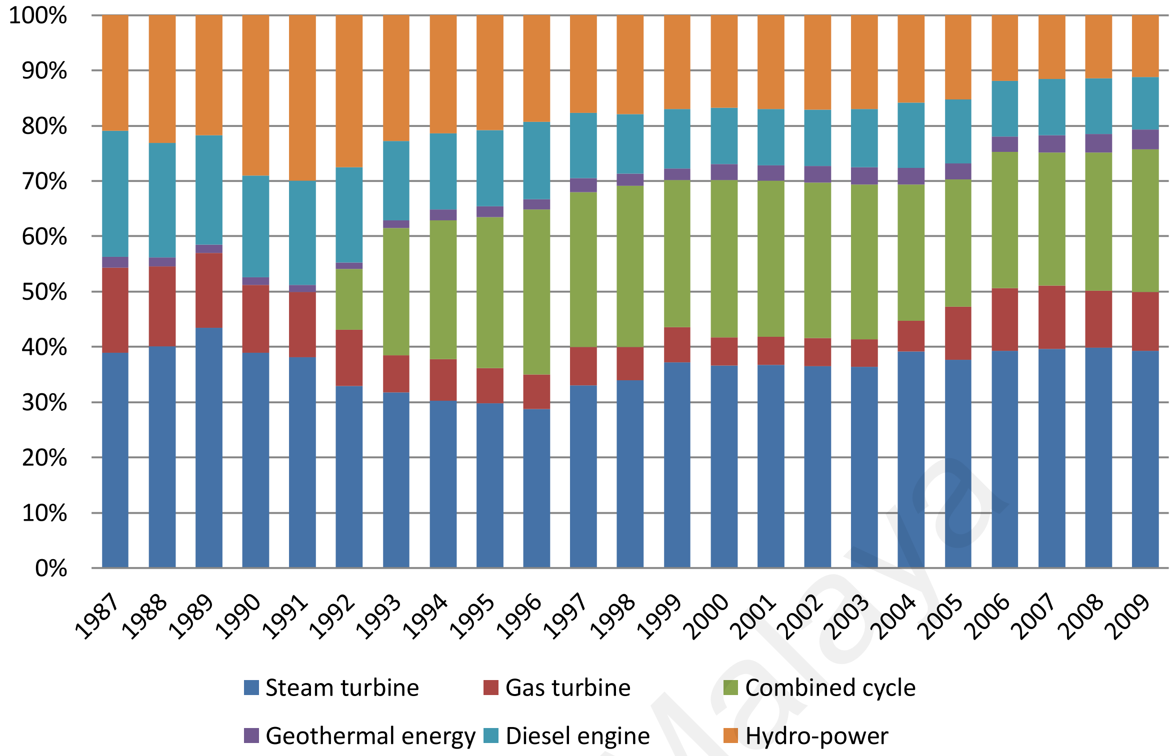

Figure 4.4: Pattern of nominal capacity for each type of power plants from 1987 to 2009

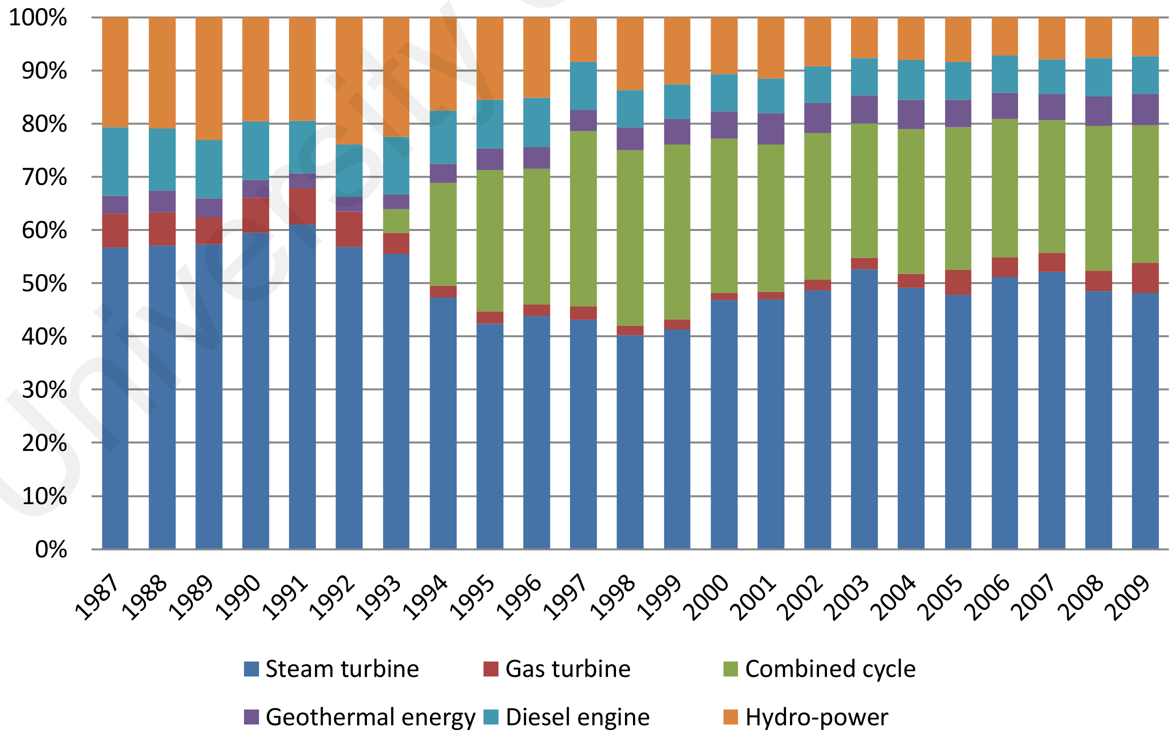

Figure 4.5: Pattern of electricity generation for each type of power plants from 1987 to 2009

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4.1.4 Capacity factor

Using Eq. (3.7) and the data presented in Tables 3.1 and 3.2, the trends of nominal capacity factors for various types of power plants from 2000-2009 are presented in Table 4.4 and shown graphically in Figure 4.6.

Table 4.4: Capacity factor in Indonesian power plants from 2001 to 2009

Year	Steam turbine (%)	Gas turbine (%)	Combined cycle (%)	Diesel engine (%)
2000	54.32	11.31	43.21	28.85
2001	58.59	12.96	44.91	29.16
2002	64.59	19.79	47.44	32.74
2003	76.51	22.07	47.75	35.28
2004	62.03	23.52	54.40	31.07
2005	63.87	24.75	58.63	30.73
2006	66.54	16.90	53.81	35.00
2007	70.44	17.01	55.55	34.06
2008	67.26	20.26	59.95	39.11
2009	69.38	29.40	56.73	41.94

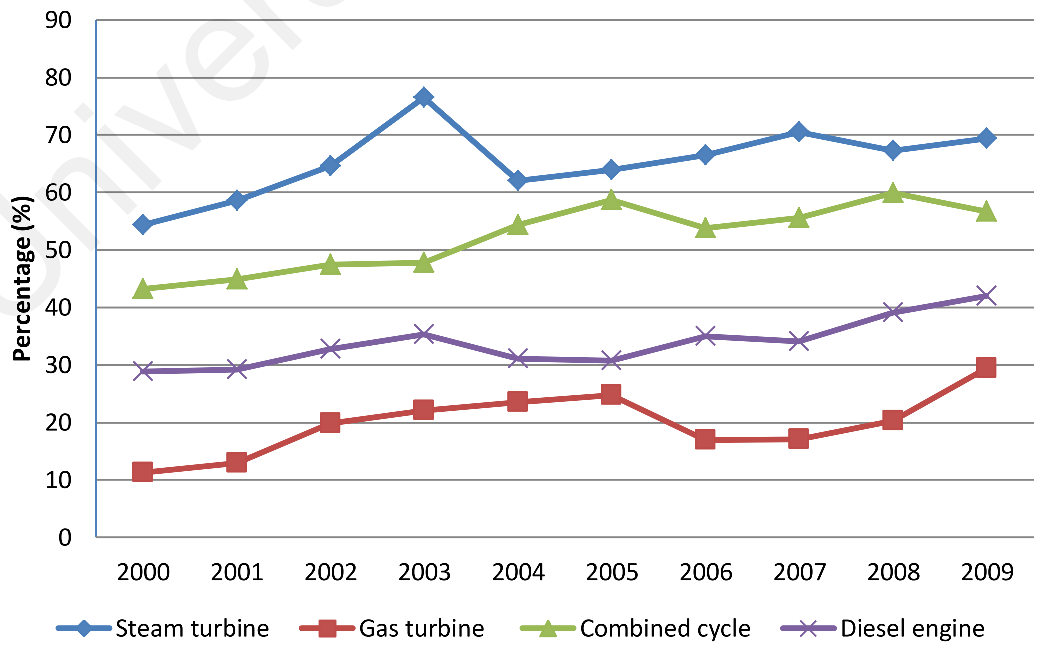

Figure 4.6: Indonesian thermal power plants capacity factor from 2000 to 2009

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The mechanisms that control the power plant capacity factors include the life span of machines, functions, maintenance, types of fuel supplied, and the technology that is equipped in power plants. Figure 4.6 shows steam turbine capacity factor is always higher than the other types of power plants. This is due to its function as a base loaded power plant that generates higher electrical power than peak load power plants, which only used during peak hours when there are very high demands for electricity.

The average capacity factors for the last ten years for steam turbine, gas turbine, combined cycle and diesel engines has been evaluated to be 65.35 %, 19.80 %, 52.24 %, and 33.79 % respectively.

4.1.5 Fuel consumption

Based on Tables 3.4 and 3.5, the total consumption of all types of fuel used in power plants in Indonesia is illustrated in Figures 4.7 and 4.8 where the development of all types of fuel consumed by power plants is presented in the figure. The trend depicted in the figure shows that the country is still lagging in terms of utilizing natural gas as the primary fuel for power plants; whilst natural gas is expected to be the fastest growing fuel in the world. Additionally, more than half of the natural gas reserves in Indonesia are exported to other countries. In response to increase domestic demands, Indonesia has established policies to prioritize domestic consumption of natural gas over exports. Furthermore, the country had to make substantial investments to maintain current production levels due to declining natural gas production from many older fields. As a short term solution, Indonesia’s natural gas production has somewhat increased due to the new LNG export project which came into full production capacity in 2010. Coal is steadily increased without any interruption due to the low operating costs and availability while diesel and fuel oil are still being used for power plants in Indonesia as a backup and starter fuel.

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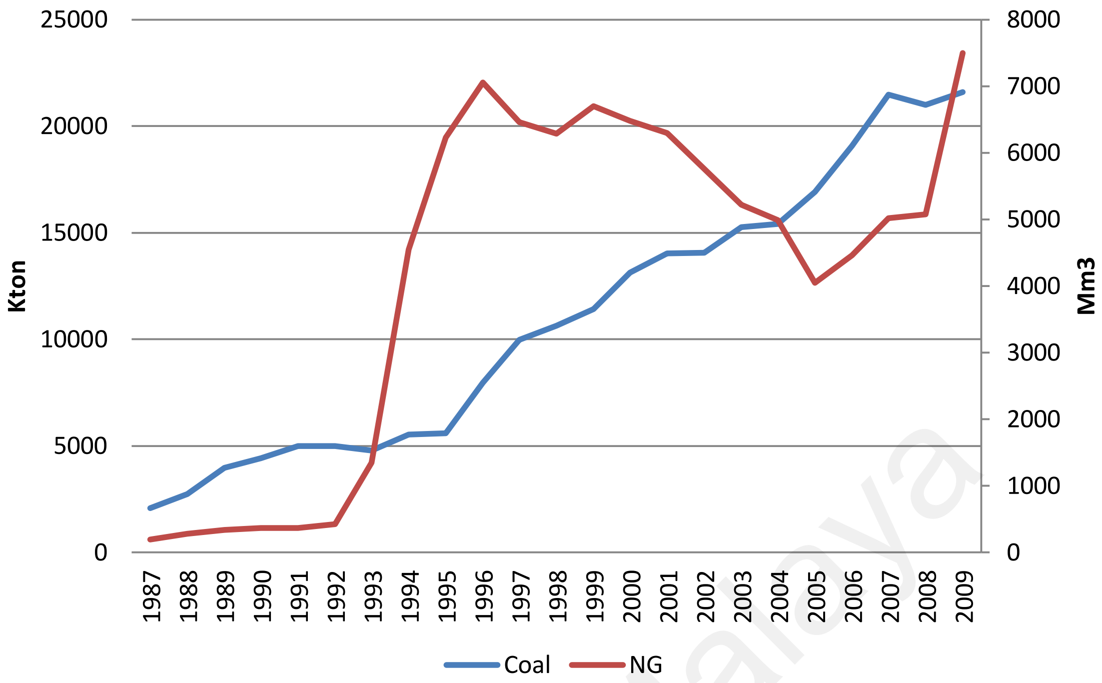

Figure 4.7: Total fuel consumed for natural gas and coal in Indonesian power plants from 1987 to 2009

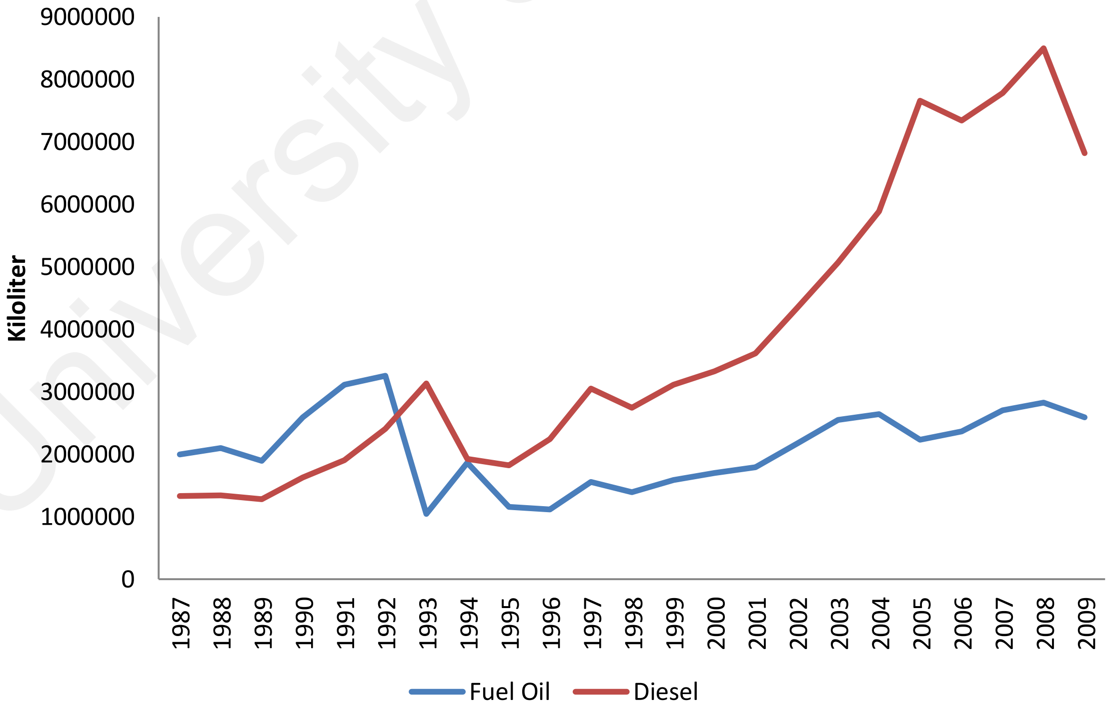

Figure 4.8: Total fuel consumed for fuel oil and diesel in Indonesian power plants from 1987 to 2009

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The average annual growth from 1987 to 2009 for natural gas was 18.02%, diesel 7.71%, fuel oil 1.19% and coal 11.21%. Using Eq. (3.8) and data from Tables 3.2 and 3.5, the average fuel consumption per unit electricity generation for each type of thermal power plants from 2000-2009 is calculated. The results are presented in Table 4.5.

Table 4.5: Average fuel consumption per unit electricity generation in Indonesian thermal power plants

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Coal (kg/kWh)	0.24916	-	-	-
Natural gas (m^3/kWh)	0.00695	0.09242	0.11838	-
Diesel (l/kWh)	-	0.26825	0.07820	0.21578
Fuel Oil (l/kWh)	0.03453	-	-	-

4.1.6 Emission prediction

The total emission in Indonesian power plants was calculated using Eq. (3.9) and Tables 3.4-3.8. The total emission in Indonesian power plants from 1987 to 2009 is presented in Table 4.6 and illustrated in Figure 4.9. For the past 23 years, the average annual growth rate of emissions from power plants was 9.44% for CO_2, 12.13% for NO_x, 5.6% for SO_2 and 14.38% for CO. As seen in Fig. 4.9, the increasing emissions of CO_2, SO_2 and NO_x were observed due to the increase in coal and diesel.

The emission per unit electricity generation is calculated using Eq. (3.13) and the results are tabulated in Table 4.7 and shown in Figure 4.10. Observations can be made from Figure 4.10 that the trend of emission per unit electricity generation of SO_2

decreased sharply between 1992 and 1996. It is noted that the country try to replace the consumption of fuel and diesel oil with natural gas which has low SO_2 emission.

The share of each type of fuel in total thermal energy consumed and total emission in 2009 are calculated by using Eq. (3.10) and (3.12) and presented in Table 4.8. The year 2009 is taken as a sample to show the share of thermal energy contribution amongst the type of power plants by the highest fuel consumed and emission produced from 1987 up to 2009. For example, about 79.18% of thermal energy used in steam turbine power plants was contributed by coal, which produced more than 85% of the SO_2, CO_2, NO_x and CO gases due to the consumption of this type of fuel. The thermal energy of natural gas is very small in comparison to coal as they are used in small percentage in steam turbine power plants. The emissions of burning natural gas, however, are lower than that of coal. Thus, if the solid fuel of coal is replaced by natural gas, a significant amount these greenhouse gas emissions may be reduced. Furthermore, diesel fuel used in gas turbine and combined cycle power plants contributed the highest amount of emissions although the thermal energy from this type of fuel is lower than that of natural gas as can be seen in Table 4.8.

Table 4.6: Total emission in Indonesian power plants from 1987 to 2009

Year	CO_2 (ton)	NO_X (kg)	SO_2 (kg)	CO (kg)
1987	14,950,100	50,031,251	248,511,580	3,479,446
1988	17,250,498	58,846,880	278,227,628	4,038,401
1989	20,054,191	71,439,496	306,844,853	4,587,168
1990	23,720,059	81,674,141	381,379,714	5,447,945
1991	27,540,821	94,454,425	447,334,189	6,273,822
1992	27,323,602	93,195,683	444,743,130	6,292,179
1993	27,158,954	96,837,484	350,021,834	7,925,251
1994	29,024,918	91,735,907	337,424,732	11,554,405
1995	32,809,651	100,042,537	310,288,340	15,596,375

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1996	36,942,518	117,532,932	345,511,144	16,782,122
1997	47,507,368	284,170,869	277,002,633	39,203,284
1998	47,336,523	274,428,233	293,816,751	36,480,250
1999	52,188,284	306,095,592	324,113,940	40,753,582
2000	61,702,014	355,101,162	430,389,396	43,861,680
2001	66,410,743	378,217,581	477,794,245	44,825,849
2002	72,234,990	409,907,640	522,576,913	46,322,612
2003	83,222,467	464,350,643	628,179,132	48,694,569
2004	82,058,886	462,481,005	590,735,968	48,219,512
2005	89,275,601	510,017,976	654,742,441	48,977,030
2006	96,985,319	528,096,307	742,911,310	47,378,584
2007	104,445,390	583,896,503	793,099,988	56,058,318
2008	105,739,195	603,967,022	781,117,740	59,553,914
2009	108,736,054	621,478,006	825,819,837	66,902,518

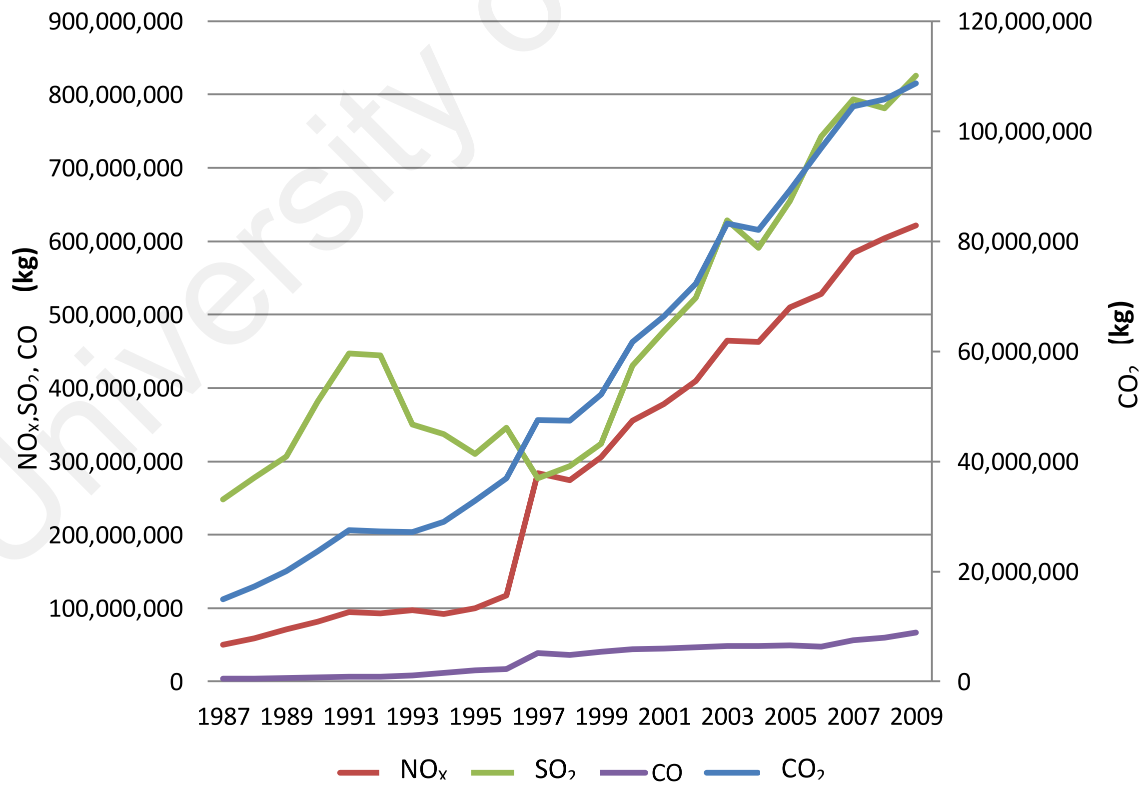

Figure 4.9: Total emission in Indonesian power plants from 1987 to 2009

Table 4.7: Emission per unit of electricity generation from 1987 to 2009

Year	CO_2 (ton/GWh)	NO_X (kg/GWh)	SO_2 (kg/GWh)	CO (kg/GWh)
1987	913	3054	15169	212
1988	922	3147	14878	216
1989	951	3389	14556	218
1990	930	3203	14957	214
1991	929	3186	15090	212
1992	924	3153	15048	213
1993	916	3265	11800	267
1994	806	2546	9365	321
1995	761	2320	7196	362
1996	785	2496	7339	356
1997	776	4644	4527	641
1998	761	4410	4722	586
1999	768	4503	4768	600
2000	787	4527	5487	559
2001	791	4504	5690	534
2002	785	4453	5677	503
2003	808	4507	6097	473
2004	790	4454	5689	464
2005	811	4635	5950	445
2006	830	4520	6359	406
2007	841	4704	6389	452
2008	816	4660	6027	460
2009	807	4615	6133	497

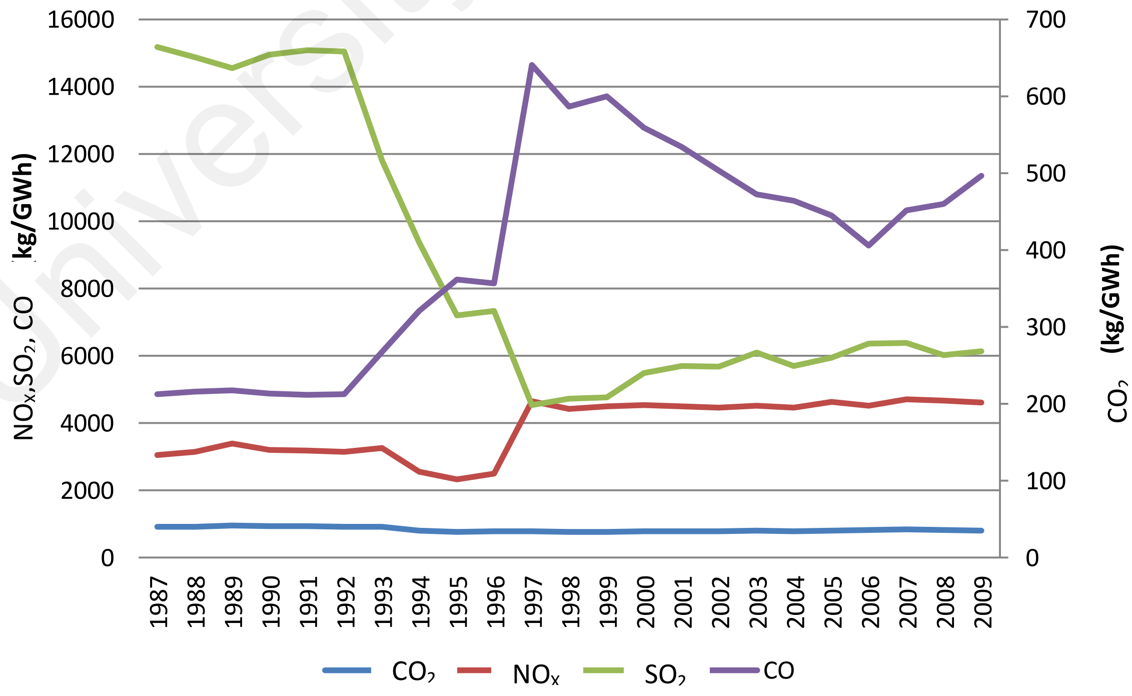

Figure 4.10: Emission per unit electricity generation from 1987 to 2009

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Between 2000 and 2009, there was detailed information of fuel consumed and electricity generated for all types of power plants. Thus, the amount of total emission and emission per unit of electricity generation in each type of power plants were more precisely determined. These data are calculated using Eqs. (3.11) and (3.13) and presented in Tables 4.9 and 4.10.

The average emission per unit electricity generation for each type of power plants in Indonesia was calculated by Eq. (3.15) using the data in Table 4.10 and the results are tabulated in Table 4.11. The data of this table has been calculated using ten years of fuel mix data. Thus, by changing the fuel mix used in thermal power plants, this data will be affected. For example, by increasing the contribution of natural gas in power plants, the emission per unit electricity generation will decrease.

The data for year 2009 in Table 4.9 is selected to show the share of each type of power plant for total emissions. The contributions of each type of thermal power plants in total emission in 2009 are presented in Figure 4.11. The figure shows that the contribution of steam turbines for all types of emission was very significant, particularly for SO_2 emission. Although diesel engines are slowly being phased out, their emission contribution is somewhat significant, mostly due to inefficient and old diesel engines are still being used in the power plants.

Figure 4.12 shows the comparison of each type of emission in all thermal power plants in Indonesia. By comparing the thermal power plants with regards to the emissions produced, the worst type of power plant is steam turbine that produced the highest amount of emissions while the best type is the combined cycle. Note that the amounts of emissions produced by diesel engine power plants are quite high although they are slowly being phased out in Indonesia. Thus by removing the inefficient diesel engine power plants off the grid cleaner energy production can be achieved in the long run.

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Table 4.8: Fuel types contribution (%) in total emission and total energy consumed in power plants in 2009

Fuel type	Pollutant	Steam turbine		Gas turbine		Combined cycle	
		Emission	Energy	Emission	Energy	Emission	Energy
Natural gas	CO_2	0.58		54.73		54.18	
	NO_X	0.33	1.7	38.64	99.94	38.11	99.94
	SO_2	0.00		15.49		15.20	
	CO	2.31		97.73		97.68	
Diesel	CO_2	-		45.27		45.82	
	NO_X	-	-	61.36	0.06	61.89	0.06
	SO_2	-		84.51		84.80	
	CO	-		2.27		2.32	
Fuel oil	CO_2	9.73		-		-	
	NO_X	4.37	19.12	-	-	-	-
	SO_2	0.18		-		-	
	CO	11.32		-		-	
Coal	CO_2	89.70		-		-	
	NO_X	95.30	79.18	-	-	-	-
	SO_2	99.82		-		-	
	CO	86.37		-		-	

Table 4.9: Total emission in thermal power plants from 2000 to 2009

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2000	CO_2 (ton)	43,368,625	1,297,211	12,171,562	4,864,616	61,702,014
	NO_X(kg)	174,424,471	7,139,520	42,923,128	130,614,043	363,228,572
	SO_2(kg)	430,204,865	40,558	135,384	8,589	487,668,076
	CO (kg)	8,575,453	58,912	7,073,129	28,154,187	10,011,830
2001	CO_2 (ton)	47,555,592	1,585,105	12,327,792	4,942,253	60,298,456
	NO_X(kg)	192,394,898	8,498,363	44,625,732	132,698,587	384,661,554
	SO_2(kg)	477,589,404	47,261	148,854	8,726	534,704,191
	CO (kg)	9,237,317	133,124	6,851,892	28,603,515	10,912,761
2002	CO_2 (ton)	51,867,959	2,135,191	13,065,147	5,166,693	66,051,720
	NO_X(kg)	209,771,988	11,336,373	50,074,520	138,724,759	407,180,603
	SO_2(kg)	522,319,187	62,529	186,074	9,122	566,489,410
	CO (kg)	9,702,065	209,454	6,508,621	29,902,472	12,030,448
2003	CO_2 (ton)	61,343,559	2,685,275	13,802,500	5,391,133	76,941,729
	NO_X(kg)	249,902,029	14,174,379	55,523,303	144,750,931	452,336,514
	SO_2(kg)	627,868,522	77,797	223,295	9,518	658,783,734
	CO (kg)	11,042,009	285,782	6,165,349	31,201,429	14,018,769
2004	CO_2 (ton)	58,468,731	2,828,225	15,327,376	5,434,554	76,098,362
	NO_X(kg)	236,444,660	14,142,238	65,977,315	145,916,791	442,496,138
	SO_2(kg)	590,360,477	73,924	291,972	9,595	619,956,676
	CO (kg)	10,576,567	514,144	5,676,069	31,452,733	14,004,790

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2005	CO_2 (ton)	62,439,954	5,330,732	15,859,362	5,645,553	84,360,090
	NO_X(kg)	257,566,296	27,774,683	73,094,925	151,582,073	480,570,474
	SO_2(kg)	654,230,453	150,733	351,287	9,968	676,894,685
	CO (kg)	11,072,125	665,918	4,565,088	32,673,898	15,643,246
2006	CO_2 (ton)	70,335,004	5,138,727	16,466,906	5,044,682	91,524,338
	NO_X(kg)	291,313,077	26,043,701	75,290,750	135,448,779	498,815,280
	SO_2(kg)	742,405,954	137,861	358,588	8,907	766,716,883
	CO (kg)	12,438,685	839,874	4,903,698	29,196,326	16,818,474
2007	CO_2 (ton)	76,111,766	5,075,710	16,998,045	6,259,870	99,338,194
	NO_X(kg)	313,121,687	25,860,081	76,838,380	168,076,356	560,215,890
	SO_2(kg)	792,590,201	137,554	361,180	11,052	832,758,948
	CO (kg)	13,735,716	792,792	5,300,526	36,229,283	18,238,138
2008	CO_2 (ton)	74,894,341	5,417,881	18,563,232	6,863,740	99,156,959
	NO_X(kg)	307,976,864	27,714,002	83,985,982	184,290,174	570,072,214
	SO_2(kg)	780,562,494	147,954	395,174	12,118	803,997,587
	CO (kg)	13,244,417	816,270	5,769,015	39,724,212	18,325,461
2009	CO_2 (ton)	77,981,359	6,430,615	16,804,001	7,520,078	97,786,632
	NO_X(kg)	323,424,767	26,539,475	69,601,038	201,912,726	598,450,699
	SO_2(kg)	825,403,426	110,870	292,264	13,277	848,150,121
	CO (kg)	13,725,859	2,690,639	6,963,222	43,522,798	17,817,668

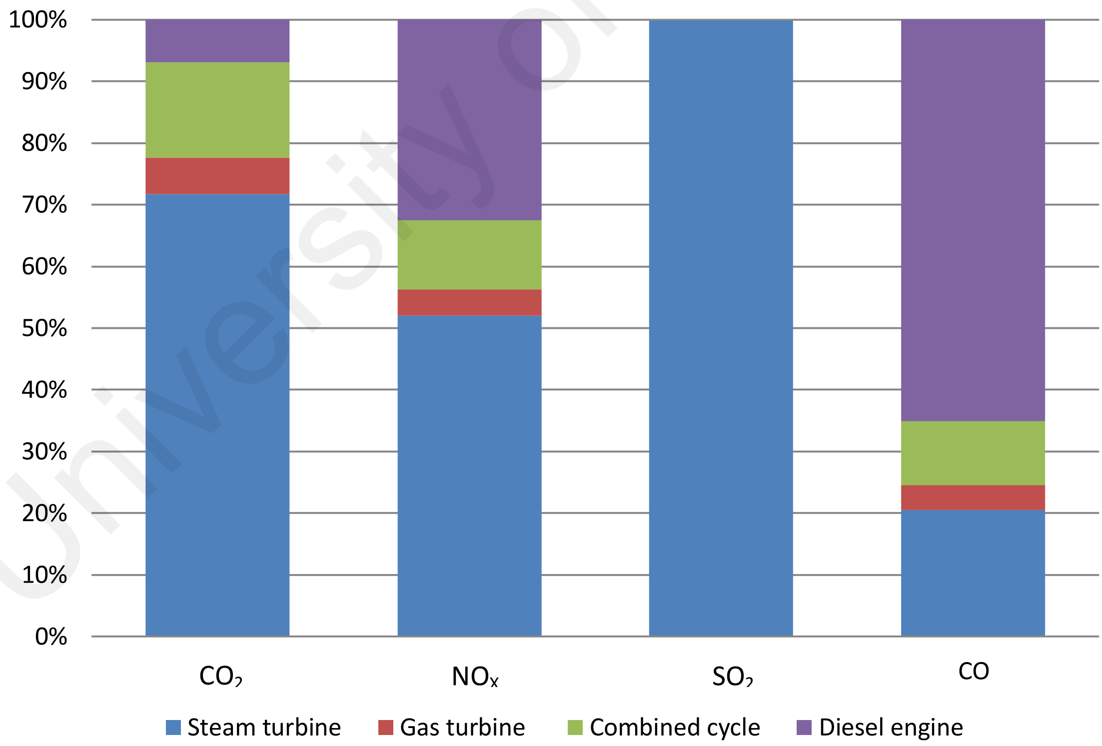

Figure 4.11: Power plant emission contribution in 2009

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Table 4.10: Emission per unit electricity generation (kg/GWh) in thermal power plants from 2000 to 2009

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2000	CO_2	993,303.52	1,036,111.12	449,483.43	754,320.94	3,233,219.01
	NO_X	3,994.97	5,702.49	1,585.11	20,253.38	31,535.95
	SO_2	9,853.30	32.39	5.00	1.33	9,892.02
	CO	196.41	47.05	261.20	4,365.67	4,870.33
2001	CO_2	995,574.19	1,086,432.80	438,103.43	747,919.64	3,268,030.06
	NO_X	4,027.78	5,824.79	1,585.90	20,081.51	31,519.97
	SO_2	9,998.31	32.39	5.29	1.32	10,037.32
	CO	193.38	91.24	243.50	4,328.62	4,856.75
2002	CO_2	984,978.05	957,914.34	439,489.61	695,382.63	3,077,764.63
	NO_X	3,983.59	5,085.86	1,684.42	18,670.90	29,424.77
	SO_2	9,918.90	28.05	6.26	1.23	9,954.44
	CO	184.24	93.97	218.94	4,024.56	4,521.71
2003	CO_2	983,542.71	1,080,158.97	461,313.51	652,679.53	3,177,694.71
	NO_X	4,006.77	5,701.68	1,855.73	17,524.33	29,088.50
	SO_2	10,066.84	31.29	7.46	1.15	10,106.74
	CO	177.04	114.96	206.06	3,777.41	4,275.47
2004	CO_2	989,603.29	889,658.69	469,488.03	608,981.90	2,957,731.90
	NO_X	4,001.91	4,448.64	2,020.93	16,351.05	26,822.53
	SO_2	9,992.05	23.25	8.94	1.08	10,025.33
	CO	179.01	161.73	173.86	3,524.51	4,039.12
2005	CO_2	1,026,432.70	882,717.62	463,574.94	630,154.41	3,002,879.67
	NO_X	4,234.06	4,599.22	2,136.59	16,919.53	27,889.40
	SO_2	10,754.71	24.96	10.27	1.11	10,791.05
	CO	182.01	110.27	133.44	3,647.05	4,072.77
2006	CO_2	1,033,335.35	1,021,412.69	477,011.27	547,799.08	3,079,558.39
	NO_X	4,279.86	5,176.64	2,181.01	14,708.30	26,345.82
	SO_2	10,907.15	27.40	10.39	0.97	10,945.91
	CO	182.74	166.94	142.05	3,170.41	3,662.15
2007	CO_2	1,025,986.27	985,957.62	477,017.59	682,944.55	3,171,906.03
	NO_X	4,220.88	5,023.33	2,156.32	18,336.94	29,737.46
	SO_2	10,684.11	26.72	10.14	1.21	10,722.17
	CO	185.16	154.00	148.75	3,952.57	4,440.48
2008	CO_2	1,032,028.95	963,864.18	456,514.09	638,725.15	3,091,132.37
	NO_X	4,243.86	4,930.44	2,065.42	17,149.65	28,389.37
	SO_2	10,755.99	26.32	9.72	1.13	10,793.16
	CO	182.51	145.22	141.87	3,696.65	4,166.25
2009	CO_2	1,041,682.04	741,366.76	418,374.23	686,263.77	2,887,686.80
	NO_X	4,320.34	3,059.66	1,732.88	18,426.06	27,538.93
	SO_2	11,025.81	12.78	7.28	1.21	11,047.08
	CO	183.35	310.20	173.37	3,971.78	4,638.70

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Table 4.11: Average emission per unit electricity generation (kg/GWh) in thermal power plants from 2000 to 2009

Emission	Steam turbine	Gas turbine	Combine cycle	Diesel engine
CO_2	1,010,647	964,559	455,037	664,517
NO_X	4,131	4,955	1,900	17,842
SO_2	10,396	27	8.07	1.17
CO	185	140	184	3,846

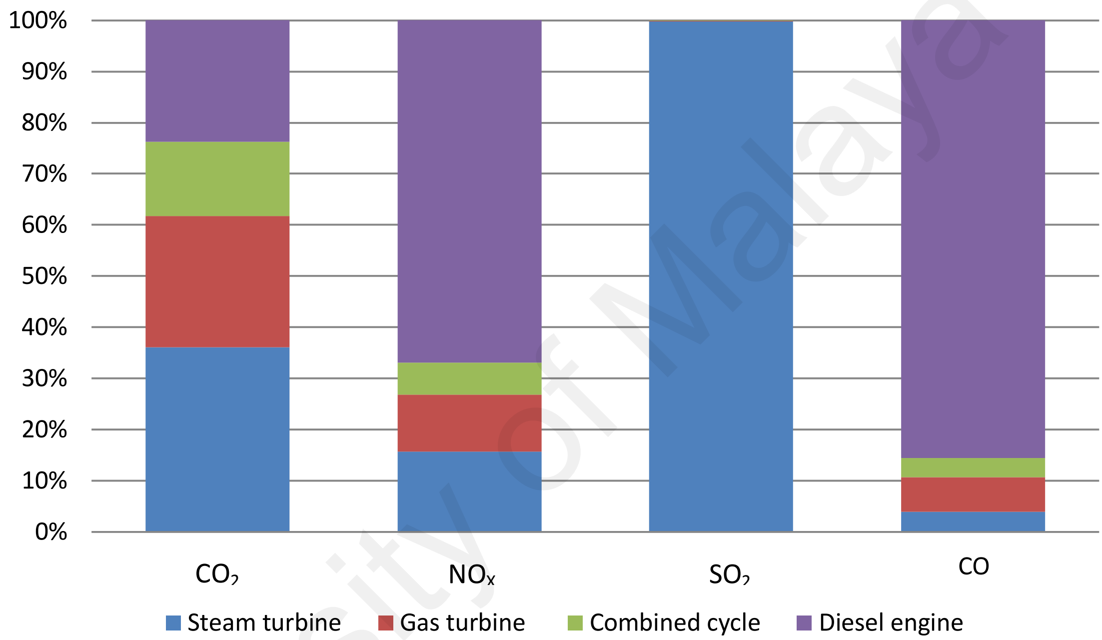

Figure 4.12: Comparison between thermal power plants with regard to emission

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4.2 Future power plant composition

4.2.1 Prediction of power plant nominal capacity

According to the planned power plant composition described in Section 2, the nominal capacities for each type of power plants are calculated and presented in Tables 4.12 and 4.13. Furthermore, Figure 4.13 shows the nominal capacities and their shares in new power plant composition in 2025. Figure 4.14 shows the pattern of nominal capacity composition from 2009 to 2025. This figure shows that there will be new types of power plant introduced into the power grid (four thermals, five renewable and nuclear power plant). It also shows that the share of thermal power plants will decrease from 85% to 72% in the new power plant composition in the future.

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Table 4.12: Nominal capacity prediction in Indonesian power plants from 2010 to 2025 in MW (Scenario 1)

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal	Diesel engine	Hydro-power	Others RE	Nuclear PP	Total
2010	13,158.32	3,537.24	8,771.59	2,442.50	2,980.63	3,520.35	1.06	262.50	34,674.19
2011	14,066.25	3,717.63	9,525.95	3,432.50	2,980.63	3,710.08	87.06	525.00	38,045.10
2012	15,036.82	3,907.23	10,345.18	4,422.50	2,980.63	3,899.81	173.06	787.50	41,552.73
2013	16,074.36	4,106.50	11,234.86	5,412.50	2,980.63	4,089.54	259.06	1,050.00	45,207.45
2014	17,183.49	4,315.93	12,201.06	6,402.50	2,980.63	4,279.27	345.06	1,312.50	49,020.44
2015	18,369.15	4,536.05	13,250.35	7,392.50	2,980.63	4,469.00	431.06	1,575.00	53,003.74
2016	19,636.62	4,767.38	14,389.88	8,382.50	2,980.63	4,658.73	517.06	1,837.50	57,170.31
2017	20,991.55	5,010.52	15,627.41	9,372.50	2,980.63	4,848.46	603.06	2,100.00	61,534.13
2018	22,439.96	5,266.06	16,971.37	10,362.50	2,980.63	5,038.19	689.06	2,362.50	66,110.27
2019	23,988.32	5,534.63	18,430.91	11,352.50	2,980.63	5,227.92	775.06	2,625.00	70,914.96
2020	25,643.51	5,816.89	20,015.97	12,342.50	2,980.63	5,417.65	861.06	2,887.50	75,965.71
2021	27,412.92	6,113.55	21,737.34	13,332.50	2,980.63	5,607.38	947.06	3,150.00	81,281.38
2022	29,304.41	6,425.35	23,606.75	14,322.50	2,980.63	5,797.11	1033.06	3,412.50	86,882.30
2023	31,326.41	6,753.04	25,636.93	15,312.50	2,980.63	5,986.84	1119.06	3,675.00	92,790.41
2024	33,487.93	7,097.44	27,841.71	16,302.50	2,980.63	6,176.57	1205.06	3,937.50	99,029.34
2025	35,798.60	7,459.41	30,236.09	17,292.50	2,980.63	6,366.35	1,291.06	4,200.00	105,624.65

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Table 4.13: Nominal capacity prediction in Indonesian power plants from 2010 to 2025 in MW (Scenario 2)

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power	Total
2010	13,602.68	3,720.54	8,925.14	1,334.96	3,294.05	3,890.44	34,767.81
2011	14,925.09	4,082.24	9,792.81	1,464.74	3,614.28	4,268.66	38,147.82
2012	16,301.13	4,458.61	10,695.67	1,599.78	3,947.51	4,662.22	41,664.92
2013	17,734.88	4,850.76	11,636.40	1,740.49	4,294.71	5,072.28	45,329.51
2014	19,230.72	5,259.89	12,617.86	1,887.29	4,656.94	5,500.09	49,152.80
2015	20,793.37	5,687.30	13,643.16	2,040.64	5,035.35	5,947.02	53,146.85
2016	22,427.91	6,134.37	14,715.64	2,201.06	5,431.18	6,414.51	57,324.67
2017	24,139.84	6,602.61	15,838.88	2,369.06	5,845.74	6,904.13	61,700.27
2018	25,935.06	7,093.63	17,016.78	2,545.25	6,280.48	7,417.57	66,288.77
2019	27,819.94	7,609.18	18,253.51	2,730.23	6,736.92	7,956.66	71,106.43
2020	29,801.35	8,151.12	19,553.57	2,924.68	7,216.74	8,523.35	76,170.82
2021	31,886.69	8,721.49	20,921.83	3,129.33	7,721.73	9,119.77	81,500.84
2022	34,083.93	9,322.47	22,363.50	3,344.97	8,253.82	9,748.19	87,116.89
2023	36,401.68	9,956.41	23,884.25	3,572.43	8,815.09	10,411.08	93,040.94
2024	38,849.21	10,625.85	25,490.15	3,812.63	9,407.79	11,111.09	99,296.72
2025	41,436.55	11,333.52	27,187.78	4,066.55	10,034.34	11,851.09	105,909.83

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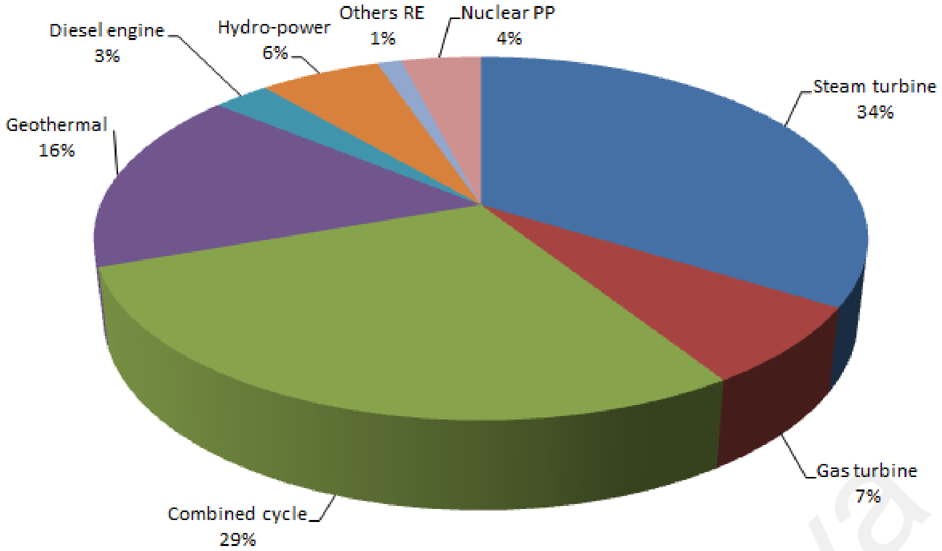

Figure 4.13: Nominal capacity (%) in Indonesian power plant composition in 2025 (Scenario 1)

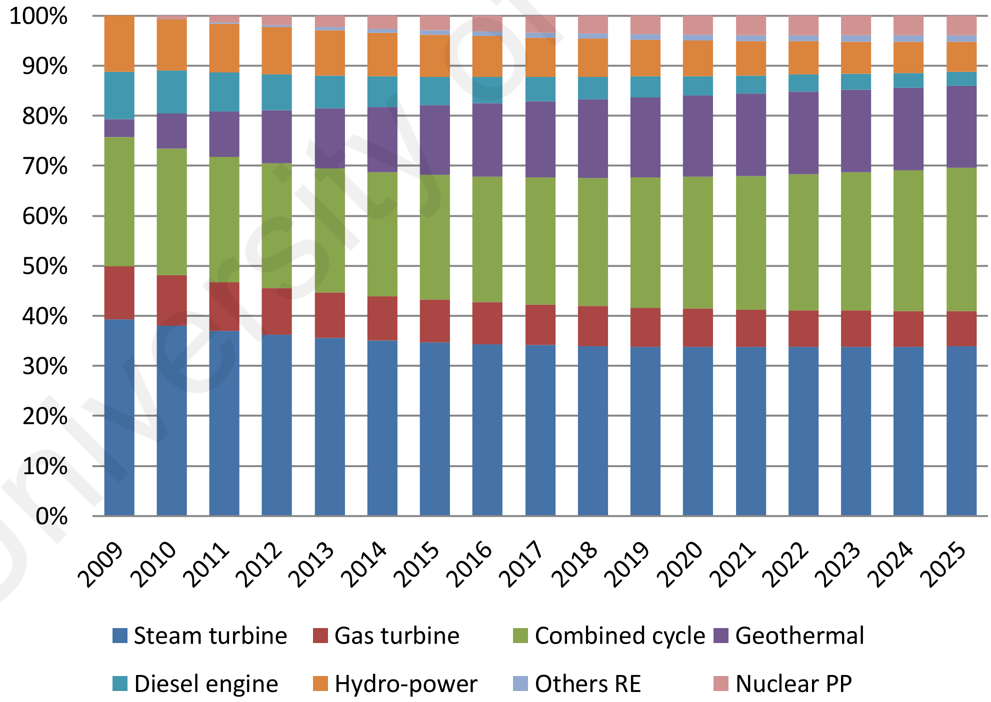

Figure 4.14: Pattern of nominal capacity for each type of power plants in Indonesian from 2009 to 2025 (Scenario 1)

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4.2.2 *Electricity generation prediction*

The potential electrical power generation was calculated using data from Table 4.12 together with Eq. (3.16) and data of average capacity factor calculated in Section 4.1.4. The prediction of electricity generation for both scenarios is presented in Tables 4.14 and 4.15.

Table 4.14: Electricity generation prediction in fossil power plants from 2010 to 2025 in GWh (scenario 1)

Year	Steam turbine	Gas turbine	Combined cycle	Diesel engine
2010	75,379	6,139	40,168	8,829
2011	80,580	6,453	43,623	8,829
2012	86,140	6,782	47,374	8,829
2013	92,083	7,128	51,448	8,829
2014	98,437	7,491	55,873	8,829
2015	105,229	7,873	60,678	8,829
2016	112,490	8,275	65,896	8,829
2017	120,252	8,697	71,564	8,829
2018	128,549	9,140	77,718	8,829
2019	137,419	9,606	84,402	8,829
2020	146,901	10,096	91,660	8,829
2021	157,037	10,611	99,543	8,829
2022	167,873	11,152	108,104	8,829
2023	179,456	11,721	117,401	8,829
2024	191,838	12,319	127,497	8,829
2025	205,075	12,947	138,462	8,829

Table 4.15: Electricity generation prediction in fossil power plants from 2010 to 2025 in GWh (scenario 2)

Year	Steam turbine	Gas turbine	Combined cycle	Diesel engine
2010	77,924	6,458	40,871	9,757
2011	85,500	7,085	44,845	10,706
2012	93,382	7,739	48,979	11,693
2013	101,596	8,419	53,287	12,721

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2014	110,165	9,129	57,782	13,794
2015	119,116	9,871	62,477	14,915
2016	128,480	10,647	67,388	16,087
2017	138,287	11,460	72,532	17,315
2018	148,571	12,312	77,926	18,603
2019	159,369	13,207	83,589	19,955
2020	170,719	14,148	89,543	21,376
2021	182,665	15,138	95,809	22,872
2022	195,253	16,181	102,411	24,448
2023	208,530	17,281	109,375	26,111
2024	222,551	18,443	116,729	27,866
2025	237,373	19,671	124,503	29,722

4.2.3 Potential fuel consumption

The potential consumption of all types of fuel in various types of power plants is calculated using Eq. (3.17) and the data of average fuel consumption per electricity generation in Table 4.5. Thus, the results of the potential fuel consumption in all types of power plants for each scenario for 2025 are presented in Table 4.16.

Table 4.16: Fuel consumption prediction in thermal power plants in each scenario in 2025

	Composition in 2009	New composition (scenario 1)	BAU (scenario 2)
Natural gas(Mm^3)	7,496.98	19,012.96	18,206.37
Diesel(ML)	6,820.32	16,205.83	21,426.33
Fuel oil (ML)	2,588.59	7,081.25	8,196.47
Coal (ktons)	21,604.46	51,096.53	59,143.76

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Table 4.16 shows that there will be an increase in consumption for all types of fuel in the first scenario by 153%, 137%, 173% and 136% for natural gas, diesel fuel, fuel oil and coal respectively. For the second scenario, the consumption of diesel fuel, fuel oil and natural gas increase up to 21,426.33 ML, 8,196.47 ML and 18,206.37 Mm^3 respectively. Whereas coal shows a significant increase to about 59,143.76ktons which is almost 3 times the amount of consumption back in 2009.

4.2.3 Emission prediction in 2025

Emissions in the year 2025 for the two different scenarios can be predicted using potential electricity generation and emissions per unit electricity generated from Indonesian power plants as shown by Eq. (3.18). The results for all scenarios are tabulated in Table 4.17 and presented in Figures 4.15 - 4.18 for CO_2, SO_2, NO_x and CO respectively.

Table 4.17: Emission in 2009 and emission prediction in each power plant and each scenario in 2025

Emission (tons)	Year (scenario)		
Power plant type	2009	2025(S1)	2025(S2)
CO_2 (Tons)			
Steam turbine	77,981,359	207,258,562	249,157,467
Gas turbine	6,430,615	12,488,214	18,974,077
Combined cycle	16,804,001	63,005,292	56,653,294
Diesel engine	7,520,078	5,866,836	19,750,802
Total	108,736,054	288,618,904	344,535,641
NO_X (Tons)			
Steam turbine	323,425	847,247	980,681
Gas turbine	26,539	64,156	97,476
Combined cycle	69,601	263,137	236,608
Diesel engine	201,913	157,523	530,305
Total	621,478	1,332,064	1,845,071

SO_2 (Tons)			
Steam turbine	825,403	2,131,904	2,467,659
Gas turbine	111	343	522
Combined cycle	292	1,117	1,004
Diesel engine	13	10	34
Total	825,820	2,133,375	2,469,221
CO (Tons)			
Steam turbine	13,726	37,854	43,816
Gas turbine	2,691	1,806	2,745
Combined cycle	6,963	25,518	22,945
Diesel engine	43,523	33,954	114,308
Total	66,903	99,134	183,816

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CO_2 emission

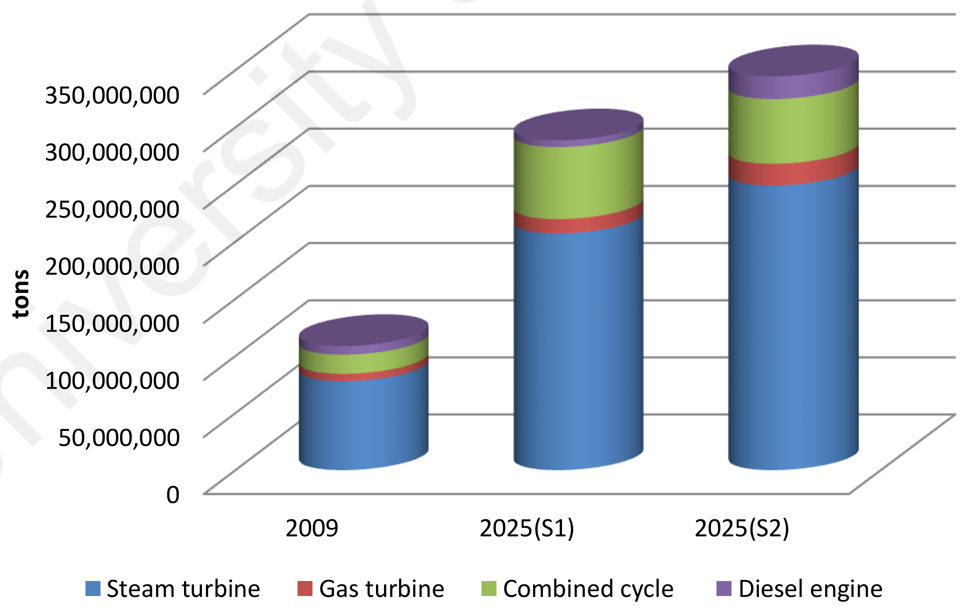

Figure 4.15: CO_2 emission for each type of power plants in 2009 and two scenarios in 2025

NO_X emission

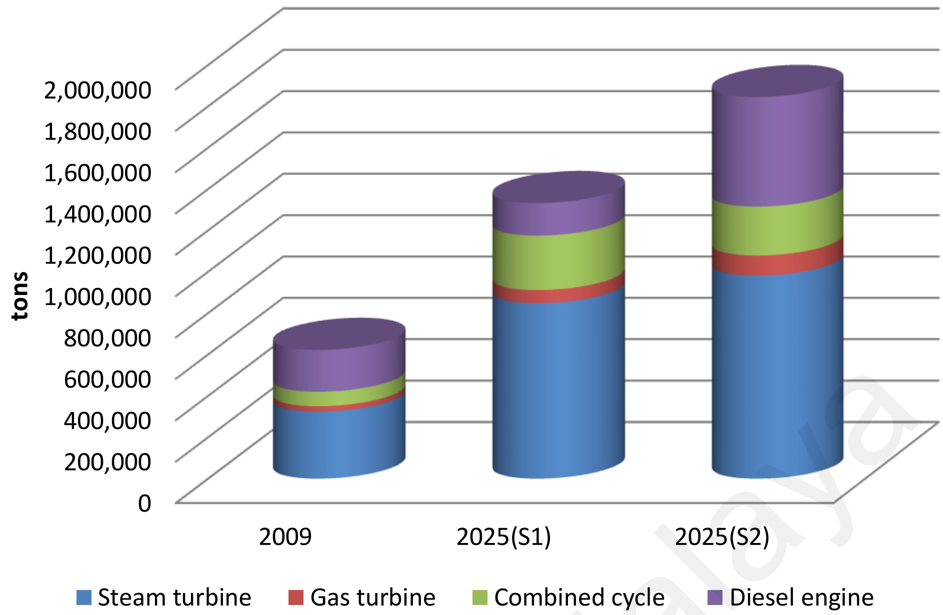

Figure 4.16: NO_X emission for each type of power plants in 2009 and two scenarios in 2025

SO_2 emission

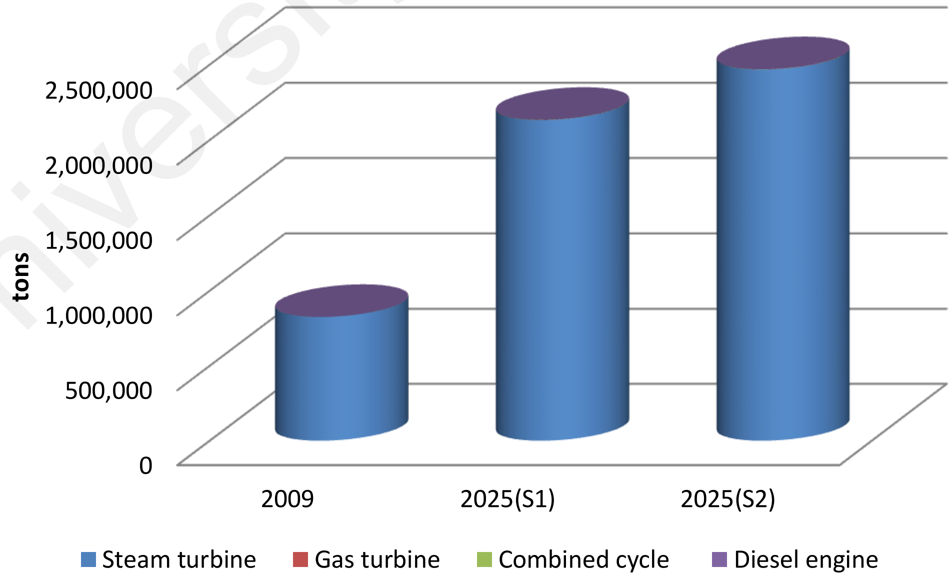

Figure 4.17: SO_2 emission for each type of power plants in 2009 and two scenarios in 2025

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CO emission

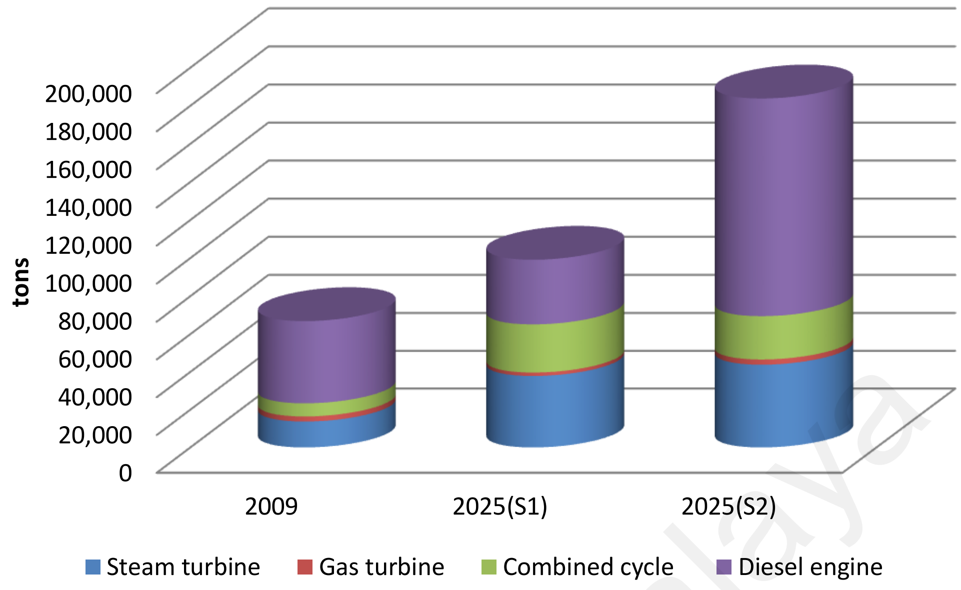

Figure 4.18: CO emission for each type of power plants in 2009 and two scenarios in 2025

4.3. Prospect of coal and clean coal technology in Indonesia

Coal is one of the most important Indonesia's commodity exports. Driven by high demand in Asia's market especially India and China, Indonesian coal industry has grown at an astonishing rate. Located near the surface for easy exploration makes Indonesian coal cheaper compared to other exporter around the world. The prospect of coal is expected to remain good in the future. When Indonesian coal importer countries experience cheap electricity price due to coal utilization in power generation, Indonesia is still using oil sources for electricity generation. Although Indonesia is the largest coal exporter, the country only consumes 20% of the country's coal output for power generation and industry.

In this current state, even though Indonesia has abundant of renewable energy sources, political and economical conditions of the country are the obstacle to develop the renewable energy. Low income of Indonesian people followed by current energy

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shortage makes coal the only option for power generation by ignoring the impact to the environment. The comparison of electricity production cost in Indonesia with different sources is presented in Table 4.18 (Meryana, 2012).

Table 4.18: Electricity production cost by various type of fuel

Type of fuel	Production cost ($/kWh)
Coal	$0.06/kWh
Natural gas	$ 0.05/kWh
Geothermal	$ 0.12/kWh
Petroleum (fuel oil, diesel)	$ 0.35/kWh

It can be seen electricity production cost using coal is cheaper compare to fuel oil, diesel or geothermal, but a little bit higher than using natural gas. However, the unstable supplies of natural gas worsen the energy shortage. During 2009-2011, Indonesian government suffered a loss about $ 3.76 billion due to gas supply delays. This condition pushes the "electricity state company" to use diesel (Purwanto, 2012).

The government plan to increase the share of coal up to 33% in 2025 by construct coal-fired power plant in near future will lead to environmental destruction. Indonesian government should take an action to minimalize the problems. One of the best ways to reduce CO_2 emission from coal-fired power plant is by adopted clean coal technology. However, clean coal technology are not yet main stream as the country struggles to meet the most basic demands for power across the entire country. Moreover, extra cost of clean coal technology is also become consideration for government makes clean coal technology and environmental destruction are not yet a priority. Although it is not an easy task, future plan is needed to cut the CO_2 emission from coal-fired power plant.

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Simple calculations have been made to estimate CO_2 reduction by using clean coal technology. The total emission of steam turbine by applying various clean coal technology in Indonesian power plants was calculated using Eq. (3.18) and Tables 3.9. The comparison of total emission of various clean coal technology for both scenario is presented in Table 4.19 and illustrated in Figure 4.19.

Table 4.19: CO_2 prediction from coal in thermal power plants by using clean coal technology in each scenario in 2025 in tons

	New composition (scenario 1)	BAU (scenario 2)	CO_2 reduction (%)
Conventional	181,581,940	210,179,240	-
SC	140,495,179	162,621,734	22.62
USC	110,026,345	127,354,370	39.4
PFBC	121,567,570	140,713,220	33.05
IGCC	110,487,994	127,888,724	39.15

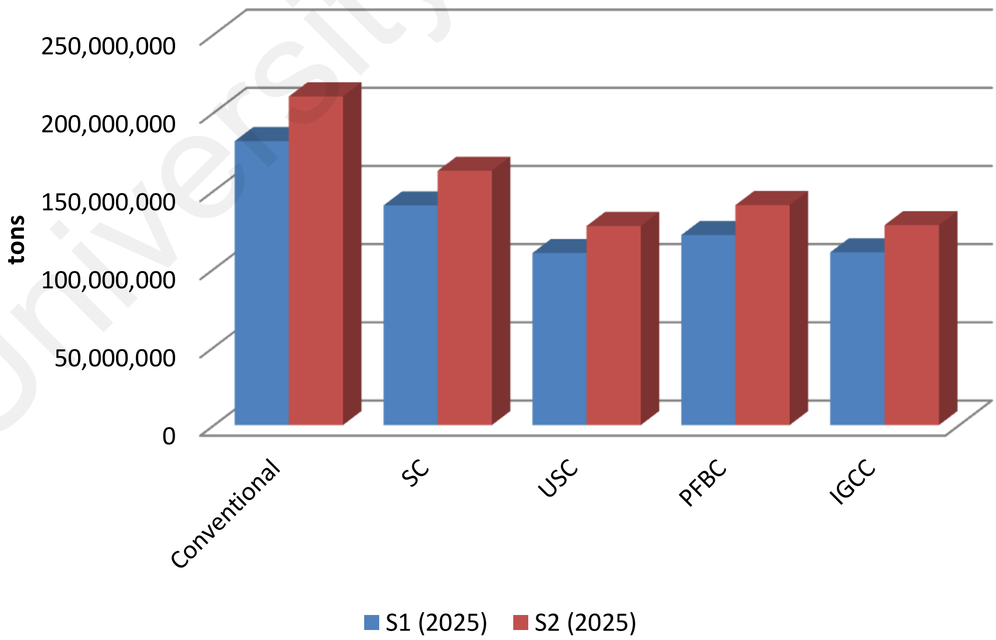

Figure 4.20: CO_2 emission prediction for clean coal technologies in two scenarios in 2025

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1. Conclusions

The calculation shown clearly if the country does not do something to increase energy security for energy sustainability, the country will face energy shortage in the future. The government tries to introduce new type of power plant such as nuclear energy, wind energy, biomass power plant and solar energy. This diversification concept will help the country not only change the structure of energy consumption that always weighted on fossil fuel, but also give a significant effect into environment. It's predicted that the country will need at least 105,000 MW by 2025. The study tries to calculate the consumption of fuel and emission that emitted from electricity generation with two different scenarios. The study shows that in 1st scenario, the consumption of fuel will increase up to 19,012.96 Mm^3, 16,205.83 ML, 7,081.24 ML and 51,096.53 ktons for natural gas, diesel fuel, fuel oil and coal respectively. For the 2nd scenario, the consumption of diesel fuel, fuel oil and natural gas increase up to 21,426.33 ML, 8,196.47 ML and 18,206.37 Mm^3 respectively. Whereas coal shown a significant increase to about 59,143.76 ktons. This study also indicates if power plant composition as planned by government, CO_2 emission will be reach 288,618,904 tons which lower compare to 344,535,641 tons by 2nd scenario. In the end of the study, the scenario to develop clean coal technology to reduce CO_2 emission in steam turbine is utilized. The result show by utilizing SC, USC, PFBC and IGCC, CO_2 could be reduce up to 22.62%, 39.4%, 33.05 and 39.15% respectively.

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5.2. Recommendation

Clean coal technologies are not yet main stream as the country struggles to meet the most basic demands for power across the entire country. The country should have a plan in the future to cut the CO_2 emission from coal-fired power plant. However, coal only short term solution for energy crisis. As non-renewable energy source, coal will be depleted someday. Therefore, the country should fully utilize the potential of renewable energy in Indonesia.

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A review on energy scenario and sustainable energy in Indonesia

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ABSTRACT

The global energy consumption is likely to grow faster than the population growth. The fuel consumption was growing from 6630 million tons of oil equivalents (Mtoe) in 1980 to 11,163 Mtoe in 2009. This projected consumption will increase 1.5% per year until 2030 and reach 16,900 Mtoe and the main drivers of this growth are mostly developing countries in Asia. Indonesia is one of the developing countries and energy supply is an important factor for all-around development. The country's energy consumption still depends on non-renewable energy such as crude oil, coal and natural gas as sources of energy. Utilization of fossil fuel continuously contributes to huge amount of greenhouse gases emission that leads to climate change. Facing such an unfavorable situation, the government of Indonesia prioritizes on energy supply securities by diversification of energy resources. The energy mixes in Indonesia based on five main resources; these are crude oil, natural gas, coal, hydropower, and renewable energy. Although the country encourages utilizing renewable energy, the contribution is only around 3%. Considering natural condition and geography, this country is blessed with great potential of renewable energy such as solar energy, wind energy, micro hydro and biomass energy. Noting the potential of renewable and sustainable energy resources in the country, the government must pay more attention on how to utilize it. Many efforts have been done to promote renewable energy such as to create energy policy and regulations, yet it still did not give any satisfactory result. Government, non-government agencies and the public should take a more proactive step to promote and use renewable energy in order to achieve the secure and environmentally sustainable energy resources.

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A review on the pattern of electricity generation and emission in Indonesia from 1987 to 2009

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ABSTRACT

The level of energy demand plays a fundamental role in today's society. It is a vital input in supporting the physical and social development of a country, as well as national economic growth. Looking at the energy demand scenario in present time, the global energy consumption is likely to grow faster than the population growth across the world. Like any other energy sectors, electricity demand has significantly increased in Indonesia over the past years. Currently, there are six types of power plants in the country. The main sources of electrical energy are generated using the gas turbines, steam turbines, combined cycles, geothermal, diesel engine and hydro-powers. Most of Indonesia's power plants are using fossil fuel for electricity generation. Substantial growth in domestic energy demand, however, would be a major challenge for Indonesia's energy supply sector in the future. Over the past decade, thermal power plants generated about 86.69% of electricity and about 13.31% was generated by renewable energy such as hydro-power and geothermal in 2009. The purpose of this study is to chronicle and show a clear view of 23 years trend of Indonesia's electricity generation industry. Furthermore, the capacity of power generation installed and electricity generation from 1987 to 2009 has been gathered for this study. The total pollutant emissions and emission per unit electricity generation for each type of power plants have been also calculated using emission factors. Also, the pattern of electricity generation and emission has been presented. The results show that the implementation and contribution of combined cycle power plants should be increased together with renewable energy and natural gas which are recommended to reduce greenhouse gas emission.

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Contents

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