Songklanakarin J. Sci. Technol.
32 (1), 81-89, Jan. - Feb. 2010

Songklanakarin Journal
of Science and Technology
http://www.sjst.psu.ac.th

Original Article

The hidden costs of fossil power generation in Indonesia: A reduction approach through low carbon society

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Received 10 July 2009; Accepted 1 January 2010

Abstract

Energy production and consumption is always accompanied with environmental and societal issues. Electricity as one final energy form plays an important role in people's activities. However, the electric utilities have focused on producing electricity in abundance and with an affordable price. The production of electricity results in undesirable emissions and environmental effects called externalities. This paper assesses the externality cost of electricity production in Indonesia by using the life cycle inventory analysis approach. In 2025, the results show that the total external costs according to the government plan are 42 billion US$. In addition, low carbon society behavior will be introduced into the Indonesian society to reduce the externality cost in the long term Indonesian electricity expansion planning. The results of low carbon society actions show that in the long term the Indonesian electricity expansion planning of 34.6 TWh of electricity demand and 7.3 GW of installed capacity can be reduced from these actions. Finally, at the end of the period, these actions are successful, and reducing the total external cost by 2 billion US$.

Keywords: electricity production, life cycle inventory, externalities, low carbon society.

1. Introduction

For most of its history, the electrical utility sector has focused on producing abundant and cheap electricity with the assistance of regulators and politicians, who subsidized all forms of energy to shield consumers from the true costs of the extraction of energy raw materials, and from the real costs of energy generation, distribution and use (Sovacool, 2009). The production of electric power involves a number of undesirable side effects, for example, the acidification caused by the emissions of sulfur dioxide from fossil-fueled power production. These impacts may be local or geographically widespread (Sundqvist, 2004). Many electricity companies endorse centralized fossil and nuclear power plants since they are able to pass most of the costs from these polluting power systems directly onto consumers and the society at large. In contrast, renewable energy provides public benefits that are not yet priced in the electricity market (Sovacool, 2009). In the economic literature those types of effects are termed externalities. The external costs are defined as those costs incurred in relation to health and environment and they are quantifiable, but not built into the cost of electricity production nowadays (Chatzimouratidis and Pilavachi, 2009). Thus, an external cost arises, when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted or compensated for (ExternE, 2005). All technologies for generating electricity are accompanied by externalities (ATSE, 2009).

Since Indonesia dependence on fossil fuel is going to increase over the next years according to the government's

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intention to use more coal in future electricity expansion, the study of the external impacts in terms of climate and health damages of fossil-fueled power plants need to be conducted. In this paper, the external costs are investigated not only for coal-fueled power plants but also for other types of fossil-fueled power plants in Indonesia. The fossil-fueled power plant types are steam power plants using coal, oil, and natural gas, combined cycle power plants using oil and natural gas, gas turbine power plants using oil and natural gas, and diesel power plants. The emissions from each type of fossil-fueled power plants will be obtained by using the life cycle inventory analysis approach. This method is powerful to analyze environmental emissions throughout a product's life.

2. Overview of Indonesia

Indonesia is the largest archipelago in the world. It consists of over seventeen thousand islands. The total population was 222 million people in 2006, which is the fourth largest population in the world after China, India, and USA. Indonesia consists of five main islands: Java, Sumatra, Kalimantan, Sulawesi, and Papua. Java is the most densely populated and developed island among these five, followed by Sumatra. The total population of Java Island is approximately 65% of the total population of the country.

Based on the Electricity Law no. 15/1985, the electricity supply activities in Indonesia include generation, transmission, and distribution with respect to the different geographical locations. Electricity generation in Indonesia is under state authority and conducted by the electricity state-owned enterprise or PLN (*Perusahaan Listrik Negara*). In 2006, the total installed capacity in the country was 30 GW (CDI-EMR, 2007). Nearly 70% of it was located in the Java-Madura-Bali (Jamali) islands (DEMR, 2006). The Jamali area consumed almost 79% of total electricity production. The Jamali electrical generation capacity is a mix that consists of 43% of coal, 39% of natural gas, 13% of hydropower, 4% of geothermal power, and the rest is oil (CDI-EMR, 2007). The transmission and distribution (T&D) losses in the Jamali system were slightly higher than the national losses. In 2006, the T&D losses in the Jamali system were 15%, consisting of technical and non technical losses with 11% and 4%, respectively. In this paper, the electricity system in Jamali is selected to analyze the external costs of its power generation.

Currently, the Indonesian government policy is to accelerate the energy diversification for electricity generation from oil to the other resources before 2012, mainly to promote coal utilization in the power sector. The total coal power plant capacity that would be installed is 10,000 MW, where in the Jamali system alone 6,650 MW would be installed.

3. Life cycle inventory

In order to analyze the environmental load of any industrial activity, like the electric power generation, the life cycle is clearly an essential point of view (Widiyanto *et al*., 2003). The concept of life cycle assessment (LCA) is to evaluate the environmental effects associated with any given activity from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth (Vigon *et al*., 1994), or well known as "cradle to grave" assessment. This technique has three components: inventory analysis, impact analysis, and improvement analysis.

The development of the life cycle inventory (LCI) data of the power generation plays a vital role on the LCA. Widiyanto *et al*. (2003) has developed the LCI for the Indonesian power generation and electricity grid mix. The study has considered the indirect and direct emissions. The indirect emission analyses, for example, the coal use, the coal mining, and the coal transportation. The direct emissions analysis calculates the average of the standard emissions of power generation pollutants and traces from the grid system. The environmental loads needed to be considered here are carbon dioxide (CO_2) due to its global warming potential, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate material (PM_{10}) due to their health damage. Furthermore, the LCI data of direct emission of power generation will be used as an input parameter in this study. It is assumed that the efficiency of new power plants is similar with the existing power plants; this is due to the unavailability of the life cycle inventory (LCI) data on new power plants.

The fossil-fueled power plant types in this study are categorized as following:

1. Coal fired steam power plant

   The generation of electricity uses steam to spin the turbine in order to produce electricity. The coal is used as the fuel to produce steam. The installed capacity of this type in Indonesia is 6,650 MW.
2. Oil fired steam power plant

   This plant uses oil as the fuel to generate steam. The existing capacity of these power plants is 900 MW.
3. Natural gas fired steam power plant

   The natural gas is used as the fuel to produce steam, similar to oil fired steam power plants. The installed capacity of this power plant type is 900 MW.
4. Natural gas combined cycle power plant

   A gas turbine generator generates electricity and the waste heat from the gas turbine is used to produce steam to generate additional electricity. This plant uses natural gas as the fuel. The existing capacity is 3,662 MW.
5. Oil combined cycle power plant

   Similar to natural gas combined cycle power plants, but this plant uses oil as the fuel. The installed capacity of this power plant type is 2,923 MW.
6. Gas turbine (natural gas) power plant

   This type of plant uses natural gas through combustion to produce electricity. The existing capacity of this power plant type is 1,673 MW.
7. Gas Turbine (diesel)

   In this type of power plant, the combustion uses diesel as fuel to generate electricity. Total existing capacity of these power plants is 2,030 MW.

8. Diesel power plant

A diesel engine coupled with a generator is used to convert mechanical energy to electrical energy. The current installed capacity of this power plant is 76 MW.

4. Hidden damage

4.1 Climate damage

The emissions from the power sector become the main focus since it is the main contributor of gases contributing to global warming. The major global warming potential that comes from the power sector is the carbon dioxide emission. In order to be able to assess and compare the external effects with each other and with costs, it is advantageous to transform them into a common unit. Thus converting external effects into monetary units result in external costs. The characteristics of damage cost of the CO_2 emissions associated with a particular generation technology, in terms of a unit of power generated, is given by:

$$CO_2\ Damage\ \cos t(\$/MWh) = CO_2\ emissions(kgCO_2/MWh) \times Unit\ damage\ \cos t(\$/kgCO_2) \quad (1)$$

The unit damage cost will be adopted from ExternE (2005), where the value of unit damage is €19/tonnes of CO_2. The exchange rate adopted for this purpose and used consistently through this paper is €1 = \$1.4. However, the inflation rate has not been considered in this paper, so that the unit damage is US dollar currency is for 2005. This number will be used here as a figure for calculating the climate damage costs for emissions from power plants in Indonesia.

The gas turbine power plant with diesel as the fuel is the biggest CO_2 producer among all power plants, about 1.23 kg of CO_2/kWh. This is due to the low efficiency process of the power plant. Typically, the efficiency of a gas turbine power plant in Indonesia is 22%. Coal fired steam power plants are on the second place with 0.922 kg CO_2/kWh. The lowest CO_2 producer is the natural gas combined cycle power plant, with 0.407 kg CO_2/kWh (see details in Table 1). Then CO_2 emissions are converted into damage costs by using Equation 1, the results are presented in Table 1. The highest damage cost of 3.27 Cents/kWh is related to the gas turbine power plant with using diesel as fuel. In the second place is the coal fired steam power plant with 2.45 Cents/kWh. The lowest damage cost comes from the natural gas combined cycle power plant, which is about 1.08 Cents/kWh.

Table 1. Measured CO_2 direct emissions and calculated CO_2 damage costs of fossil fuel power plants in Indonesia.

Power plant	CO_2 (kg/kWh)	Damage cost (Cents/kWh)
Coal Fired Steam	922	2.45
Oil Fired Steam	735	1.96
Natural Gas Fired Steam	503	1.34
Oil Combined Cycle	620	1.65
Natural Gas Combined Cycle	407	1.08
Gas Turbine (Natural Gas)	726	1.93
Gas Turbine (Diesel)	1,230	3.27
Diesel Generator	772	2.05

Source: Widiyanto *et. al.* (2003) and authors calculations

4.2 Health damage

Unlike damage costs for CO_2 emissions, health damage costs are site and region specific (ATSE, 2009). Health impacts are especially important because in terms of costs they contribute by far the largest part of the total costs, apart from costs related to global warming. A consensus has been emerged among public health experts that air pollution, even at current ambient levels, aggravates morbidity (especially respiratory and cardiovascular diseases) and leads to premature mortality (ExternE, 2005). The emissions considered on health damage in this paper are sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate material (PM_{10}) since those are the main emissions that are damaging the health.

4.2.1 SO_2 Emissions

Sulfur is generated by combustion of coal and oil since it often contains sulfur compounds. In the atmosphere, sulfur is a major acidifying pollutant and related to the cause of acid rain. Acid rain causes deterioration of cars, buildings, and historical monuments and causes lakes and streams to become acidic and unsuitable for many fishes. Sulfur dioxide (SO_2) reacts with other chemicals in the air to form tiny sulfate particles. When these are breathed, they gather in the lungs and therefire they are associated with respiratory symptoms and diseases, like difficulty in breathing, and premature death. The damage cost of the SO_2 emissions in terms of a unit of power generated is given by:

$$SO_2\ Damage\ \cos t(\$/MWh) = SO_2\ emissions(kgSO_2/MWh) \times Unit\ damage\ \cos t(\$/kgSO_2) \quad (2)$$

In terms of SO_2 emissions from power generation, the biggest SO_2 producer is the oil fired steam power plant with 1.17×10^{-2} kg of SO_2/kWh. The reason for that is that oil as the fuel for power plant contains significant sulfur compounds. The coal fired steam power plants are in the second place with 4.3×10^{-3} kg of SO_2/kWh. Meanwhile, for power plants that use natural gas as fuel, the SO_2 emissions are negligible since the amount of emissions are not significant (see details in Table 2).

Table 2. Measured SO_2, NO_x, PM_{10} direct emissions of fossil fuel power plants in Indonesia.

Power plant	SO_2(g/kWh)	NO_x(g/kWh)	PM_{10}(mg/kWh)
Coal Fired Steam	4.36	4.39	670
Oil Fired Steam	11.7	2.32	288
Natural Gas Fired Steam	negligible	2.26	negligible
Oil Combined Cycle	1.37	1.99	57.8
Natural Gas Combined Cycle	negligible	1.79	negligible
Gas Turbine (Natural Gas)	negligible	2.67	negligible
Gas Turbine (Diesel)	2.46	4.56	104
Diesel Generator	2.01	8.64	324

Source: Widiyanto *et. al.* (2003)

4.2.2 NO_x Emissions

Nitrogen oxides (NO_x) cause a wide variety of health and environmental impacts because of various compounds and derivatives in the NO_x family, including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide. NO_x is formed when fuel is burned at high temperatures, for example in a combustion process. Human health concerns include effects on breathing and the respiratory system, damage to lung tissue, and premature death. Small particles penetrate deep into sensitive parts of the lungs and can cause or worsen respiratory diseases, such as emphysema and bronchitis, and aggravate existing heart disease (EPA, 1998). Furthermore, NO_x is also one of the acidifying pollutants. The damage cost of the NO_x emissions in terms of a unit of power generated can be calculated by following formula:

$$NO_x\ Damage\ \cos t(\$/MWh) = NO_x\ emissions(kgNO_x/MWh) \times Unit\ damage\ \cos t(\$/kgNO_x) \quad (3)$$

The power plant with a diesel generator is the biggest NO_x producer among all power plants, with around 8.64×10^3 kg of NO_x/kWh. In the second place is the gas turbine power plant with 4.39×10^{-3} kg of NO_x/kWh, while a natural gas combined cycle power plant is the lowest NO_x emissions producer, with 1.79×10^{-3} kg of NO_x/kWh (see details in Table 2).

4.2.3 PM_{10} Emissions

Particulate matter 10 (PM_{10}) consists of particles with less than 10 micrometers in size. PM_{10} pose the greatest problems, since they can get deep into the lungs, and some may even get into bloodstream, causing premature death of people with heart or lung disease, and leading to aggravated asthma. Particulate matter can be directly emitted or can be formed in the atmosphere when gaseous pollutants such as SO_2 and NO_x react to form fine particles. The damage costs of the PM_{10} emissions in terms of a unit of power generated, is given by:

$$PM_{10}\ Damage\ \cos t(\$/MWh) = PM_{10}\ emissions(kgPM_{10}/MWh) \times Unit\ damage\ \cos t(\$/kgPM_{10}) \quad (4)$$

The biggest producers of PM_{10} are the coal fired steam power plants, with around 6.7×10^{-4} kg of PM_{10}/kWh, followed by diesel generator power plants with 3.24×10^{-4} kg of PM_{10}/kWh. The PM_{10} emissions of natural gas fired steam, natural gas combined cycle, and gas turbines with fuel natural gas are negligible since natural gas combustion produces low PM_{10} emissions. Details of PM_{10} emissions in power plants are presented in Table 2.

4.2.4 Health Damage Costs

The health damage is the major driving factor of external cost since it has a close relation with human activities. When investment decisions are made, about which power plant technology has to be used or where to build a power plant, it is evident that it would be of interest for the society to take environmental and health impacts into account and include the external effects into the decision process (ExternE, 2005). The unit health damage cost will be adopted from ExternE update (2005). The values of a unit damage are 4.2-11 €/kg, 5.4-15 €/kg, and 25-72 €/kg for NO_x, SO_2, and PM_{10} emission, respectively. The damage costs of SO_2, NO_x and PM_{10} are calculated by using equation (2), (3), and (4) respectively.

In terms of SO_2 emission damage costs, the oil fired steam power plant shows the highest costs among the others with 17.32 Cents/kWh and followed by the coal fired steam power plant with 6.45 Cents/kWh. The diesel generated power plant shows the highest damage costs in terms of NO_x pollutants, with 9.19 Cents/kWh. The gas turbine power plant with fuel diesel in on the second place of NO_x damage costs with 4.85 Cents/kWh. Then, for PM_{10} damage costs, the coal fired steam power plant shows higher damage costs than the other power plants, which is about 4.55 Cents/kWh. Meanwhile, the diesel generated power plant is on the second place with 2.20 Cents/kWh. Details of the health damage

Table 3. Calculated health damage costs of fossil power plants.

Power plant	SO_2 Damage (Cents/kWh)	NO_x Damage (Cents/kWh)	PM_{10} Damage (Cents/kWh)
Coal Fired Steam	6.45	4.67	4.55
Oil Fired Steam	17.32	2.47	1.96
Natural Gas Fired Steam	negligible	2.40	negligible
Oil Combined Cycle	2.03	2.12	0.39
Natural Gas Combined Cycle	negligible	1.90	negligible
Gas Turbine (Natural Gas)	negligible	2.84	negligible
Gas Turbine (Diesel)	3.64	4.85	0.71
Diesel Generator	2.97	9.19	2.20

costs are presented in Table 3. If we accumulate the total health damage costs, the oil fired steam power plant has the highest damage costs among all other power plants, with around 21.74 Cents/kWh. The coal fired steam power plant is on the second place with 15.67 Cents/kWh. On the third place is the diesel generated power plant with 14.37 Cents/kWh. It is clear that the emissions from coal oil fired power plants are dangerous.

5. Long-term electricity planning in Indonesia

In Indonesia the Department of Energy and Mineral Resources (DEMR) is responsible for the electricity planning. In 2006, the DEMR has launched the National Electricity Master Plan for 2006-2026 (DEMR, 2006). However, the master plan only roughly projected the electricity demand and installed capacity without mentioning the primary energy and fuels sources needed to fulfill the electricity demand for the planning horizon. Therefore, a comprehensive "business as usual" (BAU) scenario needs to be developed in order to show the details of the future electricity expansion plan.

This study also develops the BAU scenario based on the government planning and intention as mentioned in the National Electricity Master Plan 2006-2026. All assumptions and data required are also based on the National Electricity Master Plan 2006-2026 and the handbook of Indonesia's energy economic statistics (CDI-EMR, 2007). The BAU scenario is investigated by employing the "Long-range Alternatives Energy Planning" (LEAP) model. The LEAP is a scenario-based energy-environment modeling tool, which is developed by the Stockholm Environment Institute. The main concept of LEAP is the end-use driven scenario based analysis. The scenarios are based on comprehensive accounting of how energy is consumed, converted, and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology and other factors. In this study, the BAU scenario started from 2006 as the base year. The population growth rate is assumed to be 1% per year and the electrification ratio expected is assumed to be 93% in 2026. The demand sector was divided into four categories; household, commercial, public, and industry. The electricity demand in 2006 and expected average growth rate per 5 years are 7.6%, 8.3%, 10.8%, and 3.7% respectively. The efficiency of transformation and distribution branches will be calculated by using losses. In 2006, the losses were 15% and assumed to be reduced by 1% per five years.

Figure 1 presents the electricity demand in the BAU scenario in 2006 where the industrial sector consumed about 39 TWh or 43% of total electricity consumption, while the household sector consumed around 32 TWh. In the end of the period the demand will increase over three times than that in the base year; the household sector will take the largest share of electricity consumption by consuming 131.6 TWh or about 42% of total electricity consumption. The industrial sector will take the next place by consuming about 79.4 TWh.

Figure 2 shows the power installed capacity in the BAU scenario, where in the end of the period, the capacity is increasing over three times than compared to the base year. Total electricity generation in the BAU scenario is nearly 66 GW in 2025, increasing from 19.5 GW in 2006. The rapid electricity capacity growth is due to the high growth rate of demand. The largest electricity production plants are the coal fired steam power plants, which is 49.6 TWh in the base year and 201.4 TWh in the end of period. The second is the natural gas combined cycle power plant with 14.1 TWh in the base year and 81.1 TWh in 2025. Table 4 presents electricity production figures for each power plant type.

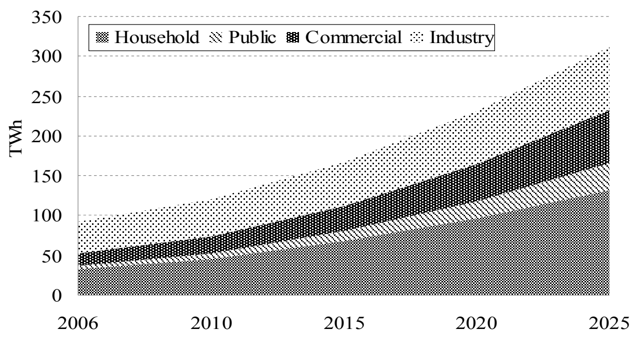

Figure 1. Electricity demand in Jamali system in the BAU scenario.

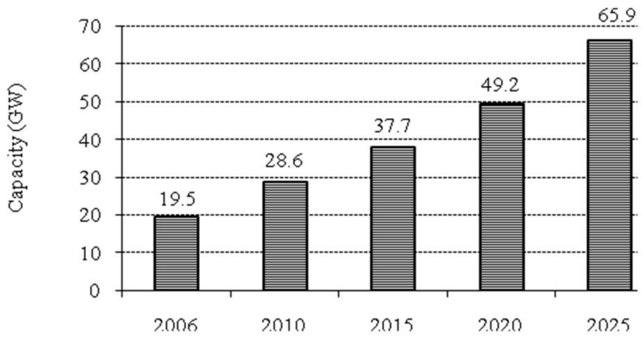

Figure 2. Installed capacity in the BAU scenario.

Table 4. Electricity generation of different power plant types in selected years.

Power Plant	Production (TWh)	
	2006	2025
Coal Fired Steam	49.6	201.4
Oil Fired Steam	3.8	4.7
Natural Gas Fired Steam	3.8	4.7
Oil Combined Cycle	9.6	13.1
Natural Gas Combined Cycle	14.1	81.1
Gas Turbine (Natural Gas)	2.4	4.0
Gas Turbine (Diesel)	3.7	0.3
Diesel Generator	0.1	0
Nuclear	0	26.8
Geothermal	6.7	9.4
Hydro	4.6	9.6
Total	98.3	355

The total damage cost of fossil fuel based electricity production in Indonesia, both for climate and health damage, is calculated in Table 9. In 2006, the total damage costs are 11.6 billion US$. Where almost 77% of the total damage comes from the coal fired steam power plants. In 2025, the total damage costs are increasing almost four times than compared to the base year, which is around 42 billion US$. The coal fired steam power plants will be the biggest damage cost contributors with 36 billion US$ or 89% of total damage costs, while the second are the natural gas combined cycle power plants (see Table 5).

6. Indonesian low carbon society

6.1 The low carbon society

The increasing people's awareness related to global warming issue lead many governments to introduce ways of emission reduction. The global emissions of greenhouse gases could give serious effects not only on climate change but also on the natural environment and human society.

Table 5. Total damage cost of fossil power plants in the BAU scenario.

Power Plant	Damage cost (10^6 USD)	
	2006	2025
Coal Fired Steam	8,990	36,501
Oil Fired Steam	893	1,110
Natural Gas Fired Steam	141	175
Oil Combined Cycle	594	809
Natural Gas Combined Cycle	420	2,419
Gas Turbine (Natural Gas)	117	193
Gas Turbine (Diesel)	460	34
Diesel Generator	16	-
Total	11,631	41,241

Those backgrounds are guiding to a new concept called "Low Carbon Society". A Low Carbon Society (LCS) can be described as (CGER, 2006):

1. Takes actions that are compatible with the principle of sustainable development, ensuring that the development needs of all groups within the society are met.
2. Makes an equitable contribution towards the global effort to stabilize atmospheric concentrations of carbon dioxide and other greenhouse gases at a level that will avoid climate change through deep cuts in global emissions.
3. Demonstrates high levels of energy efficiency and uses low carbon energy sources and production technologies.
4. Adopts patterns of consumption and behavior that are consistent with low levels of GHG emissions.

In June 2008 the Japanese government through the Prime Minister Fukuda released its new vision "Towards a Japan Low-Carbon Society (LCS)". The Japan Low-Carbon Society project is projected to reduce 70% of the CO_2 emissions by 2050 below the 1990 level. The government aims to achieve the target through innovative technologies, financial tools, and efficiency improvements (JLCSST-2050, 2008).

6.2 Introduction of low carbon society in the Indonesian Household Society

Many energy consuming devices are used in homes to make life and work more comfortable and efficient. The efficiency of lighting, cooling devices, heating devices, computer and entertainment devices in the household sector is increasing significantly over the last years. However, these newly developed efficient devices will not be widely used unless users actively adopt them. To support such low-carbon consumption, advertising systems and infrastructures should be constructed to enable consumers to obtain correct information about greenhouse gas emissions related to their consumption behavior. Through these activities, CO_2 emission from production of goods and services could be cut indirectly (JLCSST-2050, 2008).

The change of the demand composition in the future is an indicator for a good opportunity to conduct energy efficiency efforts in the household sector (see Figure 1). In this paper, we propose to introduce to the Indonesian society and in particularly to the Jamali area two kinds of LCS actions in the household sector. First, the lighting efficiency improvement is introduced to the society by replacing incandescent with compact florescent (CFL) lights. In the future, the current new technology will be cheaper than today and also will be widely used in the society. Furthermore, the increasing welfare of the people leads to the ability of the people to access new technologies that have higher efficiencies than today, including lighting. Second, to educate people so that they have a higher awareness in energy saving behaviors, such as turning off unused lighting, turning off unused computers, setting thermostats of air conditioner above 20°C or turning off air conditioners when leaving the room. Moreover, the education and promotion of LCS behaviors will be advertised on television, newspapers, internet, and others valuable media.

The reasons to implement these tools in the household sector are: a) low costs, b) easy to be implemented, and c) significant saving as well as emission reductions. Furthermore, lighting is a basic electric device that is widely used in households. When applied to the industrial sector, it is expensive and difficult to be implemented. The reasons are that the industrial equipments are expensive. When we replace them with efficient ones, it creates higher cost. The industrial sector also will consider more about the cost-benefits of replacements in the production process, for example questions like: does the replacement disrupt the production, or how long is the installment process?

In the first step, the incandescent lamps will be replaced by CFLs, which are 40 W by 8 W, 60 W by 12 W, and 100 W by 20 W, respectively. In incandescent lamp, more than 90% of the energy produced is heat, not light, and therefore incandescent are inefficient light sources. The penetration rates of the lighting efficiency improvements are assumed to be linear and the usage time is about 5 hours/day. Meanwhile, in the second step, the average electricity savings from the improvement of peoples behavior in electricity utilization is assumed to be 35, 55, and 70 kWh/household/month or 116.67, 183.33, and 233.33 Wh/day in the period of 2006-2010, 2011-2020, and 2021-2025, respectively, due to increasing people's welfare. The hours of idle use of electricity devices are 2, 3, and 4 hours per day, respectively. However, this paper does not consider the technological changes such as increasing efficiency of future electrical devices. Similarly to the first step, the penetration rates of success in awareness, education, and concerns in electricity utilization here in the second step are assumed to be linear. Details of the actions are presented in Table 6. These actions will reduce energy intensity in the base year, which is 1,369 kWh/household/year. However, lowering the energy intensity does not necessarily lead to an overall decline in the physical consumption, as an increase in the level of activity (population growth and house size) can result in an increase in consumption despite a decrease in intensity (Hughes, 2009).

Figure 3 shows the electricity demand after LCS actions introduced in the Jamali system. At the end of the period, the total electricity demand is 278 TWh, which is an increase over three times than compared to the base year. However, this figure is going down compared to the BAU

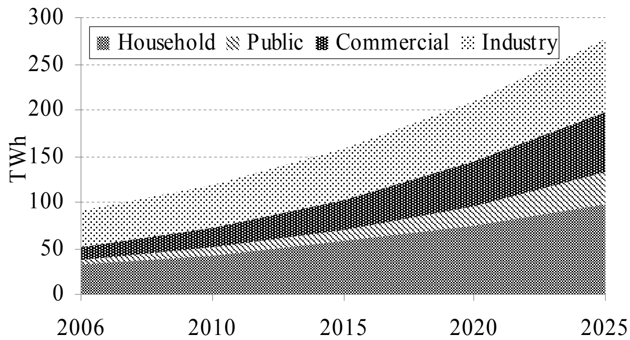

Figure 3. Electricity demand in Jamali system after LCS actions.

Table 6. Low carbon society (LCS) actions in the household sector.

Period		Scenario	Penetration
2006-2010	Efficiency Improvement	Replace incandescent 40W to CFL 8W Replace incandescent 60W to CFL 12W Replace incandescent 100W to CFL 20W	20%
	LCS Behavior	Turning off unused electricity devices	15%
2011-2020	Efficiency Improvement	Replace incandescent 40W to CFL 8W Replace incandescent 60W to CFL 12W Replace incandescent 100W to CFL 20W	60%
	LCS Behavior	Turning off unused electricity devices	55%
2021-2025	Efficiency Improvement	Replace incandescent 40W to CFL 8W Replace incandescent 60W to CFL 12W Replace incandescent 100W to CFL 20W	80%
	LCS Behavior	Turning off unused electricity devices	70%

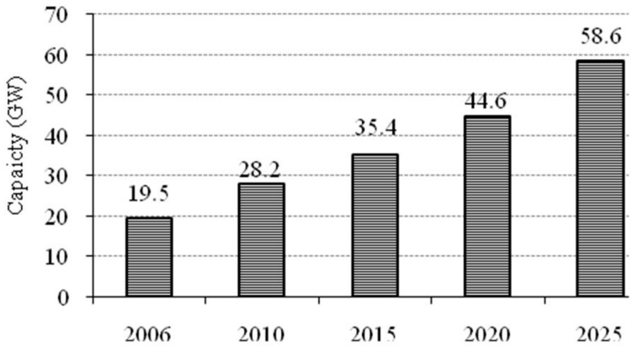

Figure 4. Power installed capacity after the LCS actions.

scenario, which is about 12.4% of the reduction. The household sector still takes the largest share of the electricity consumption by consuming 97 TWh or about 35% of total electricity consumption. If compared with the BAU scenario, these efforts succeed to reduce the electricity demand in the household sector by 34.6 TWh or 35.7% of demand reduction.

The electricity demand savings have an effect on the electricity generation savings. Figure 4 shows the power capacity installed after LCS actions were introduced in the Jamali system. In 2025, the installed capacity is 58.6 GW. The averted generation capacity is around 7.3 GW compared to the BAU scenario. In the end of the period, the electricity production is dominated by coal fired steam power plants, which have about 191.4 TWh or 57% of the otal electricity production. It decreases to 10 TWh or 5.2% for the coal fired steam power plant production in the BAU scenario. The natural gas combined cycle power plants follow on the second place with 74.7 TWh or 22% of the total electricity production. Table 7 presents electricity production figures of each power plant type after LCI actions.

In terms of total damage costs, in 2025, the coal fired steam power plants consume the highest cost among all others with almost 35 billion US$ or 89% of the total damage costs. This reduces to about 5.2% compared to the total damage cost of coal fired steam power plants in the BAU scenario. Meanwhile, the natural gas combined cycle power plants are on the second place, with damage cost of about 2.2 billion US$. This reduces to around 190 million US$ compared to the natural gas combined cycle power plant damage costs in the BAU scenario. The total damage costs in the LCS actions are 39 billion US$, which is reduced by 2 billion US$ compared to the BAU scenario at the end of the period (see Table 8).

Table 7. Electricity production of different power plant types after LCS actions.

Power Plant	Production (TWh)	
	2006	2025
Coal Fired Steam	49.6	191.4
Oil Fired Steam	3.8	4.7
Natural Gas Fired Steam	3.8	4.7
Oil Combined Cycle	9.6	13.0
Natural Gas Combined Cycle	14.1	74.7
Gas Turbine (Natural Gas)	2.4	3.2
Gas Turbine (Diesel)	3.7	0.2
Diesel Generator	0.1	0
Nuclear	0	26.6
Geothermal	6.7	9.3
Hydro	4.6	9.5
Total	98.3	337.3

Table 8. Total damage cost of fossil power plants after LCS actions.

Power Plant	Damage cost (10^6 USD)	
	2006	2025
Coal Fired Steam	8,990	34,688
Oil Fired Steam	893	1,114
Natural Gas Fired Steam	141	176
Oil Combined Cycle	594	804
Natural Gas Combined Cycle	420	2,229
Gas Turbine (Natural Gas)	117	153
Gas Turbine (Diesel)	460	24
Diesel Generator	16	-
Total	11,631	39,188

7. Conclusion

The hidden costs of electricity generation in Indonesia are analyzed in this paper. It is found that the government plan to increase coal utilization in the power sector gives a significant increase in emissions. Therefore, climate and health damage will also increase proportionally with increasing emissions. Then, when the damages are converted as external effects into monetary units they will result in external costs. In 2025, the total external costs according to the government plan are 42 billion US$.

It was also shown that to reduce external costs, two kinds of the low carbon society (LCS) actions could be introduced into the Indonesian society households, particularly into the Jamali society. The LCS actions namely, are lighting efficiency improvement and promoting energy saving behaviors. The results show that in the long term the Indonesian electricity expansion planning of 34.6 TWh of electricity demand and 7.3 GW of installed capacity can be reduced from these actions. Finally, in the end of the period, these actions are successful, and reducing the total external cost by 2 billion US$.

Therefore, the government's efforts to educate people to have more awareness in energy saving behaviors through formal education or informal education such as advertisement on television, newspaper, internet and others valuable media are necessary factors in success to introduce the LCS actions. The benefits for the society should also be shown, if they would like to adapt the LCS actions in their daily life, in order to motivate people and to increase their awareness on their electricity consumption and by this reduce the externality costs. Moreover, if the LCS actions are introduced and applied comprehensively in Indonesia, e.g. clean energy source, energy saving behavior and improving energy efficiency, it could reduce emissions from electricity generation, and thus reducing external costs.

Acknowledgments

The authors would like to acknowledge The Joint Graduate School of Energy and Environment (JGSEE) at King Mongkut's University of Technology Thonburi (KMUTT) for providing scholarships and the Sirindhorn International Institute of Technology (SIIT) at Thammasart University for providing the facilities during the study.

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