Optimizing Geothermal Energy and Hydro Power in Capacity Expansion at the Electrical System of Java-Madura-Bali

Rahmat Adiprasetya Al Hasibi, Sasongko Pramono Hadi, Avrin Nur Widiastuti

***Abstract*— Java-Madura-Bali (JAMALI) system is the biggest electrical system in Indonesia. The system covers more than 50% of total electricity demand in Indonesia. In this area, geothermal and hydro potential is very feasible to be optimized for capacity expansion of power plant in JAMALI system. This paper analyzes optimized plan in developing geothermal and hydro potential in JAMALI system. The analysis was based on the LEAP model. The developed LEAP model was consists of two scenarios. The first scenario is a reference scenario that is used to simulate the capacity expansion with the current status of geothermal and hydro power plant. In this scenario, there were no capacity additions of geothermal and hydro power plant in JAMALI system. The second one is an alternative scenario that is used to simulate the capacity expansion based on the optimized addition of geothermal and hydro power plant. The capacity expansion was based on the projection of electricity demand. The demand was projected based on population and GRDP data. The result shows geothermal and hydro potential can be used to reduce the role of coal fire power plant in JAMALI system. Based on alternative scenario, 21.69 GW of the capacity of coal fired power plant will be replaced by geothermal and hydro power plant in 2025. In the view of environmental aspect, the reduction of the role of coal fired power plant in JAMALI system will reduce the GHGs emission. The average growth rate of GHGs emission is 5.34% per year and 2.69% per year respectively for reference and alternative scenario.**

***Index Term*— geothermal energy, hydro power, LEAP model, OSeMOSYS, GHGs emission.**

I. INTRODUCTION

Electricity demand is increasing inline with the growth of population and economic activity. The electrical system of Java-Madura-Bali is the biggest electrical system in Indonesia that covers seven provinces in the three islands. This electrical system is known as the interconnection system of Java-Madura-Bali (JAMALI). In 2010, generated electricity in Indonesia is 169,77 TWh. Mostly part of this generated electricity was used to supply the electricity demand in JAMALI system that is 78.11% of total demand of Indonesia [1]. It is also reported that the primary energy used to generate electricity in JAMALI system was dominated by the use of fossil fuel such as coal, oil fuel, natural gas with the share of 40.90%, 29.13%, dan 20.14% repectively of the total electricity production in JAMALI system. Indonesia has limited reserve of coal, crude oil, and natural gas as a primary energy of electricity generation. In the other hand, Indonesia has potentially new and renewable energy that can be optimized as primary energi of electricity generation. The geothermal resource can be found in Sumatera (13,800 MW), Java and Bali (10,359.50 MW), and Sulawesi (2,000 MW). From the total of geothermal resource, the installed capacity of geothermal-based power plant is only 375 MW and located in Java and Bali. Hydro power is also very potentially renewable energy source. But, this potential is not optimally used to supply the demand of electricity. The potential of hydro power in Indonesia is about 75,674 MW and only 4,200 MW (about 5%) of hydro power plant was built. In Java and Bali, the potenstial of hyrdo power is 4,500 MW [2].

In the expansion power generaion planning, the issue of environment loading should also being considered. This issue can be adressed by optimizing the potential of renewable energy. In this paper, geothermal energy and hyrdo power will be simulated to analyze the role of these renewable energy potential in electricity supply for this electrical system. The simulation was done by LEAP software as a tool for long range energy planning [3]. The analysis also covers the role of hydro and geothermal power plant in the recution of GHG emission in power generation sector.

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II. LEAP OVERVIEW

A. *LEAP Applications*

LEAP is a supporting tool in energy planning based on scenarios. Many energy policies were conducted based on this tool. In Mexico, LEAP was used to develop of energy policy with the goal of low carbon strategy in national development plan. This document provides an economy-wide analysis of low-carbon options for mitigating greenhouse gas emissions in Latin America's largest fossil fuel–consuming country [4]. Copenhagen climate plan was also produced by LEAP. This publication shows very optimistic target that the city will reduce the CO2 emission by20% between 2005 and 2015. The final goal of was to be the first carbon neutral capital in the world by 2025 [5]. LEAP was used to produce an initial technical exploration of how China's energy systems might be altered over the coming 4 decades. This paper present strategies for China to meet ambitious goals for development and income growth at the same time as keeping greenhouse gas (GHG) emissions within very tight budgets that provide a reasonable chance of keeping global temperature increases below 2°C [6]. LEAP also capable to conduct energy planning and GHG reduction strategy for a certain sector. Integrating carbon concerns into local air pollution management was developed for Kathmandu Valley in Nepal [7]. This study shows that each scenario has certain advantages but that none alone would be able to meet all five major criteria for the city: controlling PM_{10} emissions, saving energy, using more indigenous energy sources, reducing vehicle numbers to relieve congestion, and cutting CO_2 emissions.

LEAP can be used to forecast and to analyze demand of a certain type of energy. Energy forecasting for gas sector was developed in Bangladesh [8]. This paper represents the first application of LEAP software for gas sector in the country. The result of this paper shows logistic forecast produce more accurate in energy forecasting. But, in case of Bangladesh, the linear approach is better way to do this forecasting. In electricity planning, LEAP was also used to analyze the expansion plant in generating system for JAMALI system [9], [10]. In these papers, the expansion of power plant was based on user define capacity addition. Then, LEAP calculates endogenously the need of power plant capacity to meet the demand of electricity.

In this paper, the calculation of the addition of power plant capacity is based on optimization calculation. The modul to do optimization is built-in tool in LEAP software. The optimization is based on least-cost system in power plant expansion. Thus, LEAP tries to find the combination of power plant expansion and their capacity to meet the demand of electricity. This paper simulates two different scenarios. The first scenario demonstrates the power plant expansion without any further development in hydro power and geothermal energy based power plant. The second demonstrates the influence of hydro power and geothermal energy penetration in power sector for JAMALI system.

B. Optimization in LEAP

LEAP was originally created in 1980 for the fuel wood Kenya project to provide flexible tool for long-range integrated energy planning. Then, Stockholm Environment Institute (SEI) continued the development of LEAP in 1989 and the first windows version was developed by Charles Heaps in 1990s [11]. LEAP includes the optimization calculation for power plant start in LEAP 2011 version. The latest version of LEAP 2012 has capability to link with Water Evaluation and Planning System (WEAP).

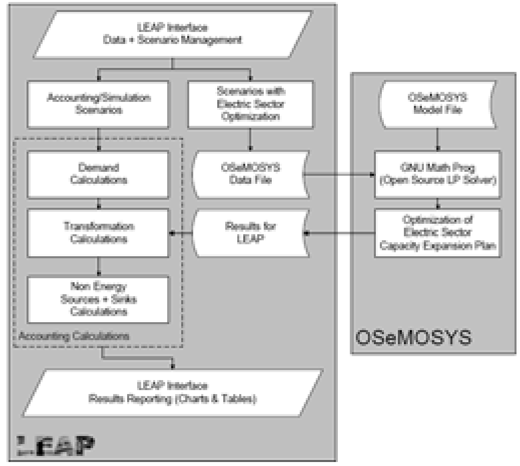

Fig. 1. The flowchart of optimization in LEAP.

The optimization in LEAP was based on The Open Source Energy Modeling System (OSeMOSYS). OSeMOSYS was created by not using proprietary software or commercial programming languages and solvers. Thus, OSeMOSYS require no financial investment. Adjustment of LEAP energy model can be used as interactive user interface of OSeMOSYS [12]. The work flow of the optimization in LEAP is shown in Fig. 1 [13]. In Fig. 1, OSeMOSYS uses input parameters from a scenario that already design in LEAP with optimization option. Based on this parameters, OSeMOSYS do optimization procedure and give the result back to LEAP. LEAP receives the result as power plant capacity to meet the demand of electricity. Then, the capacity from OSeMOSYS is stored as an exogenous capacity.

III. CURRENT STATUS OF ELECTRICITY IN JAMALI SYSTEM [12]

A. Demand side

From demand side, the electrical sistem is devided into five type of cutomer which are residential, industrial, business, social, and public. Connected capacity for each type of customer is shown in Fig. 2. It can be seen, in Fig. 2, residential customer has the largest capacity connected to the grid that is 23,087 MVA. Following residential customer, industrial and business customer has the connected capacity of 13,628 MVA and 10,303 MVA respectively. And the connected capacity of social and public customer is 1,653 MVA and 1,67 3MVA repectively. The total connected capacity in JAMALI system is 50,345 MVA in 2010.

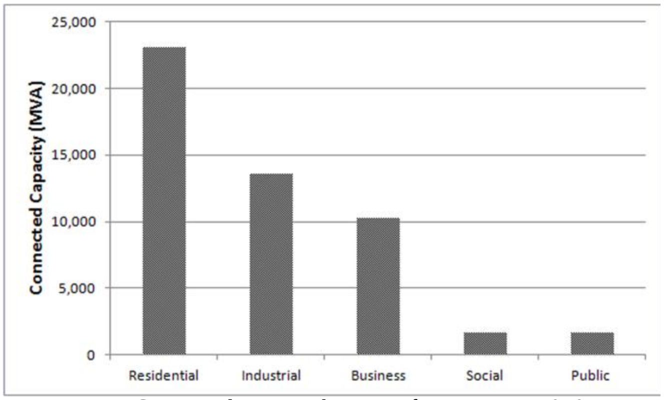

Fig. 2. Connected capacity by type of customer in 2010.

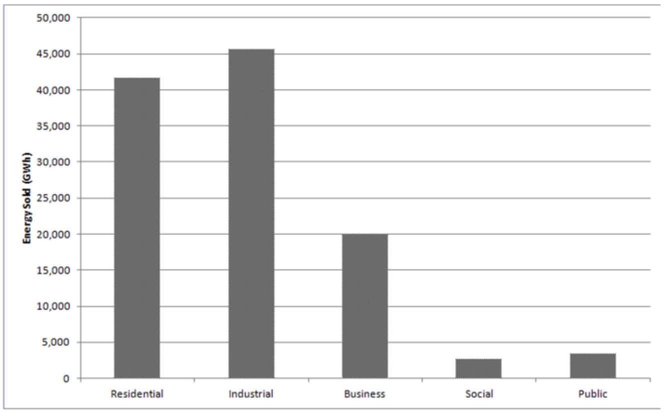

Fig. 3. Energy sold by type of customer in 2010.

Energy sold by type of customer in 2010 is shown in Fig. 3. Based on the energy sold, industrial customer has the largest amount of electricity demand. The energy sold for industrial customer is 45,638 GWh in 2010. For residential customer, the energy sold in 2010 is 41,704 Gwh. This fact shows that residential customer has the less period of peak load compare to industrial customer. The peak load period of residential customer is from 17.00 to 22.00 hour. The energy sold for business customer is 19,909 GWh or is almost half of residential customer. While energy sold for social and public customer is 2,662 GWh and 3,488 GWh respectively. The total of energy sold in JAMALI system is 113,401 GWh.

B. Supply side

The installed and rated capacity of power plant in JAMALI system is shown in Fig. 4. In Fig. 4, it can be seen that power plant in JAMALI system is dominated by steam and combine cycle power plant. Total installed capacity in JAMALI sistem is 19,060.98 MW. Most of steam power plant is fueled by coal and few of them are fueled by Residual Fuel Oil (FO). Combine cycle power plant is fueled by natural gas. In 2010, the installed capacity of steam and combined cycle power plant is 8,020.00 MW and 6,033.44 MW respectively. Gas turbine power plant that is fueled by Diesel Oil has the installed capacity of 2,113.56 MW in 2010. Diesel power plant was built in Bali Province that has installed capacity of 120.19MW.

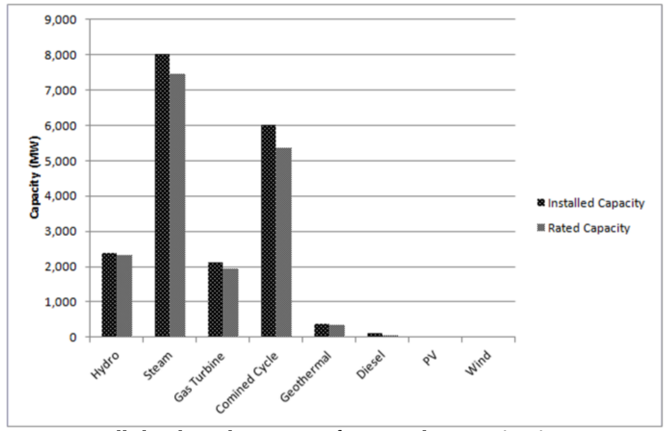

Fig. 4. Installed and rated capacity of power plant in JAMALI system in 2010.

In Fig. 3, it is also can be seen that renewable energy based power plant was built in JAMALI system, which are hydro, geothermal, photovoltaic (PV), and wind power plant. Hydro power plant has the installed capacity of 2,398.53 MW in 2010. This capacity is only 53.30% of the total potential of hydro power in JAMALI system. Geothermal power plant has the installed capacity of 375.00 MW or only 3.63% of the total potential of geothermal energy in JAMALI system. Wind power plant currently was installed in Bali Province with the capacity of 0.26 MW. Other renewable energy based power plant that was built in JAMALI system is PV based power plant. This power plant is mostly used as Solar Home System (SHS) in rural area in JAMALI system. Data of installed capacity of PV power plant is not available. The role of renewable energy based power plant in JAMALI system to meet the demand of electricity is only 14.55% of total installed capacity.

IV. METHODOLOGICAL APPROACH

LEAP is an energy planning model that consists of and end-use structural model. Based on procedural analysis of the supply and demand network, the model describes technological energy carrier utilization based on energy demand and technological change [13]. Thus, LEAP has capability to accommodate structural change and of energy carrier and efficiency of energy conversion. LEAP model consists of hierarchical structure in which energy flows from the supply point to the last point of end user. Total energy is calculated from each category or subcategory in a tree structure. Total energy demand is calculated based on the activity level and the final energy intensity for each tree.

In this study, 2010 is chosen as a base year where data of driver variable, demography and economy, is available. However, data of power plant capacity use the most recent daya in 2011. Data of power plant capacity in 2011 is as an input of capacity expansion with simple interpolation method. Based on designed two scenarios, future demand of electricity in JAMALI system will be projected for 15 years period. The role of geothermal energy and hydro power in power capacity expansion and GHG emission reduction then will be analyzed.

A. *Driver variable*

In the developed LEAP model, demography and economic data were two parameters as a driver of the activity of energy sector. Demography data consists of population and household number in the seven provinces in JAMALI system. The data was gathered from the National Statistical Council of Indonesia. The latest data in 2010 was the result of directly national survey in household sector. The number of population and household of the seven provinces in JAMALI system in shown in Table I [15]. The population in JAMALI system that consists of three islands which are Java, Madura, and Bali has the highest density in Indonesia. Almost 60% population in Indonesia is concentrated in these three islands with only total area of 7.79% of Indonesia. This results JAMALI system has the biggest electrical load in Indonesia to support all activity in this area.

TABLE I
POPULATION AND HOUSEHOLD NUMBER IN 2010

No.	Province	2010	
		Population	Household
1	D.K.I. Jakarta	9,607,787	3,584,995
2	West Java	43,053,732	10,844,769
3	Central Java	32,382,657	8,589,564
4	D.I. Yogyakarta	3,457,491	1,047,725
5	East Java	37,476,757	10,101,552
6	Banten	10,632,166	2,842,825
7	Bali	3,890,757	1,051,556
Total		140,501,347	38,062,985

The economic activity is represented by the Gross Regional Domestic Product (GRDP). GRDP of seven provinces in JAMALI system is shown in Table II [16]. The value of GRDP was based on the constant value in 2000 where the economic situation in this year is the most stable in Indonesia. Inline with the number of population, the GRDP of JAMALI area is 62.35% of total Gross National Product (GNP) of Indonesia. The capital city of Jakarta has the highest GRDP share in JAMALI area that is 30.76% of total GRDP. East Java and West Java have the share of GRDP of 24.71% and 23.24% respectively. East Java Province as an emerging province has the highest growth of 6.68% in 2010 that is higher than the capital city of Jakarta.

TABLE II
GROSS REGIONAL DOMESTIC PRODUCT IN 2010

No.	Province	2010	
		GRDP (Million USD)*	Growth of GRDP
1	D.K.I. Jakarta	44,169.96	6.54%
2	West Java	33,368.84	6.09%
3	Central Java	19,385.81	5.84%
4	D.I. Yogyakarta	2,181.45	4.87%
5	East Java	35,484.22	6.68%
6	Banten	6,012.32	5.42%
7	Bali	2,994.06	5.83%
Total		143,596.65	6.29%

* 1 USD = 9,646.00 IDR (2012)

TABLE III
ELECTRICITY INTENSITY OF RESIDENTIAL SECTOR IN 2010.

No.	Province	Electricity Intensity (MWh/Person/Year)
1	D.K.I. Jakarta	1.1271
2	West Java	0.2534
3	Central Java	0.1991
4	D.I. Yogyakarta	0.2724
5	East Java	0.2176
6	Banten	0.0886
7	Bali	0.3147

TABLE IV
ELECTRICITY INTENSITY OF NON-RESIDENTIAL SECTOR IN 2010.

No.	Province	Electricity Intensity (MWh/Thousand USD/Year)			
		Industrial	Business	Social	Public
1	D.K.I. Jakarta	0.0049	0.0053	0.0053	0.0050
2	West Java	0.0063	0.0049	0.0058	0.0063
3	Central Java	0.0042	0.0038	0.0042	0.0042
4	D.I. Yogyakarta	0.0039	0.0039	0.0039	0.0039
5	East Java	0.0042	0.0040	0.0042	0.0052
6	Banten	0.0096	0.0093	0.0091	0.0150
7	Bali	0.0059	0.0061	0.0059	0.0060

B. *Energy intensity of electricity*

The intensity of electricity is used to represent the characteristic of electricity consumption for each sectoral demand. The intensity of residential demand is represented by the amount of electricity used for each person. Thus, the intensity for residential demand is MWh per person in current year. For industrial, business, social, and public demand, the intensity is represented by the amount of electricity used for each product. The product of these demands is represented by the value added of GRDP. Thus, the intensity for these demand are MWh per Million USD in current year. The intensity of electricity in JAMALI system for residential and non-residential demand is shown in Tabel 3 and Tabel 4 respectively. The intensity of electricity then will be used in scenario development to forecast the demand of electricity in each sector.

C. *Scenario Development*

Model Assumption

In the developed LEAP model, the demand of electricity is projected based on the growth of diver variables. In household sector, the growth of electricity demand is assumed inline with the growth of population. As the increasing of population, the number of household will be increase in the same rate as the growth of population. Therefore, the demand of electricity in household sector has strong relation with the growth of population. Based on the result of population projection by national statistical council, and the national council of demography and planned family, the population projection for the seven provinces in JAMALI system is shown in Tabel 5. Based on this Table, the activity level of household sector that is represented by the number of population will be projected. The electricity demand of household sector is calculated by the product of the number of population and the intensity.

The electrification ratio is also the important parameter in the projection of electricity demand calculation in household sector. Based on the National Planning of Electricity of Indonesia, all household will have electricity connection to the grid in 2020. Then, the electrification ratio will has the value of 100% in 2020.

TABLE V
THE PROJECTION OF POPULATION.

No.	Province	Population Growth (%)		
		2010-2015	2015-2020	2020-2025
1	D.K.I. Jakarta	0.41	0.20	(0.01)
2	West Java	1.60	1.45	1.27
3	Central Java	0.26	0.16	0.01
4	D.I. Yogyakarta	0.81	0.63	0.44
5	East Java	0.31	0.19	0.01
6	Banten	2.63	2.47	2.27
7	Bali	1.07	0.91	0.77

Source: national statistical council and national council of demography and planned family, 2009

For industrial, business, social, and public sector, the projection of electricity demand is based the growth of GRDP for each province. The growth of GRDP is calculated by simple linear regression method based the historical data of GRDP. Based on this calculation, the GRDP in 2025 will has the growth of 6.5%. The activity level of non-household sector then will be projected based on the growth of GRDP. The demand of electricity is calculated by the product of the GRDP and the intensity.

Power Plant Cost Parameter

The optimization calculation in LEAP needs cost parameter of each type of power plant. The cost parameter consists of capital cost, Operation and Maintenance (O&M) cost, variable cost, and fuel cost. Cost parameter for each type of power plant is shown in Table VI. For hydro and geothermal power plant, the fuel cost is zero because it is comes from renewable resources and there is no cost for power plant fuel. The cost parameter of power plant will be used to determine the least cost combination by the OSeMOSYS to meet the electricity demand as a result of LEAP.

TABLE VI
COST PARAMETER OF POWER PLANT [14], [17].

Type of Power Plant	Cost components			
	Capital (1000 USD/MW)	O&M (1000 USD/MW)	Var. (USD/ MWh)	Fuel Cost
Steam (Coal)	1,548	36	2.15	50 USD/Ton
Combined Cycle (Natural Gas)	850	43	11.69	6 USD/MMBTU
Gas Turbine (Oil)	1,733	18	5.37	0.78 USD/Liter
Hydro	1,239	15	5.97	-
Geothermal	1,664	30	6.37	-

The Scenarios of Power Plant Expansion

In the developed LEAP model, there are two scenarios to simulate the power plant expansion in JAMALI system. The first scenario is the reference scenario that is used to simulate the expansion of power plant with no further addition of hydro and geothermal power plan in the system. Thus, the reference scenario will add new capacity of power plant with the least cost system and with the current capacity of hydro and geothermal power plant. The second scenario is alternative scenario that is used to simulate the role of hydro and geothermal power plant in the system. The addition of hydro and geothermal power plant is also based on the least cost system. For both scenarios, the time step of analysis will be each single year from based year to the end year of projection period.

V. RESULT AND DISCUSSION

A. *The Projection of Electricity Demand*

Base on the assumption of demography and economy and the intensity of electricity, the result of electricity demand by sectoral activity is shown in Fig. 5. In the fig., the electricity demand of household sector is increasing by 1.57% per year and this is as the result of the assumption of population growth. In 2025, the electricity demand of household sector will have the value of 49.25 thousand GWh. This increases by 26.31% compare to the base year demand. Non-household sectors have the same growth rate of electricity demand. This is caused by the same assumption of economic growth that is applied for these sectors. In 2025, the electricity demand of non-household sector is 166.51 thousand GWh and increases by 157.20% compare to the base year value. The total demand of electricity in 2025 is 215.77 thousand GWh and industrial sector has the biggest demand with 105.47 thousand GWh of electricity demand.

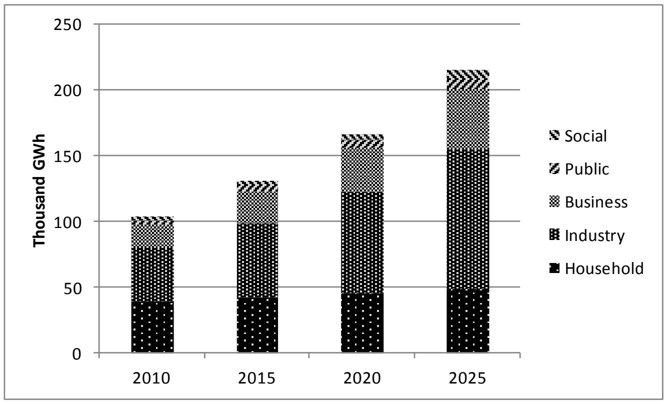

Fig. 5. The projection of electricity demand by sectoral activity.

Compare to 2010, the share of electricity demand in 2025 is different and it is shown in Fig 6. In 2010, household and industry sector almost have electricity demand with the same share. The share of household and industry is 37.58% and 39.63% respectively in 2010. In 2025, the share of electricity demand for industry will significantly increases to 49.01%. But for household sector, the share will decreases to 22.82% in 2025. For business sector, the share of electricity demand will also increases from 17.33% in 2010 to 21.43% in 2025. For public and social sector, the shares of electricity demand in 2025 have slightly difference compare to the share in 2025. In 2025, the share of electricity demand for public and social sector is 3.85% and 2.88% respectively.

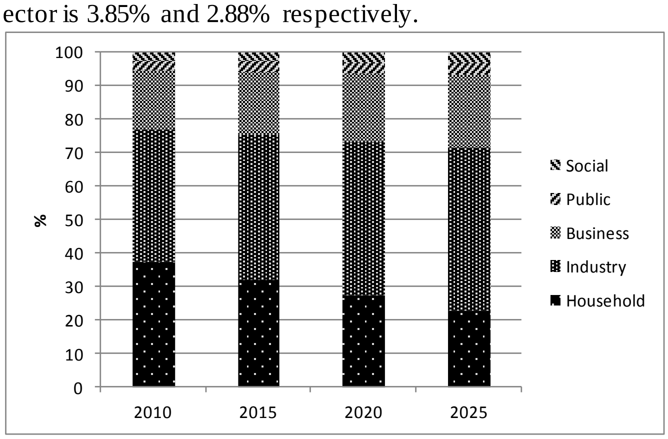

Fig. 6. The share of electricity demand by sectors.

B. *The Expansion of Power Plant Capacity*

Based on the result of the calculation of electricity demand, LEAP determines the needed capacity to meet the demand. The expansion of power plant capacity in JAMALI system based on the designed scenarios is shown in Fig. 7. Based on reference scenario, coal fired steam power plant is very dominant along the projection period. In 2025, the need of this type of power plant is 31.37 GW. By the reference scenario, other type of power plant remain has the same capacity. In the other hand, there will be capacity addition except for coal fired steam power plant. This result is caused by the optimization that sees the coal fired steam power plant is the least cost system along the projection period.

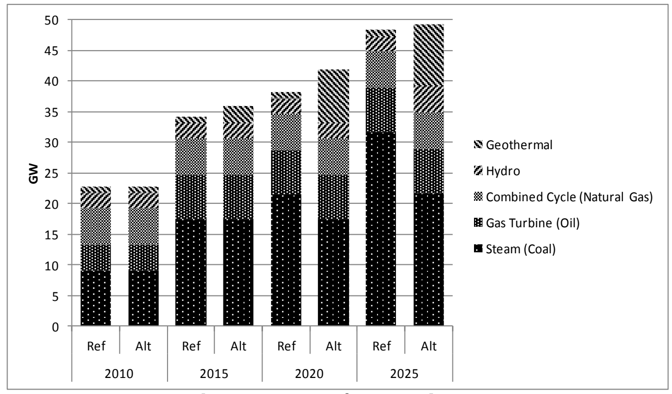

Fig. 7. The expansion of power plant capacity.

By the alternative scenario that optimized the hydro and geothermal potential, the role of coal fired power plant is significantly reduced in 2025. The total capacity of the system in 2025 is higher based on the alternative scenario compare to the reference scenario. Total needed capacity in 2025 is 49.37 GW by the alternative scenario and 48.49 GW by the reference scenario. The optimization calculation based on the alternative scenario results that geothermal power plant needs to be built earlier than hydro power plant. In 2014, first addition of geothermal power plant is occurred with the capacity of 1.81 GW. The capacity expansion of geothermal power plant is continuing to increase and reach its maximum capacity of 10.00 GW in 2021. This means that all geothermal potential will be used to generate electrical power in 2021. As the potential of geothermal reach its maximum possible capacity, hydro power plant need to be built start in 2022 by the capacity of 4.5 GW or directly to its maximum possible capacity. By the capacity expansion of hydro and geothermal power plant, coal fired power plant will need to be built by the capacity of 21.69 GW in 2025 or 31.64% less than the capacity that is produced by the reference scenario.

C. *Generated Electricity*

Generated electricity based on the designed scenarios is shown in Fig. 8. In this fig., both scenarios generated the same amount of electricity to meet the demand. In 2025, generated electricity by both scenarios will be 241.09 thousand GWh. Coal fired power plant generates electricity by 196.85 thousand GWh and 130.10 thousand GWh for reference and alternative scenarios respectively in 2025. Alternative scenario reduces the role of coal fired power plant in electricity generation by 33.90% compare to the reference scenario. In the other hand, total generated electricity of hydro and geothermal power plant is 16.30 thousand GWh and 83.12 thousand GWh for reference and alternative scenarios respectively in 2025. Based on the alternative scenario, the role of hydro and geothermal power plant is significantly increase by more than five times or 409.94% compare to the reference scenario. Based on scenarios, oil and natural gas power plant produce electricity with small different. In 2025, oil power plant produces electricity of 12.01 thousand GWh and 11.98 thousand GWh for reference and alternative scenario respectively. And natural gas power plant produces electricity of 15.92 thousand GWh and 15.98 thousand GWh for reference and alternative scenario respectively.

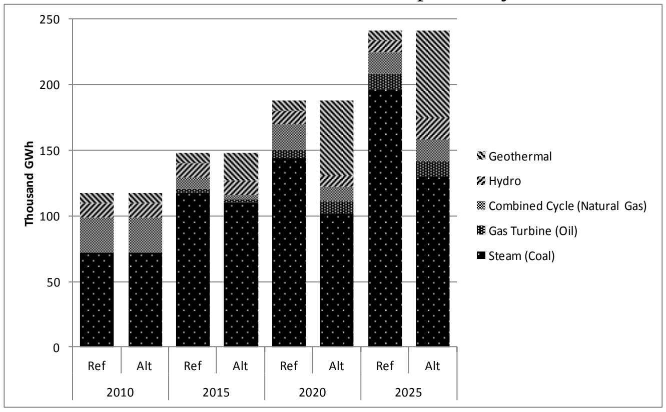

Fig. 8. Generated electricity by type of power plant.

The share of generated electricity by type of power plant is shown in Fig. 9. In this fig., it is can be seen that alternative scenario reduce the share of coal fired power plant to generate electricity in the system. By the optimization of hydro and geothermal power plant, the share of coal fired power plant can be reduced from 81.65% by reference scenario to 53.96% by alternative scenario in 2025. The role of hydro and geothermal power plant reaches it maximum value in 2022 with total share of 47.10%. In 2025, the shares of these power plants reduce to 34.48%. This is caused by no more available capacity for hydro and geothermal potential than can be used to expand the power plant capacity of hydro and geothermal. Therefore, the share of coal fired power plant is increasing in the period of 2022 to 2025 that is from 51.16% to 53.96%.

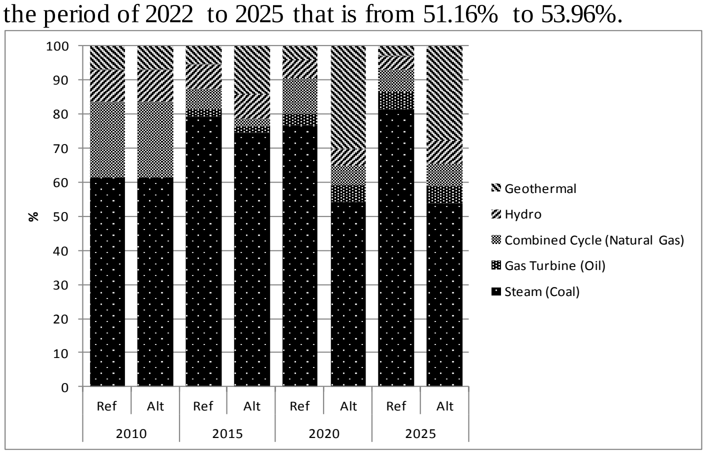

Fig. 9. The share of generated electricity by type of power plant.

D. GHGs Emission

GHGs emission that is produced from electricity generation is shown in Fig. 10. In this fig., the role of hydro and geothermal power plant in the reduction of GHGs emission is very significant. The average growth rate of GHGs emission is 5.34% per year and 2.69% per year respectively for reference and alternative scenario. In the period of 2014 to 2022, the average growth rate of GHGs emission has the negative value of -0.64% per year by alternative scenario. This is cause by the development of hydro and geothermal power plant in JAMALI system. Based on alternative scenario, the average growth rate will significantly increase to 10.82% per year in the period of 2022 to 2025 as there are no capacity additions for hydro and geothermal power plant in the system. The amount of GHGs emission in 2025 is 204.70 million Tonne CO_2 Eq. and 140.75 million Tonne CO_2 Eq respectively for reference and alternative scenario. By optimizing hydro and geothermal potential in electrical power generation, the GHGs emission can be reduced by

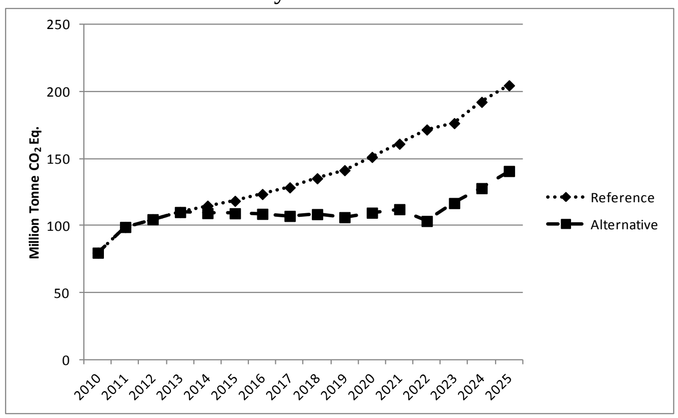

Fig. 10. The GHGs emission by scenarios.

VI. Conclusion

This paper simulates the optimized role of hydro and geothermal potential in JAMALI system. The capacity expansion in JAMALI system was based on the projection of electricity demand that will increase 5.00% per year for all provinces. In the end year of projection period, the total demand will be 215.77 thousand GWh. To meet this demand, two different which are the reference and the alternative scenarios is designed. Both scenarios is run by the least cost system. Based on the reference scenario, the total capacity expansion in 2025 is 48.49 GW. In this scenario, the role of coal fired power plant is very dominant by 31.73 GW of capacity. Based on alternative scenario, the total capacity expansion in 2025 is 49.37 GW. The capacity of coal fired power plant is reduced by 31.64% compare to the reference scenario. By the alternative scenario, the capacity expansion of hydro and geothermal power plant will reach it maximum possible capacity in 2022 with total capacity for these power plants of 14.50 GW. The alternative scenario results less GHGs emission compare to the reference scenario. The average growth rate of GHGs emission is 5.34% per year and 2.69% per year respectively for reference and alternative scenario.

Based on the result, the analysis of this study can be expanded to explore more option in GHGs reduction in the expansion of electrical power of JAMALI system. The option can be consisted of more penetration on renewable energy or the implementation of new technology in conventional electrical power generation.

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