Effect on KPIs of Energy Policies of Thailand

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Abstract

The objective of this paper is to develop a tool to evaluate key performance indicators (KPIs) of energy policies of Thailand. The KPIs are related to energy cost, degree of self-reliance of energy, environmental impact, and energy security. The evaluation tool is developed using an LP model that considers energy supplies, transformations, and demands from seven economic sectors. The LP model tries to balance entire energy system of the country by matching demand and supply of all energy types in the way that the total energy cost of the country is minimized. Current Thailand's energy policies are used for setting energy scenarios. This paper is valuable for policy makers since it provides decision makers the effects on KPIs of various energy policies and how they affect the energy supplies, transformations, and demands of the country.

***Keywords**:* energy system model, key performance indicators, energy policy, optimization.

1. Introduction

The national energy policies of countries have common ideas such as mitigation of the green-house gas emissions, increasing energy security, and providing sufficient energy supply economically. of commercial primary energy consumption in Thailand increased from 1986 to 2010 with an average growth rate of 17.83% per year while imported energy is increased with a growth rate of 18.67% per year. The world crude oil price has been increasing dramatically since 2005. Therefore, Thai government has attempted to designate the energy strategies, plans, and policies to reduce oil import.

However, the tool to evaluate the effect on energy KPIs of the entire country of various energy policies is needed. At present, when the government specifies an energy policy, for example construction of 1,000 MW nuclear power plant. It explains that the electricity security, CO_2 emission, and electricity generation cost will be better. However, we do not exactly know how many dollars are the savings in total energy cost of the country? How many tons of CO_2 emission is reduced per year?

This paper aims to develop a quantitative tool to evaluate effects on KPIs (related to energy cost, degree of self-reliance of energy, environmental impact, and energy security) of each energy policy and of all policies when they are implemented simultaneously.

Related past works are reviewed as follows. Application of large-scale economic energy models with different types of uncertainty could be found in [1]. In applying the energy models, it translated qualitative to quantitative scenarios [2]. Energy price scenarios (linear and exponential prices) were analyzed in [3]. Review of issues related to energy models based on neural network and fuzzy theory was presented in [4]. A methodology of scenario analysis using simulation model by applying economics' theory of competition was presented in [5]. It studied the effect of welfare distribution on a price reduction in the Dutch gas. In Sweden, a development of alternative transport fuels with market- and technology-oriented scenarios were explored [6]. A model of energy systems planning under uncertainty was presented in [7]. A critical review of existing energy security policies was in [8].

A scenario modeling study in the power sector of Thailand considered a range of opportunities and constraints associated with divergent set of technical and policy options [9]. A climate change with depletion of natural resources, particularly oil, natural gas and coal was studied in [10]. Energy security has been important public issue [11]. Energy security and climate change protection using an optimal cost policy was proposed by [12]. Energy security of four major energy sources (coal, oil, liquefied natural gas, and nuclear) in Korean electricity market was analyzed using the Hirschman–Herfindahl index (HHI) [13].

This paper is organized into four parts. Part 2 is methodology of the research. Part 3 provides the results and discussion of the models based on energy policy scenarios. Part 4 provides conclusions.

2. Methodology

2.1 Thailand's Energy Allocation Model

An LP model called Thailand's Energy Allocation model is developed to determine the energy KPIs of the country. The model composes of three parts, namely, primary energy supply, energy transformation, and final energy demand as shown in Fig. 1. The primary energy supply includes petroleum (crude oil and natural gas), coal, renewable energies, nuclear and others. The energy transformations include refinery, gas separator, and power plants. The refinery transforms crude oil to various petroleum products, e.g., gasoline, diesel, LPG, fuel oil, while the gas separator transforms natural gas to various natural gas products, e.g., methane, LPG. The power plants transform primary energies and some petroleum and natural gas products to electricity. There are seven demand sectors that directly consume some primary energies, petroleum and natural gas products, and electricity.

The model tries to balance the energy supply and demand for the whole country in a manner that the total energy cost is minimized. It requires inputs of energy demand from seven demand sectors. It then optimally determines quantity of each primary energy type that is needed by the transformation process and the demand sectors.

Due to page limit, the LP model cannot be presented in mathematical form in detail. However, the model is explained verbally as follows.

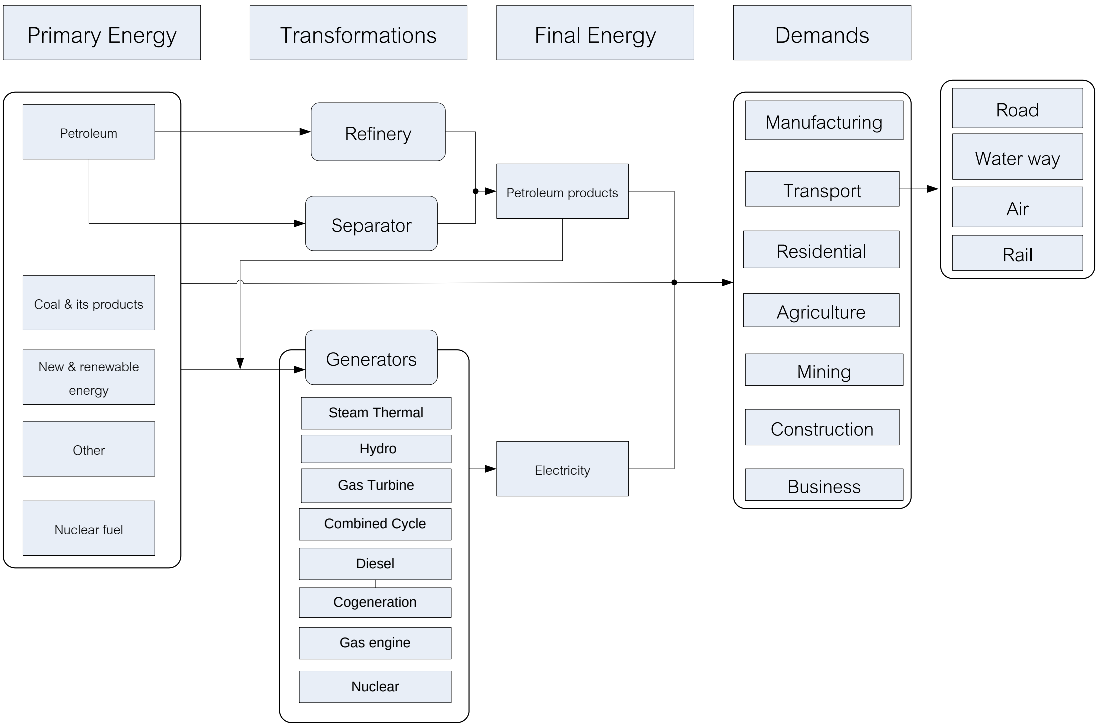

Fig. 1 Scope of Thailand's Energy Allocation Model

1. The objective function is to minimize total energy cost including costs of domestic and imported energies subtracted by costs of exported energies.
2. The model has constraints as follows.

(1) Limitation for supply of all domestic energy types and some imported energy types, namely, natural gas and electricity.

(2) Limitation of energy transformation process including capacity constraints of refinery, gas separator, and power plants. It considers the current mix of inputs and outputs which are practical technological constraints of transformation process.

(3) Demand of all energy types from seven demand sectors.

(4) Constraints to achieve the balance of energy supplies and energy demands.

(5) Constraints to calculate all energy KPIs including self-reliance indicator, emission indicator (total CO_2 emission and carbon dioxide equivalent (CO_2-e) of GHG), country's fuel diversification indicator of Herfindahl-Hirschman Index (HHI).

(6) All variables are non-negative real numbers.

The model is developed based on input data from Thailand Energy Situation 2007 [14].

2.2 Energy Policies in Thailand

This paper evaluates various energy policies. The business as usual (BAU) 2015 is the reference scenario which represents a situation that there is no action of any energy policy. There are five energy policies that the Ministry of Energy is established to solve some energy problems.

The forecasted sector demands of 2015 are obtained from a progress report of the policy for energy resources allocation from fossil energy, Thailand Research Fund (TRF), April 2008. The demands are 4,960, 177, 38,850, 177, 13,234, 6,175, and 35,627 ktoe. in agriculture, mining, manufacturing, construction, resident, commerce and transportation sector, respectively. The demand in transportation sector is totally 35,627 ktoe. which is divided into 26,881, 144, 6,093, and 2,509 ktoe. for road, rail, air, and waterway mode, respectively. All energy policies are described as followed

Policy 1: Nuclear power

It has two options, namely, 1,000 and 5,000 MW nuclear power plant installation, which are equivalent to a generation capacity of 653.22 and 3,266.10 ktoe., respectively as shown in Table 1.

Table 1 Capacity of power generation

Types of power plant	BAU 2015 (ktoe)	1000 MW of nuclear power plant (ktoe)	5000 MW of nuclear power plant (ktoe)
Hydro	691.77	691.77	691.77
Steam Thermal	3970.22	3970.22	3970.22
Gas Turbine	19.21	19.21	19.21
Combined cycle	11,229.59	11,229.59	11,229.59
Diesel	0.00	0.00	0.00
Cogeneration	1,001.76	1,001.76	1,001.76
Gas engine	1.00	1.00	1.00
Nuclear	0	653.22	3,266.10

Policy 2: Ethanol and bio-diesel promotion

The energy minister disclosed on Dec13, 2010 that Thailand would focus on promoting renewable energy usage. This would increase a degree of self-reliance of energy. This policy is from Thailand's Energy policy and Renewable Energy Development Plan (REDP) 2008-2022 that has some impacts on petroleum product demand as shown in Table 2.

Table 2 Change of demand for fuel for road transport

Fuel types	BAU 2015 (ktoe)	Renewable energy policy (ktoe)
Gasoline 91	4,911	1,217
Gasoline 95	1,230	305
Gasohol RON 91 (E 10)	274	914
Gasohol RON 95 (E 10)	1,704	5,682
High Speed Diesel	16,629	0
Bio Diesel B5	813	17,442

Policy 3: Increase use of natural gas for 5% to replace fuel oil in industrial sector

This policy will increase use of NG in industry from 3,938 ktoe in BAU situation to 4,135 ktoe. As a result, use of fuel oil in industry will be reduced from 2,540 ktoe. to 2,343 ktoe.

Policy 4: Oil pipeline at Sriracha hub

Currently and also in BAU 2015, petroleum products are transported by 16,000 liter trucks to distribution tanks. After constructing oil pipe line the fuel demand for transportation will be changed as shown in Table 3.

Table 3 Change of fuel demand of Policy 4

Fuel demands	BAU 2015 (ktoe)	Sriracha hub (ktoe)
Electricity for pipe line transport	0	6
Diesel for road transport	16,629	16,568
Palm diesel for road transport	5	4
Bio diesel B5 for road transport	813	810

Policy 5: Urban Rail Transportation Master Plan (URMAP)

The URMAP is a construction of Rapid Mass Transit system in Bangkok Metropolitan Region. It is estimated that amount of transportation for URMAP is 6,478,314,577 trips-km per year. The URMAP will reduce road transportation by own cars, taxis, public vans, and buses. From a survey of 1,152 potential passengers for URMAP, the proportion of travel mode is shown in Fig. 2. Policy 5 results in a change of fuel demand as shown in Table 4.

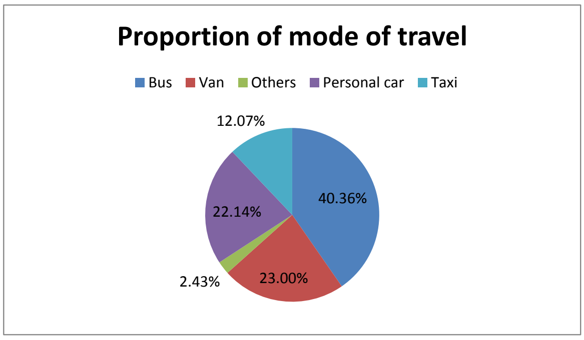

Fig. 2 Proportion of mode of travel

Table 4 Change of fuel demand for Policy 5

Fuel types	BAU 2015 (ktoe)	URMAP policy (ktoe)
Electricity for rail transport	17	40
LPG for road transport	1,004	992
Gasoline 91 for road transport	4,911	4,863
Gasoline 95 for road transport	1,230	1,218
Gasohol RON 91 (E10) for road transport	274	271
Gasohol RON 95 (E10) for road transport	1,704	1,687
High Speed Diesel for road transport	16,629	16,607
Bio diesel B5 for road transport	813	812
Compressed natural gas (CNG) for road transport	313	196

3. Results and Discussion

Each energy policy may be applied separately or simultaneously. This paper will analyze effects on KPIs of each policy both separately and simultaneously. From the fact that the construction of nuclear power plants is not easily accepted by Thai people. This paper analyzes two scenarios, namely, simultaneous policies including and excluding nuclear power plants.

There are four types of KPIs that are related to total energy cost, degree of self-reliance, emission, and energy diversification. The effects on KPIs of each energy policy and They will be discussed one-by-one as follows. Simultaneous policies are presented in Table 5.

3.1 Total cost indicator

The total energy costs of energy policies are shown in Fig. 3. It is clearly shown that policy 1, construction of nuclear power plants, can reduce total energy cost from BAU situation significantly, especially for 5,000 MW. This comes from the fact that the cost of nuclear fuel (Uranium,U_3O_8) is much cheaper than fossil fuels.

Policy 2, promotion of renewable energy, results in a greatly increase of total energy cost since unit costs of renewable energy are more expensive than fossil fuel.

Policies 3 and 4, use of NG to replace fuel oil and construction of oil pipeline can reduce total cost slightly based on the BAU situation.

Policy 5, construction of mass transit system (URMAP), can reduce total energy cost significantly, which is comparable to the construction of 1,000 MW nuclear power plants.

Due to nuclear power plant crisis in Japan, it is unlikely that Thai people will accept nuclear power plants. If the objective is to reduce total energy cost, an implementation of policy 5, construction of mass transit system (URMAP), will offer comparable total cost to the construction of 1,000 MW nuclear power plants. From Fig. 3, if policies 2 to 5 are implemented at the same time the total cost is significantly less than the construction of 1,000 MW nuclear power plants. However, the construction of 5,000 MW nuclear power plants still offers much lower total energy cost than simultaneously implementing policies 2 to 5 (excluding policy 1).

However, if Thai people can accept nuclear power plants, simultaneously implementing all policies will offer the lowest total energy cost.

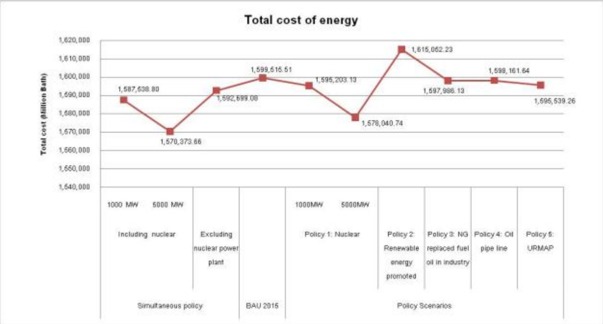

Fig.3 Total cost of energy

3.2 Self-reliance indicator

A country that relies very much on imported energies has low degree of self-reliance and energy security. This paper uses the proportion of import energy cost per total energy cost as an indicator for energy self-reliance as shown in Fig.4. The lower proportion of import energy cost per total energy cost, the more energy self-reliance for the country. Fig. 4 shows clearly that the BAU 2015 and policies 1, 3, 4, and 5 are not significantly different. Policy 2, promotion of renewable energies, is significantly better than other policies in term of energy self-reliance although, from Fig. 3, it is the worst policy related to the total energy cost.

If all policies are implemented simultaneously, the degree of self-reliance is better than the BAU2015 situation. However, it is worse than implementing policy 2 alone.

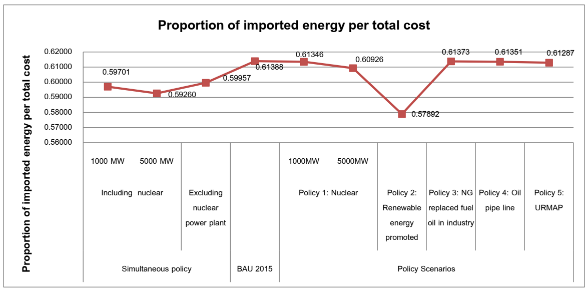

Fig.4 Proportion of imported energy

3.3 Emission indicator

The emissions from use of fuel are carbon dioxide (CO_2), sulfur dioxide (SO_2), methane (CH_4), nitrogen oxide (NO_x), and nitrous oxide (N_2O). It is possible to convert all emissions to carbon dioxide equivalent (CO_2-e). It is a summation of CO_2, 23 times of CH_4 and 296 times of N_2O. Fig. 5 shows CO_2-e of all energy policies.

With reference to BAU 2015, policy 1, construction of nuclear power plant, can reduce CO_2-e significantly especially for 5,000 MW. Policy 2, promotion of renewable energies, can reduce the emissions equivalent to 1,000 MW power plants.

Policy 3, use of NG to replace fuel oil in industry, results in slightly more CO_2-e emission than BAU 2015 since NG is limited when it is used more in industries it will be used less in power plants. From Table 5, policy 3 uses steam thermal more and use gas turbine and combined cycle less than policies 2, 4, and 5. This means that the power plants will use more coal which has more emissions than NG.

Policies 4 and 5 have only slightly less emissions than BAU 2015.

Table 5 Effects on KPIs of individual and simultaneous energy policies.

KPIs	Simultaneous policies			BAU 2015	Individual Policies					
	Including nuclear power plants		Excluding nuclear power plants		Policy 1: Nuclear		Policy 2: Renewable energy	Policy 3: NG replaced fuel oil in industry	Policy 4: Oil pipe line	Policy 5: URMAP
	1000 MW	5000 MW			1000 MW	5000 MW				
1. Economic Cost (M Baht)										
- Total cost	1,587,538.80	1,570,373.66	1,592,699.08	1,599,515.51	1,595,203.13	1,578,040.74	1,615,052.23	1,597,986.13	1,598,161.64	1,595,539.26
- Total fossil cost	1,434,882.90	1,409,683.03	1,442,051.87	1,463,609.66	1,457,288.59	1,432,091.47	1,422,106.15	1,462,153.64	1,462,255.79	1,459,679.77
-Total non fossil cost	117,960.53	125,995.27	115,951.84	101,210.48	103,219.17	111,253.91	158,250.72	101,137.12	101,210.48	101,164.13
- Total import energy cost	947,770.55	930,595.68	954,929.92	981,906.87	978,600.52	961,438.14	934,993.47	980,724.92	980,481.62	977,861.53
2. Proportion of import energy per total cost	0.59701	0.59260	0.59957	0.61388	0.61346	0.60926	0.57892	0.61373	0.61351	0.61287
3. Country Emission (Tons)										
- Carbon dioxide (CO_2)	380,513,006.83	365,950,057.69	385,430,902.12	385,430,902.12	381,219,944.25	365,950,057.69	381,475,779.82	387,381,898.15	385,353,472.95	384,391,651.31
- Sulfur dioxide (SO_2)	824,511.63	824,497.03	862,712.53	862,712.53	824,511.63	824,497.03	862,712.53	918,210.58	865,422.73	824,692.66
- Methane (CH_4)	120,432.64	120,432.64	120,432.64	120,150.18	120,432.64	120,432.64	119,369.83	120,424.86	120,421.97	119,831.34
- Nitrogen oxide (NO_x)	423,360.46	64,360.08	437,059.06	64,360.08	423,360.46	371,499.55	437,059.06	437,639.11	437,232.93	436,838.14
- Nitrous oxide (N_2O)	8,281.22	8,281.22	8,281.22	8,247.75	8,281.22	8,281.22	8,048.28	8,278.83	8,270.55	8,241.68
- CO_2-e of GHG	385,734,197.98	371,171,248.84	390,652,093.27	390,635,689.90	386,441,135.40	371,171,248.84	386,603,578.13	392,602,203.65	390,571,260.32	389,587,308.31
4. Country fuel diversification										
- Herfindahl Hirschman index	0.32317822	0.32001402	0.32474195	0.33520501	0.33519008	0.33203510	0.32433074	0.33379630	0.33505978	0.33517834
Power generation by type of power plant (ktoe)										
Hydro	691.77	691.77	691.77	691.77	691.77	691.77	691.77	691.77	691.77	691.77
Steam thermal	3,779.81	3,779.81	3,970.22	3,970.22	3,779.81	3,779.81	3,970.22	4,251.55	3,983.73	3,780.70
Gas turbine	19.21	19.21	19.21	19.21	19.21	19.21	19.21	0.00	19.21	19.21
Combined cycle	10,766.77	8,153.89	11,229.58	11,229.58	10,766.77	8,153.89	11,229.58	10,981.69	11,222.21	11,444.75
Diesel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cogeneration	1,001.76	1,001.76	1,001.76	1,001.76	1,001.76	1,001.76	1,001.76	987.54	1,001.76	1,001.76
Gas engine	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Nuclear	653.22	3,266.10	0.00	0.00	653.22	3,266.10	0.00	0.00	0.00	0.00
Total	16,913.55	16,913.55	16,913.55	16,913.55	16,913.55	16,913.55	16,913.55	16,913.55	16,919.69	16,939.20

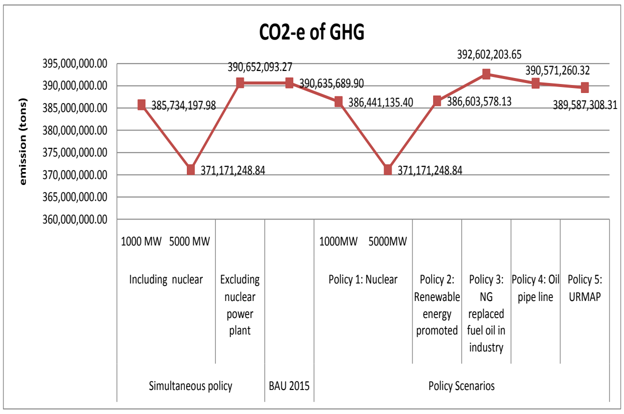

Fig.5 CO_{2-e} emission

3.4 Country's fuel diversification indicator

The diversification of energy consumption relates to energy security of the country. It is calculated by HHI as shown in Fig. 6. The lower HHI, the better. From Fig. 6, policy 2, promotion of renewable energies, results in significant reduction of HHI when compared with BAU 2015. Others policies results in slightly reduction of HHI. When all policies are implemented simultaneously, HHI is significantly reduced.

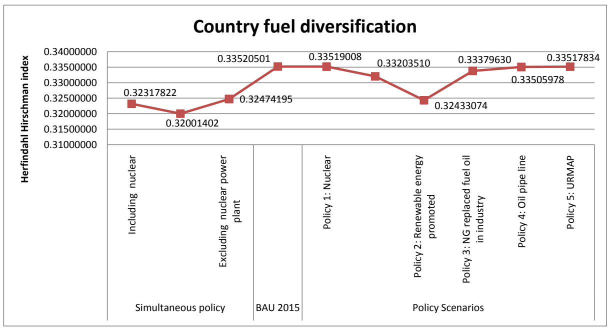

Fig.6 Diversification of energy mix

4. Conclusions

Thailand's Energy Allocation model developed in this paper is very useful for energy policy analysis. It clearly shows effects on KPIs of the entire country when energy policies are implemented. It reveals that each energy policy has both weak and strong points.

The construction of nuclear power plants is strong in total energy cost and emissions of CO_2. The promotion of renewable energy results in higher total energy cost, however the degree of self-reliance (the lowest proportion of imported energy per total energy cost) and energy diversification are improved.

The use of NG to replace fuel oil in industry results in higher CO_2-e emission than the BAU situation since the supply of NG is limited and power plants use less NG and use more coal, which results in more CO_2-e emission. Use of rapid mass transit system (URMAP) can significantly reduce total energy cost, which is comparable to the construction of 1,000 MW nuclear power plants.

From the fact that energy policies have both strong and weak points, the decision makers should have some tools to tradeoff among the weak and strong points to get some compromised solutions. Moreover, input data for energy policy analysis are subject to uncertainty and fuzziness. Thus, a further research should be conducted to develop a model that can determine compromised solutions based on uncertain or fuzzy data.

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