# Analysis and Selection of the Best Combination of Energy Policies: a Case of Thailand's Energy System

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***Abstract***

Energy policies have good and bad points based on energy indicators. Moreover, many policies may be simultaneously implemented. Thus, to select the best combination of the policies is not an easy task. This paper aims to analyze energy indicators of three energy policies with eight combinations of the policies and to propose a technique to tradeoff between good and bad points in order to select the best combination of the policies. An energy model that allocates energy supplies to satisfy energy demands in the way that minimizes the total energy cost of the country is used to determine the energy indicators for eight combinations of the energy policies. This paper considers five energy indicators, namely, total cost of energy, proportion of imported energy cost per the total energy cost, amount of emitted equivalent carbon dioxide, diversity of country's energy usage, and social acceptance on nuclear power plant. Since the energy indicators have different dimensions and are difficult to tradeoff, they are transformed into satisfaction levels on a scale of zero to one. Then the weights of energy indicators are obtained from 21 expert opinions. Based on the energy expert opinions, the indicator on social acceptance on nuclear power plant is the most important which is more than twice as important as other indicators. Finally, the best combination of the energy policies, which are promotion of ethanol and bio diesel usage and promotion of coal usage, is selected based on the weighted average of satisfaction levels. This paper is beneficial to energy policy and decision makers.

***Keywords**:* energy allocation model, energy indicators, energy policies selection.

## 1. Introduction

In 2008, energy policies of a country are announced by the Thai government. They address issues of energy development including energy production, distribution, and consumption.

The European Union (EU) has adopted the energy policy aiming to maximize the use of renewable energy sources to reduce the dependence on fuel from non-EU countries, to minimize emissions from carbon sources, and to decouple energy costs from oil prices [1]. Turkey is an agriculture-based country that has a lot of agriculture wastes. Thus, its energy policy is to promote the use of agriculture wastes as renewable energy sources [2]. The energy policy of Trinidad and Tobago focuses on energy efficiency on seven areas, namely, local content, renewable energy, infrastructure development, electricity, regional and international initiatives, fiscal regime, and pursuit of new LNG opportunities [3]. In China, there are great differentiations among areas. Three energy policies based on the regional differentiations are developed including network-based centralized energy supply zone, diversified energy utilization zone, and new energy utilization zone [4]. Climate change and fossil fuel depletion are the main drivers for considering alternative energy resources for Abu Dhabi of United Arab Emirates [5]. It has a recommendation to implement a mixed policy of feed-in-tariff and the quota system for renewable energy electricity generation in order to meet its 7% target by 2020.

This paper considers 3 energy policies for Thailand, namely, policy 1: nuclear power plant installation with a capacity of 1,000 MW, policy 2: promotion of ethanol and bio diesel usage, and policy 3: promotion of coal usage in industry and power plant.

Since the energy policies are not mutually exclusive, there are many alternatives to select and implement a set of policies. There are 8 alternatives to select the policies which will be discussed later.

Energy indicators measure economic, social, and environmental impacts on energy use [6]. Hence the indicators are the tool for analyzing and setting the energy policy goals. The South Africa [7] uses seven indicators of sustainability for energy sector including 1) energy sector carbon emission per capita, 2) level of most significant energy-related local pollutant, 3) households with access to electricity, 4) investment in clean energy, 5) resilience to external trade impacts, 6) burden of energy investments on the public sector, and 7) energy intensity.

The effect of the energy indicators in Baltic States is identified by [8]. The indicators include the energy use per capita, energy intensity, end-use intensities, energy security as the net energy import dependence, and environmental impact indicator. The macroeconomic indicators of energy policies in developing country are analyzed by [9]. These indicators are emission intensity ratio and energy-intensity ratio. The policy instrument designed to affect development and dissemination of new technologies is evaluated by [10]. The indicators are called outcome indicators that describe the process of technical change and program outcome in scope of socio-technical systems.

The energy policy indicators for sustainability are clarified and reviewed by [6]. They defined the indicators in three groups, namely, the security of energy supply, competitive energy market, and environmental protection.

This paper considers 5 energy indicators, namely, total cost of energy, proportion of imported energy cost per the total energy cost, amount of emitted equivalent carbon dioxide, diversity of country's energy usage, and social acceptance on nuclear power plant.

Each policy has good and bad points based on the indicators. For example, a nuclear power plant can effectively reduce carbon dioxide emission of the country. However, social acceptance is its major problem.

Moreover, the dimensions of indicators are greatly different. For example, the total cost of energy is in million Baht; $CO_2$ emission is in tons; and social acceptance is 'yes' or 'no'. This makes it difficult to tradeoff among indicators with different dimensions and magnitudes. This paper proposes to convert the values of indicators to 'satisfaction levels' that range from 0.0 to 1.0 and are dimensionless.

Since the indicators have different degree of relative importance (weight) dependent on viewpoints of decision makers, a survey should be conducted to determine the weights. Then, the average value of the weights is used for further analysis.

This paper proposes that the best alternative of energy policies should be selected based on the weighted average of satisfaction levels of all indicators.

This paper is divided into four sections. Section 2 presents methodology. Results are presented and discussed in section 3 and finally concluded in section 4.

## 2. Methodology

The methodology in this paper is divided into 7 steps as shown in Fig. 1.

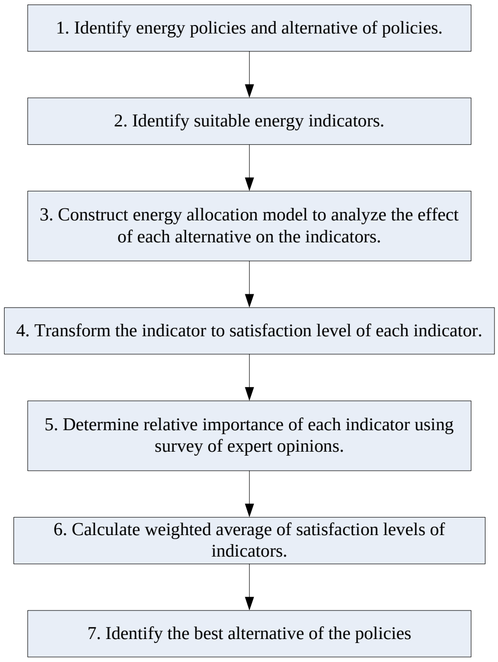


Fig. 1 Steps of the methodology

### 2.1 Energy policies and alternatives to select policies

There are three energy policies under consideration. They are explained as follows.

Policy 1: Nuclear power plant installation with a capacity of 1,000 MW

According to Thailand Power Development Plan 2010-2030 (PDP 2010) [11] issued by Electricity Generating Authority of Thailand, there is a plan to build a 1,000 MW nuclear power plant in 2020. It is equivalent to 653.22 ktoe. Table 1 shows that when the nuclear power plant is operated, the steam thermal, combined cycle, and gas engine power plants will be operated less. Note that BAU stands for business as usual situation which means that no energy policy is selected and implemented.

Table. 1 Electricity generation based on policy 1

| Types of power plant | Electricity generation (ktoe) | |
|---|---|---|
| | BAU | 1,000 MW of nuclear power plant |
| Hydro | 691.77 | 691.77 |
| Steam thermal | 3,970.22 | 3,418.76 |
| Gas turbine | 19.21 | 19.21 |
| Combined cycle | 11,229.58 | 11,128.82 |
| Diesel | 0.00 | 0.00 |
| Cogeneration | 1,001.76 | 1,001.76 |
| Gas engine | 1.00 | 0.00 |
| Nuclear | 0.00 | 653.22 |

Policy 2: Promotion of ethanol and bio diesel usage

This policy was issued by ministry of energy in January 2009 [12]. It is to promote ethanol usage in cars and motorcycles more than 3 million liters per day and to promote bio diesel for 3 million liters per day in 2011. As a result, the demands of fuels for road transport are changed as shown in Table 2**.**

Table. 2 Demands for road transport of policy 2

| Fuel types | BAU (ktoe) | Promotion of ethanol and bio diesel (ktoe) |
|---|---|---|
| Gasoline 91 | 4,911 | 1,217 |
| Gasoline 95 | 1,230 | 305 |
| Gasohol 91 (E10) | 274 | 914 |
| Gasohol 95 (E10) | 1,704 | 5,682 |
| High speed diesel | 16,629 | 0 |
| Bio diesel | 813 | 17,442 |

Policy 3: Promotion of coal usage in industry and power plant

This policy is to promote coal usage in industry to reduce the demand of fuel oil by 50% and to increase coal usage in steam thermal power plants for 50 %. The input parameters are changed as shown in Tables 3 and 4.

Since the energy policies are not mutually exclusive, it is possible to select more than one policy. There are 8 alternatives to select and implement a set of policies as shown in Fig. 2. Alternative 1 means that no policy is selected. Alternatives 2, 3, and 4 select policies 1, 2, and 3, respectively. Alternatives 5, 6, and 7 select two policies simultaneously. Alternative 8 selects all three policies.

Table. 3 Demands of coal in manufacturing sector of policy 3

| Fuel types | Demand in manufacturing sector (ktoe) | |
|---|---|---|
| | BAU | Increase coal usage policy |
| Anthracite | 253 | 281 |
| Bituminous | 3,230 | 3,586 |
| Coke | 71 | 79 |
| Briquettes & Other coal | 6,319 | 7,015 |
| Lignite from Krabi source | 10 | 11 |
| Lignite from other sources | 1,641 | 1,822 |
| Fuel oil | 2,540 | 1,270 |

Table. 4 Demands of coal for steam thermal power plant of policy 3

| Fuel types | Demand in steam thermal power plant (ktoe) | |
|---|---|---|
| | BAU | Increase coal usage policy |
| Bituminous | 2,227 | 3,341 |
| Lignite from Maemoh source | 4,193 | 6,290 |
| Produced gas (Natural gas) | 1,359 | 429 |
| Sale gas (Natural gas) | 2,506 | 791 |
| High speed diesel | 6 | 2 |
| Fuel oil | 819 | 258 |

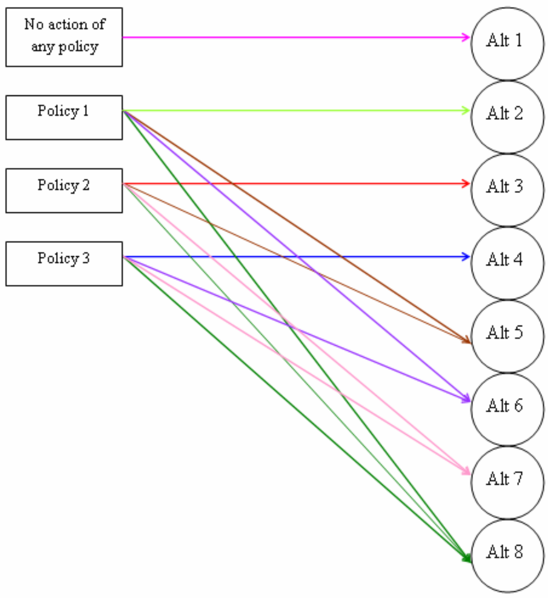


Fig. 2 Alternatives to select energy policies

## 2.2 Energy indicators

There are five energy indicators under consideration, which are explained as follows.

1) Total cost of energy

This indicator represents total energy costs of indigenous and imported energy, unit in million Baht. Note that Baht is the currency of Thailand and one US$ worth about 32 Baht. This indicator reflects amount of money that Thai people have to pay for energy.

2) Proportion of imported energy cost per total energy cost

This indicator is related to a degree of self reliance of energy. The lower proportion of imported energy means the higher degree of self reliance.

3) Amount of emitted equivalent Carbon dioxide ($CO_{2\text{-eq}}$)

This indicator measures amount of greenhouse gases (GHG) that released by the combustion of all fuel types. The amount of $CO_{2\text{-eq}}$ of GHG is calculated from total amount of carbon dioxide ($CO_2$), 23 times of methane ($CH_4$) and 296 times of nitrous oxide ($N_2O$). The emission factors are from IPCC 2006, Volume: Energy with tier 1 calculation [13].

4) Diversity of country's energy usage

This paper uses the Herfindahl-Hirschman Index (HHI) [14]. In this case the energy is divided into five types, namely, coal, natural gas, petroleum and petroleum products, alternative energy and hydropower, and nuclear power.

$$HHI = \sum_{\rho} p_{\rho}^{\,2} \qquad (1)$$

when

$p_\rho$ Proportion of country's energy type $\rho$

$\rho$ set of five energy types

5) Social acceptance on nuclear power plant

Although the nuclear power plant has strong points on energy cost and $CO_2$ emission, social acceptance in Thailand is still a major problem. This paper considers the opinions of most Thai people that do not accept nuclear power plant. The score of 1 for this indicator means 'not accept' while the score of 0 means 'accept'. Thus any alternative that has policy 1, nuclear power plant installation, has a score of 1 for social acceptance, otherwise has a score of 0.

## 2.3 Energy Allocation model

A Thailand's Energy Allocation model developed by Sirindhorn International Institute of Technology [15] is used to calculate energy indicators based on energy policies that are implemented. It is an LP model that tries to balance demand and supply of energies for entire country with an objective of minimizing total energy costs.

The framework of the model consists of three parts, namely, primary energy supply, energy transformation, and energy demand from various sectors as shown in Fig. 3.

## 2.4 Satisfaction levels of energy indicators

Since the energy indicators have different dimensions and are difficult to tradeoff, they are transformed into satisfaction levels of energy indicator $i$ for alternative $k$ ($\alpha_{i,k}$) on a scale of 0.0 to 1.0. Note that the best alternative has the satisfaction level of 1.0 while the worst one has the level of 0.0.

$$\alpha_{i,k} = \frac{Max_i - Value_{i,k}}{Max_i - Min_i} \qquad (2)$$

where

$i$ is index of energy indicators

$k$ is index of alternatives

$Max_i$ is maximum value of energy indicator $i$ for all alternatives

$Min_i$ is minimum value of energy indicator $k$ for all alternatives

$Value_{i,k}$ is the value of energy indicator $i$ for alternative $k$

## 2.5 Relative importance of the indicators

Energy indicators may have different degree of relative importance (weight). Moreover, the weights may be different dependent on individual viewpoints. Thus, reliable weights should be average values of weights from many expert opinions.

An Analytic Hierarchy Process (AHP) technique [16] is used to determine the weights by letting individual expert considers pair-wise comparison of indicators. The weights are assigned on a scale of 1 to 9. If indicators A and B are equally important, they have score of 1. If indicator A is extremely more important than indicator B, indicators A and B have the score of 9 and 1/9, respectively.

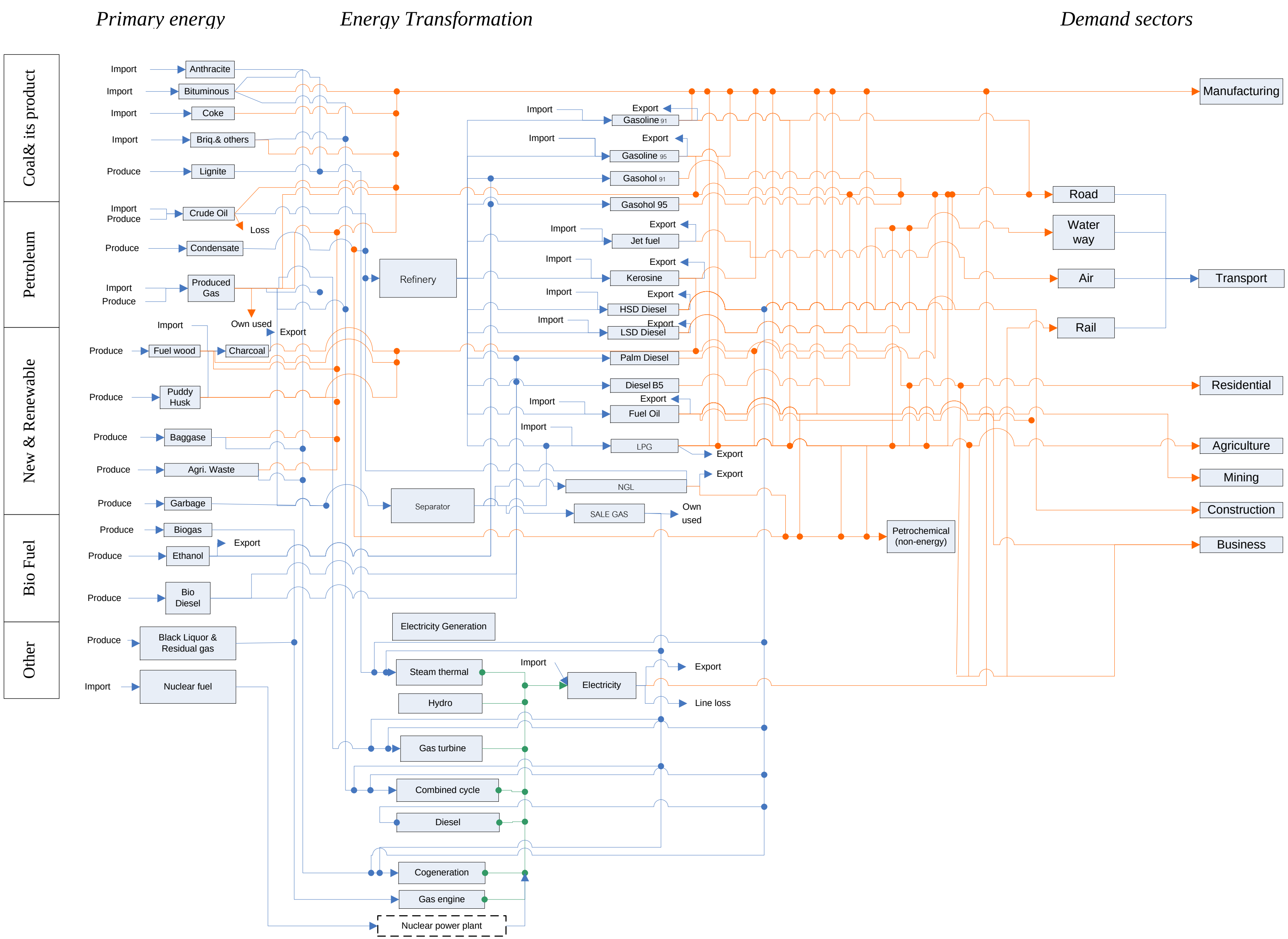


Fig. 3 Thailand’s energy allocation model

A survey was performed by sending 54 questionnaires to Thai energy experts. There are 23 respondents. However, two respondents have incomplete answers and they cannot be analyzed. Thus, the weights are calculated from 21 expert opinions.

### 2.6 Weighted average of satisfaction levels of indicators

The best alternative to select energy policies should be identified based on the weighted average of satisfaction levels of the indicators of alternative $k$ ($W_k$). The alternative $k$ that has the maximum values of $W_k$ should be selected. $W_k$ is calculated using formula 3.

$$W_k = \sum_i RI_i * \alpha_{i,k} \qquad (3)$$

where

$RI_i$ is relative importance of indicator $i$

## 3. Results and Discussions

The values of energy indicators of each alternative are presented in Table 5. It indicates that each alternative of energy policies has both good and bad points. For example, alternative 2 (policy 1: nuclear power plant installation) has very low emission of equivalent $CO_2$ but the social acceptance is not good. Alternative 3 (policy 2: promotion of ethanol and Bio diesel) has the highest total cost of energy but it is good at the emission of equivalent $CO_2$. Alternative 4 (policy 3: promotion of coal usage) has very low total energy cost but the emission of equivalent $CO_2$ is the worst.

When the values of energy indicators in Table 5 are presented to energy experts, most experts feel that it is difficult to comprehend since the indicators have different dimensions, units, and magnitude. Thus, they are transformed into the satisfaction levels ($\alpha_{i,j}$) as shown in Table 6. Most energy experts feel that the satisfaction levels are very easy to understand since they have the same scale from 0.0 to 1.0 and have no dimension. The value of 0.0 is the worst, 1.0 is the best, and around 0.5 is moderate.

Table. 5 Energy indicators of energy policy alternatives

| Alt. | Total cost of energy Indicator ($10^6$ Baht) | Proportion of imported energy per total cost | CO2-eq of GHG (tons) | Diversity of country's energy usage (HHI) | Social acceptance on nuclear power plant |
|---|---|---|---|---|---|
| 1. | 1,596,466.47 | 0.61010 | 390,635,689.90 | 0.33146 | 0.00 |
| 2. | 1,591,524.45 | 0.60970 | 384,024,917.13 | 0.33186 | 1.00 |
| 3. | 1,609,510.95 | 0.57747 | 386,603,578.13 | 0.32405 | 0.00 |
| 4. | 1,574,301.26 | 0.61634 | 403,623,645.32 | 0.31924 | 0.00 |
| 5. | 1,602,034.89 | 0.57338 | 382,968,414.37 | 0.32102 | 1.00 |
| 6. | 1,569,982.28 | 0.61531 | 399,988,481.56 | 0.31850 | 1.00 |
| 7. | 1,584,538.62 | 0.58038 | 399,591,533.55 | 0.31087 | 0.00 |
| 8. | 1,579,729.44 | 0.57802 | 395,956,369.79 | 0.30941 | 1.00 |

Based on the survey of 21 expert opinions and AHP technique, the average value of relative importance of energy indicators are summarized in Table 7. It reveals that the social acceptance on nuclear power plant is the most important which is more than twice as important as other indicators. Other four indicators are approximately equally important.

Table. 6 Satisfaction levels based on the indicators

| Alt. | Satisfaction levels | | | | | | RANK |
|---|---|---|---|---|---|---|---|
| | Total cost of energy | Proportion of imported energy per total cost | $CO_{2\text{-eq}}$ of GHG | Diversity of country's energy usage | Social acceptance on nuclear power plant | Total | |
| 1. | 0.3300 | 0.1453 | 0.6288 | 0.0180 | 1.0000 | 2.1221 | 6 |
| 2. | 0.4550 | 0.1545 | 0.9489 | 0.0000 | 0.0000 | 1.5584 | 8 |
| 3. | 0.0000 | 0.9047 | 0.8240 | 0.3480 | 1.0000 | 3.0767 | 2 |
| 4. | 0.8907 | 0.0000 | 0.0000 | 0.5620 | 1.0000 | 2.4527 | 5 |
| 5. | 0.1891 | 1.0000 | 1.0000 | 0.4827 | 0.0000 | 2.6718 | 4 |
| 6. | 1.0000 | 0.0240 | 0.1760 | 0.5952 | 0.0000 | 1.7952 | 7 |
| 7. | 0.6318 | 0.8371 | 0.1952 | 0.9348 | 1.0000 | 3.5989 | 1 |
| 8. | 0.7534 | 0.8919 | 0.3712 | 1.0000 | 0.0000 | 3.0165 | 3 |

Table. 7 Average values of relative importance of indicators

| Values | Relative importance of indicators | | | | |
|---|---|---|---|---|---|
| | Total cost of energy | Proportion of imported energy cost per total cost | $CO_{2\text{-eq}}$ of GHG | Diversity of country's energy usage | Social acceptance on nuclear power plant |
| Average | 0.1572 | 0.1710 | 0.1331 | 0.1615 | 0.3772 |
| S.D | 0.1016 | 0.1167 | 0.0797 | 0.1148 | 0.1991 |

Since each energy indicator has different degree of relative importance, the satisfaction levels of the indicators must be adjusted by the relative importance and the best alternative is selected based on the weighted average of the satisfaction levels. Table 8 presents the weighted average of satisfaction level of each alternative. From Table 8, the alternative 7 has the highest weighted average value of 0.7966. This means that the alternative 7 is the best alternative (based on the values of energy indicators calculated using the energy allocation model and relative importance of indicators obtained from expert opinions). Note that alternative 7 is a combination of policy 2: promotion of ethanol and bio diesel usage and policy 3: promotion of coal usage. This alternative does not include policy 1: nuclear power plant installation.

Table. 8 Satisfaction level adjusted by the relative importance

| Alt. | Satisfaction levels | | | | | | RANK |
|---|---|---|---|---|---|---|---|
| | Total cost of energy | Proportion of imported energy per total cost | $CO_{2\text{-eq}}$ of GHG | Diversity of country's energy usage | Social acceptance on nuclear power plant | Weighted average | |
| 1. | 0.0519 | 0.0248 | 0.0837 | 0.0029 | 0.3772 | 0.5405 | 4 |
| 2. | 0.0715 | 0.0264 | 0.1263 | 0.0000 | 0.0000 | 0.2243 | 8 |
| 3. | 0.0000 | 0.1547 | 0.1097 | 0.0562 | 0.3772 | 0.6978 | 2 |
| 4. | 0.1400 | 0.0000 | 0.0000 | 0.0908 | 0.3772 | 0.6079 | 3 |
| 5. | 0.0297 | 0.1710 | 0.1331 | 0.0780 | 0.0000 | 0.4118 | 6 |
| 6. | 0.1572 | 0.0041 | 0.0234 | 0.0961 | 0.0000 | 0.2808 | 7 |
| 7. | 0.0993 | 0.1432 | 0.0260 | 0.1510 | 0.3772 | 0.7966 | 1 |
| 8. | 0.1184 | 0.1525 | 0.0494 | 0.1615 | 0.0000 | 0.4819 | 5 |

If the relative importance of each indicator is equal, the total values of satisfaction levels of indicators (in Table. 6) can be used to select the best alternative without adjusting by the relative importance. In this case the alternative 7 is still the best.

Based on a discussion with energy experts in Thailand, they feel that the proposed methodology is helpful to comprehend the good and bad points of each energy policy. The energy allocation model is simple but effective to reflect the demand and supply of all types of energy required in the country. It can determine energy indicators of any combinations of energy policies. The methodology also helps reducing bias of decision makers for selecting energy policy alternative.

## 4. Conclusions

This paper proposes a methodology to analyze energy indicators of energy policy alternatives and to select the best alternative for selecting a combination of the energy policies. Since the energy indicators have different dimensions and magnitude, it is difficult to tradeoff among them to select the best alternative. This paper proposes to convert the indicators to the satisfaction levels of the indicators which have the same magnitude and are dimensionless. The relative importance of indicators is determined from the survey of energy expert opinions. Based on the weighted average of satisfaction levels of indicators, the best alternative is identified.

Important findings are summarized as follows. Based on the energy expert opinions, the indicator on social acceptance on nuclear power plant is the most important which is more than twice as important as other indicators. Other indicators, namely, total energy cost, proportion of imported energy cost per total cost, emission of equivalent $CO_2$, and diversity of energy usage are approximately equally important. Based on the values of energy indicators calculated from the energy allocation model and the relative importance of indicators obtained from expert opinions, the policy 2: promotion of ethanol and bio diesel in transportation and policy 3: promotion of coal usage in industry and electricity generation should be implemented at the same time. However, the policy 1: nuclear power plant installation should not be implemented.

This paper has significant contributions as follows. Firstly, it provides a methodology to determine energy indicators of energy policies, to convert the indicators to satisfaction levels to be easy for trading off, to determine relative importance of indicators based on energy expert opinions, to calculate weighted average of satisfaction levels of indicators which are the basis for selecting the best alternative of energy policies. Secondly, it conducts a survey of energy expert opinions to know the relative importance of each indicator. Thirdly, it identifies the best alternative of energy policies.

The limitations of this paper are as follows. This paper considers only three energy policies and five energy indicators, which are not exhaustive. There are many other interesting policies and indicators for further research. The relative importance or weight of each energy indicator comes from the average opinions of many experts. This average method does not reflect the difference of individual opinion. Further research should be conducted by analyzing the best alternative based on individual opinion and see whether there is a consensus of the opinion. A frequency distribution of the best alternatives based on individual opinion is also interesting.

## 5. Acknowledgement

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