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Optimal combination of energy sources for electricity generation in Thailand: A revisit using maximum entropy with 4 targets

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Abstract:

The method of Maximum Entropy proposed in Golan, Judge and Miller (1996). This research uses maximum entropy to calculate the optimal combination of the energy sources for electricity generation for Thailand. It aims at four targets that the country needs to trade-off. They are cost, risk, pollution and capacity factor. Seven sources of energy are taken to the analysis. They are solar, wind, hydro, oil, gas, coal and nuclear power. According to the study, when capacity is the first priority, nuclear power is usually the chosen one as it offers the highest capacity in production. When capacity is secondary and pollution is taken into account, wind power remains the first choice. However, when considering only cost and risk, with capacity and pollution factors being excluded, natural gas becomes the best option. All in all, this study has discovered a new way to choose energy sources that reflect policymakers' priority, whether it is cost, risk, pollution, or capacity.

Keywords: Optimization, electricity generation, energy sources, maximum entropy, multiple targeting

1. Introduction

The start of ASEAN causes widespread of social and economic development of member countries due to free movement of goods and services and skilled workers. This is an important part in the economy that makes the countries grow exponentially. It raises the use of electricity significantly and inevitably.

ASEAN member countries such as Laos PDR and Myanmar are distributors of electricity or inputs such as natural gas to Thailand. When these countries are developing their economic and social advances after attending the ASEAN Community, electricity demand in those countries rise to serve the production and households rather than selling electricity to neighboring countries.

The solution requires the development of sustainable energy sources. The alternative is nuclear power which can produce enough electricity for domestic use. However, this choice may be opposed by wider public. But if Thailand chooses the choice it is necessary to understand the management of nuclear power plants, uranium and nuclear waste. Nuclear power plant is advantage in many ways. Another alternative is Power comes from coal, natural gas, wind, solar and other clean energy. Government needs to be clarified to ensure that the power plant will produce electricity sufficient and no pollution to occur in the long term.

This study aims at forecasting the demand for electricity and the ability to generate electricity in Thailand. The result will be used in the planning of electricity, and the selecting of the correct type of electric power plant for Thailand.

2. Literature Reviews

The method of Maximum Entropy proposed in Golan, Judge and Miller (1996). Literatures reviews of technique for the portfolio optimization by using maximum entropy include Samuel Morley, Sherman Robinson and Rebecca Harris (1998), Edward Z. Shen and Jeffrey M. Perloff (2001), Ximing Wu (2003), Tatcha Sudtasan and Komsan Suriya (2012) and Tatcha Sudtasan and Komsan Suriya (2014).

For studies on the method and model of energy enterprise project portfolio selection and optimal allocation of resources such as Wu Yunna, Chen Jian, Liu Chao and Wang Hepling (2013). The results found that, the new rural biomass energy projects and nuclear power plant are the major power generation groups.

It tries to set four objectives which are cost, risk, pollution and capacity factor. The study of capacity factor, there are several works such as Yangbo Du and John E. Parsons (2010) and U.S. Environmental Protection Agency (EPA) (2014) who develop a model of the dynamic structure of capacity factor and point out capacity factor. However, it has seven parameters to optimize from seven sources of energy. In this case, mathematical program does not process when the number of equation is less than the number of parameters. The best way to solve this problem is to use maximum entropy. Therefore, the usage of maximum entropy is to serve the multi-objective optimization with limited information.

3. Methodology

This research uses maximum entropy to calculate the optimal combination of the energy sources for electricity generation for Thailand. It aims at four targets that the country needs to trade-off. They are cost, risk, pollution and capacity factor. It solves the system following the guideline of Golan, Judge and Miller (1996). Seven sources of energy are taken to the analysis. They are solar, wind, hydro, oil, gas, coal and nuclear power.

The study forms four information equations as follows:

Information 1: Cost

$$\sum_{k=1}^{7} \mathrm{UnitCost}_k \mathrm{Energy}_k = \mathrm{TargetCost} \tag{1}$$

where

Cost	is the cost of producing 1 MWh of electricity,
Energy	is portion of each source of energy that generates electricity which is unknown,
TargetCost	is the target of unit cost of producing 1 MWh of electricity set by policy makers.

Information 2: Risk

$$\sum_{k=1}^{7} \mathrm{RiskIndex}_k \mathrm{Energy}_k = \mathrm{TargetRisk} \tag{2}$$

where

RiskIndex	is the human dead toll of producing 1 MWh of electricity,
Energy	is portion of each source of energy that generates electricity which is unknown,
TargetRisk	is the target of human dead toll of producing 1 MWh of electricity set by policy makers.

Information 3: Pollution

$$\sum_{k=1}^{7} \mathrm{CO_2Emission}_k \mathrm{Energy}_k = \mathrm{TargetPollution} \tag{3}$$

where

$\mathrm{CO_2}$Emission	is the emission of carbon dioxide to the atmosphere from producing 1 MWh of electricity,
Energy	is portion of each source of energy that generates electricity which is unknown,
TargetPollution	is the target of the emission of carbon dioxide to the atmosphere from producing 1 MWh of electricity set by policy makers.

Information 4: Capacity factor

$$\sum_{k=1}^{7} \mathrm{CapacityFactor}_k \mathrm{Energy}_k = \mathrm{TargetCapacityFactor} \tag{4}$$

where

CapacityFactor	is the ratio of the actual annual megawatt hours of electrical energy production per megawatt of capacity of a power plant divided by 8,760 MWh, the total energy that could be generated by a plant of one megawatt capacity operated continuously at full capacity throughout the 8,760 hours in a year.
Energy	is portion of each source of energy that generates electricity which is unknown.
TargetCapacityFactor	is the target of the ratio of the actual annual megawatt hours of electrical energy production per megawatt of capacity of a power plant divided by 8,760 MWh, the total energy that could be generated by a plant of one megawatt capacity operated continuously at full capacity throughout the 8,760 hours in a year.

Maximum entropy equation:

To solve for seven unknowns of portion of each source of energy that generates electricity when we have only four information equations, it is impossible to do with other techniques but maximum entropy. The maximum entropy will construct a Lagragian function that tries to maximize the entropy function by using all the information equations as constraints. The Lagrangian function can be written as follows.

$$\begin{aligned} L \quad &= -\sum_{k=1}^{7} Enegy_k lnEnergy_k \\ &= \lambda_1\left(TargetCost - \sum_{k=1}^{7} Cost_k Energy_k\right) + \lambda_2\left(TargetRisk - \sum_{k=1}^{7} RiskIndex_k Energy_k\right) \\ &+ \lambda_3\left(TargetPollution - \sum_{k=1}^{7} CO_2Emission_k Energy_k\right) \\ &+ \lambda_4\left(TargetCapacityFactor - \sum_{k=1}^{7} CapacityFactor_k Energy_k\right) \end{aligned} \tag{5}$$

where L	is Lagrangian function.
Energy	is portion of each source of energy that generates electricity which is unknown
ln	is natural logarithm.
TargetCost	is the target of unit cost of producing 1 MWh of electricity set by policy makers.
TargetRisk	is the target of human dead toll of producing 1 MWh of electricity set by policy makers.
TargetPollution	is the target of the emission of carbon dioxide to the atmosphere from producing 1 MWh of electricity set by policy makers.

TargetCapacityFactor	is the target of the ratio of the actual annual megawatt hours of electrical energy production per megawatt of capacity of a power plant divided by 8,760 MWh, the total energy that could be generated by a plant of one megawatt capacity operated continuously at full capacity throughout the 8,760 hours in a year set by policy makers.
Cost	is the cost of producing 1 MWh of electricity.
RiskIndex	is the human dead toll of producing 1 MWh of electricity.
$\mathrm{CO_2}$Emission	is the emission of carbon dioxide to the atmosphere from producing 1 MWh of electricity.
CapacityFactor	is the ratio of the actual annual megawatt hours of electrical energy production per megawatt of capacity of a power plant divided by 8,760 megawatt-hours, the total energy that could be generated by a plant of one megawatt capacity operated continuously at full capacity throughout the 8,760 hours in a year.
λ	is Lagrange multiplier.

The technique to estimate parameters Energy can be presents step by step as follows:

Step 1: Use the formula of the concentrate maximum entropy of Golan, Judge and Miller (1996) as follows to find.

$$\mathrm{l}(\lambda) = \textstyle\sum_{\mathrm{t}=1}^{4} \lambda_{\mathrm{t}} * \mathrm{Target_t} + \ln\left(\Omega(\lambda)\right) \tag{6}$$

where

$$\Omega(\lambda) = \sum_{\mathrm{k}=1}^{7} \exp(-\lambda_1.\,\mathrm{Cost_k} - \lambda_2.\,\mathrm{RiskIndex_k} - \lambda_3.\,\mathrm{CO_2Emission_k} - \lambda_4.\,\mathrm{CapacityFactor_k}) \tag{7}$$

Step 2: Find $\frac{\partial l}{\partial X_1}, \frac{\partial l}{\partial X_2}, \frac{\partial l}{\partial X_3}$ and $\frac{\partial l}{\partial X_4}$ and set them to zero.

The derivatives are as follows:

$$\frac{\partial \mathrm{l}}{\partial \lambda_1} = 0 = \mathrm{TargetCost} + \frac{1}{\Omega(\lambda)} \tag{8}$$

$$\begin{gathered}
(-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost_1} - \lambda_2.\mathrm{RiskIndex_1} - \lambda_3.\mathrm{CO_2Emission_1} - \lambda_4.\mathrm{CapacityFactor_1})}.\,\mathrm{Cost_1} \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost_2} - \lambda_2.\mathrm{RiskIndex_2} - \lambda_3.\mathrm{CO_2Emission_2} - \lambda_4.\mathrm{CapacityFactor_2})}.\,\mathrm{Cost_2} \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost_3} - \lambda_2.\mathrm{RiskIndex_3} - \lambda_3.\mathrm{CO_2Emission_3} - \lambda_4.\mathrm{CapacityFactor_3})}.\,\mathrm{Cost_3} \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost_4} - \lambda_2.\mathrm{RiskIndex_4} - \lambda_3.\mathrm{CO_2Emission_4} - \lambda_4.\mathrm{CapacityFactor_4})}.\,\mathrm{Cost_4} \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost_5} - \lambda_2.\mathrm{RiskIndex_5} - \lambda_3.\mathrm{CO_2Emission_5} - \lambda_4.\mathrm{CapacityFactor_5})}.\,\mathrm{Cost_5} \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost_6} - \lambda_2.\mathrm{RiskIndex_6} - \lambda_3.\mathrm{CO_2Emission_6} - \lambda_4.\mathrm{CapacityFactor_6})}.\,\mathrm{Cost_6} \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost_7} - \lambda_2.\mathrm{RiskIndex_7} - \lambda_3.\mathrm{CO_2Emission_7} - \lambda_4.\mathrm{CapacityFactor_7})}.\,\mathrm{Cost_7}
\end{gathered}$$

$$
\begin{gathered}
\frac{\partial \mathrm{l}}{\partial \lambda_2} = 0 = \mathrm{TargetRisk} + \frac{1}{\Omega(\lambda)} \qquad (9) \\
(-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_1-\lambda_2.\mathrm{RiskIndex}_1-\lambda_3.\mathrm{CO_2Emission}_1-\lambda_4.\mathrm{CapacityFactor}_1)}.\,\mathrm{RiskIndex}_1 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_2-\lambda_2.\mathrm{RiskIndex}_2-\lambda_3.\mathrm{CO_2Emission}_2-\lambda_4.\mathrm{CapacityFactor}_2)}.\,\mathrm{RiskIndex}_2 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_3-\lambda_2.\mathrm{RiskIndex}_3-\lambda_3.\mathrm{CO_2Emission}_3-\lambda_4.\mathrm{CapacityFactor}_3)}.\,\mathrm{RiskIndex}_3 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_4-\lambda_2.\mathrm{RiskIndex}_4-\lambda_3.\mathrm{CO_2Emission}_4-\lambda_4.\mathrm{CapacityFactor}_4)}.\,\mathrm{RiskIndex}_4 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_5-\lambda_2.\mathrm{RiskIndex}_5-\lambda_3.\mathrm{CO_2Emission}_5-\lambda_4.\mathrm{CapacityFactor}_5)}.\,\mathrm{RiskIndex}_5 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_6-\lambda_2.\mathrm{RiskIndex}_6-\lambda_3.\mathrm{CO_2Emission}_6-\lambda_4.\mathrm{CapacityFactor}_6)}.\,\mathrm{RiskIndex}_6 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_7-\lambda_2.\mathrm{RiskIndex}_7-\lambda_3.\mathrm{CO_2Emission}_7-\lambda_4.\mathrm{CapacityFactor}_7)}.\,\mathrm{RiskIndex}_7
\end{gathered}
$$

$$
\begin{gathered}
\frac{\partial \mathrm{l}}{\partial \lambda_3} = 0 = \mathrm{TargetPollution} + \frac{1}{\Omega(\lambda)} \qquad (10) \\
(-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_1-\lambda_2.\mathrm{RiskIndex}_1-\lambda_3.\mathrm{CO_2Emission}_1-\lambda_4.\mathrm{CapacityFactor}_1)}.\,\mathrm{CO_2Emission}_1 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_2-\lambda_2.\mathrm{RiskIndex}_2-\lambda_3.\mathrm{CO_2Emission}_2-\lambda_4.\mathrm{CapacityFactor}_2)}.\,\mathrm{CO_2Emission}_2 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_3-\lambda_2.\mathrm{RiskIndex}_3-\lambda_3.\mathrm{CO_2Emission}_3-\lambda_4.\mathrm{CapacityFactor}_3)}.\,\mathrm{CO_2Emission}_3 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_4-\lambda_2.\mathrm{RiskIndex}_4-\lambda_3.\mathrm{CO_2Emission}_4-\lambda_4.\mathrm{CapacityFactor}_4)}.\,\mathrm{CO_2Emission}_4 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_5-\lambda_2.\mathrm{RiskIndex}_5-\lambda_3.\mathrm{CO_2Emission}_5-\lambda_4.\mathrm{CapacityFactor}_5)}.\,\mathrm{CO_2Emission}_5 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_6-\lambda_2.\mathrm{RiskIndex}_6-\lambda_3.\mathrm{CO_2Emission}_6-\lambda_4.\mathrm{CapacityFactor}_6)}.\,\mathrm{CO_2Emission}_6 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_7-\lambda_2.\mathrm{RiskIndex}_7-\lambda_3.\mathrm{CO_2Emission}_7-\lambda_4.\mathrm{CapacityFactor}_7)}.\,\mathrm{CO_2Emission}_7
\end{gathered}
$$

$$
\begin{gathered}
\frac{\partial \mathrm{l}}{\partial \lambda_4} = 0 = \mathrm{TargetCapacityFactor} + \frac{1}{\Omega(\lambda)} \qquad (11) \\
(-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_1-\lambda_2.\mathrm{RiskIndex}_1-\lambda_3.\mathrm{CO_2Emission}_1-\lambda_4.\mathrm{CapacityFactor}_1)}.\,\mathrm{CapacityFactor}_1 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_2-\lambda_2.\mathrm{RiskIndex}_2-\lambda_3.\mathrm{CO_2Emission}_2-\lambda_4.\mathrm{CapacityFactor}_2)}.\,\mathrm{CapacityFactor}_2 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_3-\lambda_2.\mathrm{RiskIndex}_3-\lambda_3.\mathrm{CO_2Emission}_3-\lambda_4.\mathrm{CapacityFactor}_3)}.\,\mathrm{CapacityFactor}_3 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_4-\lambda_2.\mathrm{RiskIndex}_4-\lambda_3.\mathrm{CO_2Emission}_4-\lambda_4.\mathrm{CapacityFactor}_4)}.\,\mathrm{CapacityFactor}_4 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_5-\lambda_2.\mathrm{RiskIndex}_5-\lambda_3.\mathrm{CO_2Emission}_5-\lambda_4.\mathrm{CapacityFactor}_5)}.\,\mathrm{CapacityFactor}_5 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_6-\lambda_2.\mathrm{RiskIndex}_6-\lambda_3.\mathrm{CO_2Emission}_6-\lambda_4.\mathrm{CapacityFactor}_6)}.\,\mathrm{CapacityFactor}_6 \\
-\boldsymbol{e}^{(-\lambda_1.\mathrm{Cost}_7-\lambda_2.\mathrm{RiskIndex}_7-\lambda_3.\mathrm{CO_2Emission}_7-\lambda_4.\mathrm{CapacityFactor}_7)}.\,\mathrm{CapacityFactor}_7
\end{gathered}
$$

Step 3: Use Newton method to solve for $\lambda_1, \lambda_2, \lambda_3$ and λ_4. This is done by using fsolve function in Matlab.

Step 4: Calculate the Lagragian, $\mathrm{l}(\lambda)$

Step 5: Use the formula of Golan, Judge and Miller (1996) to find the parameter Energy by plugging $\lambda_1, \lambda_2, \lambda_3$ and λ_4 into the formula.

$$
\mathrm{Energy_k} = \frac{\exp(-\lambda_1.\,\mathrm{Cost_k} - \lambda_2.\,\mathrm{RiskIndex_k} - \lambda_3.\,\mathrm{CO_2Emission_k} - \lambda_4.\,\mathrm{CapacityFactor_k})}{\sum_{\boldsymbol{k}=\mathbf{1}}^{\mathbf{7}} \exp(-\lambda_1.\,\mathrm{Cost_k} - \lambda_2.\,\mathrm{RiskIndex_k} - \lambda_3.\,\mathrm{CO_2Emission_k} - \lambda_4.\,\mathrm{CapacityFactor_k})} \qquad (12)
$$

or it can be written as:

$\lambda_1, \lambda_2, \lambda_3$ and λ_4 into the formula.

$$\mathrm{Energy_k} = \frac{\exp(-\lambda_1.\mathrm{Cost_k} - \lambda_2.\mathrm{RiskIndex_k} - \lambda_3.\mathrm{CO_2Emission_k} - \lambda_4.\mathrm{CapacityFactor_k})}{\Omega(\lambda)} \tag{13}$$

Step 6: Calculate the Entropy, $-\sum_{k=1}^{7} \mathrm{Energy_k} \ln \mathrm{Energy_k}$

4. Data

Data of Cost of energy are collected from U.S. Energy Information Administration (2013). The cost is in dollars. This is because Thailand has never used nuclear power. Therefore, we would like to compare the relative cost of nuclear power and other energy sources

Data of risk index are collected from the World Health Organization (2011). The paper evaluates the total risk per unit energy output (one Terawatt-year) by the total deaths caused by each energy system. The World Health Organization focuses on air pollution from institutions. Occupational health and safety statistics track the deaths of workers in the different industries.

Data of pollution are according to World Energy Council (2013). This paper evaluated the footprint of nuclear. There are many other areas where nuclear power consumes fewer resources than other electricity generators. Actually, when compared to natural gas, coal, hydro, wind, solar and petroleum. Nuclear is the most land efficient and energy-dense source of power. Evaluating these different features of its footprint shows that nuclear is one of our most executable solutions to surely decarbonize the economy.

Data of capacity factor are collected from U.S. Energy Information Administration (2013). Capacity factors are often outputs in energy-economic models, based on estimated generation and taking into account any curtailment that is necessary. The maximum availability factor is generally the input to the model and represents the highest possible capacity factor.

All the data are shown in table 1 as follows:

Table 1: Data of cost, risk index, pollution and capacity factor of each energy sources.

Plant Type	**Cost of total system ($/MWh)**	**Risk index (Human dead toll per MWh per year)**	**Pollution (kg CO2-e/MWh)**	**Capacity Factor (%)**
Solar (Photovolatic)	130	0.44	104	19.4
Wind	80.3	0.15	15	32.3
Hydro	84.5	1.40	120	38.1
Oil	66.3	36.0	866	11.7
Natural Gas	66.3	4.00	499	46.5
Coal	95.6	60.0	1372	59.7
Nuclear	96.1	0.04	40	90.1

Sources: Cost from U.S. Energy Information Administration (2013), risk index from the World Health Organization (2011), pollution from World Energy Council (2013) and capacity factor from U.S. Energy Information Administration (2013).

Due to many factors are different. You have to make an adjustment to normal by bringing the greatest division. The results obtained will be between 0 and 1. All data are shown in table 2 as follows:

Table 2: Normalized data of cost, risk index, pollution and capacity factor of each energy sources.

Plant Type	Cost of total system ($/MWh)	Risk index (Human dead toll per MWh per year)	Pollution (kg CO2-e/MWh)	Capacity Factor (%)
Solar (Photovolatic)	1	0.007	0.076	0.215
Wind	0.618	0.003	0.011	0.358
Hydro	0.650	0.023	0.087	0.423
Oil	0.510	0.600	0.631	0.130
Natural Gas	0.509	0.067	0.364	0.516
Coal	0.735	1	1	0.663
Nuclear	0.739	0.001	0.029	1

Sources: Cost from U.S. Energy Information Administration (2013), risk index from the World Health Organization (2011), pollution from World Energy Council (2013) and capacity factor from U.S. Energy Information Administration (2013).

5. Result

Due to the incompatible with the optimal values of lambda cannot be found by using a computer program. Therefore, it is necessary to estimate these lambda values by our judgement. In addition, the more cost, risk and pollution arise, the less we want. So, it is obviously seen that the value of lambda1, lambda 2 and lambda 3 must have positive values, while the lambda 4 has negative value because the more the capacity is, the more we desire.

Originally, lambda should be calculated by changing targets from one to another. Hence, when target is changed, the lambda value must also change. Unfortunately, this paper cannot calculate lambda value; thereby, what the best we can do for now is to pick up some numbers to represent these lambda values. Furthermore, if we carefully look at the equation 8 to equation 11, these equations show that each target has relationship with one another. As a result, choosing the lambda value will not change the proportion of energy sources as shown in table 3 and table 4

Table 3 explains results from targeting the lowest cost with high capacity but allowance for high risk and pollution. In this case that we focus only on the cost of pollution, the result shows that oil and natural gas have the highest proportion compare to other energy sources. If we focus only on the pollution, wind energy has the largest proportion because it has the least pollution. Nuclear power has the largest proportion when we focus only risk and only capacity factor. Although, if we focus on cost and risk, natural gas has a large proportion because it has low cost and risk. If we focus on cost and pollution, wind has a large proportion. Nuclear power has a large proportion when we focus on cost and capacity factor. If we focus on risk and pollution, wind has the largest proportion. Nuclear power plan has a large proportion when we focus on risk and capacity factor. When we focus on pollution and capacity factor, nuclear power has a large proportion. Finally, when we focus on three variables simultaneously, wind has a large proportion when we focus on cost, risk and pollution. If we focus on cost, risk and capacity factor, nuclear power has a large proportion.

Nuclear power has a large proportion when we focus on cost, pollution and capacity factor. If we focus on cost, risk, pollution and capacity factor. The largest proportion is nuclear power.

However, if we focus only pollution or pollution together with other variables, wind has the largest proportion because it has the least pollution. Wind is a natural source of energy, which has only first investment and no fuel surcharge.

Nuclear power has the largest proportion if we focus only risk or only capacity factor. If we focus on capacity factor with other variables, nuclear power always has the largest proportion. The significance of nuclear power increases by 0.320 if we focus on risk, pollution and capacity factor. This proportion is the highest when comparison with other variables. Nuclear power is affordable, if use a lot. Nuclear power is unlimited if used nuclear fuel rods Reprocess. It does not cause the greenhouse effect.

Table 4 explains results from targeting the lowest cost with lower capacity but also lower risk and pollution. In this case has the proportion of any energy sources same as table 3. Nuclear power has the largest proportion if we focus only risk or only capacity factor. If we focus on capacity factor with other variables, nuclear power always has the largest proportion. The significance of nuclear power increases by 0.320 if we focus on risk, pollution and capacity factor. This proportion is the highest when comparison with other variables.

Table 3: Results from targeting the lowest cost with high capacity but allowance for high risk and pollution

Targets															
Cost target	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Risk target	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pollution target	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Capacity target	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Lambda															
Lambda1 (Cost)	1	0	0	0	1	1	1	0	0	0	1	1	1	0	1
Lambda2 (Risk)	0	1	0	0	1	0	0	1	1	0	1	1	0	1	1
Lambda3 (Pollution)	0	0	1	0	0	1	0	1	0	1	1	0	1	1	1
Lambda4 (Capacity)	0	0	0	-1	0	0	-1	0	-1	-1	0	-1	-1	-1	-1
Entropy	1.926	1.897	1.898	1.905	1.887	1.896	1.9	1.811	1.845	1.841	1.817	1.841	1.847	1.745	1.753
Proportions:															
Solar	0.091	0.171	0.172	0.106	0.110	0.111	0.068	0.190	0.126	0.126	0.124	0.081	0.082	0.139	0.091
Wind	0.152	0.171	0.183	0.123	0.185	0.199	0.132	0.203	0.146	0.156	0.223	0.158	0.170	0.171	0.188
Hydro	0.146	0.168	0.170	0.131	0.173	0.176	0.135	0.185	0.153	0.154	0.194	0.158	0.161	0.166	0.175
Oil	0.176	0.094	0.099	0.098	0.118	0.124	0.121	0.060	0.064	0.067	0.076	0.080	0.084	0.040	0.051
Natural gas	0.176	0.161	0.129	0.144	0.200	0.162	0.179	0.134	0.160	0.128	0.170	0.201	0.162	0.132	0.168
Coal	0.130	0.063	0.068	0.166	0.058	0.063	0.153	0.028	0.073	0.079	0.026	0.067	0.073	0.032	0.030
Nuclear	0.129	0.172	0.180	0.233	0.157	0.166	0.213	0.200	0.278	0.291	0.186	0.255	0.269	0.320	0.298
Max proportion	0.176	0.172	0.183	0.233	0.200	0.199	0.213	0.203	0.278	0.291	0.223	0.255	0.269	0.320	0.298

Source: Calculation using Matlab

Table 4: Results from targeting the lowest cost with lower capacity but also lower risk and pollution

Targets															
Cost target	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Risk target	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Pollution target	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Capacity target	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Lambda															
Lambda1 (Cost)	1	0	0	0	1	1	1	0	0	0	1	1	1	0	1
Lambda2 (Risk)	0	1	0	0	1	0	0	1	1	0	1	1	0	1	1
Lambda3 (Pollution)	0	0	1	0	0	1	0	1	0	1	1	0	1	1	1
Lambda4 (Capacity)	0	0	0	-1	0	0	-1	0	-1	-1	0	-1	-1	-1	-1
Entropy	1.926	1.897	1.898	1.905	1.887	1.896	1.9	1.811	1.845	1.841	1.817	1.841	1.847	1.745	1.753
Proportions:															
Solar	0.091	0.171	0.172	0.106	0.110	0.111	0.068	0.190	0.126	0.126	0.124	0.081	0.082	0.139	0.091
Wind	0.152	0.171	0.183	0.123	0.185	0.199	0.132	0.203	0.146	0.156	0.223	0.158	0.170	0.171	0.188
Hydro	0.146	0.168	0.170	0.131	0.173	0.176	0.135	0.185	0.153	0.154	0.194	0.158	0.161	0.166	0.175
Oil	0.176	0.094	0.099	0.098	0.118	0.124	0.121	0.060	0.064	0.067	0.076	0.080	0.084	0.040	0.051
Natural gas	0.176	0.161	0.129	0.144	0.200	0.162	0.179	0.134	0.160	0.128	0.170	0.201	0.162	0.132	0.168
Coal	0.130	0.063	0.068	0.166	0.058	0.063	0.153	0.028	0.073	0.079	0.026	0.067	0.073	0.032	0.030
Nuclear	0.129	0.172	0.180	0.233	0.157	0.166	0.213	0.200	0.278	0.291	0.186	0.255	0.269	0.320	0.298
Max proportion	0.176	0.172	0.183	0.233	0.200	0.199	0.213	0.203	0.278	0.291	0.223	0.255	0.269	0.320	0.298

Source: Calculation using Matlab

Nevertheless, the results indicated that, when any of the factors was set as 0, policymakers did not include that factor in making decision on energy sources. On the contrary, when any of the factors was set as 1 or -1 depending on cases, the factor that offered negative impacts (in case that) or positive impacts (in case that) when the value was high was policymakers' priority. According to the results, energy sources whose characteristics were compatible with policymakers' priority appeared to have larger proportion in the results than other energy sources.

To illustrate, in the case that we focus only on the cost of pollution, the result shows that oil and natural gas have the highest proportion compare to other energy sources. This conforms to the fact that the cost per 1 MWh of these two energy sources has the lowest cost compare to others. Another example, if we focus only on the pollution, wind energy has the largest proportion because it has the least pollution. From these examples indicate the compatible between the estimate value in our model and the real data.

In conclusion, the maximum entropy study did not yield complete results as expected due to technical problems. However, the results reflected the actual data and were usable for sorting energy sources by their proportion. Although the proportions could not be precisely specified, we could tell from the results which energy sources should be prioritized in keeping with country development.

According to the study, when capacity is the first priority, nuclear power is usually the chosen one as it offers the highest capacity in production. When capacity is secondary and pollution is taken into account, wind power remains the first choice. However, when considering only cost and risk, with capacity and pollution factors being excluded, natural gas becomes the best option.

All in all, this study has discovered a new way to choose energy sources that reflect policymakers' priority, whether it is cost, risk, pollution, or capacity.

6. Conclusion

The use of renewable energy, including oil, natural gas and coal causes environmental impact was somehow way. The best approach is to use energy-saving and efficiency. In addition, policy makers should be to oversee the implementation of measures to ensure compliance with environmental standards and using technology to control pollution. At the same time it must take appropriate measures to minimize the impact on communities and the environment.

The development will cause an impact and changing both the good and the bad together, this will bring both advantages and disadvantages compared. If there are more advantages should encourage development and establish measures to eliminate disadvantages that have minimal impact. The construction power plant has both advantages and disadvantages as well. If you are considering building a power plant is beneficial to economic and social development. It should also be encouraged to continue. At the same time, it must take appropriate measures to minimize the impact for that to happen in the future.

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