Ranking of Renewable Energy for The National Electricity Plan in Thailand Using an Analytical Hierarchy Process (AHP)

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Abstract- Awareness of environmental burdens and uncertainty about the quantity and price of fossil fuels are challenges to efficient energy supply and use. Therefore, energy planning is an important mechanism in addressing these challenges. The objective of this study was to prioritize renewable energy types as a guideline for targeting Thailand's power generation plan using an analytical hierarchy process (AHP). Six expert groups with different backgrounds related to the renewable energy field in Thailand were involved through questionnaire surveys for a prioritization exercise. Five main criteria and eight associated sub-criteria were studied. Seven of the renewable resources were selected according to the Alternative Energy Development Plan (AEDP2015). The results showed that solar energy had the highest ranking score, followed by biomass, small hydropower, biogas from wastewater/solid waste, wind energy, biogas from energy crops, and waste to energy. Compared with AEDP2015, the results of this research showed significant differences. Although this research was performed for academic purposes, its result can be useful as a model for stakeholders, policy makers, and decision makers who are involved in the energy policy sector.

Keywords Renewable energy resources, Analytical hierarchy process, National electricity plan, Energy policy.

1. Introduction

Energy, especially electricity, is a major factor in the development of Thailand. The cost of producing electricity plays an important role in industrial production, agriculture, transportation, household electricity consumption, and improvements in the quality of life in urban and rural areas. The country's development and socio-economic growth from the past to the present has led to increased energy use, although energy is limited and scarce, especially fossil fuel [1]. Thailand is still dependent on imports of fossil energy from abroad. In the last five years (2012-2016), Thailand has imported all kinds of primary energy, approximately 55-61% of the total primary energy used [2]. The high dependence on fossil fuel sources can lead to many problems, such as price fluctuation, greenhouse gas emission, and low energy security [3-5].

Renewable energy is a way to respond to this challenge. Currently, renewable energy technologies have been developed and can replace fossil fuel to limit damage to the environment from electricity generation techniques [6-8]. This replacement has become more tangible as its costs have been reduced, and its efficiency has been enhanced. In addition, renewable energy can also create economic, social, and environmental benefits. To apply renewable energy in the national energy plan, it is a challenge for energy management, especially in terms of energy efficiency and supply. Therefore, there is an urgent need to accelerate the management of energy efficiency to ensure that Thailand will continue to have stable and sustainable energy in the future. A key mechanism for energy management is energy planning [9-12].

In Thailand, there are five energy plans to operate the energy policy in the country. However, the Alternative Energy Development Plan (AEDP) is the most critical for the Thai renewable energy policy. The main point of AEDP is to set goals and guidelines for the production and use of renewable energy in the electricity, heating, and biofuels sectors [13]. AEDP was first established in 2012 and set a target for using 25% of renewable energy in 10 years (2012-2021). For the electricity sector, the target was 10% of the final energy use, with the intention to produce the energy from solar energy, wind energy, small hydropower, biomass, biogas, waste to energy, and other new forms of energy, without prioritization [2,14]. In 2015, the AEDP was revised to increase the portion of utilized renewable energy to 30% [10]. In addition, it has prioritized the alternative renewable options as follows: waste to energy, small hydropower, biogas from wastewater/solid waste, biomass, biogas from energy crop, solar cell, and wind energy. The prioritization of renewable energy sources in AEDP was based on the cost of electricity generation, social and environmental benefits and government policies. Academic studies and systematic decision-making techniques were not taken into consideration. Furthermore, the prioritization also does not cover all relevant dimensions. The resulting prioritization seems to be only an inference from the existing data.

An analytical hierarchy process (AHP) is a useful tool for addressing quantifiable and intangible criteria that can make an assessment difficult [15-17]. It breaks a complex decision into explicit goals, alternatives and criteria, then prioritize criteria and evaluate alternatives in terms of those criteria in which easy to understand for people. In addition, AHP can identify the data inconsistency and help researchers to deal with the issues that are needed. Many studies have been performed using AHP in the energy sector [18-22]. A prior study [23] evaluated the suitable energy resource in Turkey by using AHP. Another study [24] used AHP for ranking various renewable and non-renewable electricity production technologies in the United States, indicating that financial incentives for solar, wind, hydropower, and geothermal should be promoted. In India, AHP was used to evaluate barriers to solar energy growth and found that political and regulatory aspects were the most influential barriers [25]. Although there are many studies with AHP in the energy sector, the planning of renewable energy for electricity production in Thailand is a unique case. In fact, the planning for the Thai electricity supply from renewable sources has not considered using systematic decision-making techniques or determined the simultaneous technical, environmental, social, and economical criteria.

Based on these weaknesses and the gap of this constructive plan, the objective of this study was to investigate the application of AHP for decision-making related to the national electricity plan in Thailand. The main criteria related to decision-making for renewable energy sources were proposed in this study.

1.1. Fossil fuel and renewable energy in Thailand

Fossil fuel in Thailand can be divided into two main categories: (1) petroleum energy and (2) coal. Approximately 57% of petroleum energy is imported from foreign countries, while 43% is supplied within the country, consisting of natural gas, crude oil, and liquid natural gas [26]. In the case of coal, Thailand has produced only one type of coal, lignite, and the other types (i.e., bituminous, coke, and others) were imported from neighboring countries, especially Indonesia. Most of the coal was used as fuel for electricity production and heat in industrial sectors [27].

Fossil fuel is a main fuel for electricity production, accounting for approximately 87.31%. With this fraction, approximately 70% is natural gas, and 19% is coal, while fuel oil and diesel oil are a small fraction, approximately 0.5%; the remaining sources are renewable energy and hydropower [28]. The government encourages all stakeholders to produce electricity from renewable resources by revising the target of AEDP (year 2015-2036). Its target is adjusted to 30% share of renewable energy. The target for 2036 is 20.11% of the national electrical demand to be produced by renewable energy [29]. The government has focused on the type of renewable energy that can replace fossil fuel and simultaneously solve social problems, for example, municipal solid waste and agricultural waste residues.

Consequently, these renewable sources were the priority for promotion in the energy policy plans. It has been estimated that wastes have the potential to produce approximately 550 MW for electricity production and biomass has a potential of 5,570 MW, as shown in Table 1. In terms of ordering the 7 types of renewable energy, the AEDP2015 has set the merit order [10] as shown in Table 2. However, the order was ranked by using a top-down approach that lacks integration between government agencies and stakeholders [30].

Table 1. Status and targets of Alternative Energy Development Plan (AEDP) in 2036

Type of renewable energy	**Capacity (MW)**	
	2014	**2036**
Solar energy	1,299	6,000
Wind energy	225	3,002
Hydropower (small)	-	2,906
Hydropower (large)	142	376
Waste (MSW and Industrial waste)	66	550
Biomass	2,452	5,570
Biogas (Waste/Wastewater)	312	600
Biogas (Energy crop)	-	680
Total	4,496	19,684

Source: [10]

Table 2. The merit order of purchasing electricity from renewable energy sources

Order	1	2	3	4	5	6	7
Type of renewable energy	Waste	Small hydropower	Biogas	Biomass	Energy crop	Solar energy	Wind energy

Source: [10]

2. Methodology

We have divided this study into six main sections that consist of (1) an overview of Thailand's energy and alternative energy data; (2) questionnaire development; (3) target group; (4) survey implementation; (5) data analysis by AHP; and (6) final ranking of renewable energy sources in Thailand. The details of each step are explained in the following sections. The AHP analysis was processed through Business Performance Management Singapore (BPMSG) to calculate the priorities for a set of criteria based on pairwise comparisons [21].

2.1 Background information

Information related to alternative renewable energy in Thailand was gathered from the literature, stakeholders, and expert consultations. The documents related to the Multi Criteria Decision Making (MCDM), AHP, Thai electricity production, and energy policy in Thailand were reviewed through government documents, books, web links, and scientific journals that were already mentioned in Introduction section.

2.2 Questionnaire and survey

In this study, the questionnaire was divided into five main parts: (1) information about respondents; (2) pairwise comparison of main criteria; (3) pairwise comparison of sub-criteria; (4) pairwise comparison of renewable energy choices in Thailand; and (5) open-ended form for unstructured comments from respondents. The structured form was used for pairwise comparisons and was linked to five main criteria and their associated eight sub-criteria. The main criteria and sub-criteria were generated from a focus group meeting consisting of 27 people from stakeholders such as policy makers, the Electricity Generating Authority of Thailand (EGAT), the Ministry of Industry, lecturers from universities, energy experts, private sector partners for electricity production, and users. The details of each criterion are illustrated in Fig. 1. The seven alternative choices of renewable energy in Thailand are (1) solar energy, (2) biomass, (3) wind energy, (4) biogas from energy crops, (5) biogas from wastewater/solid waste, (6) waste to energy, and (7) small hydropower plant. These choices were obtained from the Alternative Energy Development Plan 2015 [10]. The details of the main criteria and sub-criteria can be explained as follows:

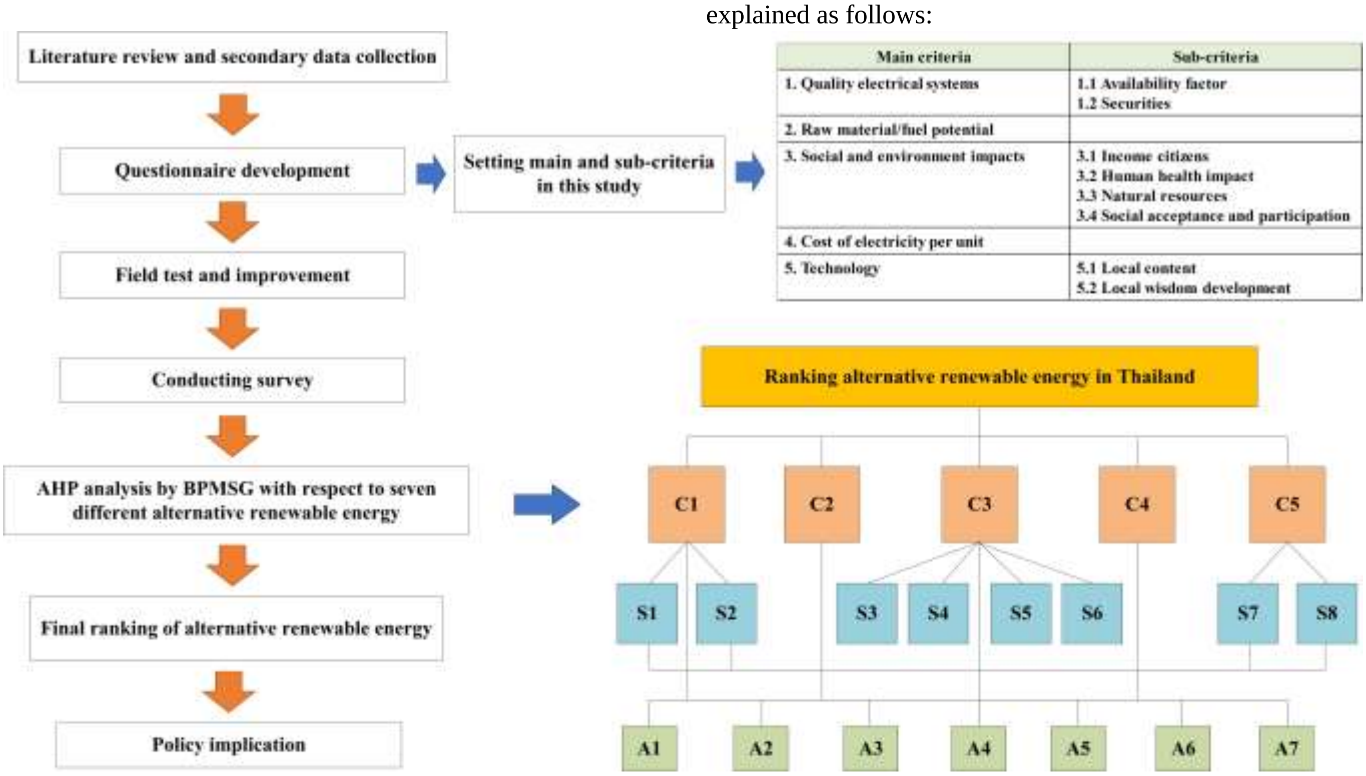


Fig. 1. Steps for applying the analytical hierarchy process in the study

Quality electrical systems refers to the production and distribution of electricity at frequencies and voltages in the required range. This criterion will consist of two sub-criteria:

(1) Availability factor – the availability of electricity in both quantity and time. Renewable energy sources in electric power generation should be able to provide fast power and proper capacity.
(2) Security – the ability to manage power supply in the system. This sub-criterion is related to continuing to provide a reliable, affordable, and efficient supply of electricity.

Raw material/fuel potential refers to the availability of raw materials in terms of volume and quality for producing electricity continuously throughout the life-cycle of a power plant.

Social and environment impacts refer to the social and environmental effects of renewable power generation, which consist of four sub-criteria:

(1) Income citizens – the direct and indirect effect of renewable power generation on the income of citizens.
(2) Human health impact – the pollutants emitted by the power plants must be at or below the standard thresholds so that they do not affect the health of the people and the organisms.
(3) Natural resources – actions from renewable power generation that directly or indirectly affect natural resources such as air, soil, water, and forest.
(4) Social acceptance and participation – acceptance by the public and stakeholders of the decision-making process or development of a power plant project.

Cost of electricity per unit refers to the costs that cover investment cost, operation cost, and maintenance cost for producing electricity.

Technology refers to the ability to transfer technology to the country and job creation and consists of two sub-criteria:

(1) Local content –the technology can support the use or production of equipment within the country.
(2) Thai traditional knowledge technology – the application of Thai traditional knowledge to support the development of technology.

2.3 Focus group

In this study, the respondents were specifically defined because the topic of this research is very specific and related to a group of experts. Therefore, the respondents were divided into six groups as shown in Table 3.

2.4 AHP application to rank renewable energy sources in Thailand

The step of applying AHP consisted of several steps as shown in Fig. 1. The first step was started by setting the target and was followed by the selection of alternatives. The judgment of alternative selection was based on the main criteria and sub-criteria. The AHP diagram was created to show the relationship between the target, the criteria, and alternatives in a hierarchical structure. A pairwise comparison was required for comparing among criteria and among alternatives. To compare quantitative values, the criteria weights were attained in decision option performance scores. On a nine-point scale, the stakeholders were asked to express preferences for one criteria/alternative over another in each pair. The explanation of the scale for the pairwise comparison is shown in Table 4.

Table 3. Information about the respondents who answer the questionnaire.

Number of group	Stakeholders	Respondents
Group I	Agency responsible for policy and plan development of renewable energy	- Energy Policy and Planning Office, Ministry of Energy - Department of Alternative Energy Development and Efficiency, Ministry of Energy
Group II	State enterprise that produces and distribute electricity in Thailand	- Electricity Generating Authority of Thailand (EGAT) - Provincial Electricity Authority (PEA)
Group III	Agency responsible for electricity purchasing and regulatory commission	- Energy Regulatory Commission (ERC)
Group IV	Energy experts who have more than 10 years of experience in the energy research field	- Researchers and lecturers from universities
Group V	Private sector individuals with business in the renewable energy field	- The Federation of Thai Industries
Group VI	Public sector individuals who have knowledge of energy and renewable energy in Thailand	

Table 4. Description of scale for pairwise comparisons

Level of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favor one activity over another.
5	Strong more importance	Experience and judgement strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another; and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.

After obtaining the pairwise comparison result, the next step is to transfer the weights to a matrix, which is a method unique to the AHP [31]. The square matrix of pairwise comparisons A=[a_{ij}] will be filled in as shown in the example of equation (1).

$$Aw = \begin{bmatrix} 1 & p & q \\ 1/p & 1 & r \\ 1/q & 1/r & 1 \end{bmatrix} \quad (1)$$

The consistency index (CI) can be calculated by equation (2)

$$CI = \frac{\lambda\max - n}{n-1} \quad (2)$$

where λmax is the maximum eigen value of A, and n is the size of the matrix (n × n)

The consistency ratio (CR) can be calculated by equation (3)

$$CR = \frac{CI}{RC} \quad (3)$$

where RC is a random consistency of the matrix A that can be estimated using a standard table proposed by [32] as shown in Table 5. If CR is equal to or less than 0.1, the results are acceptable. If it is not, then they should be revised again.

Table 5. Random consistency

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: [32]

3. Results and Discussion

3.1 Results

The study presented here evaluated and prioritized seven alternative renewable energy sources in Thailand with five main criteria and eight sub-criteria that covered all aspects that concerned stakeholders.

The criteria-wise preference analysis indicated that social and environmental impacts were the most favored, whereas technology was the least. The cost of electricity production criteria required higher electricity quality and raw material/fuel potential. Based on the responses obtained from the questionnaire survey, the highest percentage of weight was given to social and environment impact (40.6%), followed by the cost of electricity production (19.8%), electricity quality (17.8%), raw material/fuel potential (13.2%), and technology (8.6%). The results are shown in Fig. 2.

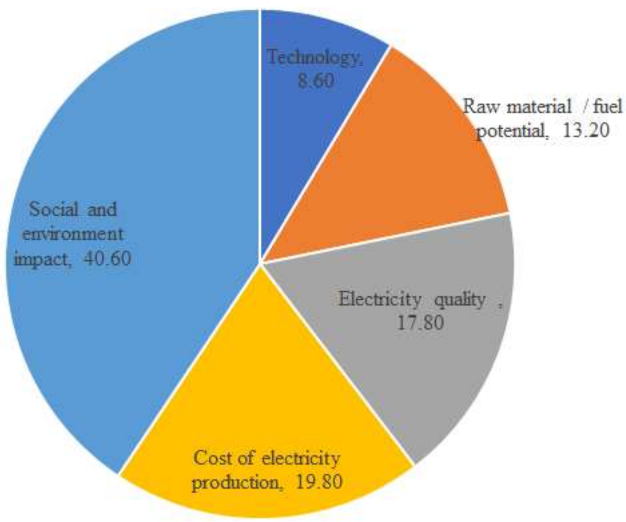
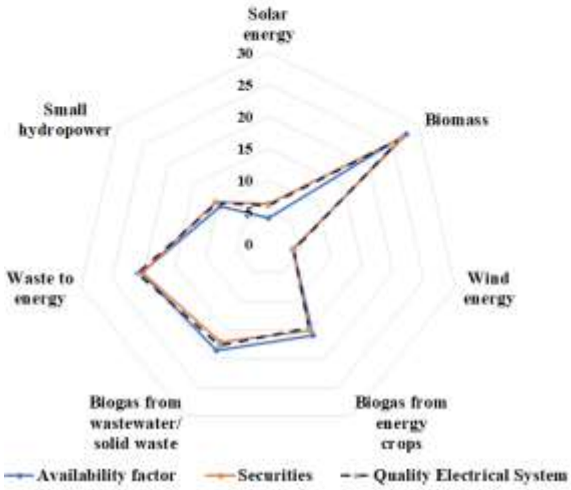
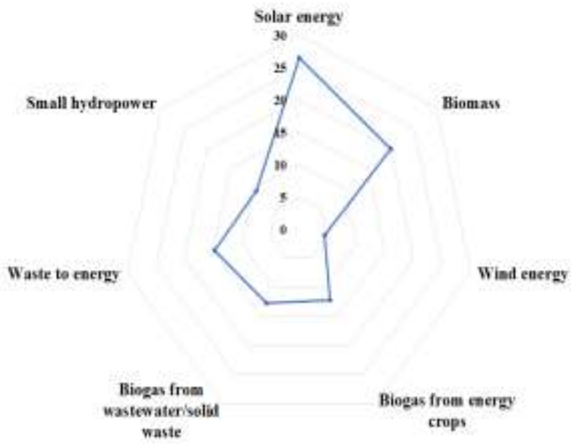


Fig. 2. Weights of the five main factors for determining the renewable energy order.

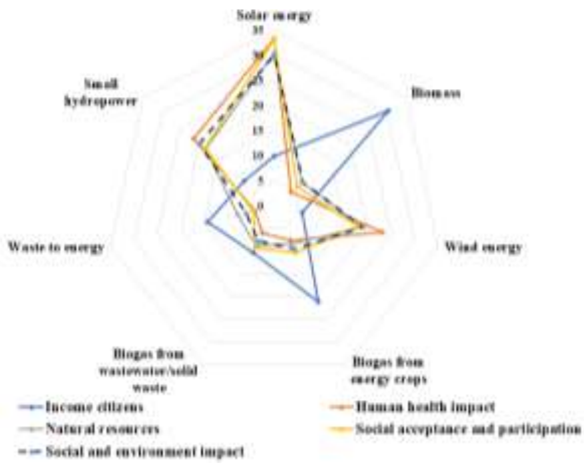
The prioritization results are shown in Fig. 3. In the case of a quality electrical system (Fig. 3a), it can be seen that biomass was very much preferred and closely followed by waste to energy, biogas from wastewater/solid waste, and biogas from energy crops, while small hydropower, wind, and solar energies were less valued for this criterion. This result means that respondents were of the opinion that biomass fuels in Thailand are well-equipped in terms of management and ability to make the fuel system more stable, reliable, and efficient than other fuels. In terms of material/fuel potential (Fig. 3b), solar energy was the most preferred, with a strong lead over the other alternatives. On the other hand, wind energy was ranked the lowest according to material/fuel potential. In terms of social and environment impact, solar energy had the highest priority score, but this score was close to that for small hydropower and wind energy (as shown in Fig. 3c). The lowest priority score was given to waste to energy, followed by biogas from wastewater/solid waste and biomass. While wind energy was ranked top priority in terms of cost of electricity per unit criterion, biogas from wastewater/solid waste and biomass were ranked the lowest, as shown in Fig. 3d. However, all seven alternatives were similar in their scores, which means that there seems to be no special preference among alternatives for this criterion. Most of the respondents placed equal importance among the alternatives. The technology criterion illustrated that biogas from wastewater/solid waste was the top priority (Fig. 3e), while the lowest priority as wind energy.



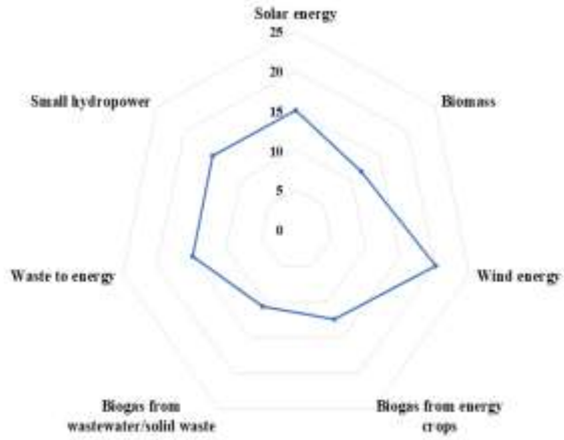
(a) Quality electrical system



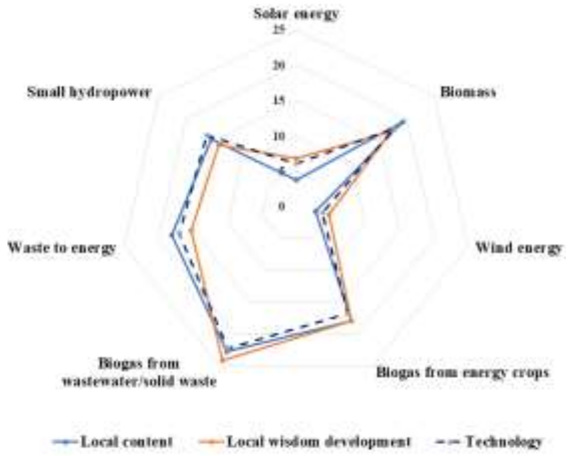
(b) Raw material/fuel potential



(c) Social and environment impacts



(d) Cost of electricity per unit



(e) Technology

Fig. 3. Priority of alternatives based on main criteria and sub-criteria

The overall results for prioritizing renewable energy in Thailand are presented in Fig. 4. In this study, the results indicated that all alternatives are important and closely compete with each other. For the benefit of the nation, it is nevertheless necessary to decide which way is the best option. As illustrated in Fig. 4, the top ranked renewable energy was solar energy, followed by biomass and small hydropower. The worst alternative was very clearly waste to energy. At the same time, the three other alternatives had similar rankings. It should be noted that solar energy was the highest ranked in terms of its social and environmental impacts and raw material/fuel potential but placed sixth for both the quality electrical system and technology criteria, and it was ranked the top priority for the overall ranking. This ranking occurred because the weight assigned (Fig. 2) to criteria was a great influence on the final ranking. Alternatives with social and environmental influences were ranked as the top priority because the weights of these criteria were very significant compared to the weights of the other criteria.

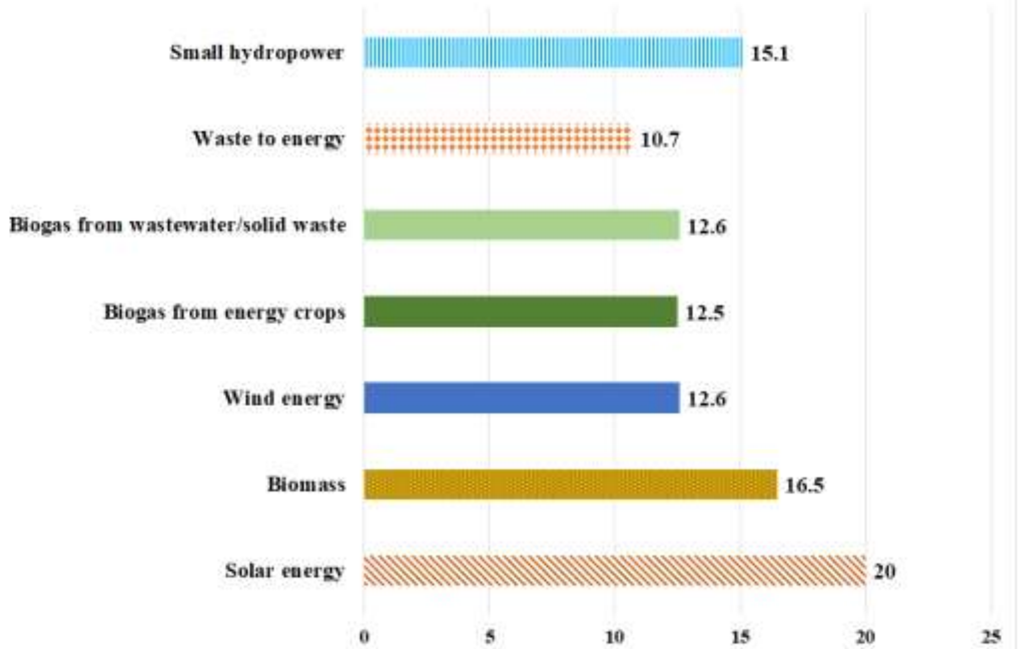


Fig. 4. Overall priority of alternatives corresponding to all criteria

When assessing all alternatives presented among the criteria used in ranking, we found that the alternatives related to combustion for converting energy to electricity (i.e., waste to energy, biogas from energy crops, and biogas from wastewater/solid waste) were least preferred in terms of social and environmental criteria. In contrast, these alternatives were most preferred for the quality electrical system and technology criteria, as shown in Fig. 5. Without the combustion process, solar energy, small hydropower, and wind energy were most preferred in terms of social and environmental criteria. However, solar and wind energies are still in doubt in terms of the technology and quality electrical system criteria in Thailand.

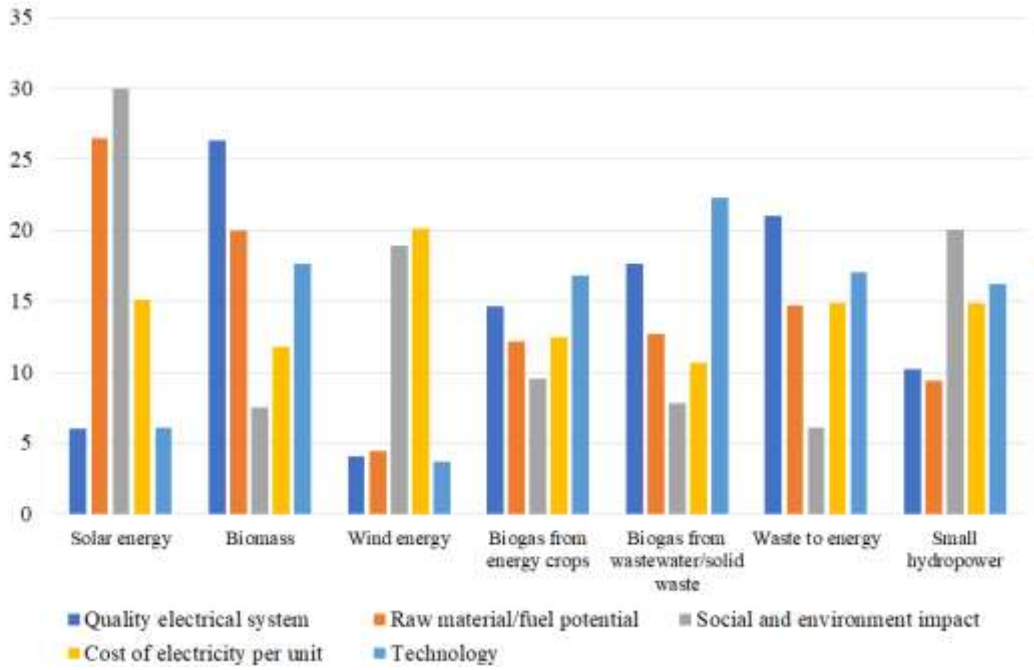


Fig. 5. Weight contribution of criteria for each alternative

4. Discussion

4.1 Comparison of ranking renewable energy alternatives with the AEDP2015 plan

The renewable energy alternative ranks from the AEDP2015 differed greatly from those determined in this study, as shown in Table 6. The first priority from the AEDP2015 was waste to energy, while the ranking obtained from this study gave it the lowest priority. Moderate differences occurred between biomass and wind energy, as biomass was ranked fourth, and wind power was been ranked fifth according to AEDP2015, but they are ranked fourth and seventh, respectively, in this study.

Table 6. Comparison of the rankings between AEDP2015 and this study

Renewable sources	Result of ranking alternatives	
	In this study	AEDP2015
Solar energy	1	6
Biomass	2	4
Wind energy	5	7
Biogas from energy crop	6	5
Biogas from wastewater/solid waste	4	3
Waste to energy	7	1
Small hydropower	3	2

The waste to energy option presents the greatest difference between the two ranking systems. The Thai government has declared that the problem of municipal solid waste (MSW) as a national agenda item. Therefore, all government agencies are trying to find a solution to solve the problem. It is believed that if the waste is burned in a power plant for electricity production, then the problem will be solved. In fact, many obstacles occur during the planning of a power plant from waste energy; for example, it is difficult to find a suitable location because of the NIMBY (Not In My Back Yard) concept, the availability of waste quantity, and legal interpretation. This result can imply that the ranking from AEDP2015 may not consider all factors or weights between factors, especially in terms of social and environmental factors. This factor is actually an important criterion when we plan to build a new power plant in Thailand. Many projects have failed due to resistance from local populations or non-governmental organizations (NGOs). Environmental issues are an important issue for building a new power plant, even though the project itself has undergone an environmental impact assessment. This reason is a major reason that social and environmental impacts obtained the highest weighting criteria in the AHP. Solar energy has the highest rank in this criterion because the raw material was already clean, and there are less emissions when converting energy to electricity. The current policy in Thailand is mostly a top-down approach that lacks integration among government departments, excluding stakeholders and changes in external factors that influence electric power generation. Therefore, using AHP can integrate stakeholder opinions on renewable energy for the national electricity plan in Thailand.

5. Conclusions

This study is the first attempt to apply the AHP methodology to rank renewable resources in Thailand. The framework of the AHP model consisted of the main criteria and sub-criteria on which each renewable resource was evaluated. These criteria were classified as quality electrical system, raw material/fuel potential, social and environmental impacts, cost of electricity per unit, and technology.

The model results demonstrate that social and environment impacts are the most important criteria (40.6%), followed by the cost of electricity production (19.8%), electricity quality (17.8%), raw material/fuel potential (13.2%), and technology (8.6%). Biomass is very much preferred in terms of a quality electrical system, while solar energy has a strong lead in raw material/fuel potential and social and environmental impacts. Among the seven renewable resources, the results indicated that solar energy is the most preferred option. Biomass and small hydropower are also important, but waste to energy obtained the lowest score as an alternative in this study. Compared with AEDP2015, the results of this study were substantially different due to different decision-making processes. In comparison to the conventional process, the results of the AHP were more reliable and robust and reflected systematic decision-making because it determined all of the factors obtained from the stakeholders. Thus, it is suggested that the Thai government should add the AHP analysis as one step of creating the framework of promoting renewable energy in Thailand.

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References

[1] Kyophilavong P, Shahbaz M, Anwar S, Masood S. The energy-growth nexus in Thailand: Does trade openness boost up energy consumption? Renewable and Sustainable Energy Reviews, 2015, 46, 265-274.

[2] DEDE. Alternative Energy Development Plan (AEDP2012-2021) In: Department of Alternative Energy Development and Efficiency M o E, ed. Bangkok Ministry of Energy 2012.

[3] Bridges A, Felder F A, McKelvey K, Niyogi I. Uncertainty in energy planning: Estimating the health impacts of air pollution from fossil fuel electricity generation. Energy Research & Social Science, 2015, 6, 74-77.

[4] Nethengwe N S, Uhunamure S E, Tinarwo D. Potentials of Biogas as a Source of Renewable Energy: A Case Study of South Africa. International Journal of Renewable Energy Research 2018, 8 (2), 1112-1123.

[5] Ren J, Dong L. Evaluation of electricity supply sustainability and security: Multi-criteria decision analysis approach. Journal of Cleaner Production, 2018, 172, 438-453.

[6] Arslan R, Ulusoy Y. Utilization of waste cooking oil as an alternative fuel for Turkey In. *5th International Conference on Renewable Energy Research and Applications* United Kingdom IEEE Xplore; 2016:149-152.

[7] Menanteau P, Finon D, Lamy M-L. Prices versus quantities: choosing policies for promoting the development of renewable energy. Energy Policy, 2003, 31 (8), 799-812.

[8] Sewchurran S, Davidson I E. Optimisation and Financial Viability of Landfill Gas to Electricity Projects in South Africa In. *5th International Conference on Renewable Energy Research and Applications* Birmingham, UK: IEEE Xplore; 2016:518-527.

[9] Arnone D, Croce V, Paterno G, Rossi A, Emma S, Miceli R, Di Tommaso A O. Energy Management of Multi-carrier Smart Buildings for Integrating Local Renewable Energy Systems In. *5th International Conference on Renewable Energy Research and Applications* Birmingham, United Kingdom IEEE Xplore; 2016:845-850.

[10] DEDE. Alternative Energy Development Plan: AEDP2015. In: DEDE, ed. Bangkok Ministry of Energy 2015.

[11] Harrouz A, Abbes M, Colak I, Kayisli K. Smart grid and renewable energy in Algeria In. *6th International Conference on Renewable Energy Research and Applications* San Diego, CA, USA IEEE Xplore; 2017:1166-1171.

[12] Tri Winarno O, Alwendra Y, NMujiyanto S. Policies and Strategies for Renewable Energy Development in Indonesia In. *5th International Conference on Renewable Energy Research and Applications* Birmingham, UK IEEE Xplore; 2016:270-272.

[13] Achawangkul Y. Thailand's Alternative Energy Development Plan, Bangkok. Ministry of Energy 2017.

[14] Khaenson W, Maneewan S, Punlek C. Assessment of the Environmental Impact of Biomass Electricity Generation in Thailand International Journal of Renewable Energy Research, 2018, 8 (1), 301-312.

[15] Demirtas O. Evaluating the Best Renewable Energy Technology for Sustainable Energy Planning International Journal of Energy Economics and Policy 2013, 3 (Special issue), 23-33.

[16] Salvarli H, Salvarli M S. Assessment of Renewable Energy Resources in Line with the Targets Specified in the Turkish Strategic Plan and Application of the AHP Method. International Journal of Renewable Energy Research, 2018, 8 (2), 1016-1024.

[17] Tahri M, Hakdaoui M, Maanan M. The Evaluation of Solar Farm Locations Applying Geographic Information System and Multi-Criteria Decision-Making Methods: Case Study in Southern Morocco Renewable and Sustainable Energy Reviews, 2015, 51, 1354-1362.

[18] Ahmad S, Tahar R M. Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia. Renewable Energy, 2014, 63, 458-466.

[19] Aljamel S A, Badi I A, Shetwan A G. Using Analytical Hierarchy Process to Select the Best Power Generation Technology in Libya The International Journal of Engineering and Information Technology 2017, 3 (2), 159-163.

[20] Colombo E, Romeo F, Mattarolo L, Barbieri J, Morazzo M. An impact evaluation framework based on

sustainable livelihoods for energy development projects: an application to Ethiopia. Energy Research & Social Science, 2018, 39, 78-92.

[21] Goepel K D. Business Performance Management Singapore (BPMSG). In. *Online Tools* Vol 2018. Singapore 2018.

[22] Gusmerotti N M, Corsini F, Borghini A, Frey M. Assessing the role of preparation for reuse in waste-prevention strategies by analytical hierarchical process: suggestions for an optimal implementation in waste management supply chain. Environment, Development and Sustainability, 2018.

[23] Erol Ö, Kılkış B. An energy source policy assessment using analytical hierarchy process. Energy Conversion and Management, 2012, 63, 245-252.

[24] Stein E W. A comprehensive multi-criteria model to rank electric energy production technologies. Renewable and Sustainable Energy Reviews, 2013, 22, 640-654.

[25] Sindhu S P, Nehra V, Luthra S. Recongnition and Prioritization of Challenges in Growth of Solar Energy using Analytical Hierarchy Process: Indian Outlook Energy, 2016, 100, 332-348.

[26] DMF. Annual report 2016. In. Bangkok: Department of Mineral Fuels, Ministry of Energy; 2016.

[27] Suramaythangkoor T, Gheewala S H. Potential alternatives of heat and power technology application using rice straw in Thailand. Applied Energy, 2010, 87 (1), 128-133.

[28] EGAT. The Proportion of Fuel Consumption for Electricity Production In. Vol 2018. Bangkok: Electricity Generating Authority of Thailand 2015.

[29] GIZ. Thailand Renewable Energy Policy Update 10/15. In. Bangkok: Federal Ministry for Economic Affairs and Energy 2017.

[30] Chanthawong A, Dhakal S. Stakeholders' perceptions on challenges and opportunities for biodiesel and bioethanol policy development in Thailand. Energy Policy, 2016, 91, 189-206.

[31] Saaty T L. The Analytic Hierarchy Process. New York: McGraw-Hill, 1980.

[32] Saaty R W. The Analytic Hierarchy Process-What it is and How it is used Mathl Modelling 1987, 9 (3-5), 161-176.