AHP Model for Selection of Sustainable Energy: A Focus on Power Generation and Supplying for End-users

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***Abstract*— AHP is one of important technology management tools for decision making that is used during technology selection process, and applied prior to acquisition of a new technology. In the last decade, AHP was discussed by numerous studies, covering wide-variety of areas, focusing on many criteria and sub-criteria, for the purposes of selecting, allocating, evaluating, or benchmarking different alternatives of technology. The use of AHP for selecting the source of renewable energy as the alternative for the non-renewable source of energy is important, especially to the environmental conscious' end-users, or those who are living in the rural area. However, in the field of sustainable energy, AHP application for power generation focusing on the end-users is still limited. As a result, this study aims to develop an AHP model, by investigating the suitable group of criteria, sub-criteria, and alternatives that will suit the needs of the end-users. This model will helps the relevant parties to identify the most suitable sources of technology for power generation to solve the end-users' needs. To do this, secondary data were collected from the relevant empirical studies. Based on the descriptive analysis, it was found that the previous studies have ranked and prioritized each of these criteria, sub-criteria, and alternatives differently, which implies a specific AHP model for the end-users should be developed. With the findings, this study has developed an AHP model comprising of four major criteria, each with three sub-criteria, and five alternatives. This model is being verified by an ongoing research in Malaysia.**

***Keywords*—** *Analytic hierarchy process, Malaysia, MCDM, renewable energy, technology selection*

1. Introduction

Analytic Hierarchy Process (AHP) is "a theory of measurement through pairwise comparisons and relies on the judgements of experts to drive priority scale [1]." This method was developed by Saaty, T.L. from 1971 to 1975 [2]. It is one of popular multi-criteria decision making (MCDM) methods widely used in various applications [3], to make a decision that is rational with efficient choices [4]. When compare to the other MCDM methods, AHP is faster for doing analysis, with comprehensive logic, widely used and applied for technology evaluation and selection of sustainable energy [5]. In addition, AHP is also adaptable, does not involve complex mathematical model, and using hierarchy structure that is more focused and transparent [6]. Moreover, AHP method is flexible to be integrated with the other MCDM methods [7]. Hence, AHP is always used together with the other methods. Besides selection process, AHP is also used for allocating, evaluating, and benchmarking of alternatives [8]. As a result, AHP was applied in various areas including resource management, corporate policy and strategy, public policy, energy planning, and logistics and transportation planning [6]. AHP applications were also seen in various disciplines, such as mathematic, business and management, economics, computer science, environment science and technology, and social studies [9].

In the meantime, the world has recorded increasing energy demands from both developed and emerging economies, which has elevated the challenges on energy supply. The solution to this problem comes from renewable energy with clean, environmental friendly and abundant resources [10]. Based on a report from the United Nations in the trends of consumption and production of energy, household sector is representing up to 25% of energy consumption in the developed economies, and even more from the developing economies. However, the diffusion of new energy technologies in the developing economies has been slow [11]. As a result, the end-users have failed to take advantages of a cost-effective renewable

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energy. Although uncertainty is slowing the adoption of energy saving by the end-users, some studies are showing doubt on this hypothesis [12]. Therefore, the end-users should select the suitable sources of renewable energy for the household usage. One of the tools for this selection process is AHP. Correspondingly, the literature on AHP for selecting the sources of power generation focusing on the end-users is relatively low. In fact, the criteria, sub-criteria, and alternatives used are quite varied from one study to another. For instance, [2] was using national economy, health, safety and environment, and political factors as the examples of criteria for energy selection. Meanwhile, [13] were using cost per unit power, social impact, technical, location, and environment as the criteria for selecting renewable energy. In contrast, [14] was using technical, economic, social, and environmental as the selecting criteria. These variations are expected since different industries have applied wide-variety of criteria for AHP [7]. With all of these reasons, this study believed there is a need for a specific AHP model for the selection of power generation that focuses on the end-users. As a result, this study aims to develop an AHP method that will include the suitable criteria, sub-criteria, and alternatives for selecting sustainable energy focusing on power generation for the end-users. As an early part of the ongoing research, this study will address on the following questions:

a) What are the AHP criteria for selecting sustainable energy for power generation?
b) What are the AHP sub-criteria for selecting sustainable energy for power generation?
c) What are the AHP alternatives for selecting sustainable energy for power generation?

2. Study methodology

This review paper gathered secondary data from relevant AHP articles, searched via Google Search engine with "AHP, sustainable, renewable energy.pdf" as the keyword. Google Search engine is used for its ability to maximize the number of articles hit. The relevant articles were collected from open-access online journals and unlocked resources. The following requirements were used in the selection of relevant articles: (a) articles must be empirical study, (b) articles must be written in English, (c) articles must be published in the recent years from 2010 to 2019, (d) articles must at least related to AHP (e.g., Fuzzy AHP, AHP combined with other MCDM methods), (e) articles must be related to sustainable or renewable energy for power generation, such as home, building, and rural area (excluding vehicle/automotive), and (f) articles must provide complete information about the criteria, sub-criteria, and the alternatives for power generation. Data extracted from the articles were descriptively analyzed according to the questions addressed earlier (i.e., criteria, sub-criteria, and alternatives). Based on the search procedures and selection requirements, this study managed to gather 11 highly relevant articles. Two of the articles focused on Turkey, one on China/Turkey/USA, while the rests on Colombia, Indonesia, Iran, India, Lithuania, and China. This size indicates that even though the total number of AHP-related publications is increasing [9]; the number of empirical studies in the topic of power generation is still low. This also justifies the objective of the study that is to develop suitable criteria, sub-criteria, and alternatives for power generation according to the previous empirical study. In comparison, previous studies that applied systematic review to investigate AHP criteria on a general theme has found only 33 suitable articles from 2005 to 2015 publication years [7], and 14 articles from 2003 to 2015 [15].

3. AHP criteria for selecting sustainable energy for power generation

Based on the data gathered from 11 most relevant articles, the AHP criteria for selecting energy for power generation is summarized in Table 1. As shown in the table, there are 14 criteria for selecting sustainable energy for power generation, in which each of the articles is using either four or five criteria. Despite of various criteria have been used by the past empirical studies, it was obvious that environmental, economic, technical, and social are the four most popular criteria with AHP method. This is evidenced by six (of 11) articles in Table 1. Besides that, other MCDM methods have been found to use more or less similar criteria for analysis, such as environmental, economic, technical, and socio-political by [16], environmental, technical, economic-financial, and socio-political by [17], and environmental, technical, economical, and social by [18]. Meanwhile, some criteria are almost identical by nature, such as between technical and technological, and social, social-ethics, and socio-political. However, this study has recorded them as separate criteria to maintain originality of terminologies, although they can be used interchangeably.

Table 1. AHP criteria for selecting sustainable energy

Sources \ Criteria	Environmental	Economic	Technical	Technological	Social	Social-Ethics	Socio-Political	Institutional-Political	Capacity	Cost	Quality	Risk	Security	Job Creation
[14]	√	√	√		√									
[19]	√	√	√		√							√		
[20]	√	√	√		√									
[21]	√	√	√		√									
[22]	√	√		√		√		√						
[23]	√	√	√		√									
[29]	√	√		√			√							
[31]	√								√	√			√	√
[32]	√	√	√		√									
[33]	√	√		√			√							
[34]	√	√		√			√				√			

Among these four important criteria (i.e., environmental, economic, technical, and social), a previous study has found that the overall priorities given to technical was 24.7%, followed by environmental (21.7%), social (19.6%), and economic (17.8%) [19]. Meanwhile, another study has found environmental criterion was weighted at 0.526, followed by technical (0.318), social (0.126), and economic (0.108) [20]. In addition, [21] have found the weight of index for economic (0.6427) is higher than social (0.2083), technical (0.101), and environmental (0.048). In contrast, environmental was weighted at 0.315, technical at 0.279, social at 0.209, and economic at 0.197 by [14]. Meanwhile, [22] have found where the economic criterion was weighted at 0.384, while the environmental at 0.243. Based on these examples, it can be summarized that the overall ranking and priorities of criteria given to environmental, economic, technical, and social is different between studies.

4. AHP sub-criteria for selecting sustainable energy for power generation

The AHP sub-criteria for selecting energy for power generation are summarized in Table 2. Each of the articles is focusing between two to six sub-criteria, with three sub-criteria being the average. When looking at the sub-criteria for environmental, economic, technical, and social, it was found that emission, land, and ecosystem are among the popular themes for environmental. Meanwhile, investment cost, and operation and maintenance cost are the main sub-criteria for economic, whereas efficiency, reliability, and technological maturity are the main sub-criteria for technical. Besides that, social acceptability, social benefits, and job creation appeared to be the common sub-criteria for social. Based on the listed sub-criteria, this study has found that each of the sub-criteria was prioritized differently from one study to another. For instance, a study on social sub-criteria has weighted social benefits at 0.547, while social acceptance at 0.453 [14]. In contrast, [23] have weighted social acceptance at 0.611, while job creation at 0.593. Different ranking and prioritization was also observed between studies for the other sub-criteria.

Table 2. AHP sub-criteria for selecting sustainable energy

Criteria	Sub-criteria	Sources
Environ-mental	Gas emissions, requirement of land and water resources, visual impact, hazardous waste	[19]
	NO_x emission, CO_2 emission, land use	[23]
	Pollution, emission, noise, land use, consumer acceptance	[31]
	Impact on ecosystem, CO_2 emission	[32]
	Pollutant emission, land requirements, need of waste disposal	[29]
	Particle emission, land use	[20]
	Degree of social acceptance, land use, number of jobs provided	[21]
	Pollutant emission, land requirements, impact on ecosystem	[33]
	Contribution of renewable energy resources to the total energy balance, effect on climate change and pollution cuts, treatment of waste, compliance with local natural conditions	[22]
	Impact on the ecosystem, CO_2 emissions	[14]
	Pollutant emission, land requirement, requirement for waste disposal	[34]
Econo-mic	Investment cost, operation and maintenance cost, payback period, service life	[19]
	Investment cost, operation and maintenance cost	[23]
	Investment cost, operation and maintenance cost, service life, payback period	[32]
	Implementation cost, availability of funds, economical value	[29]
	Investment cost, operation and maintenance cost	[20]
	Investment cost, operation and maintenance cost, generating capacity	[21]
	Job creation, investment cost, operation and maintenance cost	[33]
	Economic efficiency, technology's competitiveness, production cost, value of the technological complex	[22]
	Investment costs, expense management, lifetime, repayment period	[14]
	Implementation cost, economic value, affordability	[34]

Techni-cal	Efficiency, maturity of technology, spare parts availability, infrastructure, reliability	[19]
	Efficiency, exergy (rational) efficiency	[23]
	Energy production capacity, technological maturity, reliability, safety	[32]
	Efficiency, exergy efficiency	[20]
	Hours of equipment utilization, power capacity, technical efficiency	[21]
	Energy production capacity, technological maturity, reliability, safety	[14]
Techno-logical	Risk and feasibility, continuity and predictability, reliability, duration of preparation and implementation, local technical knowhow	[29]
	Duration of preparation and implementation, continuity and predictability of performance, technical feasibility	[33]
	Technology's rated capacity, technology's reliability, technology's innovativeness, durability of technology	[22]
	Continuity and predictability of the performance, risk, local technical knowledge	[34]
Social	Acceptability of local residents, local job creation, energy for rural health and education, installation on indigenous lands	[19]
	Social acceptability, job creation	[23]
	Social benefits, social acceptability	[32]
	Social acceptability, job creation	[20]
	Land use, sulphur dioxide emission, carbon dioxide emissions	[21]
	Social benefit, social acceptability	[14]
Social-Ethics	Influence on social welfare, influence on sustainable development of society, public acceptance/opinion	[22]
Socio-Political	Compatibility with national energy policy objective, political acceptance, social acceptance, labor impact	[29]
	Compatibility with national energy policy objective, political acceptance, social acceptability	[33]
	Government policy, labor impact, social acceptance	[34]
Instituti onal-Political	Compliance with international obligations, legal regulation of activities, technology's autonomy, support of government institutions, political organizations, influence on sustainable development of energy	[22]
Capacity	Installed capacity, reliability, service life	[31]
Cost	Investment, maintenance and operating cost, other life cycle costs	[31]
Quality	Sustainability, durability, distance to user	[34]
Risk	Natural phenomena, armed conflict, investment risk, technological obsolescence	[19]
Security	Risks, disruptions, disasters	[31]
Job Creation	Job opportunities, economic impact, regional development	[31]

5. AHP alternatives for selecting sustainable energy for power generation

Table 3 has summarized 13 possible alternatives for power generation. Each of the articles has investigated between four to eight alternatives, where five alternatives are common. These alternatives comprised of wind, biomass, geothermal, solar, and hydropower. As a matter of fact, six (of 11) articles in Table 3 have listed all five alternatives in the studies. Other alternatives are small and large hydropower, thermal, nuclear, and ocean. Diesel and gas that are non-sustainable energy were also studied as alternatives for energy generation. Although hydropower, small hydropower, and large hydropower are quite identical and similar in the way they generate electricity, this study has treated them as separate alternatives to maintain originality of terminologies used in the articles.

Table 3. AHP alternatives for selecting sustainable energy

Sources \ Alternatives	Wind	Biomass	Geothermal	Solar	Solar PV	Hydropower	Small Hydropower	Large Hydropower	Thermal	Nuclear	Diesel	Gas	Ocean
[14]	√	√	√	√		√							
[19]	√	√			√		√						
[20]	√	√	√	√		√							
[21]	√	√	√		√	√							√
[22]	√	√	√			√				√		√	
[23]	√	√		√			√	√	√	√	√		
[29]	√	√	√	√		√							
[31]	√	√	√	√		√				√			
[32]	√	√	√	√		√							
[33]	√		√	√		√							
[34]	√	√	√	√		√							

Among these five popular alternatives (i.e., wind, biomass, geothermal, solar, and hydropower), a previous study has weighted the importance of solar energy at 0.439, followed by wind (0.380), geothermal (0.318), hydropower (0.289), and biomass (0.150) [20]. In contrast, [14] has ranked wind first, followed by biomass, geothermal, solar, and hydropower. Another study has rated the utility degree of alternatives for biomass at 0.5415, followed by hydropower (0.5230), wind (0.4981), and geothermal (0.4241) [22]. In addition, [21] have ranked wind higher than biomass, and hydropower. Meanwhile, a previous study has weighted wind energy at 0.238, while biomass at 0.155 [19]. Therefore, just like the findings on criteria and sub-criteria, the overall ranking and priorities for alternatives given to wind, biomass, geothermal, solar, and hydropower is also different from one study to another.

6. AHP model for selecting sustainable energy for power generation

According to Table 1, environmental, economic, technical, and social are the popular criteria for power generation. For this reason, this study has decided to focus on the environmental, economic, social, and technical as the main criteria for selecting sustainable energy for power generation. In fact, in the context of sustainable development, sustainability has been long categorized into environmental, economic and social [24]. Based on the criteria mentioned above, this study has named "impact on society, pollutant emission, and land use" as the sub-criteria for environmental; "investment cost, operation and maintenance cost, and payback time" as the sub-criteria for economic; "social acceptability, social benefits, and job creation" as the sub-criteria for social; while "efficiency, reliability, and technological maturity" as the sub-criteria for technical. The selection of these sub-criteria is based on the discussion from Table 2. Accordingly, five alternatives were taken from Table 3 based on their popularity from previous studies. These alternatives are wind, biomass, geothermal, solar, and hydropower. As displayed in Figure 1, an AHP model for selecting suitable sources of sustainable energy for power generation that will meet the needs of end-users is proposed.

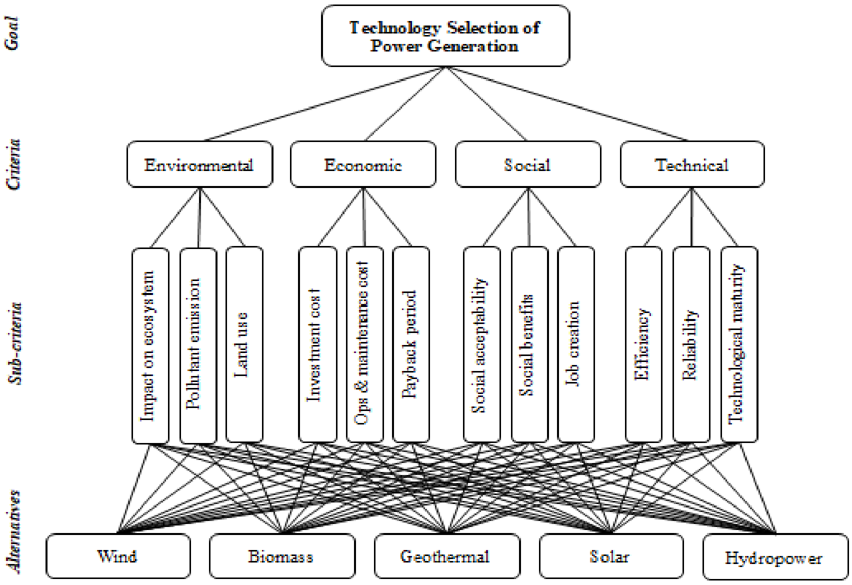

Figure 1. AHP method for selecting sustainable energy for power generation

7. Current energy scenario and future application in Malaysia

Malaysia is strategically located in the middle of equatorial line with a very conducive climate suitable for various sources of sustainable energy for power generation. Despite of that, a previous study has found Malaysia is relied heavily on the non-renewable resources to supply energy to the end-users, both in the urban and rural areas. Even though Malaysia has diversified its sources of non-renewable resources, due to rapid growth in demand and increasing concern on global climate change, Malaysia must develop a renewable energy for the end-users [25]. Meanwhile, the end-users intention to use renewable energy in Malaysia was found to be related to perceived ease of use, perceived behavioural control, awareness, relative advantage and cost reduction [26]. Besides that, a previous study has found consumers in Malaysia do have awareness and intention to used energy efficient appliances [27]. This implies that the end-users do have the intention not just to use energy efficient appliances but also renewable energy as the source of power generation for household usage. However, the selection process of the renewable energy needs to be done correctly, which is in this case with AHP.

AHP for power generation has been studied previously in Malaysia by [28] with four sources – hydropower, solar, biomass, and wind. They have found renewable energy to have great potential to develop a sustainable electricity system. However, this study believed that geothermal need to be investigated too in order to understand how it fair with the others. Moreover, more studies are needed to narrow down the knowledge gap regarding the application of AHP for selecting power generation in Malaysia. This is crucial since the previous studies have ranked and prioritized the criteria, sub-criteria, and alternatives in a different ways. For example, there were two AHP studies in Turkey that resulted with different alternatives, i.e., [20], and [29]. Besides that, fuel cell technology that is not in the list has the potential to be a competitive alternative for power generation in Malaysia. Fuel cell uses is presently perceived as significant energy transformation systems with great promise. Unfortunately, Malaysia is facing economic and infrastructural challenges, besides lack of local expertise, public perception, and industrial support for fuel cell [30]. Due to these challenges and since fuel cell technology can utilize any sources of the sustainable energy (i.e., wind, biomass, geothermal, solar, and hydropower), a future AHP study should also focus on the most practical sources of sustainable energy to feed power for fuel cell technology in Malaysia.

8. Conclusions

AHP is one of decision making tools for selecting, allocating, evaluating, or benchmarking a new technology. Although AHP has been used in wide-variety of areas, previous studies have resulted in different priorities with different set of criteria, sub-criteria, and alternatives on the sources of renewable energy for power generation. This suggests that depending on the context and location, the result from a single AHP study cannot be necessarily generalizable. Therefore, it is necessary to develop a specific AHP model, which is in this case for the end-users, due to increasing demands for renewable energy by the households. Despite of some limitation in data collection, this study has managed to identify four criteria, each with three sub-criteria, and five alternatives for selecting the suitable sources of power generation with renewable energy. This AHP model is currently being verified and applied by an ongoing research in Malaysia. Hopefully this model will be able to solve the problem with end-users selection on the suitable sources of renewable energy for the household usage. For future research agenda, this study is recommending an AHP study to focus on the best source of sustainable energy for the purpose of feeding power towards fuel cell technology.

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