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# Decision Support for the Selection of Electric Power Plants Generated from Renewable Sources

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***Abstract*—**Decision support based upon risk analysis into comparison of the electricity generation from different renewable energy technologies can provide information about their effects on the environment and society. The aim of this paper is to develop the assessment framework regarding risks to health and environment, and the society's benefits of the electric power plant generation from different renewable sources. The multicriteria framework to multiattribute risk analysis technique and the decision analysis interview technique are applied in order to support the decision-making process for the implementing renewable energy projects to the Bangkok case study. Having analyses the local conditions and appropriate technologies, five renewable power plants are postulated as options. As this work demonstrates, the analysis can provide a tool to aid decision-makers for achieving targets related to promote sustainable energy system.

***Keywords*—**Analytic Hierarchy Process, Bangkok, Multiattribute Risk Analysis, Renewable Energy Technology.



## I. Introduction

THE energy system is built upon energy supply and end-use technology. The aim of energy system is to deliver energy services to end-users. The term energy service is the benefits that the energy offers. In household sector, energy services include illumination, cooked food, comfortable indoor climate, and refrigeration. In commercial and industrial sectors, heating and cooling are mostly demanded following by the lighting purpose. Electricity is the energy carrier that usually consumes in all sectors of the economy. The energy chain that delivers energy services start with the extraction of primary energy that can be one or several steps, and conversion into final energy such as electricity, petroleum products, natural gas, coal, and hydrogen. The end-use technologies convert final energy into so-called useful energy which provides the service demand.

Energy services are a combination of end-use technologies, infrastructures, labors, materials, and primary energy resources. Each of these inputs carries a price tag, and they are partly substitutable for one another. From the consumer's perspective, the important issues are the economic value or utility derived from the services. Consumers are often unaware of the upstream activities required to produce energy services. One way to capture the importance of energy services is to show the impact on human health and environmental effects of energy transformation.

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The environmental consequences of energy use make up a significant fraction of human impacts on the environment. Energy provision involves large volumes of material flows and large-scale infrastructure to extract, process, store, transport, and use it as well as to handle the waste. Electricity which common use in the urban area, is of particular interested in this study. Electricity generation from fossil fuel leads to an increased levels of air pollution, greenhouse gas (GHG) emissions, and exposure of the population to ionizing radiation, which in turn cause an increase risk to health of the exposed population. The electricity generates from renewable sources can be affected to the human health and environment as well but in a small fraction, depending on their technologies.

This paper aims to describe the decision support analysis into comparing electricity generation from different renewable energy technologies. The study was developed a hypothetical case study to evaluate how certain renewable energy technologies effect the environment and society as well as risks of electricity production from renewable sources. The potential of renewable energy is based upon the situation of the city of Bangkok, Thailand. Accordingly, the second part of this paper describes the aspects related to appropriate renewable energy technologies. The third part presents methodologies. The fourth part illustrates the application of a case study. Finally, discussion and conclusion part summarizes major findings of the study.

## II. Selection Of The Renewable Energy Technologies

The intense attention directed towards sustainable energy system gives high priority to renewable energy that would have a minimal impact on the environment, human health, and the quality of life. However, the energy system must guarantee that energy production is always sufficient to meet the demand. Electricity is quite unique comparing to other energy forms. It must be produced by the time it is needed. In this study, the energy supply system in Bangkok considers that electricity is provided by the national grid together with the electricity generation from renewable sources. It should be noted that the potential of renewable sources depends on climate to climate and region to region. Therefore, the selection of technologies focuses on main renewable sources for which commercial technologies are already at hand and have a potential for electricity production in the Bangkok context. These technologies are solar energy, biomass, biogas, and municipal solid waste (MSW). Table I provides an estimating contribution of renewable energy to total final energy consumption in Thailand. It should be noted that the data presented in Table I are focused only electricity generated from renewable sources. The following sub-sections are briefly discussed each technology.

TABLE I
ESTIMATING CONTRIBUTION OF ELECTRICITY GENERATED FROM RENEWABLE SOURCES IN THAILAND [1]

| Energy Source | Final Consumption (GWh) | | Primary Unit ($MW_e$) | |
|---|---|---|---|---|
| Total final energy consumption (GWh) | 2005<br>121,229 | 2016<br>232,210 | 2005 | 2016 |
| Residues for power | 9,596 | 21,628 | 2,191 | 4,938 |
| Short rotation plants for power | 0 | 7,955 | 0 | 1,298 |
| Biogas for power | 357 | 3,275 | 45 | 400 |
| Solid wastes for power | 33 | 3,196 | 2.5 | 384 |
| Small hydro | 347 | 2,651 | 90 | 688 |
| Wind | 0.25 | 588 | 0.19 | 447 |
| Solar PV | 36 | 175 | 29 | 125 |
| Total renewable sources | 10,369 | 39,468 | - | - |
| % to total final energy consumption | 8.55% | 17.0% | - | - |

### *A. Solar Thermal Power Plant*

Solar thermal technologies convert solar radiation into thermal energy (heat) by means of solar collectors or concentrators, which are then used to produce steam for driving turbine and generator. The thermal efficiency of the plant is about 15% of the sun's energy. Basically, solar thermal system consists of four components, including collector, receiver, transport-storage system and power conversion system. Several studies and experiences have shown that solar thermal power plants are one of the most economic forms of solar electricity generation [2]. An average solar energy potential in Thailand is about 18.5 $MJ/m^2$-day. The potential of solar energy in Bangkok is 17.0 $MJ/m^2$-day. In 2005, Thailand utilized solar energy approximately 20 ktoe in forms of thermal energy and electrical energy [1]. Power generation by concentrating solar power technologies are currently in operation in Thailand, including Parabolic Trough and Dish Engine. There has been much progress in the construction of solar power plants around the country. From environmental point of view, this system requires large land areas but has no other environmental impacts.

### *B. Photovoltaic Power Plant*

Solar energy can be converted into electricity by means of photovoltaic (PV). Solar cell costs are the most important element of the PV economic viability. The modules account for approximately 50% of the PV power plant. Solar cells themselves account for about half of the module cost, or approximately 20% of the total system cost. The production of solar cells leads to the emissions of GHGs. However, taking a life cycle perspective of a PV plant, it will produce more electric energy during its life than it takes to build it [2]. In Thailand, there was a proposed target of solar PV by the Promotion of Renewable Energy Technologies (PRET) Project, which is a project under the co-operation between the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy and the Danish International Development Agency (DANIDA). The targets proposed by the working group are 110 MW before 2011, 250 MW before 2015, and 500 MW before 2024, respectively [3].

### *C. Biomass Power Plant*

The source of biomass energy is in a form of plant-derived material such as wood, herbaceous crops, and forest residues. Biomass is produced by photosynthesis. The rate at which solar energy is converted into biomass through photosynthesis ranged from 3.3% for the so-called C3 plants (e.g., wheat, rice, and trees) to 6.7% for C4 plants (e.g., maize and sugar cane). Biomass can be converted to modern form of energy like electricity. The appropriate technologies in Thailand are conventional combustion system, fluidized-bed combustion system, and suspension firing. In addition, gasification technologies enable biomass to be used for large-scale electricity generation through a combined cycle power plant. In Thailand, the amount of agricultural residues is about 61 million tons a year, of which 41 million tons, is equivalent to about 426 PJ of energy, was unused. The most promising residues are rice husk, bagasse, oil palm residue, and rubber wood residue. It was estimated that energy potential from four main agricultural residues, including bagasse, rice husk, palm oil wastes, and wood residues, was 11,200 GWh/yr or 2,985 MW of power capacity [4].

### *D. Biogas*

Anaerobic digestion is a process which takes place in almost any biological material, but is favored by warm, wet, and airless conditions. Anaerobic digestion also occurs in situation created by human activities. These have been developed as energy sources. One is the biogas which is generated in concentrations of sewage or animal manure, and the other is landfill gas which is produced by domestic refuse buried in landfill sites. This gas can be used as a fuel to run the engine for electricity generation. In Thailand, more and more farms and factories are interested in the biogas project as it reduces the environmental problems and gives value to the waste. Biogas technologies that are fully used in Thailand, including anaerobic cover lagoon (ACL), upflow anaerobic sludge blanket (UASB), anaerobic baffle reactor (ABR), continuously stirred tank reactor (CSTR), anaerobic fixed film (AFF), and fixed dome. Based on a study by [4], biogas resources from industrial wastewater and live stocks manure have potential of 7,800 and 13,000 TJ/yr.

### *E. Municipal Solid Waste*

MSW can be generated electricity via the incineration and refused-derived-fuel (RDF). These technologies are widely used to manage solid waste in large communities. They tend to take the replacement of landfilling technique, lessening area constraints in highly urbanized areas and growing concerns about hazards posed to future generations. However, incineration is a hotly debated issue while it is a means to extract value from wastes through energy production. The social fear is kept alive by number of studies reporting emissions of heavy metals, acid gases, and chlorinated organic compounds. Recent study by [5], MSW incineration has the potential to cover 8% of Thailand's electricity demand. In the Bangkok Metropolitan Area only, power production via conventional incineration of MSW can be 2 TWh/yr. This amount can be increased to 3 TWh/yr if hybrid power plants employing integrated natural gas-fired topping cycles are employed. In the case of gasification scenario, the total amount of electricity production can be as high as 4 TWh/yr.

## III. Methodologies

The study developed a multicriteria framework for the evaluation of alternative collections of risk analysis in to support the decision strategies for implementing renewable energy projects. An important goal of this exercise is to apply a framework to multiattribute risk analysis technique. Another approach that was applied in this study is the decision analysis interview technique. In the later approach, the analyst worked with the experts to build the model and to elicit preferences. Decision analysis techniques have been used in various risk analysis approaches to energy and environmental decisions and policies e.g., [6], [7], [8], [9].

### *A. Multiattribte Risk Analysis*

The multiattribute risk analysis is a structured approach to decision-making process that employs systematic analyses to give a better understanding of the problem and to facilitate a better informed choice. The methodology can be divided into four steps: (i) structure the decision problem; (ii) assess possible impacts of each alternative; (iii) identify the decision makers' preferences and values; and (iv) evaluate and compare alternatives [10]. Fig. 1 shows a conceptual framework of risk analysis in value tree evaluation. For further literature that provides a more description of the decision analysis theory, see [11], [12], [13], [14].

The method includes techniques for finding suitable alternatives among the various possible countermeasure strategies. Value trees help analysts to consider all factors that have impacts on the decision, for example the risk to human health and the environment. The authors [9] claim that the greatest advantage of using multiattribute risk analysis is that it explicitly conceptualizes the underlying values in the decision-making process. The structured approach of multiattribute risk analysis provides the analysts with a common framework from which to approach the issues. By defining each factor in the analysis and following a logical analytical sequence, the multiattribute risk analysis enhances the communication between the concerned parties. The given-preference statements show how important each factor is relative to the others.

In structuring a value tree for risks, the objective is defined as the minimization of a specific risk or an adverse effect possibly resulting from any of the decision alternatives. In this study, the major categories of risks and criteria were identified based on literature i.e., [15], [6], [7]. On the top of each value tree is the most general objective to minimize risk in the defined decision context. Other objectives are located on lower levels according to the level of details in such a way that the most specific objectives are situated on the lowest level. The contents of any objective above the lowest level are defined by the objectives connected to it and located immediately beneath in the hierarchy.

### *B. Identification and Selection of Criteria*

The selection of criteria is the most sensitive part of the multicriteria approach. In this work, it has separated into two analyses, including risk analysis and society's benefits. For risk analysis, the setting to be considered is the minimization of risks and adverse effects related to an outcome of different renewable power plants. The high level objectives include the minimization of adverse health and environmental effects. These objectives are decomposed into factors, for instance occupational health effects, the disturbance of ecological balance, and changes in the global climate. The goal of the process is to focus on the objective rather than on specific consequences of the decision alternatives [6]. For example, the harmful environmental effects of acid rain are assessed to be a risk to the environment. Minimization of the disturbance of the environment is therefore identified as an objective.

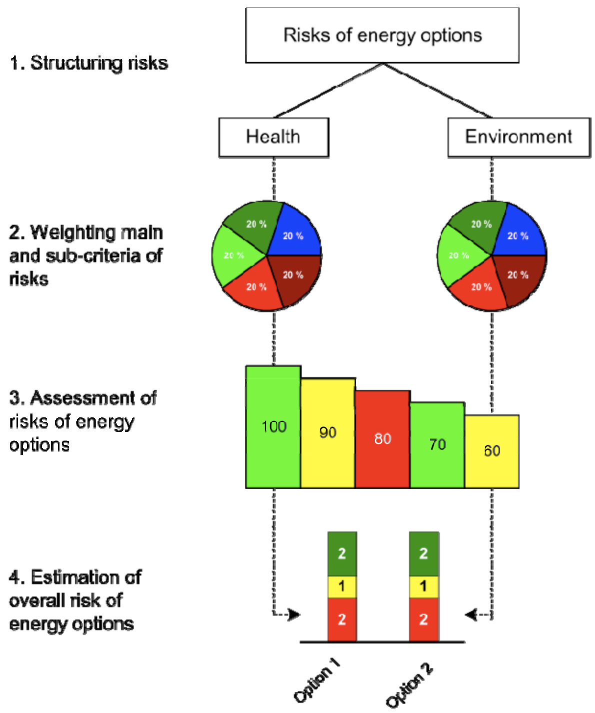


Fig. 1 Framework of risk analysis in value tree evaluation

Taking the advantage of a value tree analysis, this method allows comparing risks of the alternatives energy production to the corresponding benefits and to adverse consequences of decisions accepted in other sectors of the society.

According to society's benefits analysis, three aspects that compose the overall benefit of the society are identified as (i) the economy, (ii) factors related to health, safety and the environment, and (iii) political factors. They are each further decomposed into operational sub-criteria, as follows:

- Cheap electricity – the importance of the availability of cheap electricity;
- Foreign trade – the effects of this power production on foreign trade balance;
- Capital resources – alternative uses of capital in the country;
- Natural resources – the alternatives' effect on the use of both national and global natural resources;
- Unavoidable pollution – the pollution load known to be caused under normal operation;
- Accidents and long-term risks – the probability and consequences of a major accident, and the risks of generation methods;
- Centralization – factors related to the centralization of economic and political power; and
- Independence – the importance of a self-supporting energy system and use of indigenous technology.

### *C. Evaluation Method*

The analytic hierarchy process (AHP) was selected in this study. There are three main reasons to support the use of AHP method: (i) AHP has a systematic approach to set priorities and trade-off among goals and criteria. AHP uses a ratio scale by human judgments instead of arbitrary scales [16], [17], [18]; (ii) AHP can measure all tangible and intangible criteria in the model [19], [20], [21]; and (iii) AHP is a relatively simple, intuitive approach that can be accepted by analysts [22], [23]. Because of these reasons, this study preferred AHP to other weighting techniques to solve the problem.

AHP is a well-known technique that decomposes a decision problem into several levels in such a way that they form a hierarchy. AHP model assumes a unidirectional hierarchical relationship among decision level. In AHP, the top element of the hierarchy is the overall goal for the decision model. The hierarchy decomposes from the general to a more specific attribute until a level of manageable decision criteria is met. AHP is conceptually easy to use, but it is divisionally robust, so that it can handle the complexities of the real world problems [24], [25].

AHP can assist the analysts and decision-makers to evaluate a problem in the form of a hierarchy of references through a series of pairwise comparisons of relative criteria. Relative weights are determined through pairwise comparison. The method can be applied by breaking down the unstructured complex scorecard problems into component parts. Hierarchical orders are then arranged by forming value tree structures. Subjective judgment on the relative importance of each part is represented by assigning numerical values. These values are selected in accordance to pairwise comparison scale [2]. To evaluate the pairwise comparison there are some computer-based tools for individual as well as group-decision support.

## IV. RESULTS OF A CASE STUDY: BANGKOK

In the case study, the software Web-HIPRE (HIerarchical PREference analysis in the World Wide Web) was employed to support the process of pairwise comparisons in the AHP process. Web-HIPRE is developed at the Systems Analysis Laboratory, Aalto University (previously Helsinki University of Technology), Finland (www.sal.hut.fi), and has been used previously in several applications, see for example [26], [27], [28].

Risk analysis regarding the selection of electric power plants generated from renewable energy sources in Bangkok was evaluated according to risks and society's benefits. The analysis was structured hierarchy value trees by separating from risks and society's benefits (Fig 2 and 3). In the evaluation processes, a group-decision method has been adopted. Data feeding into the evaluation process were derived from interview with experts and other technical literature. Due to a limited time, the experts with backgrounds of solar energy, biomass, and MSW technologies have a meeting together in addition with on-line discussions. The results are shown in Tables II and III according the risks and society's benefit, respectively. Detail of the evaluation results are also shown in Fig. 2 and 3.

TABLE II
EVALUATION WEIGHTS OF THE RISK ANALYSIS

| | Solar Power | PV Plant | Biomass | Biogas | MSW |
|---|---|---|---|---|---|
| Health | 0.030 | 0.044 | 0.086 | 0.069 | 0.271 |
| Environment | 0.030 | 0.064 | 0.213 | 0.052 | 0.141 |
| Overall | 0.059 | 0.108 | 0.299 | 0.121 | 0.413 |

TABLE III
EVALUATION WEIGHTS OF THE SOCIETY'S BENEFIT

| | Solar Power | PV Plant | Biomass | Biogas | MSW |
|---|---|---|---|---|---|
| Health, safety and environment | 0.078 | 0.021 | 0.134 | 0.051 | 0.048 |
| Economy | 0.031 | 0.035 | 0.134 | 0.093 | 0.041 |
| Politics | 0.033 | 0.014 | 0.153 | 0.102 | 0.032 |
| Overall | 0.143 | 0.070 | 0.420 | 0.246 | 0.121 |

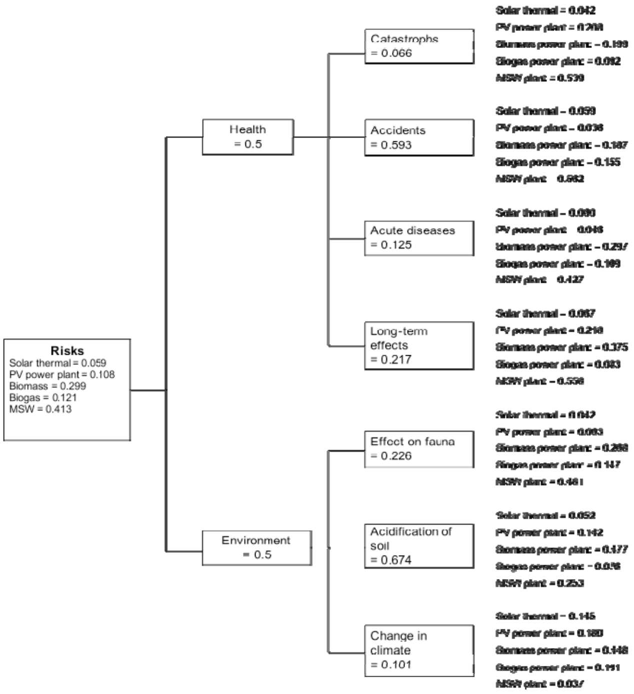


Fig. 2 Criteria weights of the risk analysis of different renewable power plants

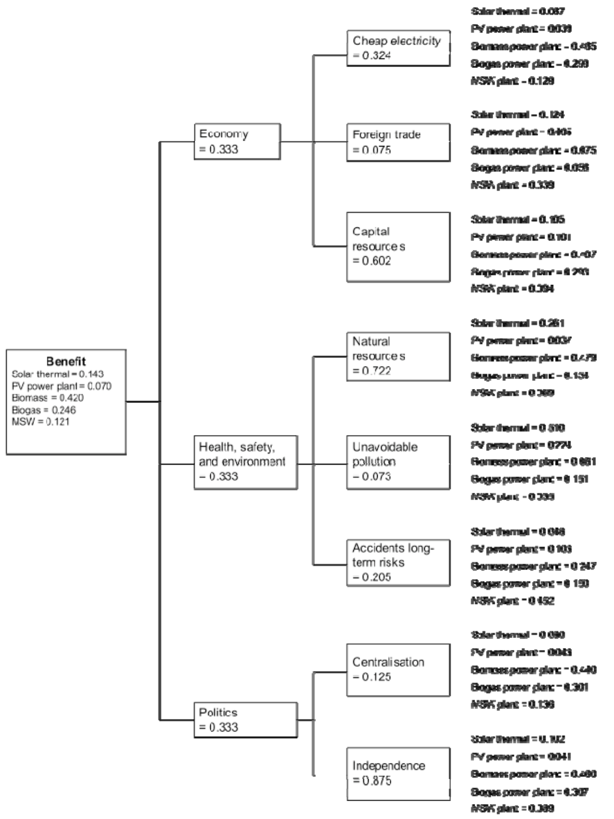


Fig. 3 Criteria weights of the society's benefits analysis of different renewable power plants

## V. Discussion And Conclusion

The study is focused on the risk analysis in the context of the multicriteria framework. It is not intended to show on the mathematical aspects of AHP. During the processes from defining the problem to interpretation of the results, there has been an interaction with the actors as well as literature review. The use of software enabled to facilitate the calculation process. One of the most important parts in this analysis is to choose the criteria because they are the tools that enable alternatives to be compared from a specific point of view. Selecting criteria is very delicate part in formulating the problem in the decision analysis, and thus it requires the utmost care. Depending on case by case and its application, numbers of criteria rely on the availability of both quantitative and qualitative data.

According to Table II, it is shown that MSW and biomass have the high risk with relative weights of 0.413 and 0.299, respectively. On the other hand biogas and PV plant have much lower values of relative weights of 0.121 and 0.108. The solar thermal power plant has the lowest risk among others with relative weights of 0.059.

The society's benefit as shown in Table III, biomass has the most benefit to the society with a relative weight of 0.420. It is followed by biogas, solar thermal, and MSW power plants. Their corresponding relative weights are 0.246, 0.143 and 0.121, respectively. The PV power plant has the lowest society's benefit due to the high investment cost and the life cycle impacts to the environment are longer than other alternatives.

Based on the obtained results, solar thermal power plant has the potential to be the best promising type for electricity generation in Bangkok corresponding to the risk, and followed by the PV plant. It is not surprisingly that solar energy technologies have lower risk to the human health and the environment. Bangkok has long sunshine per day, therefore, the availability of the resource is high. Regarding the benefit to the society, biomass has the highest potential and followed by biogas. This can be explained by the agricultural based economy of the neighboring cities around Bangkok. Biomass is indigenous resource, therefore, utilization this kind of domestic resource can make the energy system independence from the outside. On the other hand, PV plant and MSW have the low rating. This is due to the high investment cost of PV and the society's fear of the chemical substances of the MSW process.

It is found that this work demonstrates a useful approach to deal with multidimensional energy issue. The use of multicriteria framework together with decision analysis interview technique can be used as a decision support and enable to produce data and information for assistance in solving complex problems. The future advances are anticipated the results obtained under AHP method by comparison with the results achieved by applying other method and sensitivity analysis.

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