Using Analytical Hierarchy Process to Select the Best Power Generation Technology in Libya

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Abstract—**Selection of an appropriate power generation technology is a complex process. Because it is necessary to consider and take into account a wide range of parameters. The investment in the power generation field is too costly while resources are limited. This paper presents the determination of these parameters, which influence the selection of power generation technology in particular for developing countries. This paper answers the question of the best suitable technology for Libya because the investment in this field is so costly and making a wrong decision is not allowed, otherwise it will consume the big margin of the initial budget. Four main criteria are included, that is economic, environmental, technical and social. A sub-criteria are also included to support this decision. The performances of six technologies of a power generation are evaluated by Analytic Hierarchy Process (AHP) using expert choice software and the best technology is selected. The results showed that the solar photovoltaic power generation is the best technology. By means of the sensitivity analysis, it was found that the best alternative is not sensitive to a change in the weights estimated by the AHP.**

Index Terms: **Power, Generation, Multi Criteria, AHP, Select.**

I. INTRODUCTION

In last decades, the population of the world has increased madly. This increment is more concentrated in the developing countries, and Libya is not exception from this population growth. Most of activities and equipment's operate and depend on electricity. This change can not go ahead without building new power stations to fulfill the gap between power generation available and future demand. Power generation and the availability of electricity can be considered as the backbone of other industries. For developing countries electricity is one of the most important because all other needs depend on it.

There are some other research papers conducted about power generation in Libya which concentrated on the renewable power generation and dealt with a single technology to generate power.

This paper covers the gap by comparing some different technologies to facilitate the decision making process for selecting among these technologies. Yildirim and Erkan [1] studied the increasing consumption of electricity that lead countries to build additional power units. There are some technical and economical differences of the energy sources; generation planning is used to determine the best unit type for additional capacity. The assessment of costs in support of decision making should reflect these national policy objectives. It was found that the economic parameters vary between countries, even between regions, also change with time.

According to Hipkin [2], South Africa has limited financial resources which restrains technological adoption and expansion. Operations and maintenance staff were challenged to handle new technologies with existing systems and procedures. In technology transfer (TT) to developing countries, the high importance score for maintenance support. Leonard-Barton's [3] assertion that maintenance is one of the most problematic issues in technology management.

Zhouying [4] indicated and pointed out that the economic and technological gap between developed and developing countries can largely be explained by the level of soft technology and soft environments between the two sets of countries. It concluded that shortage of soft technology experts is the core problem.

Widiyanto [5] draws the attention and importance of a set of criteria for optimized selection includes five areas of concern; energy economy, energy security, environmental protection, socio-economic development and technological aspects for electrical power generation. According to Breeze [6], at the beginning of the twenty-first century, the new power plant offering the cheapest source of electricity appears to be the gas-fired combined cycle power station. It is the cheapest and quickest to build and relatively easy to maintain. The fuel is the most significant determinant of electricity price, so while gas is cheap, so is electricity. There are some other factors such as the effect of power production on the environment and on human health, factors which society pays for but not the electricity producer or consumer directly. These factors are called externalities.

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Also, Aljamel [7] suggested and indicated that the capital, the fuel and O&M costs are at the top of the criteria which effect the power generation directly in the developing countries.

II. ANALYTIC HIERARCHICAL PROCESS (AHP)

The AHP method was first mentioned in 1980 by Saaty [8], and later elaborated. Since then it has become very popular and used in many applications and in different variants. Multi-criterial AHP method belongs to Multiple Criteria Decision Making tools (MCDM). Every day, people need to make different kinds of decisions and their mind will be occupied with choosing the best options they are faced. Most of the time, these kinds of decisions can be hard to make or their complexity does not let the decision makers to choose the best decision. Nowadays, it is possible to solve complex decisions with mathematical models [8].

AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales. AHP is also one of the best known and most widely used in MCDM and a decision support tool, which is used to solve complex decision problems. This method has been one of the most efficient and widely used tools, which researchers applied to solve MCDM problems in different variable areas such as political, economic, social, and engineering management. AHP is one of the widespread applications in decision-making process [9]. A multi-level hierarchical structure of objectives, criteria, sub criteria, and alternatives are used in this method. After that a set of pairwise comparisons will be used to reach appropriate results. These comparisons are used to obtain the weights of importance of the decision criteria. AHP ranks the alternatives of decision and when the decision maker has multiple criteria, it helps to make the best decision. Hence, it considers a powerful and flexible multi-criteria decision-making tool for dealing with complex problems where both qualitative and quantitative aspects need to be considered.

Three important principles are made in the AHP method. The first one is to structure the model, which the complex decision problem is structured into a hierarchy. By the use of AHP, it would be possible to arrange the goal, criteria, and alternatives in a hierarchical structure. At least the hierarchy structure consists of three levels: goal is on the top, criteria is in the middle, and decision alternatives at the bottom. The second one is to make a comparison between alternatives and the criteria. This pairwise judgment starts from the second level and finishes at the lowest level, which are alternatives. The last one is the modulation of priorities. In each level, the criteria are compared pairwise according to their levels of influence and based on the specified criteria in the higher Level.

Let a_{ij} (i=1,2,3,...,M, and j=1,2,3,...,N) denote the performance value of the i-th alternative (i.e., Ai) in terms of the j-th criterion (i.e., C_j). Also denote as W_j the weight of the criterion C_j. Then, the core of the typical MCDM problem can be represented by the following decision matrix

	Criterion				
	C_1	C_2	C_3	.....	C_N
Alt.	W_1	W_2	W_3	....	W_N
A_1	a_{11}	a_{12}	a_{13}	....	a_{1N}
A_2	a_{21}	a_{22}	a_{23}	....	a_{2N}
A_3	a_{31}	a_{32}	a_{33}	....	a_{3N}
.....	......	....	....	....	....
A_M	a_{M1}	a_{M2}	a_{M3}	....	a_{MN}

In the AHP, the pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10% [8]. The CR coefficient is calculated as follows. First the consistency index (CI) needs to be estimated. This is done by adding the columns in the judgment matrix and multiply the resulting vector by its priorities (i.e., the approximated eigenvector) obtained earlier. This yields an approximation of the maximum eigenvalue, denoted by λ_{max}. Then, the CI value is calculated by using the formula: CI = (λ_{max} - n)/(n - 1). Next the consistency ratio CR is obtained by dividing the CI value by the Random Consistency index (RCI) as given in table 1. When these approximations are applied to the previous judgment matrix it can be verified that the following are derived: λ_{max} = 3.136, CI = 0.068, and CR = 0.117. If the CR value is greater than 0.10, then it is a good idea to study the problem further and re-evaluate the pairwise comparisons.

Table 1. Random Consistency Index

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Finally, given a decision matrix the final priorities, denoted by $A_{i\,AHP}$, of the alternatives in terms of all the criteria combined are determined according to the following formula:

$$A_{AHP}^{i} = \sum_{j=1}^{N} aij\, wj, for\ i = 1,2, \dots . M$$

In this paper, to do pairwise comparisons a scale of nine levels is used as a comparison standard. The numbers show the intensity of importance. For example, number 1 means equally important and number 9 means absolutely important. Table 2 shows the numerical rating for verbal judgment of preference.

III. CASE STUDY

Before any decision can be taken to select a power generation technology to generate electricity, it is very important to carry out research to determine all parameters which they influence and support the correct decision for such selection. There is no way to allow a misleading decision or it can be very harmful to the economy of a developing country. All possible parameters which effect and lead to a correct decision to use the power generation technology have been taken into consideration. The hierarchy structure of AHP is shown in figure (1).

Table 2. Numerical Rating for Verbal Judgment of Preference

Importance degree	Descriptions	Explanation
1	Equally important	Criteria *i* and *j* are of equal importance
3	Weakly important	Criteria *i* is weakly more important than objective *j*
5	Strongly important	Criteria *i* is strongly more important than objective *j*
7	Very strongly important	Criteria *i* is very strongly more important than objective *j*
9	Extremely important	Criteria *i* is extremely more important than objective *j*
2,4,6,8	Intermediate values	For example, a value of 8 means that Criteria *i* is midway between strongly and more important than objective *j*

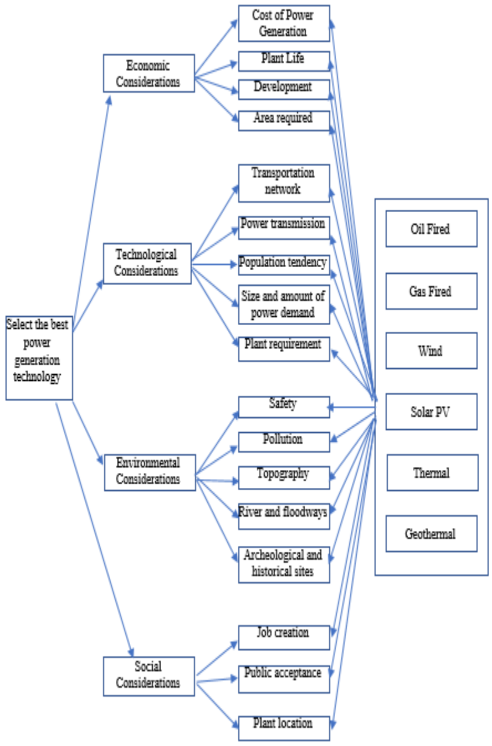

Figure 1. Hierarchic Structure of the Problem

To determine the appropriate criteria, the authors decided to consult some university staff members, also by writing to expert engineers in some power stations in Libya. A questionnaire was used to collect the information by some experts in the field of power generation technologies. The results collected and gathered in this paper took into account the economically, environmental, social and technical criteria as shown in Table (3).

Table 3. Criteria for the AHP Method

Qi	Criteria	Sub-criteria
Q1	**Economic**	Investment cost Operation & maintenance cost Fuel cost Plant life Development
Q2	**Environmental**	Emissions Land use Noise River and floodways Archaeological and historical sites
Q3	**Technological**	Efficiency Safety Reliability Power transmission Size & amount of power demand
Q4	**Social**	Job creation Public acceptance social benefits

Q_i: criteria index

Some of these criteria effect the population around the power plant, others may have some effect on the safety of society in developing countries such as a nuclear power plants. Some of these criteria can be considered in some countries but is not a vital and important affect, because some technology cannot be applicable due to the absence of climatic causes such as hydropower or other reasons.

It should be noted that in developing countries some technologies are more appropriate than others, the following technologies are considered in this paper:

- Oil fired power generation.
- Gas fired power generation.
- Wind power generation.
- Solar photovoltaic power generation.
- Solar Thermal power generation.
- Geothermal power generation.

In addition, some technologies are excluded from the selection for some reasons such as:

- Diesel engines are normally used at small scale (Villages) or emergency cases.
- Fuel cells power generation technology cannot compete with its high installation costs compared with other generation technologies. With the exception of the PAFC (Phosphoric Acid Fuel cell). Fuel cells are unproven commercially.
- Some of developing countries are far from the sea and oceans. The second reason, developing countries cannot rely on the tidal power technology that is the problem when the two levels of sea and basin are the same where the power generation stops.

To develop AHP model, pairwise comparison matrix is created. In this matrix, each criterion and sub-criteria compared with other criteria and sub-criteria individually as shown in Table (4).

Table 4. Pairwise Comparison

	Q1	Q2	Q3	Q4
Q1	1	5	4	6
Q2	0.20	1	5	4
Q3	0.25	0.2	1	5
Q4	0.166	0.25	0.2	1

The consistency rates are calculated. It was found that all the consistency rates are less than 0.1, thus, this low rate indicates a good level of homogeneity in comparison estimates.The weights of the main and sub-criteria are found, and then these weights are multiplied in order to find the final weights. Then the sub criteria are compared to the alternative technologies. Table 5 shows the pairwise comparison matrix of the general and organizational structure of the technology's sub-criteria.

Table 5. Results Summary of Criteria, Weight and CR

Criteria	Weight	CR	Sub- criteria	weight
Economic	0.571	0.08	Investment cost	0.355
			Operation & maintenance cost	0.108
			Plant life	0.060
			Development	0.048
Environmental	0.256	0.07	Emissions	0.104
			Land use	0.040
			Noise	0.063
			River and flood ways	0.036
			Archaeological and historical sites	0.014
Technological	0.123	0.06	Efficiency	0.059
			Safety	0.009
			Reliability	0.021
			Power transmission	0.021
			Size & amount of power demand	0.012
Social	0.051	0.09	Job creation	0.036
			Public acceptance	0.010
			Social benefits	0.004

CR: Consistency Ratio

After the AHP methodology is applied to the problem, the best technology is determined. Table 6 shows the results. It can be seen from Table 6, that the Solar Photovoltaic power generation is the best technology.

Table 6. Results of AHP Method

Technology	Importance Value	Rank
Solar photovoltaic power generation	0.206	1
Solar thermal power generation	0.196	2
Geothermal power generation	0.176	3
Gas fired power generation	0.165	4
Wind power generation	0.144	5
Oil fired power generation	0.114	6

In AHP model, sensitivity analysis is crucial in determining if solution is implemental and robust. A sensitivity analysis is performed to verify the best alternative among all the alternatives. Figure 2 shows the model sensitivity analysis.

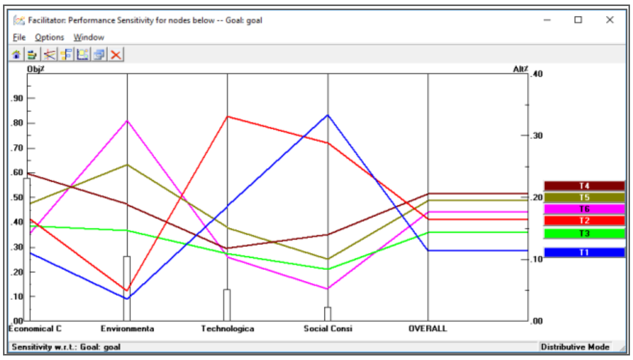

Figure 2. Sensitivity Analysis

In the model, each criterion's weight is changed between 0.5 to 1.0. It can be seen from Figure (2), that the best alternative T4 is not sensitive to a change in the weights estimated by the AHP.

IV. CONCLUSION

The aim of this paper is to select the best power generation technology in Libya using AHP. It is well known that Multi-Criteria Decision Making (MCDM) techniques are gaining popularity in sustainable energy management. Besides, it includes both quantitative and qualitative criteria which some of them may include uncertainty and sometimes they may be conflicting. AHP method enables the decision maker to evaluate a larger number of criteria using pairwise comparisons and also to calculate the consistency. This raises the credibility of the decision. However, AHP generates a decision based on the comprehensive analysis of a problem and the combination of relevant information, based on the knowledge, experiences and preferences of the various participants involved in the decision-making process. AHP analysis performed and the main quantitative and qualitative attributes are presented. The AHP estimates weights and priorities and suggests the best alternative considering all the criteria. Based on these analyses weights for technologies assessment were ranked, and the results show that the PV power generation technology is the suitable technology. The results of sensitivity analysis showed that the best alternative T4 is less sensitive to a change in the weights estimated by the AHP.

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