Science, Technology and Development 37 (4): 184-194, 2018
ISSN 0254-6418 / DOI: 10.3923/std.2018.184.194

Prioritization of Various Renewable Energy Resources for Pakistan using Analytical Hierarchy Process

Farid Bakhtiar Khan and Aleem Ahmed

Pakistan Council for Science and Technology, Islamabad, Pakistan

Abstract: Pakistan has been struggling to overcome its energy deficiency issues for quite some time due to its extraordinary energy problems including heavy reliance on costly imported furnace oil, depleting natural gas reserves, severe power outages, high line-losses, etc. However, the efforts directed towards finding alternative, effective and lasting energy solutions are more intensive now than ever before. Renewable energy resources found in abundance in Pakistan, including solar, wind and biomass, have huge technical potential to meet the energy requirements. Present study is based on inputs from energy experts through a survey, prioritize various renewable energy resources taking into account factors including environmental impact, efficiency, cost, installed capacity, reliability, estimated potential and social acceptance. Analytic Hierarchy Process (AHP) is employed as decision making tool. The study ranked wind energy as the top priority among the three renewable alternates, followed by biomass and solar energy w.r.t. Pakistan to supplement future energy demands.

Key words: Analytical hierarchy process, Alternative energy, Pakistan's renewable energy scenario, Solar energy, Wind energy, Biomass.

INTRODUCTION

Energy is one of the most important instruments for economic progress and is often regarded as the lifeline of an economy. The energy demands are directly proportional to the population growth and expansion of economic activities. Historically, Pakistan has been subjected to energy demand suppression due to limited energy supplies, which has resulted in unavailability of energy particularly to the industrial sector. The energy crisis in Pakistan has worsened in the past decade particularly in summers, when the electricity consumers have to face long hours of power outages. In order to prevent the generating stations from being overloaded; the electricity supply is cut down to a huge number of users (load shedding). In summers, the duration of load shedding is 8-10 hours per day in the urban areas and up to 20 hours in the rural areas. From the past few years, few hours of load shedding have become common even in winters; despite the fact that there is no cooling load during this period. Pakistan's increasing energy shortage has large potential economic effect:

- Since the past few years, there has been an average increase of 3.4 % per year in the imports of crude oil (Qurashi *et al*., 2009).
- There was an annual increase of about 7% during 2003-8 in the use of electricity; against a generation growth of about 4.8% in the same period (Qurashi *et al*., 2009).
- The transmission and distribution losses in the system are around 25%, which are very high.
- Severe power outages started in 2007 and are still ongoing.

One of the key factors responsible for the country's severe energy shortfall is that it has a very imbalanced energy mix. Figure 1 depicts the primary energy supplies by source in 2017; wherein the shares of gas (natural), oil, hydro-electricity, coal, LNG import and nuclear energy are roughly 38%, 34%, 10%, 8%, 6%, 2% and 1%, respectively (Pakistan Energy Year Book, 2017); whereas, the share of renewable energy is less than 1% (0.8%). Unfortunately, the share of renewable and alternative energy resources, with the exception of hydro, is very small in the overall energy mix of the country and need special attention of the policy makers.

To meet its energy demands, Pakistan imports major portion of its fossil fuel from other countries which makes it a net importer of energy. The oil import bill of Pakistan has been continuously on the rise during the past decade and petroleum worth US $11.7 billion was imported by Pakistan in the year 2014-15 (http://www.cssforum.com.pk/general/news-articles/61571-energy-crisis-important-articles-4.html).

Corresponding Author: Farid Bakhtiar Khan, Pakistan Council for Science and Technology, Islamabad, Pakistan
E-mail: faridbakhtiar@gmail.com

Oil import is a heavy burden on GOP's foreign exchange and almost 50% of the total coal consumed is also imported. Pakistan is no more self-sufficient even in natural gas and there is no gas available to CNG gas stations for two days a week. The country is exploring the possibilities of importing natural gas from Qatar or Iran, which will make it net importer of natural gas too.

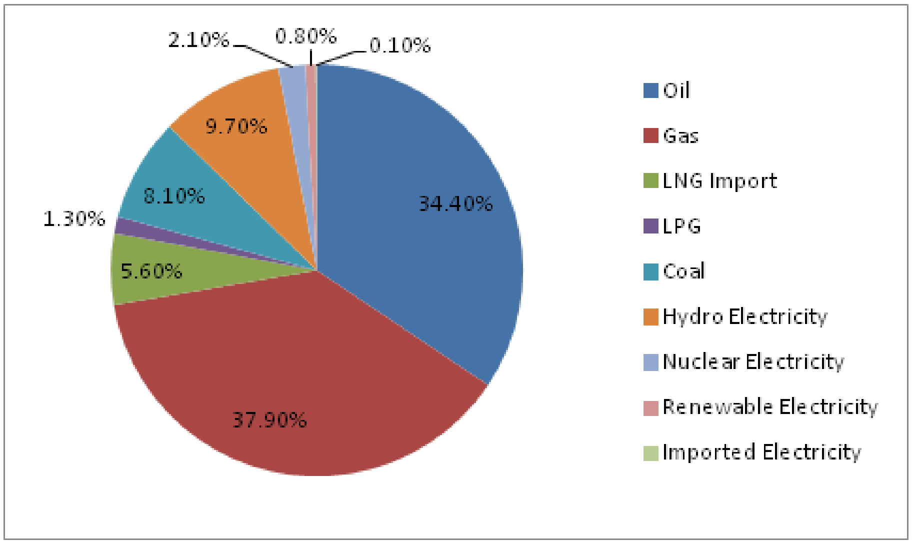

Fig. 1: Primary energy supplies by source.

Source: Pakistan Energy Yearbook 2017, Ministry of Energy (Petroleum Division), Hydrocarbon Development Institute of Pakistan.

Currently, Pakistan, being a net importer of oil products, is likely to become an importer of natural gas. It has to cope with energy security and fuel supply chain issues and, therefore, it must exclude (or reduce) fossil fuels from its plans for power generation to the extent possible. To manage energy crisis in the country, renewable energy is a viable option. Renewable energy and other alternative sources of energy may have the following impact:

- increase the energy security.
- supplies at lesser-cost and other socioeconomic benefits.
- decrease pollution and alleviate climate change.
- deliver isolated supplies near demand centres which in turn will reduce losses (transmission and distribution) and enhance access in remote regions.

Pakistan has a huge renewable energy resource potential. Due to wide distribution of solar energy in Pakistan and its availability in abundance gives Pakistan an excellent opportunity to benefit from solar energy technologies. There is an annual average of 4 kWh/meter 2/day and 3,000 hr/yr of sunshine in most regions of the country. As far as wind is concerned, commercially exploitable wind resources exist in many parts, especially, in southern Sindh and coastal Balochistan. Along the coastal belt of Pakistan, there exists a 60 km wide and 180 km long wind corridor from Gharo-Kati Bandar to Hyderabad (www.aedb.org.pk). The potential for wind power generation in this corridor is around 50,000 MW (http://www.slideshare.net/kashifmateen/pakistan-energy-scenario-a-case-for-renewable-energy). There are other sites for wind power generation in northern areas. Less than 50 MW micro hydel power plants have an available potential of more than 1200 MW; particularly, in the mountainous regions of Khyber Pukhtunkhwa province and Northern Areas of the country. The water falls in the canal network of Punjab and Sindh provinces also have potential for micro power plants. The country also has large sources of biomass energy in the form of crop residues, animal waste in the form of bagasse, rice husk and dung produced by the country's agriculture and livestock sector. Pakistan's major cities are overburdened with solid wastes/municipal wastes from different sources. About 8000 tons of solid waste per day is produced in Karachi only (Jilani, 2007

With the view of harnessing and investing in various renewable energy resources (RER), it is needed to prioritize these resources depending on various parameters; for which the present study has been conducted. The scope of the study has been kept limited to only three resources namely solar, wind and biomass.

One of the methods for informed decision making is Analytical Hierarchy Process (AHP), in which a multiple-choice criteria is arranged into a hierarchy, the relative significance of these criteria is evaluated, alternatives for each criterion are compared, and an overall ranking of the alternatives is determined. The concept of AHP was developed by an American mathematician, Thomas Saaty, at the University of Pittsburgh in 1980 (Saaty, 2008).

The scope of the present study is limited to rating three areas of alternative energy resources available freely in the country, i.e., solar, wind and biomass energy resource. Also the study does not discuss the conventional energy resources, such as furnace oil whose import costs billions of dollars to the national exchequer or the natural gas, in which the country is no more self-sufficient and the domestic consumers have been experiencing gas load shedding of up to six hours due to constant depletion of this energy resource in the country.

Likewise, amongst various renewable resources available in the country, only the more common ones and those available in abundance, such as the solar energy, wind energy and biomass have been considered in the study. The less common renewable energy resources, such as, geothermal energy, wave energy, etc., have not been considered due to the following two reasons:

(a) these are not available in abundance in the country,

(b) the technologies for harnessing these renewable energy resources are relatively less mature as compared to solar, wind and biomass.

It is pertinent to mention that the aim of the study was not to replace the conventional energy resources but only to prioritize those renewable energy resources that can supplement the conventional energy resources to meet the country's energy demand.

HIERARCHICAL DECISION MODELING FOR ENERGY RESOURCE SELECTION

Algarín *et al*. (2017) have used the AHP as a decision making tool for planning of rural renewable energy in Colombia. Different sets of criteria and sub criteria, including social, economic, technological and environmental, were taken into account as basis for prioritization.

Usman *et al*. (2015) have used multi criterion decision approach for evaluation of alternative power systems at domestic level in Pakistan, wherein customer's requirements were identified through the use of AHP.

A hierarchical decision model was presented by Wang *et al.* (2009) for the selection of energy resources for China in future. It was discussed that decisions about energy alternatives are crucial for a fast-developing country, like China. Renewable energy, nuclear energy, natural gas, petroleum and coal were discussed as alternatives of energy resources for China. For rating and selection of energy resources, Hierarchical Decision Modeling (HDM) with sensitivity analysis was used. The basic concept of HDM and AHP is the same except the use of different scales for pair-wise comparison and quantification techniques for judgment. The results ranked the energy resources in the order of renewable energy, coal, nuclear energy, natural gas and petroleum; whereas, the current energy infrastructure was found to be the most critical criterion for energy resource selection, using sensitivity analysis.

In order to evaluate different energy sources for the US, Gholamnezhad and Saaty used AHP model in 1982 (Gholamnezhad and Saaty, 1982). AHP was also used by Daniel *et al*. (2008) to prioritize the renewable energy resources available in India. To prioritize various renewable energy resources, a number of key parameters, e.g., cost, efficiency, social and environmental impact, etc., were considered. The scales for these key parameters were fixed on the basis of a survey, carried out earlier. For each attribute and each pair of alternatives, the result of the survey was stated in order of preference in the form of a fraction between 1/9 and 9.

From the selection of the most appropriate system in Mauritania, a study was carried out by Rujula and Dia (2010), where multi-criteria analysis was presented. Various energy sources, technologies for water desalination processes and water use, six scenarios and five criteria, namely, economic costs, operation and maintenance costs, potential, adequacy and environment, were analyzed. The multi-criteria analysis revealed that, for each scenario, the best solution was found to be photovoltaic-reverse osmosis the preferred solution in some cases, whereas, reverse-osmosis powered by concentrating solar parabolic or wind energy was more suited in others.

AHP was used as a decision-making tool to enhance the application of solar energy technologies in Jordan in 1993 (Elkarmi and Mustafa, 1993). Current study stressed to enhance the share of renewable energy in overall energy mix at the global level in general and for the developing countries in particular, as they offer good conditions for different renewable energy resources. It has been further emphasized that the use of incentives and privatization schemes and economic instruments by the governments would help to achieve this goal of increasing the utilization of renewable energy.

RENEWABLE ENERGY SCENARIO OF PAKISTAN

A review about non-renewable and renewable energy scenario of Pakistan in quantitative terms of supply, generation and exploitation of existing resources, was presented by Sheikh (2010). The study was mainly focused on the presentation of data about renewable energy installations in Pakistan, current activities, projects, planning and achievements of public sector renewable organizations. Effective planning, use of technologies and exploitation of renewable energy resources were suggested in the end.

RER can be defined as "the energy flows that are refilled at the same rate as they are used". Solar radiations are considered as the source of most renewable energy sources. Solar radiation can be used directly for electricity generation or heating.

Similarly, indirect solar radiations are responsible for other forms of energy such as wind energy, wave energy, running water energy from plants and animals (biomass).

The use of renewable energy resources allowed to avoid different types of environmental damages associated with the use of nuclear fuels and fossil fuels. Liquid pollutants or gaseous pollutants are not released during their operations. Renewable energy resources provide energy security and do not exhaust because they are replenished at the same rate, at which they are depleted. Majority of the renewable energy resources are secure, as foreign powers cannot turn them off.

Solar energy, wind energy, micro hydel and biomass energy are the major RER of Pakistan that are not only technologically viable but also have prospects for exploitation at commercial level. Pakistan can take advantage from these resources by either supplementing the existing energy resources or using them as primary energy resources in areas where other options are not available. Currently, Pakistan, like most developing countries, is having serious challenges of energy shortage due to more energy demand and less energy supplies.

The huge renewable energy resources of Pakistan can be used not only to bridge the gap between energy demand and supplies but also provide electricity to remote rural areas, where grid connected electricity is not available. In the fast changing power sector, renewable energy resources are a better option as it is modular. The lead-time from installation to operation, both for wind and solar technologies is short and when used in decentralized areas their generating capacity can be enhanced. The government would also like to harness more and more renewable energy and this is also reflected in the energy policies of government. In fact, it has been decided to increase the share of renewable energy in the primary energy mix up-to 10% by the year 2030.

Foreign companies have good business prospects for investing in the renewable energy in Pakistan which is worth millions of US Dollars. Solar energy, wind energy, small hydro projects, waste-to-energy, biomass, all are good areas for investment. About 9,700 MW by 2030, from renewable and non-conventional sources of energy, has been envisaged in the renewable energy policy of Pakistan. The potential growth in the renewable energy sector in Pakistan may be due to the following factors:

- There is a huge gap in the demand and supply of electricity,
- Various types of renewable energy resources are available in abundance in Pakistan,
- The energy policies of the government are conducive.

1. Solar energy

Majority of the area of the country (95%) has an average solar global insolation 5-7 kWh/m^2 having a persistence factor of 85%. Baluchistan and North Eastern part of Sindh province have sun shines between 7-8 hours daily or approximately more than 2300-2700 hours per annum; providing ideal conditions for exploiting solar energy (Sheikh, 2010). However, the generation of electricity from solar energy or solar heating is still in its infancy despite these excellent conditions. Stand alone photovoltaic systems for generating electricity have been installed in some rural areas having capacity between 100-500 W/unit.

According to some survey report, tens of thousands of villages in Pakistan do not have electricity and with the current pace of development in the energy sector, they are likely to remain without electricity for quite some time. In the 1980s, about 18 photovoltaic systems, having a combined output of 440KW, were installed by the government in different parts of the country; however, for one reason or the other, they were not operational in the 1990s.

Under these circumstances, Pakistan Council for Renewable Energy Technologies (PCRET) and Alternative Energy Development Board (AEDB) have carried out some renewable energy projects; however, due to weak financial and technical human resources, the status of these organizations, no major breakthrough may be expected from them in near future. In the private sector, a few dozens of manufacturers and suppliers are engaged in renewable energy business in the country.

About 3,000 household units were electrified by AEDB, having a combined power generation of 200 kW in various parts of the country, including, D.G. Khan, Rawalpindi (Punjab), Kohat (KPK), Tharparkar (Sindh), Turbat/Kalat (Balochistan), etc., 80W panel with lighting system was provided to each household unit. The private sector has also installed about 500 kW of PV systems in the country. On the solar thermal side, there are examples of using solar dryers, desalination units, solar cookers and solar water heaters on limited scale and its impact in the overall energy scenario is negligible. Generally speaking, the combined PV installations are less than 1000 kW and the solar thermal units in the range of 10,000 units in the country. To overcome the energy crisis, the country needs to have mega/macro PV project on commercial scale.

2. Wind energy

In the coastal areas of Sindh and Baluchistan and in a few areas of KPK the wind flows at a speed of 5-7 m/s (Sheikh, 2010). Two projects, namely, ‘Wind Power Potential Survey of Coastal Areas of Pakistan (Phase-I)’ and ‘Wind Mapping of Northern Areas of Pakistan (Phase-II)’ have been undertaken by Pakistan Meteorological Department (PMD) in financial collaboration with Ministry of Science and Technology (MoST) The wind power potential of Pakistan that is economically viable has been estimated around 50,000 MW. In the first half decade of the year 2000s, there had been no large wind energy conversion system with a capacity greater than 500W. Small number of micro-plants with a capacity of 300-500 W for generating electricity and around 100 wind power plants were in use for water pumping in coastal Sindh and Baluchistan. Small wind turbines (0.5-10 kW capacity per unit) with a combined generating capacity of 145 kW were installed by PCRET by the end of 2010.

Under the grid connected electricity program on commercial basis, the government decided to install 100 MW wind power through AEDB in 2005 at Gharo-Keti Bandar, however, it is still under implementation. The first Wind Power Plant of commercial scale (6 MW) was installed in 2009, with the help of a firm from Turkey, which is to be expanded up to 250 MWs (www.aedb.org.pk).

Micro-wind turbines were installed in the universities of Baluchistan for R&D and, around 40 small wind turbines, having a total generation capacity of around 10 MW, were installed in Karachi by AEDB. PCRET has also installed micro-wind turbines of 500 W each in the rural areas of Sindh and Baluchistan, having power generation of around 150 kWs.

3. Biomass energy

Mankind has used biomass as an energy source since time immemorial. For low income households in Pakistan, biomass constitutes the major share of their everyday requirements in the form of firewood, dung and crop residues. Community biogas plants offer brilliant prospects for using biogas energy in rural areas. Fuel-efficient cook stoves have been successfully installed in various parts of the country, while other initiatives include research on E-10 gasoline pilot project and biodiesel production. Bagasse from sugarcane, municipal and industrial wastes have excellent potential for the generation of electricity (Mirza *et al*., 2008).

The total available potential for biogas generation in the country is more than 14 million m^3/day (Sheikh, 2010). PCRET designs and develops biogas plants and disseminates them. In the past few years, PCRET has installed thousands of plants having a capacity of normally 5 m^3//day and an estimated life of up to 5 years. Similar plants have also been installed by the private sector and NGOs. These plants are becoming increasingly popular amongst the rural community particularly the farmers of Punjab. However, advanced and latest digesters that can maintain internal thermal temperature (under difficult environment producing more gas) are needed to be introduced to make them more viable.

The Landhi cattle colony in Karachi, having hundreds of thousands of cattle, provides excellent potential of electricity generation through biogas. With funding from New Zealand Aid (NZAID), AEDB is working on biogas project in this locality and the pilot phase of the project would generate 250 kW. Eventually, this will be expanded to around 30 MW, in addition, to producing 1,500 tons of organic fertilizer per day. AEDB is also providing technical assistance to an 8 MW biogas power plant at Shakarganj Mills (Sheikh, 2010).

METHODOLOGY

A questionnaire-based survey was conducted and the questionnaire was disseminated only to experts in the field of energy. The survey participants were asked to put values in the matrix according to Saaty's Scale. A multi criteria decision-making method, namely, analytic hierarchy process, was used in the study and a pair-wise comparison was made. To begin with the overall hierarchy of the decision is laid out. This hierarchy discloses different alternatives/options available and the factors to be considered for making the decision. This is followed by doing a number of pair-wise comparisons. Consequently, the factor evaluation and factor weights were determined. Detailed methodology and the information requested from the respondents of the survey and AHP have been elaborated in the following sections.

1. Analytic hierarchy process

Most of the decision-making problems depend on multiple factors. For instance, considering a new employment opportunity, one may take into account the initial salary, the fellow workers, career growth, job location, nature of the job, the additional incentives, etc.

These circumstances where different decision-making factors may be evaluated, e.g., the multi factor evaluation process (MFEP) decisions were made comfortably. However, when accurate decision-making were difficult, the method of AHP developed by Saaty was used (http://www.scribd.com/doc/854630/AHP-Textbook). This process involves a pair-wise comparison and the overall hierarchy of the decision is laid out. This hierarchy disclosed identification of different alternatives/options available and the factors to be considered for making the decision, followed by doing a number of pair-wise comparisons. Consequently, the factor evaluation and factor weights were determined.

AHP is becoming increasingly popular due to its usefulness over other decision-making methods,, particularly, in research (Eddi and Hang, 2001). It is considered as a strong and flexible multi-criteria decision-making tool by the scientists and researchers when solving complex decision-making problems (Elkarmi and Mustafa, 1993). This approach involves logical breaking of a complex decision-making problem into multiple but interlink sub-problems in the form of levels of a hierarchy. The AHP approach involves a hierarchical structure which allows a comparison of various alternatives and prioritization criteria logically and more effectively. This method is flexible and dynamic and helps in arriving at a consensus decision, besides involving group discussions and dynamic discussions. To screen out inconsistent decisions, a consistency test may also be employed.

In this method, while making pair-wise comparison; a subjective assessment of relative importance is used, which is converted to weights or a set of overall scores. This gives the problem a hierarchal structure and arrangement. For the application of AHP, Saaty developed the following steps (Daniel *et al*., 2008):

1. Identification of the purpose of the issue - First of all, the main purpose of the issue or problem and the criteria that affects the main purpose is identified.
2. Structuring of the issue on the basis of hierarchy of goal, criteria, sub-criteria, and alternative.
3. In the next level of hierarchal arrangement:
   - Pair-wise comparison of elements following Saaty's Scale (Table 1) Normalisation of the elements in each column of the matrix to obtain a local priority vector. The columns are averaged individually and each member of the columns is divided by the averaged value of the column and computing the average over the rows of the resulting matrix.
   - For making consistent decisions, the consistence ratio of the matrix of decisions is calculated using the average Random Index (R.I.) given in Table 2 is used.

Table 1: Scale of preferences used by Saaty in the pair-wise comparison process.

Numerical rating	Verbal Judgments of preferences between alternatives i and alternatives j
1	Alternative i is similarly significant to Alternative j
3	Alternative i is a little more significant than Alternative j
5	Alternative i is strongly more significant than Alternative j
7	Alternative i is very strongly more significant than Alternative j
9	Alternative i is exceptionally more significant than Alternative j
	In-between values of 2,4,6 and 8 are considered as Intermediate values

Table 2: The average Random Index (R.I.) and its corresponding size of matrix.

Size of matrix	R.I.	Size of matrix	R.I.
1	0	6	1.24
2	0	7	1.32
3	0.58	8	1.41
4	0.9	9	1.45
5	1.12	10	1.49

4. Repetition of Step 3, for all the elements/factors in a subsequent level, with respect to each criterion in the former/earlier level.
5. Finally, the local priority vectors over the hierarchy getting an overall priority for each alternative

Saaty (1980) quoted a number of decision-making problems, including, project selection, energy policy, measuring business performances, for the application of this approach.

2. Using AHP for the prioritization of renewable energy resources in Pakistan

Current energy situation in the country demands reviewing the prioritization and selection of energy resource in Pakistan. Renewable energy resources are an important viable solution to the energy crisis of Pakistan. Of different renewable energy resources, the right choice in the investment of particular type of renewable energy resource, that has the best utility, is of critical importance. To arrive at a more accurate and best possible decision, various options of available renewable energy resources need to be logically evaluated. Saaty's AHP is an excellent tool to evaluate Pakistan's various renewable energy resources.

For ranking and evaluation of different alternative energy resources of Pakistan, the following information was required:

- Types of alternative energy need to be evaluated
- Criteria to be considered in the decision-making process for selection of alternative energy resources
- Weights given to the criteria by the local experts
- Pair-wise comparison between various criteria
- Pair-wise comparison between various renewable energy resources w.r.t. each criterion
- Ranking of various energy resources in order of hierarchy and priority

Present study has a limited scope of evaluating and ranking only the biomass, solar and wind which are the three most significant renewable energy resources. The criteria identified are as under:

i. Cost (CT)
ii. Efficiency (EFF)
iii. Estimated Potential (ES.PT)
iv. Environmental Impact (E.I)
v. Installed Capacity (I.C.)
vi. Reliability (RE.)
vii. Social Acceptance (S.A.)

As the first step, various energy resources and the elements of criteria were placed in a decision hierarchy (Fig. 2). In order to prioritize the alternative energy resources in Pakistan, the decision hierarchy follows three levels:

a) The lower level of the hierarchy represents the three alternative energy resources, namely solar, wind and biomass
b) The seven criteria parameters namely CT., E.I, EFF, I.C, ES.PT, RE and S.A. have been listed in the middle level in decision hierarchy
c) The overall and final decision has been placed in the top most level of the decision hierarchy.

The criteria parameters identified above were organized into a matrix. For comparing each attribute, Numerical Rating was assigned from the comparisons as shown in Table 2.

The judgments' matrices corresponding to the pair-wise comparison of elements at each level of the hierarchy are presented in Fig. 2.

A questionnaire designed and developed was disseminated and a survey was carried. The questionnaire was disseminated only to those who were experts or who were knowledgeable in the field of energy. The survey participants were asked to put values in the matrix according to Saaty's Scale.

Various parameters, considered for the overall rating of alternative energy resources, have been compared pair-wise as shown in Table 3. A (7 × 7) matrix has been used for entering the values of the respective criteria. A value of one (1) has been written when a criterion is self-compared as may be seen in the diagonal elements of the matrix. When a criterion is compared with other criteria of the matrix Saaty's Scale value is written. For example a value of three (3) is written in the $(2 \times 7)^{th}$ position of the matrix; this means that the 2^{nd} criterion EFF has twice the importance as that of the 3^{rd} EI. It can be observed that the values beneath the diagonal are the reciprocal of the values over the diagonal. This means that only the decisions above the diagonal and in the upper triangle of the matrix are required.

Table 3: Comparison (pair-wise) of the criteria matrix with respect to the goal.

	CT.	EFF.	E.I.	I.C.	ES.PT.	RE.	S.A.
CT.	1	1	3	6	6	3	3
EFF.	1	1	2	3	3	3	5
E.I.	0.333333	0.5	1	1	3	0.333333	1
I.C.	0.166667	0.333333	1	1	1	0.333333	0.3333333
ES.PT.	0.166667	0.333333	0.333333	1	1	1	1
R.E.	0.333333	0.333333	3	3	1	1	3
S.A.	0.333333	0.2	1	3	1	0.333333	1

Table 4: Calculating the priority vector from the decisions in Table 1.

	CT.	EFF.	E.I.	I.C.	ES.PT.	RE.	S.A.	PVE
CT.	0.3	0.27027	0.264706	0.333333	0.375	0.333333	0.209302	**0.297992**
EFF	0.3	0.27027	0.176471	0.166667	0.1875	0.333333	0.348837	**0.254725**
E.I	0.1	0.135135	0.088235	0.055556	0.1875	0.037037	0.069767	**0.096176**
I.C	0.05	0.09009	0.088235	0.055556	0.0625	0.037037	0.023256	**0.058096**
ES.PT	0.05	0.09009	0.029412	0.055556	0.0625	0.111111	0.069767	**0.066919**
RE	0.1	0.09009	0.264706	0.166667	0.0625	0.111111	0.209302	**0.143482**
S.A	0.1	0.054054	0.088235	0.166667	0.0625	0.037037	0.069767	**0.082609**

Table 4 shows that priority vector (PVE) was calculated from the decisions matrix in Table 3. Vector in each column of the matrix was normalized when each value of the column was divided by that column's total and averaging over the rows of the resulting matrix. Consequently, 0.297992, 0.254725, 0.096176, 0.058096, 0.066919, 0.143482, 0.082609 are the local priority vectors (PVE).

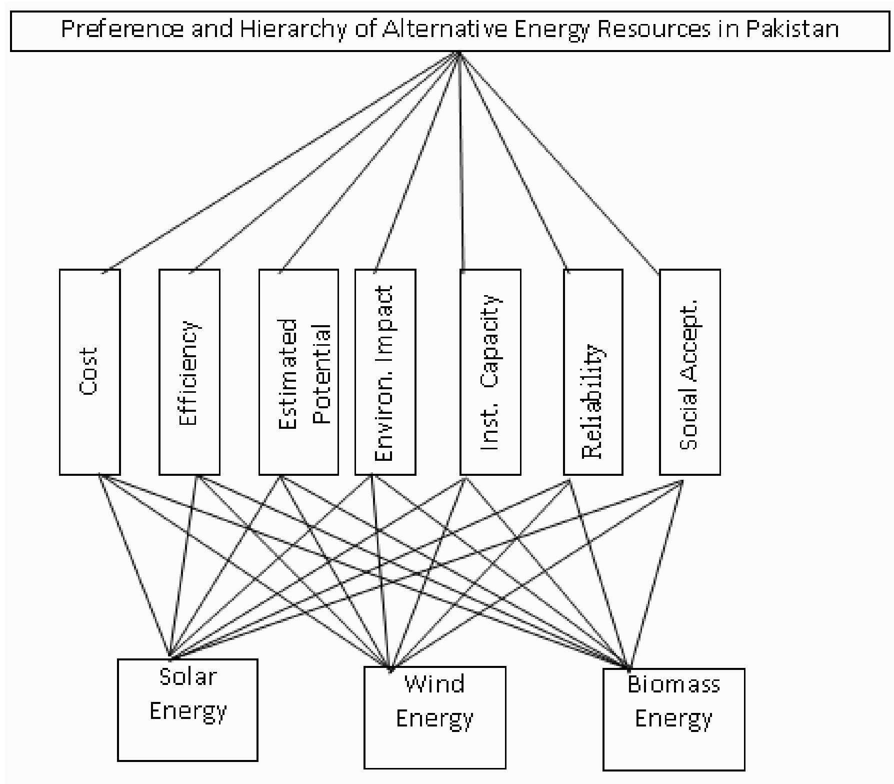

Fig. 2: Prioritizing the renewable energy resources of Pakistan, using the AHP model.

Following procedure is adopted to perform a consistency check:

$$\begin{pmatrix} 1 & 1 & 3 & 6 & 6 & 3 & 3 \\ 1 & 1 & 2 & 3 & 3 & 3 & 5 \\ 0.333333 & 0.5 & 1 & 1 & 3 & 0.333333 & 1 \\ 0.166667 & 0.333333 & 1 & 1 & 1 & 0.333333 & 0.333333 \\ 0.166667 & 0.333333 & 0.333333 & 1 & 1 & 1 & 1 \\ 0.333333 & 0.333333 & 3 & 3 & 1 & 1 & 3 \\ 0.333333 & 0.2 & 1 & 3 & 1 & 0.333333 & 1 \end{pmatrix} \begin{pmatrix} 0.297992 \\ 0.254725 \\ 0.096176 \\ 0.058096 \\ 0.066919 \\ 0.143482 \\ 0.082609 \end{pmatrix}$$

---Eqn (1)

$$= \begin{pmatrix} 2.269612 \\ 1.963606 \\ 0.71216 \\ 0.431129 \\ 0.431129 \\ 1.105283 \\ 0.618096 \end{pmatrix}$$

From equation 1 above the value of Lambda was found as under:

$$\begin{pmatrix} 2.269612 \\ 1.963606 \\ 0.71216 \\ 0.431129 \\ 0.431129 \\ 1.105283 \\ 0.618096 \end{pmatrix} = \lambda \begin{pmatrix} 0.297992 \\ 0.254725 \\ 0.096176 \\ 0.058096 \\ 0.066919 \\ 0.143482 \\ 0.082609 \end{pmatrix}$$

The value of Lambda (λ) found by resolving the matrix above is given as under:

(λ) = 7.396968

To compute the consistency index (C.I.) the following equation (2) was used:

C.I (Consistency Index) = (λ-n) / (n-1) ….Eqn (2)

= 7.396968 – 7 / (7-1)

= 0.396968 / 6

= 0.066161

Equation (3) was used to find the consistency ratio (C.R.)

C.R (consistency ratio) = (C.I) / (R.I) …. Eqn (3)

= 0.066161 / 1.32

= 0.050122

Table 2 shows that for n=7 the value of R.I. is 1.32 and C.R. is less than 10% indicating consistency of judgments in Table 3. Moreover higher value of C.R. means less consistency while a lower value means more consistency.

It is worth mentioning that the decision makers revise the judgments if they are inconsistent and make them consistent. Tables 5-11 present matrices where pair-wise comparison of each type of alternative energy is carried out with different criteria. The C.R. and PVE calculated for each matrix has also been shown on each of the corresponding Table.

Table 5: Energy resources are compared pair-wise to the cost (CT) criterion.

CI=0.01458, RI=0.58, CR=0.025137

	Solar	Wind	Biomass	PVE
Solar	0.083333	0.0625	0.1	**0.081944**
Wind	0.416667	0.3125	0.3	**0.343056**
Biomass	0.5	0.625	0.6	**0.575**

Table 6: Energy resources are compared pair-wise to the Efficiency (EFF) criterion

CI=0, RI=0.58, CR=0

	Solar	Wind	Biomass	PVE
Solar	0.1	0.1	0.1	**0.1**
Wind	0.6	0.6	0.6	**0.6**
Biomass	0.3	0.3	0.3	**0.3**

Table 7: Energy resources are compared pair-wise to the Environmental Impact (EI) criterion.

CI=0.016246, RI=0.58, CR=0.028011

	Solar	Wind	Biomass	PVE
Solar	0.608696	0.631579	0.5	**0.580092**
Wind	0.304348	0.315789	0.428571	**0.34957**
Biomass	0.086957	0.052632	0.071429	**0.070339**

Table 8: Energy resources are compared pair-wise to the Installed Capacity (IC) criterion.

CI = 0.004604, RI = 0.58, CR = 0.007939

	Solar	Wind	Biomass	PVE
Solar	0.166667	0.181818	0.142857	**0.163781**
Wind	0.5	0.545455	0.571429	**0.538961**
Biomass	0.333333	0.272727	0.285714	**0.297258**

Table 9: Energy resources are compared pair-wise to the Estimated Potential (ESPT) criterion.

CI = 0.070664, RI=0.58, CR=0.121834

	Solar	Wind	Biomass	PVE
Solar	0.818182	0.870968	0.692308	**0.793819**
Wind	0.090909	0.096774	0.230769	**0.139484**
Biomass	0.090909	0.032258	0.076923	**0.066697**

Table 10: Energy resources are compared pair-wise to the Reliability (RE) criterion.

CI= 0.001848, RI=0.58, CR=0.003186

	Solar	Wind	Biomass	PVE
Solar	0.111111	0.1	0.117647	**0.109586**
Wind	0.333333	0.3	0.294118	**0.30915**
Biomass	0.555556	0.6	0.588235	**0.581264**

Table 11: Energy resources are compared pair-wise to the Social Acceptance (SA) criterion.

CI = 0.004604, RI=0.58, CR=0.007939

	Solar	Wind	Biomass	PVE
Solar	0.545455	0.571429	0.5	**0.538961**
Wind	0.272727	0.285714	0.333333	**0.297258**
Biomass	0.181818	0.142857	0.166667	**0.163781**

To determine the overall ranking of different alternatives, the weights throughout the hierarchy were aggregated. For calculation of the overall ranking priority, vectors of the alternatives were multiplied with the priority vectors of the criteria. Finally, the overall ranking of three alternative energy resources was determined.

$$\begin{pmatrix} 0.081944 & 0.1 & 0.580092 & 0.163781 & 0.793819 & 0.109586 & 0.538961 \\ 0.343056 & 0.6 & 0.34957 & 0.538961 & 0.139484 & 0.30915 & 0.297258 \\ 0.575 & 0.3 & 0.070339 & 0.297258 & 0.066697 & 0.581264 & 0.163781 \end{pmatrix} \begin{pmatrix} 0.297992 \\ 0.254725 \\ 0.096176 \\ 0.058096 \\ 0.066919 \\ 0.143482 \\ 0.082609 \end{pmatrix}$$

$$= \begin{pmatrix} 0.228566 \\ 0.398243 \\ 0.373192 \end{pmatrix}$$

1) Wind energy = 0.398243
2) Biomass energy = 0.373192
3) Solar energy = 0.228566

The results of this prioritization process show that wind energy has the highest priority (39.82%), followed by biomass energy (37.31 %) while solar energy has the lowest priority (22.85%). Calculating the priority vector for the criteria parameters, the experts gave highest priority to cost (0.2979) whereas efficiency (0.2547) and reliability (0.1434) have been ranked 2nd and 3rd respectively. Other criteria parameters have been given relatively less priority by the experts. Thus, the experts have considered cost, efficiency and reliability as more important parameters while selecting alternative energy resources for Pakistan.

CONCLUSION

Potential for renewable energy resources exists in Pakistan, however, the resources to harness these energy resources are limited. There is a dire need to prioritize these renewable resources in order of importance. The objective of this study was to prioritize various renewable energy resources (RER) for Pakistan, in order of their significance the evaluations of each alternative energy resource were carried out on the basis of multiple criteria and it was concluded that:

- The highest ranked RER for Pakistan is wind (39.82%) followed by biomass (37.32%) and solar (22.86%) as the last ranked
- While prioritizing various criteria, the highest ranked criterion was the cost (29.79%), whereas efficiency (25.47%) and reliability (14.34%) were 2nd and 3rd followed by EI (9.6%), SA (8.2%), EP (6.7%) and IC (5.8%).

Wind energy source was found to be the most significant RER and the best prospect in Pakistan for future. This result is also in line with different initiatives taken both in public and private sectors. The maturity of the wind energy technology and its high growth rate even globally makes it one of the fast-growing energy resources. Keeping in view the current economic conditions of Pakistan, the top ranking of the cost criterion is understandable and rationale.

While wind is still the champion in RER in Pakistan, biomass is catching up fast. There is a gap of only 2.5% between wind (39.8%) and biomass (37.3%), solar is way behind (22.9%) in the list of priorities. This shows that the trend is changing and experts might be considering biomass energy as a close competitor to wind energy. Two main reasons for this changing trend could be the affordable cost and reliability. Also, biomass has the potential of operating as base-load energy sources compared to wind and solar which are intermittent technologies. Government initiatives, such as, "Policy Recommendations for the use of biodiesel as an Alternative Fuel" also justifies the narrowing down of the gap between wind and biomass. Solar energy has been ranked the lowest because power generation from it is costly and the technology is relatively immature.

REFERENCES

Algarín, C.R., A.P. Llanos and A.O. Castro, 2017. An analytic hierarchy process based approach for evaluating renewable energy sources. Int. J. Energ. Econ. Pol., 7(4): 38-47.

Daniel, J., V.R.V. Nandigana, A. Bensely and S. Iniyan, 2008. Evaluation of the significant renewable energy resources in India, using analytical hierarchy process. Proceedings of 19th International Conference on Multiple Criteria Decision Making MCDM for Sustainable Energy and Transportation Systems. Jan.7-12, 2008. New Zealand.

Eddi, W.L. and L. Hang, 2001. Analytic hierarchy process, an approach to determine measures for business performance. Meas. Bus. Perform., 5(3): 30-36.

Elkarmi, F. and I. Mustafa, 1993. Increasing the utilization of solar energy technologies (SET) in Jordan: Analytical hierarchy process. Energ. Policy, 21(9): 978-984.

Gholamnezhad, A.H. and T.L. Saaty, 1982. A desired energy mix for the United States in the year 2000: An analytic hierarchy approach. Int. J. Policy Inform. Syst., 6(1): 47-64.

http://www.cssforum.com.pk/general/news-articles/61571-energy-crisis-important-articles-4.html.

http://www.scribd.com/doc/854630/AHP-Textbook.

http://www.slideshare.net/kashifmateen/pakistan-energy-scenario-a-case-for-renewable-energy.

Mirza, U.K., N. Ahmad and T. Majeed, 2008. An overview of biomass energy utilization in Pakistan. Renew. Sust. Energ. Rev., 12(7): 1988-1996.

Pakistan Energy Yearbook, 2017, HDIP, Islamabad.

Qurashi, M.M., T. Hussain, I. Hayee and F. Saleem, 2009. Policies and strategies for successful implementation of employment-generating programmes in renewable energies, biotechnology, agriculture, environment and ICTs. Proceedings of "COMSATS-COMSTECH National Seminar, 11-12 August, 2009.

Jilani, S., 2007. Municipal solid waste composting and its assessment for reuse in plant production. Pak. J. Bot., 39(1): 271-277.

Rujula, A.A.B. and N.K. Dia, 2010. Application of a multi-criteria analysis for the selection of the most suitable energy source and water desalination system in Mauritania. Energ. Policy, 38(1): 99-115.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. Int. J. Serv. Sci., 1(1): 83-98.

Saaty, T.L., 1980. The Analytic Hierarchy Process, New York: McGraw Hill. International, Translated to Russian, Portuguese, and Chinese, Revised editions, Paperback (1996, 2000), Pittsburgh: RWS Publications.

Sheikh, A.M., 2010. Energy and renewable energy scenario of Pakistan. Renew. Sust. Energ. Rev., 14: 354-363.

Usman, M., U. Ahmad and N. Mehmood, 2015. A review on optimization of Pakistan's alternative energy resources at domestic level. J. Multidiscip. Eng. Sci. Technol., 2(5): 999-1004.

Wang, B., D.F. Kocaoglu and J. Yang, 2009. A decision model for energy resource selection in China. Proceedings of PICMET (Portland International Conference on Management of Engineering & Technology). August 2-6, 2009, Portland, Oregon USA.

www.aedb.org.pk.