4th International Conference on
Energy, Environment and Sustainable Development 2016 (EESD 2016)

Development of AHP Model for Ranking of Cook Stove Technologies for Sindh Province, Pakistan

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Abstract

Pakistan is a developing country and facing energy crises for over a decade. Majority of the country's population is living in rural areas and associated with agro-economy. A large number of these rural communities are without on-grid energy system and even have no means to utilize the locally available resources to meet their energy needs. Renewable energy sources, which are attaining highest ever attention, are considered as most suitable for meeting energy needs of rural communities around the globe. Pakistan's huge renewable energy potential is thus highly regarded as a key to overcome the on-going energy crisis subject to investment in appropriate technologies. Amongst other renewable energy sources, biomass energy can be a vital energy source to meet energy demand of the rural communities. In this study an AHP based decision model has been developed to assess the three alternatives cook stove technologies for Sindh Province. The result of this study lays foundation to carry this work by implementation of development of AHP model.

Keywords: *Biomass, Cookstove, Renewable Energy, AHP, MCDM*

1. Introduction

Pakistan is an agrarian country, having great potential in waste of biomass for energy production. A pressing challenge for Pakistani government is energy crisis, while government is spending additional amount (seven billion dollars per year) on import of fossil fuel. More than 70% of its total population cultivate agriculture, and per capita income is about US$480. Share of agriculture in GDP is 35%. As an increment in population's growth rate, there is huge demand of energy, which is increasing as an average of 24% per year [1]. Inhabitants use biomass, as an energy sources for future. Traditional fuels like crop residues, dung, and fire-wood, showing a vigorous role in meeting the energy demand of low-income urban and rural house-holds in Pakistan. Biomass is one of such resources that could play a considerable role in energy mix. Defining precisely, biomass is a biological material derived from dead or living organisms. It can be used as a source of energy (mostly referred from plants or plant base materials), contributing in both fuel and recycling of waste. As an energy source, biomass can be used directly via combustion to produce heat or indirectly after converting it into different ways of bio-fuel. Technology has its own benefits, depending on the biomass sources and the form of energy needed [2]. Since the beginning of human history, primitives and open fire stoves have been used for cooking and heating purpose. They were having different sizes and shapes, adapted from innumerable culture and food preparation. Due to continuous progress in society, more sophisticated stoves model are introduced. Today's modern kitchens exposes many types of standardized and specialized cooking devices are available, from teapots to toaster and gas cooktops.

But still in many developing countries, the poor burns biomass energy to encounter their household cooking needs. These open fires are fairly inefficient at converting energy into heat for cooking; the amount of biomass fuel needed each year for basic cooking can reach up to 2 tons per family. There is mounting indication that burning biomass inefficiently tends to climate change at regional as well as global level. Suggesting that the climate change debates needs to take house hold energy issues into consideration. About 730 million tons of biomass burned each year in developing countries, and more than 1 billion tons of carbon dioxide emitted out into the atmosphere. These emissions could be controlled with better fuels and more efficient cook stoves. Such problems could be solve by interchanging traditional cook stoves with improved or efficient cook stoves. Generally, the house-holds are dependent on biomass energy [3]. Most of biomass power intake in domestic region is for space heating and cooking and functions. In rural areas biomass strength is consumed in old and inefficient techniques due to which most of the power capability is vanished. The precept belongings of biomass strength for family sector are gas wooden, crop residues and animal dung beside that such things are also used as a manure. Biomass compensates 22% of cooking gas in urban areas while in rural regions it does 92% [4].

2. TYPES OF COOKING STOVES

Cooking stoves are mainly categorized into three categories;

1. Traditional cook stove
2. Efficient/Improved cook stove
3. Biogas cook stove

2.1. Traditional cook Stove

The household rural technology that is currently used for cooking is very archaic and is haphazardly or gained by placing three stones in a triangular position with enough of space in between, to place the twigs and biomass material for burning. Most often, food is cooked on inefficient cooking stoves in closed areas with no ventilation. Use of such technologies emit noxious and hazardous end products. The cooking stoves which is used traditionally, is called traditional cook stoves. These stoves may be built under ground or over ground by placing three stones in U shape. Containers are placed above those stones. TCS are very reasonably-priced and smooth to apply therefore notwithstanding of being inefficient they are broadly universal and may be found in many nations at some stage in the world. Heat transferring to the cooking pot is very low, resulting into low efficiency. Health is affected by using TCS due to the smoke it emits. Occasional current efficiency is maximum up to 20% and 3 stone fireplace stoves are hazardous, having high emissions of CO and particulate matter (Johnson, 2005) [5].

2.2. Efficient/improve cook stove

ECS are made with the assist of contemporary scientific rules for better warmness switch quotes, reduces emissions and advanced efficiency. The intention for the arrangement/improvement of an ICS is to overwhelm the defaults of the TCS using cheap price and the use being simple. Experimentally it is observed that the dangerous emission by way of 40-75% is lessens by ICS, they also growth the efficiency of gas by means of 30% (Johnson, 2005). To get rid of smoke from cooking area, a chimney is connected with ECS. Stoves with chimney emits much less emission and also its price is expanded by the addition of chimney. They decrease down the internal air pollutants and characteristic a healthier combustion. Normally maximum of the ECS are stoves in which the requirement for the gas to be burnt is the air presence and the warmth produced due to that is supplied for cooking. The procedure of ignition in an ICS of gasifier type consist of following steps, initially the fuel is burnt within the presence of air at the bottom a part of range, through which different gases releases that can be burnt again within the existence of air at the pinnacle part of stove.

2.3. Biogas cook stove

In agricultural communities, combustible gas is used as cooking gas which is mainly composed of methane, carbon dioxide, and hydrogen sulphide. It is formed by fermenting animal and human wastes in lack of oxygen (an anaerobic process). Solids residual when the fermentation is complete, are used as organic fertilizer.

Specifically for the low pressure gas flames from digesters or storage holders, the design of Biogas stoves are developed. The biogas stove design must allow specific issues which will occur while burning gas, particularly biogas. For illustration, biogas burns over a narrow range of mixtures containing 9 to 17 percent of biogas within the air. If the burning fire has an excessive amount of gas, the burn is going to be incomplete and poor, giving off toxic carbon monoxide gas and contain plenty of smoke particles.

As compared to the traditional cooking stoves which is an open fire, the design of a biogas stove have substantial health advantages. In biogas stoves cooking is smokeless and this lessens the respiratory and eye infections problems among women and children. The biogas stove is designed in such a way that methane is mixed with double the quantity of air before being burned. In a huge scale, it is not attractive: the usage of biogas on a large scale is not economically viable and it is very difficult to growth the performance of the biogas system.

3. Analytical Hierarchy Process (AHP)

AHP is one of the key branches of Multi criteria decision making (MCDM) where multi criteria are considered and resolved in complex decision making. Figure 1 below shows the different branches of MCDM.

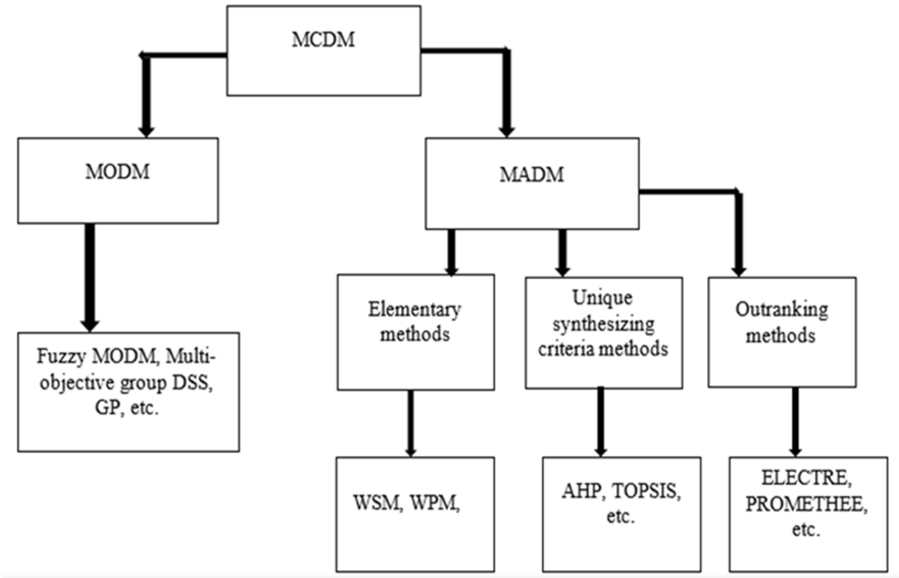

Figure 1: Hierarchy of MCDM Methods

The two main branches of MCDM are Multi Attribute Decision Making (MADM) and Multi Objective Decision Making (MODM).

Analytical Hierarchy Process (AHP) is the sub branch of MADM. The Analytical Hierarchy Process (AHP) was adopted because it is a decision-making tool well suited to multifaceted problems where a basic cost-benefit analysis is simplistic. It is a process that facilitates discussion among the designers and other stakeholders. Furthermore, it generates documentation thus lending transparency to the decision making rationale. The process is based both on mathematics and psychology to provide an overall answer and differs from other decision-making models by encompassing both known and unknown data. The essence of the process is that judgment is used to evaluate the problem as well as factual information and expert opinion. This is particularly useful in the case of evaluating solar collector technologies where the varying scale and prototype nature of some of these systems gives uncertainties when drawing a direct comparison between their operating characteristics [8]. Saaty, who originated AHP in the 1970s, described applications ranging from transportation planning to choose a school for his son [9].

More recently, AHP and other Multi-Criteria Decision-Making (MCDM) methods have been applied to many issues in energy planning, as reviewed by Pohekar and Ramachandran [10], along with other energy selection decisions including the assessment of oil pipeline inspections and energy resource allocation for households [11-13]. AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales. The AHP method evaluates pairwise comparisons, which are used both to compare the alternatives with respect to the various criteria and to estimate criteria weights. The use of pairwise comparisons can allow decision makers to weight coefficients and compare alternatives. It can easily adjust in size to accommodate decision making problems due to its hierarchical structure [15]. In AHP, we decompose a complex problem into a hierarchy with goals (objective) at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. The elements at a given hierarchy level are compared in pairs to show their preference with respect to each of the elements at the next higher level. The AHP is a tool that is being consistently used for the implementation and growth of technology throughout the energy sector [16]. In this sector, it is typical to find a large choice of technologies, surrounded by controversial issues and variations in expert opinion. This makes AHP a particularly valuable tool that can be used to help obtain a consensus. In essence, AHP simplifies a complex decision by decomposing the problem into a hierarchy of ‘criteria’ or sub problems to be analysed individually. To illustrate how the process works, a simple example is first provided based on the selection of a School [17].

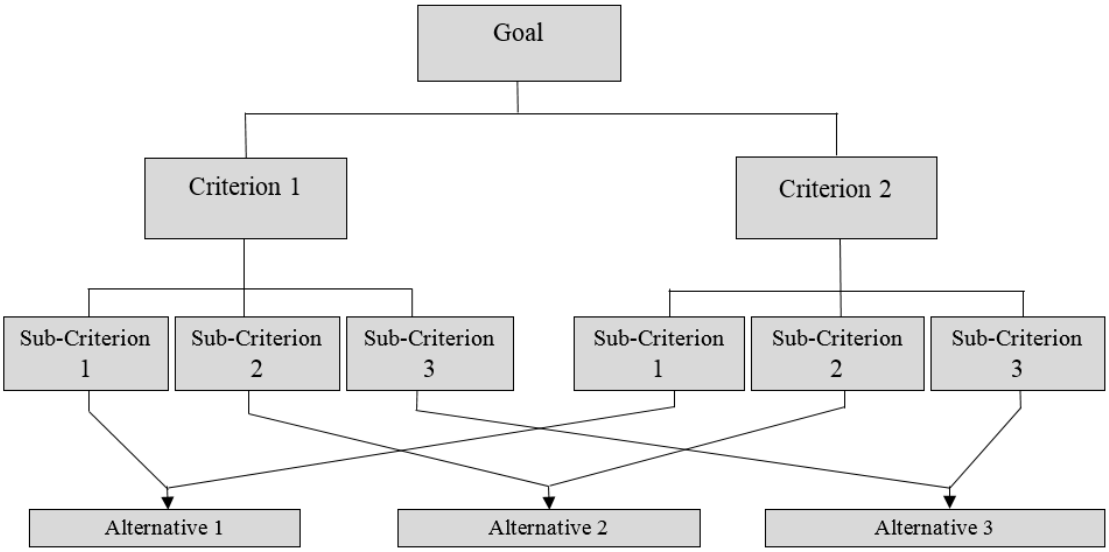

Figure 2: Shows the generalized hierarchy for AHP to achieve a specific goal.

The alternatives are first compared against each criterion through a pair-wise comparison matrix. Using factual data or judgement, each alternative is scored on a scale of 1–9 (1-equal, 9-Extremely more importance) against the other alternatives to show their preference (see Table 1). If an alternative is worse, a reciprocal value is produced, e.g. 1/9. The matrix is then normalized by dividing a cell by its corresponding column total. The average of the row of the normalized table provides a priority vector (i.e. the preference in comparison to the other alternatives) for each alternative for the criterion analysed.

Table 1. Pair-wise comparison scale values of 1-9 will be used to identify the intensity of preference between two elements, as referred by Saaty

Intensity of Importance	Definition
1	Equal Importance
2	Weak or Slight
3	Moderately More Importance
4	Moderate Plus
5	Strongly More Importance
6	Strong Plus
7	Very Strongly More importance
8	Very, Very Strong
9	Extremely More Importance

Important: It may be noted that scale 2, 4, 6 and 8 indicate compromise values of importance i.e. intermediate values between two adjacent judgments.

4. Development of AHP Model for ranking of Cook stoves for Sindh province.

AHP has been applied in various areas such as social sciences, politics, engineering, education sciences, government and manufacturing [21]. Five steps are generally involved in AHP method. Following defining the problem, a decision hierarchy from top-down is designed. Structuring has first the goal, leading to a criteria and further a sub-criteria, which then result in selection of substitutes. The goal of this study is set to determine the best cook stove alternative. Consequently, AHP version for accomplishing this goal has been shown as presented in Figure 5.

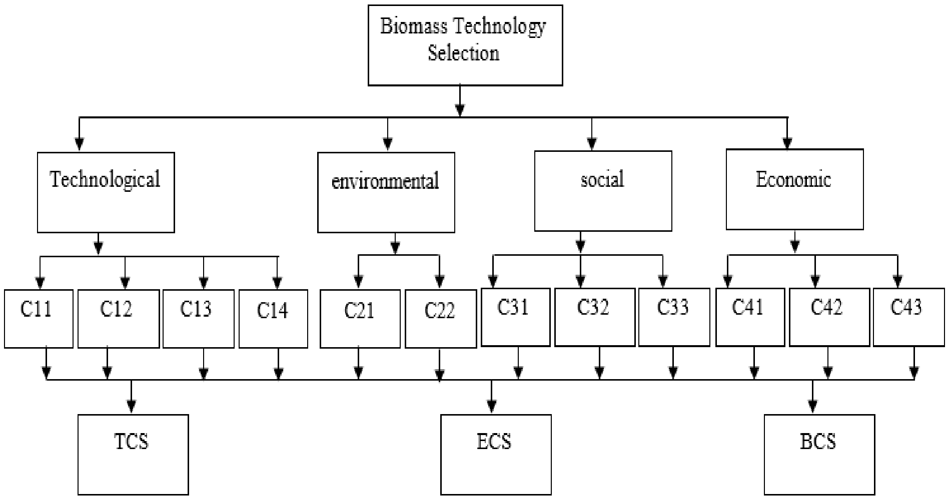

Figure 3: AHP Model for cooking Stove

Based on these criteria and taking into consideration that energy planning is altogether not a simple task, particularly with respect to sustainability concerns, Multi criteria decision making (MCDM) methodology based on Analytical Hierarchy Process (AHP) will be used to evaluate biomass energy alternative for Sindh. AHP method will use to acquire criteria's weights and to rank the best alternatives.

Table 2. Description about Main Criteria and Sub-Criteria

Main Criteria	Sub-Criteria
C1: Technological	C11: Design C12: Repair and Maintenance C13: Efficiency C14: Availability
C2: Environmental	C21: Particulate Matter C22: Other Pollutants
C3: Social	C31: Community Acceptance C32: Convenience of Use C33: Impact on Quality of Life
C4: Economic	C41: Investment Cost C42: Operating and Maintenance cost C43: Affordability

In this research, the implementation of MCDM towards an assessment of alternatives is undertaken. With a view to examine and rank those alternatives i.e. TCS, ECS, BCS and sustainability criteria, four main sustainability criteria are acknowledged from the literature viz. Technological, Environmental, Social and Economic [6,7,14]. Similarly, numerous sub-criteria have been recognized for all of these 4 criteria as indexed in table.

Table 2 lists all criteria, sub criteria taking into consideration in the regard to select the best cook stove. The Main Criteria and Sub-Criteria in this AHP model are listed in the Table 2 which are identified from the literature as well as duly suit the energy and environmental system problem in a developing country like Pakistan [18, 19, 20]. In applying the AHP process, pairwise comparisons are made to determine the importance of one element of the decision problem with another (e.g. main criteria, sub-criteria and alternatives scenarios). A questionnaire will be developed for obtaining the criteria weights and subjective judgments from key position holders in the energy policy making process as well as energy experts in the utilities and academia. Experts shall be asked to make pairwise comparisons of the criteria with respect to the goal and sub-criteria with respect to each criterion. Respondents shall be asked to express their relative judgment of one element versus another on Saatay's 1-9 scale. The aggregate matrices will be developed for the main criteria, sub-criteria and three alternatives by taking out the average of the pairwise comparison matrices that will be obtained from the survey instrument. This has been accomplished by employing a C language program. Subsequently consistency of average matrices and weights of all the criteria, sub-criteria and alternatives have been determined by employing another C language program which are presented in A significantly small consistency ratio (CR) preferably ≤0.1 will be considered as acceptable [8,9]. The detailed flow chart of AHP methodology employed in the C language program is given as under:

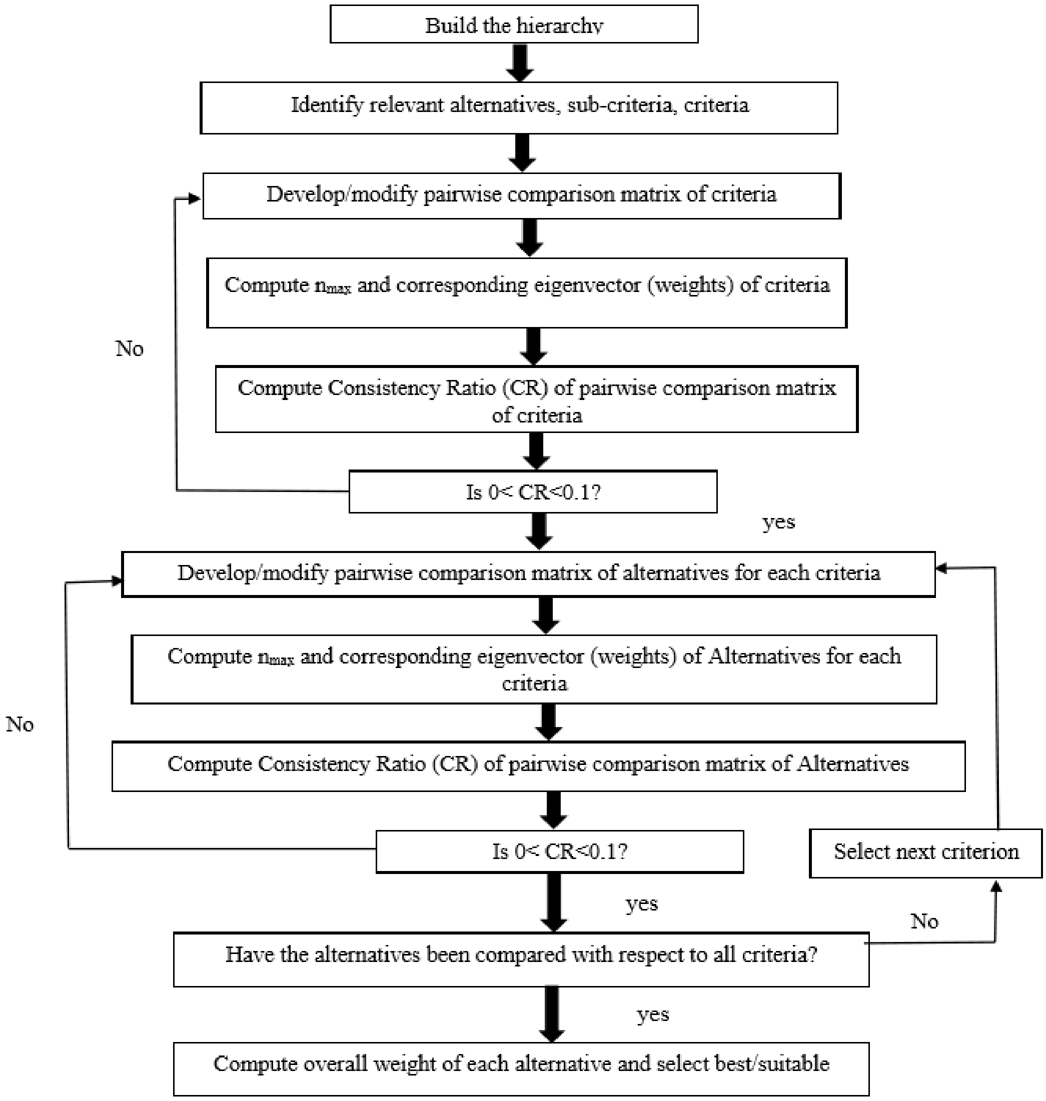

Figure 6: Shows the detailed flow chart of AHP methodology employed in the C language program

Consistency implies coherent judgment on the part of the decision maker regarding the pairwise comparisons. Mathematically, we say that a comparison matrix A is consistent if

$$a_{ij} a_{jk} = a_{ik} \text{ for all i, j and k}$$

To determine whether or not a level of consistency is reasonable, we need to develop a quantifiable measure for the comparison matrix A. A normalized matrix N in which all the columns are identical such as:

$$N = \begin{pmatrix} w_1 & w_1 & \dots & w_1 \\ w_2 & w_2 & \dots & w_2 \\ \vdots & \vdots & \vdots & \vdots \\ w_n & w_n & \dots & w_n \end{pmatrix}$$

And

$$A = \begin{pmatrix} 1 & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_2} \\ \frac{w_2}{w_1} & 1 & \dots & \frac{w_1}{w_2} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_1} & \dots & 1 \end{pmatrix}$$

A is consistent if

$$Aw = nw$$

For case if A is not consistent

$$A\overline{w} = n_{\max}\overline{w}, n_{\max} \geq n$$

The closer n_{max} is to n, the more consistent is the comparison matrix A. on this basis, AHP computes the consistency ratio as,

$$CR = \frac{CI}{RI}$$

CI= consistency index of A

$$= \frac{n_{\max} - n}{n-1}$$

RI = random consistency index of A

$$= \frac{1.98(n-1)}{n}$$

If $CR \leq 0.1$ the level of inconsistency is acceptable. Otherwise, the inconsistency is high and the decision maker may need to re-estimate the element a_{ij} of A realize better consistency.

We compute the value of n_{max} from $A\overline{w} = n_{\max}\overline{w}$ by noting that the ith equation

$$\sum_{t=1}^{n} a_{ij}\overline{w}_t = n_{\max}\overline{w}_t \text{ Where t= 1, 2, … n}$$

Given,

$$\sum_{i=1}^{n} \overline{w}_t = 1, \text{ we get}$$

$$\sum_{i=1}^{n}\left(\sum_{i=1}^{n} a_{ij}\overline{w}_t\right) = n_{\max}\sum_{i=1}^{n}\overline{w}_t = n_{\max}$$

This means that the value of $n_{\max}$ can be determined by first computing the column vector $A\overline{w}$ and then summing the elements.

5. Conclusion

A large number of these rural communities are without on-grid energy system and even have no means to utilize the locally available resources to meet their energy needs. Renewable energy sources, which are attaining highest ever attention, are considered as most suitable for meeting energy needs of rural communities around the globe. Pakistan's huge renewable energy potential is thus highly regarded as a key to overcome the on-going energy crisis subject to investment in appropriate technologies. Amongst other renewable energy sources, biomass energy can be a vital energy source to meet energy demand of the rural communities. In this study an AHP based decision model has been developed to assess the three alternatives cook stove technologies for Sindh Province.

In this article, the AHP based decision model for ranking for three alternative cook stove technologies for Sindh province of Pakistan has been developed. The result of this study lays foundation to carry this work by implementation of development of AHP model.

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