SELECTION AND RANKING OF MULTIFACETED CRITERIA FOR THE PRIORITIZATION OF MOST APPROPRIATE CONVERSION TECHNOLOGY FOR BIOMASS TO BIOFUEL IN INDIAN PERSPECTIVE USING ANALYTIC HIERARCHY PROCESS

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ABSTRACT

In present Indian scenario, global warming, decrement of fossil fuel and other international issues have led to the decision to exploit renewable energy for the sustainable development. One of those Renewable sources is biomass energy which can provide a good quality Energy. Conversion of biomass to energy is undertaken using three main conversion technologies named as Thermo-chemical, Bio-chemical and Chemical. Each type of Biomass Conversion Process has its limitations, and thus choosing the most appropriate amongst them as per the requirement is very important to gain the optimal benefits. To deal with such complex decision making problems, The Analytic Hierarchy Process (AHP) a Multi criteria Decision Model introduced by Thomas Saaty, is an effective tool for dealing such situation .It may support the decision maker to set priorities and make the finest decision. The AHP helps to capture both subjective and objective aspects of a decision by sinking complex decisions to a series of pairwise comparisons and then combine the results. In this methodology selection and ranking of criteria is the most crucial step.

In this research, we have selected and ranked seven multifaceted criteria Technology Maturity, Conversion Efficiency, Availability of Technology Provider, Initial Cost, Operational Cost, Emissions and Land Requirement by using AHP (Super Decision Software) to determine the most appropriate Conversion Technology for Biomass to Biofuel in Indian Perspective.

Keywords: Biomass Energy, Multi criteria Decision Model, Biomass to Biofuel Conversion Technology, AHP, Super Decision Software

I. INTRODUCTION

In India increasing electricity demand had been planned to be met mostly by fossil-fuel based generation while ignoring the native renewable resources. It is clear from the potential of biomass in India that various feed stocks are available for conversion to the bio-fuels as well as for power generation applications. The biofuels produced from the renewable resources could help to minimize the fossil fuel consumption. Biofuels produced from biomass such as plants or organic waste could help to reduce the India's dependence on fossil fuel and it would mitigate global warming. This may due to the CO_2 released in burning equals the CO2 tied up by the plant during photosynthesis and thus does not increase the net CO_2 in the atmosphere [1]. In Indian context, Biomass is mainly obtained from as Agriculture Residue, Animal Excreta, Energy Farming, Sewage Waste, Tannery Waste, Brewery Waste, Slaughter House Waste and food &Vegetable Waste.

Conversion of biomass to Biofuel can be done by means of three main conversion technologies named as thermo-chemical, bio-chemical and Chemical. In Thermo chemical conversion Technology, the biomass is converted in biofuel by the process of combustion, gasification and pyrolysis. In Bio Chemical conversion Technology two main processes are used, fermentation and an-aerobic digestion while in Chemical conversion technology Transesterification Process is used [2].

Each type of Biomass Conversion technology has its advantages and disadvantages. Due to difficulty in selecting the optimal option amongst various Biomass Conversion Technology, a powerful multi-criteria decision analysis model is needed. It is necessary that such a model can analytically break a complex decision problem into smaller but related sub problems; a model that can incorporate qualitative and quantitative information on conversion Technology.

Therefore, Analytical Heirchical Process (AHP) introduced by Thomas Saaty is considered to be an appropriate methodology to be employed for developing the required model. The AHP model formulated in this study consists of three levels. At the top level is the goal of the model followed by the criteria at level two while conversion Technologies are at the Third level, named, alternatives. In this methodology selection and ranking of criteria is the most important step.

In this study seven multifaceted criteria **Technology Maturity** (Reliability of Technology in present time)**, Conversion Efficiency** (Biomass to Energy conversion efficiency)**, Availability (**Number of Available Technology providers)**, Initial Cost (**Initial Installation Cost)**, Operational Cost** (Recurring Cost ,Excluding cost of Biomass)**, Emissions** (Air, Water & Land) in Conversion process and **Land Requirement (**Land Requirement for Plant Setup)are selected from the literature review and discussion with experts from different sectors that are related to the problem. A selection methodology based on **AHP (Super Decision Software)** is used to rank these criteria.

II. VARIOUS METHODS OF CONVERSION TECHNOLOGY FOR BIOMASS TO BIO FUEL

The vast stores of biomass available in India have the potential to displace significant amounts of fuels that are currently derived from fossil fuels. Energy security, energy flexibility, and rural development are other drivers that support the use of biomass to produce fuels, chemicals, and other products. There are various conversion technologies that can convert biomass resources into power, heat, and fuels for potential use. Figure 1 summarizes the various bio energy conversion processes.

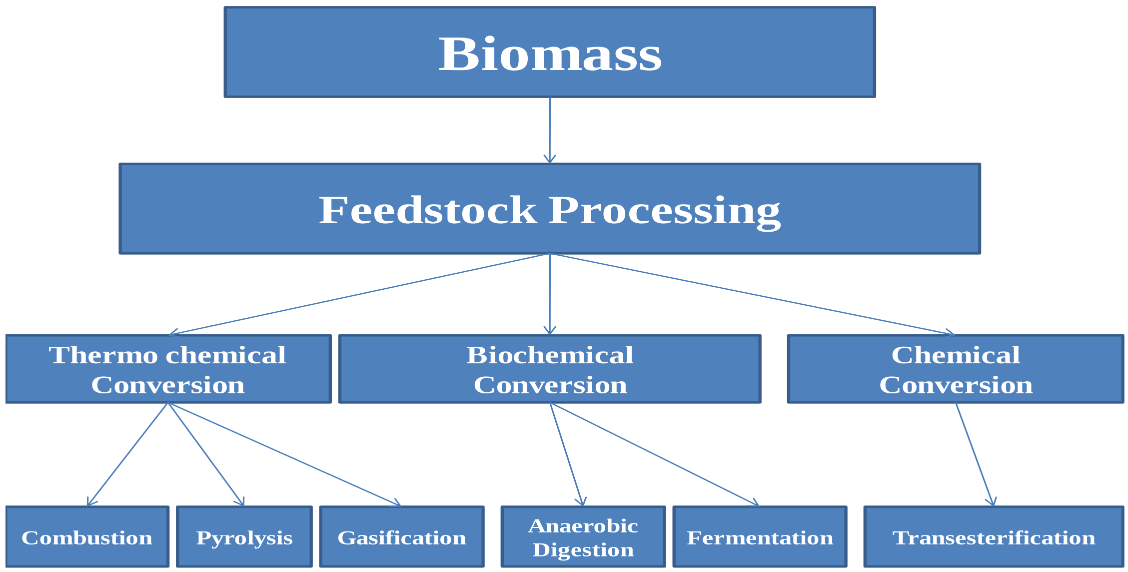

Fig-1: Various methods of Conversion Technology for Biomass to Bio Fuel

As shown in fig-1, Conversion technologies of biomass to Biofuel can be categorized into three main conversion technologies named as thermo-chemical, bio-chemical and Chemical. A Brief discussion of above mentioned Conversion Technologies for Biomass to Biofuel is given below.

2.1. Combustion

The world fuel consumption is continuously increased in past and will strongly increase in the future.Combustion systems for electricity and heat production are similar to most fossil-fuel fired power plants. With the help of this process the chemical energy stored in biomass is converted into heat energy, mechanical power and also in electricity by different process. The biomass fuel is burned in a boiler to produce high-pressure steam. The steam produced is introduced into a steam turbine, which cause causes the turbine blades to rotate. The turbine is connected to an electric generator. It is possible to burn any type of biomass but in practice combustion is reasonable only for biomass with moisture content less than 50%. Biomass with high moisture content is better suited to biological conversion processes [3].This process is a extensively available and viable technology. Combustion boilers are available in diverse designs, depending on relevance and biomass characteristics.

2.2. Gasification

In Gasification Process biomass is converted into a combustible gas mixture by the partial oxidation of biomass at high temperatures. The low calorific value gas produced with this process can be burnt directly or used as a fuel for gas engines and gas turbines. The gases produced by this process can be used as a feed stock for the production of chemicals[4].There are a large number of different biomass feedstock types for use in a gasifier, each with diverse characteristics, including dimension, shape, bulk density, moisture content, energy content, chemical composition, ash fusion characteristics. Feedstock with higher moisture contents result in a lower gasification thermal efficiency, as energy is needed to evaporate the water, with the resulting steam also affecting the gas composition. Ash is the inorganic material (or mineral content) in biomass which cannot be gasified. Besides feedstock moisture and ash properties, the size of the biomass fed into the gasifier can have a large influence on the gasification reaction – the required sizing is mainly a function of feeding rate, residence time, tar production, temperature and gasifier efficiency, which need evaluation for each individual gasifier and feedstock. Preparation of biomass, such as drying and/or sizing is needed to some extent for most combinations of feedstock and gasifier type. Gasification produces almost zero emissions and its non-hazardous by-products (nitrogen, argon, sulphur and slag) are very marketable. Gasification plants use significantly less water than traditional coal-based plants and, using commercially proven tec hnology [5].

2.3. Pyrolysis

Pyrolysis is one of a number of possible paths by which we can convert biomass to higher value products. Pyrolysis of biomass is obtained from primary products like char, gases and vapors. At ambient temperature the vapors condensed into a dark brown viscous liquid. The practice of charcoal manufacture from biomass is generally referred to as a slow pyrolysis process based on the rate in which heat is imparted to the biomass. Whereas under “fast pyrolysis” conditions the product distribution is noticeably altered and shifts the distribution primarily to a liquid bio-oil product. To achieve the high bio-oil yields of fast pyrolysis it is also necessary to prepare the solid biomass feedstock in such a manner that it can facilitate the required heat transfer rates. There are three primary heat transfer mechanisms available in designing reaction vessels: convection, conduction, and radiation. To adequately exploit one or more of these heat transfer mechanisms as applied to biomass fast pyrolysis requirements, it is necessary to have a relatively small particle for introduction to the reaction vessel. This ensures a high surface area per unit volume of particle. Because of small linear dimensions the whole particle achieves the desired temperature in a very short residence time. Preparation of biomass is important for better performance of this process. [6].

2.4. Fermentation

Fermentation processes from any Biomass that contains sugar could derive Bioethanol. The various raw materials used in the production of ethanol via fermentation are suitably classified into three main types of raw materials: sugars, starches, and cellulose materials. Sugars (from sugarcane, sugar beets, molasses, and fruits) can be converted into ethanol directly. Starches (from corn, potatoes, and root crops etc.) must first be hydrolyzed to fermentable sugars by the action of enzymes from malt or molds. Cellulose (from wood, agricultural residues and industrial waste) must similarly be converted into sugars. Once simple sugars are formed, enzymes from microorganisms can voluntarily ferment them to ethanol. The most widely used sugar for ethanol fermentation is molasses which contains about 50 wt. % of sugar and about 50 wt. % of organic and inorganic compounds, including water. Since molasses contains microorganisms which can disturb the fermentation, the molasses is taken initially to the sterilizer and then to the fermenter [7]. Most agricultural biomass containing starch can be used as a potential substrate for the ethanol fermentation by microbial processes.

2.5. Anaerobic Digestion

In Anaerobic digestion (AD) organic material is directly converted to a Biogas which is a mixture of mainly methane and carbon dioxide with small quantities of other gases such as hydrogen sulphide. The biomass is converted in anaerobic environment by bacteria, which produces a gas with energy of about 20–40% of the lower heating value of the feedstock [8]. It is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen to manage waste and/or to produce energy. The digestion process starts with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers and make them available for supplementary bacteria. Then sugars and amino acids are converted into carbon dioxide, hydrogen, ammonia, and organic acids by Acidogenic bacteria .These resulting organic acids are converted into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide with the help of Acetogenic bacteria. As a final point, methanogens convert these products to methane and carbon dioxide.

Anaerobic Digestion is a commercially proven technology and is widely used for treating high moisture content organic wastes, i.e.80-90% moisture. Biogas can be used directly in spark ignition gas engine and gas turbines and can be upgraded to higher quality i.e. natural gas quality, by the removal of CO2. The overall conversion efficiency can be21% [9]. As with any power generation system using an internal combustion engine as the prime mover, waste heat from the engine oil and water-cooling systems and the exhaust could be recovered using a combined heat and power system.

Almost any biomass except lignin (a major component of wood) can be converted to biogas including animal and human wastes, sewage sludge, crop residues, industrial processing byproducts, and landfill material.

2.6 Transesterification

Biodiesel, which refers to fatty acid alkyl esters, has attracted considerable attention as an environmentally friendly alternative fuel for diesel engines. Since the oil produced from biomass resources have high viscosity, it is necessary to reduce the viscosity in order to use them in a common diesel engine. There are various methods used to solve this problem, amongst these methods the transesterification reaction produce the products commonly known as biodiesel. Biodiesel can be synthesized by the transesterification reaction of a triglyceride with a primary alcohol in the presence of catalysts. Amongst primary alcohols, methanol is favored for the transesterification due to its high reactivity and the least expensive alcohol [10]. Furthermore, methanol has a low boiling point, thus excess methanol from the glycerol phase is easily recovered after phase separation. The choice of a catalyst for the transesterification mainly depends on the amount of Free Fatty Acid (FFA) and of raw materials. Biodiesel has several advantages as a renewable, biodegradable, and nontoxic fuel.

III. SELECTION OF MULTIFACETED CRITERIA AND METHODOLOGY

There is a big variety of Multi criteria Decision Making methods, but all have the same goal, to estimate the best alternative among several options, based on predefined criteria. One of possible methods is AHP method, which offers a frame of effective tools in complex decision situations, and helps to simplify and speed up natural process of decision making. AHP method is based on breakdown of a complex situation into simple components, where hierarchical system of the problem and pairwise comparisons are made in order to ensure the quantification of qualitative judgments.

The Selection of multifaceted criterion is very crucial step of this process. Various criteria like **Technology Maturity, Conversion Efficiency, Availability of Technology Provider, Initial Cost, Operational Cost, Emissions and Land Requirement** are selected from the literature review and discussion with experts from different sectors that are related to the problem improves the effectiveness and correctness of the decision as shown in Table no.1.

Table No.1- Multifaceted Criteria and Its Description

Criteria	Description
C1.Maturity	Reliability of Technology in present time
C2.Efficiency	Biomass to Energy conversion efficiency
C3.Availability	Number of Available Technology providers
C4.Initial Cost	Initial Installation Cost
C5.Operational Cost	Recurring Cost (Excluding cost of Biomass)
C6.Emissions	Emissions (Air, Water & Land) in Conversion process
C7.Land Requirement	Land Requirement for Plant Setup

The benefit of the proposed model is that it increases the effectiveness of the decision by allowing participation of different experts. Multiple decision makers are often preferred rather than a single decision maker, to avoid bias and minimize partiality in the decision process. Since decisions made in the energy sector affect all society and sectors, these decisions should not be made by the initiative of one man or through one sector. The criteria will be pairwise compared for importance to establish their priorities with respect to the goal. The Conversion Technologies will be pairwise compared for preference to establish their priorities with respect to each criterion. The results of all these comparisons will be combined to give the best alternative with the highest priority. The goal and criteria are one comparison group with the goal as the parent and the criteria as the children. The criteria will be pairwise compared with respect to the Goal for importance. Each criterion connected to the alternatives forms a comparison group with that criterion as the parent and the alternative as children [11, 12, 13]. The alternatives will be pairwise compared with respect to the criterion for preference as shown in Fig.2 given below.

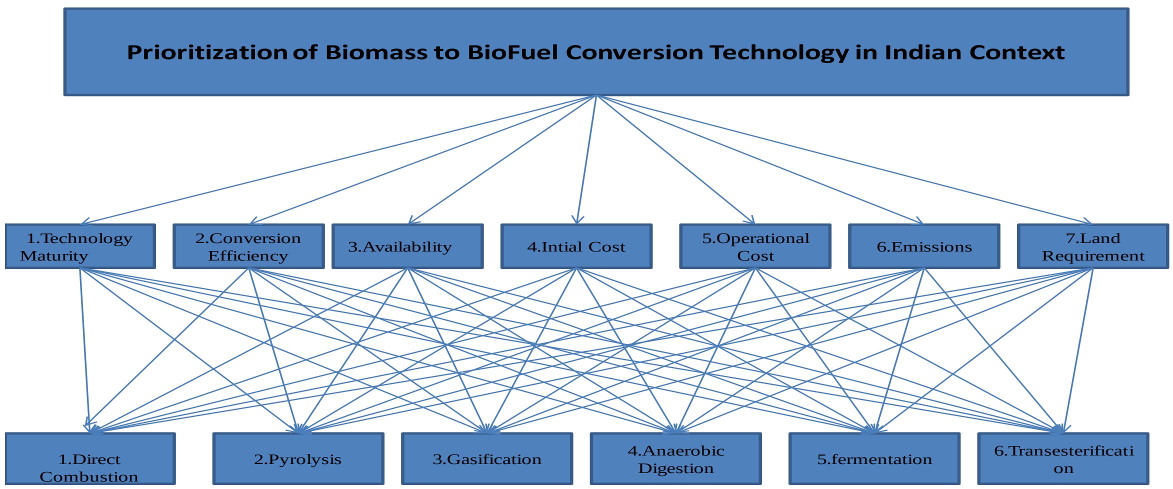

Fig 2: The hierarchy of biomass priority

In this research SuperDecisions software designed by **William J. Adams** is used for the implementation for decision making. It decomposes a problem systematically and incorporates judgments on intangible factors alongside tangible factors. In the SuperDecisions software a decision model is made up of clusters, nodes and links. Clusters are groupings of nodes which are logically related factors of the decision. Connections are made among nodes to establish comparison groups. In a hierarchy the links go only downward: from the goal node to the criterion nodes and from each Criterion node to the alternative nodes. Below is a screenshot of the Biomass Conversion technologies hierarchy as it appears in the software in Fig.3

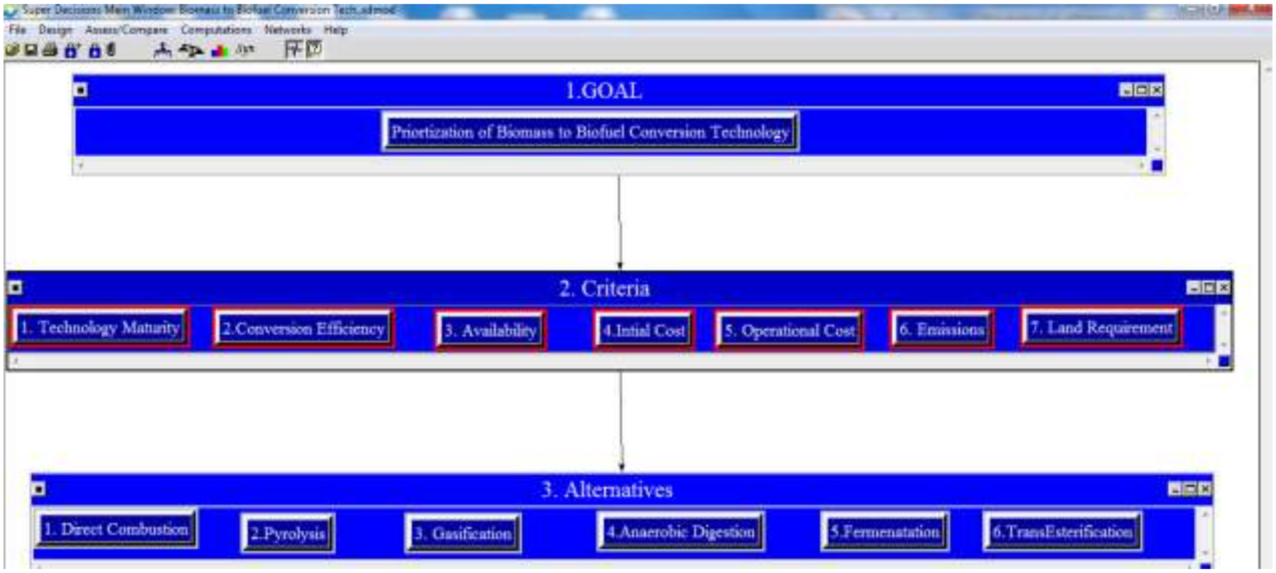

Fig 3: The hierarchy of links in Super Decision Software

The pairwise comparison judgments are made using the Fundamental Scale of the AHP and the judgments are arranged in the pairwise comparison matrix. The pairwise comparison judgments used in the AHP pairwise comparison matrix are defined as shown in the Fundamental Scale of the AHP given by Thomas Satty below in Table 2.

Table .2: The Fundamental Scale of the AHP

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	An activity is favored very strongly over another
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Used to express intermediate values	
Decimals	1.1, 1.2, 1.3, …1.9	For comparing elements that are very close

In AHP, the numbers in the cells in a matrix, by convention, indicate the dominance of the row element over the column element; a cell is named by its position (Row, Column) with the row element first then the column element. While using AHP with the help of Super Decision Software only the judgments in the unshaded area need to be made and entered because the inverse of a judgment automatically entered in its transpose cell. The diagonal elements are always 1, because an element equals itself in importance. If the number of elements is n the number of judgments is *n* (*n*-1)/2 to do the complete set of judgments. As per discussion with experts from different sectors that are related to the problem Intensity of importance are provided for Pairwise Comparison as shown in Table-3.

Table 3: Matrix showing Pairwise Comparison

Goal	1. C1	2. C2	3. C3	4. C4	5. C5	6. C6	7. C7
1.Technology Maturity (C1)	1	1/2	1/3	1/3	1/2	5	3
2.Conversion Efficiency (C2)		1	1/2	1/3	1/2	4	5
3.Availability (C3)			1	3	4	5	4
4.Initial Cost (C4)				1	3	4	3
5.Operational Cost (C5)					1	3	3
6.Emissions (C6)						1	1/3
7. Land Requirement (C7)							1

As per above discussion, in Super Decision software, the rest of the judgments are filled automatically as shown in table-4

Table-4: Complete Matrix showing Pairwise Comparison in Super Decision Software

	1. C1	2.C2	3.C3	4.C4	5.C5	6.C6	7.C7
1. Technology Maturity (C1)	1	0.5	0.333	0.333	0.5	5	3
2.Conversion Efficiency (C2)	2	1	0.5	0.333	0.5	4	5
3. Availability (C3)	3	2	1	3	4	5	4
4.Intial Cost (C4)	3	3	0.333	1	3	4	3
5. Operational Cost (C5)	2	2	0.25	0.333	1	3	3
6. Emissions (C6)	0.2	0.25	0.2	0.25	0.333	1	0.333
7. Land Requirement (C7)	0.333	0.2	0.25	0.333	0.333	3	1

The priorities of an AHP pairwise comparison matrix are obtained by solving for the principal eigenvector of the matrix. The mathematical equation for the principal eigenvector w and principal eigenvalue λmax of a matrix A is given below. Matrices have had more than one eigenvector; the principal eigenvector which is associated with the principal eigenvalue λmax (that is, the largest eigenvalue) of A is the solution vector used for an AHP pairwise comparison matrix. $Aw = \lambda max\ w$. The priorities for the criteria in the goal column, when normalized, are the original priorities derived by pairwise comparison [14].

IV.RESULTS AND DISCUSSION

As per literature review and discussion with experts from different sectors that are related to the problem seven multifaceted criteria **Technology Maturity** (Reliability of Technology in present time)**, Conversion Efficiency** (Biomass to Energy conversion efficiency)**, Availability (**Number of Available Technology providers)**, Initial Cost (**Initial Installation Cost)**, Operational Cost** (Recurring Cost ,Excluding cost of Biomass)**, Emissions** (Air, Water & Land) in Conversion process and **Land Requirement (**Land Requirement for Plant Setup) are selected.

A selection methodology based on AHP (Super Decision Software) is used to rank these criteria. This methodology involves a procedure for the aggregation of expert opinion using the seven selection criteria related to conversion Technology of Biomass to Biofuel ,that are appropriate for India.

Experts involved in the assessment found that the **Availability of Technology providers** is the most important criteria having the priority of **0.3213,** followed by **Initial Cost** , **Conversion Efficiency and Operational Cost, with** the priorities of **0.2242, 0.1352 and 0.1323** respectively. While other criteria **Technology Maturity, Land Requirement and Emissions** have lower scores **0.0974, 0.0542 and 0.0351** respectively. The Results above mentioned is shown below in the screenshot from super decision software in Fig.4.

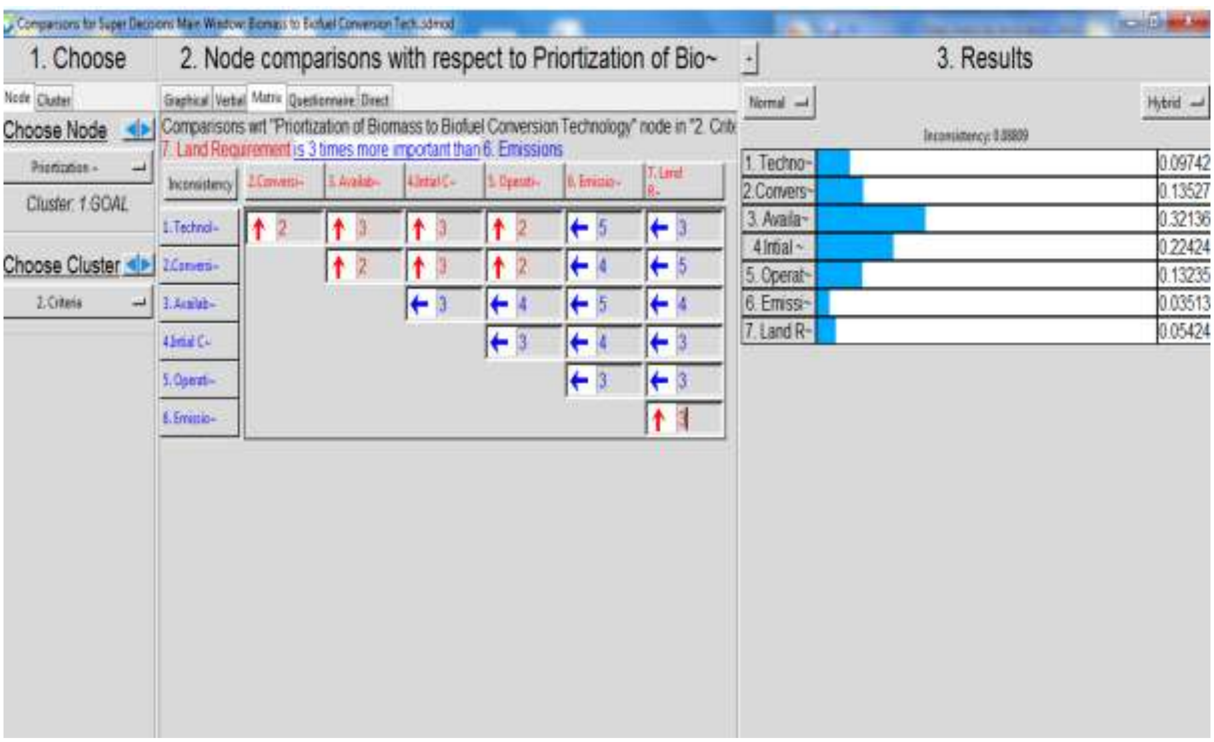

Fig.4: The screenshot from super decision software showing priorities.

The results of the above decision can also be shown as below in Table 5.

Table 5: Priorities of Different Criteria

Inconsistency	0.08809	
Name	Normalized	Idealized
1. Technology Maturity	0.097417579	0.303139053
2.Conversion Efficiency	0.135267202	0.420917581
3. Availability	0.32136268	1
4.Intial Cost	0.224239283	0.697776366
5. Operational Cost	0.1323508	0.411842471
6. Emissions	0.035127162	0.10930691
7. Land Requirement	0.054235294	0.168766621

It is very clear from the above results that the criteria related to **Availability of Technology Provider** is more important than any other criteria followed by **Initial Cost** , **Conversion Efficiency and Operational Cost** . While **Technology Maturity, Land Requirement and Emissions** are given least Priority. The benefit of the proposed model is that it increases the effectiveness of the decision by allowing participation of different experts. Since decisions made in the energy sector affect all society and sectors, these decisions should not be made by the initiative of individual or through one sector.

V. CONCLUSION

It is predictable that electricity demand in India is going to rise in future. To develop a sustainable electricity generation system country has to incorporate renewable resources for electricity generation. Sustainable development balances the energy production and consumption with minimal negative impact on the environment Renewable energy systems as a part of sustainable development bring environmental, energetic and economic benefits such as reduction of GHG, reliable energy supply ,economic saving by using natural resources and wastes as feedstock. Production of biofuels from organic material is one of the alternative renewable energy systems. Biofuels can be produced and converted to energy in different kinds of conversion plants with different scales that use various conversion technologies. Biofuels can be used for generating centralized as well as decentralized heat, electricity and energy [15].

In this study, an overview of various Conversion Technologies of Biomass to Biofuel in Indian Context is given. It was found that there are sufficient conversion Technologies are available but each option has its own limitations. In this type of situation Multi criteria Decision Making (MCDM) methodologies increasingly popular in decision making for sustainable energy systems because of their ability to integrate the multi-criteria and complex nature of these systems. One of possible methods is AHP method, which offers a frame of effective tools in complex decision situations, and helps to simplify and speed up natural process of decision making. In AHP method Selection and ranking of Criteria is most critical and important step.

In this study Selection and ranking of Criteria for Prioritizing Conversion Technology of Biomass to Biofuel in Indian Context has been done. The criteria identified are such that a holistic evaluation of a particular Conversion Technology is provided to a decision-maker. An AHP (Super Decision Software) model is developed to meet out the purpose..

The model framework consisted selection and ranking of criteria and on which each Conversion Technologies of Biomass to Biofuel was appraised. The study classified these criteria as **Technology Maturity, Conversion Efficiency, Availability of Technology Provider, Initial Cost, Operational Cost, Emissions and Land Requirement**. The Priorities of Biomass to Biofuel are shown below in **screenshot from super decision software in fig-5.**

The model results showed criteria related to **Availability of Technology Provider** is most important than any other criteria followed by **Initial Cost**, **Conversion Efficiency and Operational Cost**. While **Technology Maturity, Land Requirement and Emissions** are given least Priority. The emphasis on these criteria demonstrates that availability of Technology provider,financial and Conversion efficiency are vital in Biomass to Biofuel Conversion in Indian Scenario.

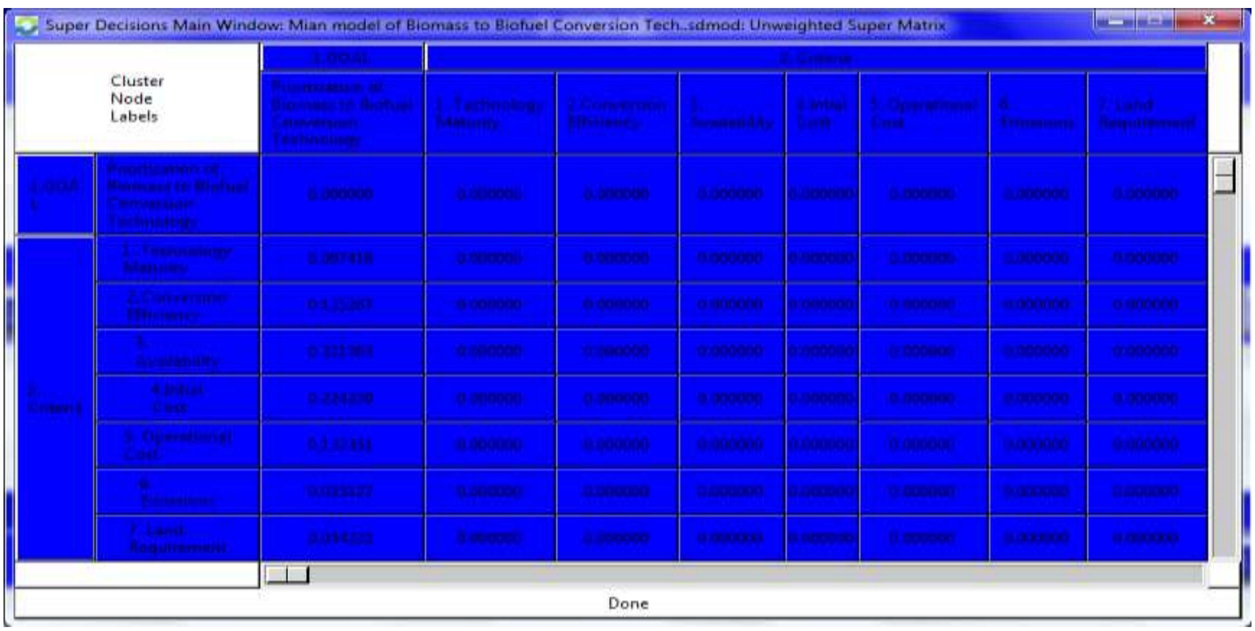

Fig.5: The screenshot from super decision software showing priorities in unweigthed Matrix

It should be noted that the model's application is country-specific, since the strategic criteria depend on the countries specific Biomass energy characteristics and development needs. In terms of Biomass Energy Planning, the ranking of Criteria involved in this study is useful to Energy Planners in determining investment priorities in the field of Biomass Energy. The method used and the results obtained from this study can be used in the further research.

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