Journal of Research Administration
Society of Research Administrators International

ANALYTIC HIERARCHY PROCESS TO DETERMINE OPTIMAL RENEWABLE ENERGY SOURCES FOR INDIA'S POWER SECTOR

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Abstract

Traditional energy generation sources like coal are reducing very drastically, so the unconventional renewable sources like wind, solar or hydro are the need of the hour. This chapter provides an analytical hierarchy to select green energy sources in India. Four alternatives – solar, wind, biomass, and hydro-power have been assessed on the basis of technical, economical, environmental and social impact. On technical grounds, generation capacity, availability, capacity and efficiency have been evaluated. In case of environment, particulate matter (PM), carbon emission (CO_2) and land requirements has been analyzed. Under social category job creation and compensation rate have been considered. Economical parameters are operational life, capital cost, construction time, fixed operational & maintenance cost and fuel cost. The weights of priority and preferential classification of the criteria and sub-criteria have been calculated by pair-wise comparisons. The results show that bio-mass energy is the preferable alternative under technical and social category while wind may be the choice when evaluated on environmental and economical grounds. Solar is also comparable on economical basis but overall priority consign to biomass followed by hydro-power, wind energy and solar energy.

1. Introduction

Renewable Energy (RE) options have sparked increased interest in both developed and developing countries in recent years; in developed countries for renewable energy sources, and in developing countries to satisfy the energy demand. Renewable energy sources are essential for an energy-scarce country's long-term economic growth, ensuring that various sectors' economic development efforts are not hampered by energy scarcity. Even after more than 50 years of independence, India's remote rural areas have been unable to expand. India's electricity demand is rising in order to meet the country's current economic growth plans. The supply of growing amounts of energy is a necessary condition for a country's economic development [1]. Globally, the rapid decline of fossil fuel supplies has necessitated an intense hunt for renewable energy sources to meet today's demand [2]. Fossil fuels are reliable sources of energy, but they are not long-term solutions. In addition to the immediate harm they cause, such as fine dust emissions from burning oil and mercury contamination from coal combustion, these have long-term and permanent consequences for the environment. India is responsible for about 6.65% of overall global carbon emissions, ranking fourth behind China (26.83%), the United States (14.36%), and the European Union (9.66 %) [3]. India imported 195 million tons in 2016–2017, and 213 million tons in 2017–2018, according to a survey from the Center for Monitoring Indian Economy [4]. As a result, finding alternative sources of power generation is critical. There are lot of obstacles to overcome in the creation of energy solutions to fossil fuels [5]. Renewable energy sources are critical for ensuring long-term energy security and lower emissions [6]. By 2022, India hopes to provide 175 GW of clean energy, with 100 GW coming from solar energy, 10 GW from bio-power, 60 GW from wind power, and 5 GW from small hydropower projects [7]. There are many options open, including nuclear, biomass, solar, wind, and hydroelectric. It's not easy to forecast which energy options would be the most effective in the long run, as well as which ones should be invested in and how much should be invested. In addition, many factors influence the growth of energy alternatives, including geography, economy, social demands, and politics. An energy source that is ideal for one city could be the wrong option for another. The selection of energy alternatives is influenced by a number of factors, including cost and protection. It is necessary to examine which parameters to be used in the decision-making process when comparing energy options, as well as how to weigh various criteria. This research uses the analytic hierarchy method (AHP) to analyze energy choices and establish a structured methodology and decision support mechanism to assist municipalities in selecting the best options.

2. Renewable Energy in India

India is the world's third-largest energy producer and user. As of March 31, 2021, India's national electric grid has an installed capacity of 382.15 GW [14]. Also India's grid-connected power generation capacity from conventional renewable power or large hydroelectric power stations was from 45.70 GW and from non-conventional renewable technology was estimated to be around 87.02 GW [15,17]. Bids are being sought for the construction of another 115 GW, bringing the overall installed capacity of non-conventional renewable electricity to 175 GW by March 31, 2022. The Indian renewable energy industry is the world's fourth most lucrative renewable energy market. As of 2019, India was ranked fifth in wind energy, fifth in solar energy, and fourth in clean energy installed capability [18]. In every sector of the Indian economy, energy is required for growth. Therefore, India must rapidly adapt to the current and most promising clean energy technology, as well as the use of energy-efficient technologies.

2.1 Solar Energy

India has a large population and abundant solar energy, making it an excellent location for solar power. India has an abundance of solar energy resources. Over India's land mass, solar radiation of around 5,000 trillion kWh per year is incident. The installed capacity was 33.73 GW as of December 31, 2019, accounting for 2% of utility electricity generation [19]. In November 2020, the selling price of solar photovoltaic power dropped to Rs.2.00 per kWh, which is lower than any other form of power generation in India. In India, land acquisition is a problem for solar farm projects. Some state governments are experimenting with new approaches to fix land scarcity, such as installing solar panels over irrigation canals [20]. This permits solar energy to be collected while reducing irrigation water depletion due to solar evaporation. One of the main drawbacks of solar energy is that it only generates electricity during daylight hours, not at night or on cloudy days. Grid storage will help to overcome this downside.

2.2 Wind Power

Wind energy has become the country's fastest-growing clean energy source. Wind power development in India began in December 1952, when a renowned power engineer, Maneklal Sankalchand Thacker, launched a project with the Indian Council of Scientific and Industrial Research (CSIR) to investigate the possibility of harnessing wind power in the region. [21]. The gross installed wind power capacity was 38.789 GW as of February 28, 2021, making it the world's fourth highest installed wind power capacity. In March 2021, the levelised tariff was RS.2.77 per kWh [22]. In the fiscal year 2018–19, wind power produced 62.03 TWh, or nearly 4% of overall electricity production, accounting for nearly 10% of India's total installed power generation capability.

2.3 Biomass

Given the benefits it provides, biomass has always been a significant energy source for the world. It is sustainable, readily available, carbon-neutral, and has the ability to generate substantial rural jobs. For rural villages and urban clusters of decentralized settlements, biomass is very significant in the Indian energy matrix. Around 32% of the country's overall primary energy consumption also derives from biomass and over 70% of its population relies on biomass for its energy requirements. Biomass currently available in India is measured at about 500 million tons per year. Biomass power/co-generation policy has been implemented by the Ministry since middle 1990. There have been over 500 biomass power and biogases cogeneration projects for power supply to the grid in the country with a total capacity of 9806MW [23].

2.4 Hydropower

Hydropower schemes are divided into two categories depending on their size: big and small hydropower. Small hydro power plants with a capacity of 25MW or less are rated as small hydro in India. India has the fifth-largest installed hydroelectric power capacity in the world. India's installed utility-scale hydroelectric capacity was 46,000 MW as of March 31, 2020, accounting for 12.3% of the country's total utility power generation capacity. India produced 156 TWh (excluding small hydro) of hydroelectric power in fiscal year 2019–20, with an average capacity factor of 38.71 percent. The Ministry of New and Renewable Energies (MNRE) is concerned for small hydropower. 92.5 percent of India's hydroelectric power is generated by the government sector. According to the International Hydropower Association, India's gross hydropower capacity is 660,000 GWh/year, with 540,000 GWh/year (79%) remaining undeveloped. India ranks fourth in the world in terms of undeveloped hydropower capacity, behind only Russia, China, and Canada, and fifth in terms of overall potential, trailing only Brazil [24].

3. Analytic Hierarchy Process (AHP)

The AHP is a calculation methodology that uses expert experience to conduct pairwise analyses of decision parameters and rank decision alternatives. Consistency review in the AHP detects discrepancies in expert feedback; incorrect expert input is omitted from the judgment issue study to guarantee the authenticity of expert information. The AHP allows professionals to fine-tune their judgment in a reaffirmation mechanism, allowing for impartial decision-making. After its inception in the 1980s, the AHP has been used in a variety of decision-making applications [8]. Many researchers have concentrated on using the AHP to plan renewable energy systems [9-12]. This methodology's main stages are as follows [13]:

Step-1: Create a hierarchy of levels for the decision challenge, with the target at the top, followed by requirements, sub-criteria, and alternatives at the bottom.

Step-2: By assigning a numerical value to each variable at the appropriate stage, pairwise comparisons may be performed.

Step-3: To get preference weights for each criteria/alternative, determine the maximal eigenvalue, consistency index (CI), consistency ratio (CR), and normalized eigenvector for each reference matrix.

Step-4: To generate an aggregate priority score for alternatives, combine the decisions at different levels of hierarchy.

Table 1 Scale's explanation for pair-wise comparisons.

Importance Rating	Definition	Explanation
1	Equal Importance	Two actions are equally important.
3	Moderate Importance	An activity has a marginal advantage over another.
5	Strong Importance	An activity has a strong advantage over another.
7	Very strong Importance	An action is highly favoured over another, and its superiority is reflected in practice.
9	Extreme Importance	The data that supports one activity above another is of the highest quality.
2,4.6.8	Intermediate	Middle state between two actions

3.1 Criteria and Sub-Criteria

A preliminary list of fourteen sub criteria, divided into four categories: technical, economic, social and environmental is compiled.

3.1.1 Technical –This criteria determines the technological importance of the renewable energy to be used with the scope of the subsequent following four sub-criteria as:

- Generation Capacity- The term "generation" refers to the amount of electricity generated over a period of time. The majority of electric power plants use some of the energy they generate to run the facility.
- Availability- The availability of a power plant is described as the number of hours it will generate electricity in a given period divided by the number of hours in the period. A power plant may be out of operation for a variety of reasons, including maintenance or upgrades, as well as environmental conditions such as short of sunlight or wind. The availability of a plant is influenced by the nature of the machinery, its maintenance, the type of fuel used, the plant's configuration, and how it is run.
- Capacity- A power plant's capacity is the quantity of electricity it produces during a given time span divided by the quantity of electricity it might have generated if it had operated at full ability during that time. The type of fuel used and the configuration of the plant have a significant impact on capacity.
- Efficiency-. The amount of usable energy we can get from a given energy source is referred to as efficiency. The efficiency coefficient is the ratio of output energy to input energy calculated as a percentage. Efficiency improvements that are associated with high plant stability and low power costs are commonly considered to be economically advantageous. There is no unit that is fully energy efficient. Heat is the most common source of wasted energy, which dissipates into the air and cannot be recovered economically.

3.1.2 Economical – This criteria takes into account economic requirements provide for the integration of project gains and costs, as determined by the scope defined in the following sub criteria as:

- Operational Life- The operational life of a device refers to the amount of time that the equipment will be used according to the manufacturer's requirements. The incremental transition in the properties of materials over long periods of time is a well-known phenomenon. Engineered materials, processes, and designs can be impacted by these improvements in their ability to execute their intended purpose. Not all modifications are harmful, but it is common knowledge that the aging process results in a steady loss of output capabilities.
- Construction Time- The capital cost of a power plant, which is based on the plant's construction time, has a significant impact on the cost of electricity produced. Construction time is determined by a number of factors, including plant size,

technology, the start date of construction, and the administrative arrangement surrounding contractors, services, and licensing bodies.

- Capital Cost- The cost of property, the cost of required structures, and the cost of all necessary machinery for the plant's construction are all included in capital costs. Capital expenses do not include labor costs or plant repair costs.
- Fixed O & M cost- Employee benefits, as well as funds expended on electricity, goods, and utilities for the power plant's operation, are included in operational costs. Maintenance is needed in the event of faults that could result in the suspension of operations. Repair costs are smaller than the harm caused by a power plant malfunction, and it improves the plant's credibility and trust index.
- Fuel Cost- Fuel costs apply to the money invested on obtaining the raw materials used to run a power plant. Extraction or mining of gasoline, storage, and potential fuel production for use in a power plant are all possible fuel costs. These also take into account the cost of disposing of any waste produced as a result of its use. Fuel prices can vary significantly across time periods and areas due to a variety of factors, including demand, supply, and policy considerations.

3.1.3 Social- These standards take into account the number of local jobs provided in rural communities for the construction, maintenance, and repair of renewable systems, as well as the renewable system that is installed on their properties.

- Job Creation- During the construction, maintenance, and decommissioning of power plants, a large number of workers are employed. For several decades, the growth and prosperity of local societies where plants were developed was dependent on them.
- Compensation Rates/External Cost- Power plants can no longer emit toxic gases, ruin spectacular habitats, be intrusive, or have any other negative impact on people's lives without being compensated. Compensation thresholds are designed to help people regain their lost quality of life. Compensation prices apply to remuneration paid to members of the local population who have been personally impacted by the construction and operation of power plants. The cost or value that is not reflected in the selling price of a product because it is not included in the production price or demand price is known as an external cost. This term is most often applied to harmful environmental externalities such as air pollution, which harms human health, crops, or materials although the polluter does not bear any direct or indirect consequences.

3.1.4 Environment- The environmental standards take into account the effect of the project's implementation of renewable energy on the atmosphere, as measured by gas emissions and land and water resource requirements.

- Particulate Meter (PM)- Particulate matter is the total amount of particles floating in the air, all of which are dangerous. Dust, smoke, spores and fluid droplets are all part of this diverse combination of organic and inorganic particles. Scale, structure, and origin of these particles are all different. PM contains microscopic solids or droplets that can be inhaled, resulting in major health issues. Since particles smaller than 10 micrometers in diameter will penetrate deep into the lungs and even enter the bloodstream, they pose the greatest health risk.

- CO_2 Emission- Carbon dioxide (CO_2) is a colorless, odorless, and non-poisonous gas that is produced by the combustion of carbon and in the respiration of living organisms. It is a greenhouse gas. Emissions are defined as the release of greenhouse gases and/or precursors into the atmosphere over a defined area and time period. One of the worst greenhouse gas contributors is CO2. So, renewable energies' potential to reduce CO_2 emissions is important factor in their selection.
- Land requirement- The amount of land needed by each power plant is a major consideration in their assessment. Land is important, particularly near urban areas where power plants are located. Buildings' optical interference and noise from power plant facilities are impossible to quantify financially, but they both have a detrimental impact on life quality.

Table 2: Data for Technical group [14, 15, 16, 25, 26]

Renewable Energy Sources	Generation Capacity (MW) as on 30 sep. 2020	Avalability (%)	Capacity (%)	Efficiency %
Solar	36,050.74 (40.4%)	20	22.4	9.5
Wind	38,124.15 (42.7%)	38	32.1	35
Hydropower	4,739.97 (5.3%)	50	29.6	80
Biomass	10,145.92 (11.4%)	80	70.0	25-40

Table 3: Data for Environment group [16, 25, 26]

Renewable Energy Sources	Particulate Matter (PM) mg/kwh	Emission, g-CO2/kWh	Land Requirement (km2/1000 MW)
Solar	101	53.4-250	35
Wind	20	9.7-123.7	100
Hydropower	5	3.7-237	750
Biomass	269	35-178	5000

Table 4: Data for Social Group [16, 25, 26]

Renewable Energy Sources	Jobs Creation (employees/500 MW)	Compensation Rates/External Cost (eurocents/kwH)
Solar	5370	0.24
Wind	5635	0.16
Hydropower	2500	0.56
Biomass	36055	2.65

Table 5: Data for Economical Group [16, 25, 26]

Renewable Energy Sources	Operational Life (years)	Construction Time (years)	Capital Cost (euro/kW)	Fixed O&M Cost (Euro/kwh yr)	Fuel Cost (eurocents/kWh)
Solar	30	1	4167	16.67	0
Wind	40	1	1250	25	0
Hydropower	40-50	2-8	2417	72.5	0
Biomass	20-25	2	1667	60.83	2.05

Table 6: Pair wise comparison of categories and sub categories for renewable energy source power plants

Category	**Technical**				**Environmental**			**Social**		**Economical**					
Priority Weights	**0.549**				**0.3**			**0.054**		**0.097**					
Renewable Energy Sources	**GC1**	**Availability**	**Capacity**	**Efficiency**	**PM2**	**Emission g-CO2**	**LR3**	**JC4**	**CR5**	**OL6**	**CT7**	**Capital Cost**	**Fixed O&M Cost**	**Fuel Cost**	**Priorities**
Solar	0.022	0.012	0.001	0.004	0.005	0.014	0.013	0.005	0.001	0.005	0.0013	0.0003	0.018	0.008	0.108
Wind	0.031	0.032	0.003	0.015	0.020	0.117	0.005	0.007	0.000	0.011	0.0013	0.0039	0.007	0.008	0.260
Hydro power	0.002	0.096	0.002	0.078	0.039	0.024	0.002	0.002	0.001	0.017	0.0001	0.0008	0.001	0.008	0.273
Biomass	0.0	0.210	0.014	0.022	0.0	0.059	0.0	0.0	0.0	0.0	0.0004	0.0024	0.002	0.0	0.359

	05				02		01	34	05	02				01	
Total	0.060	0.350	0.019	0.120	0.066	0.214	0.020	0.047	0.007	0.034	0.0032	0.0074	0.028	0.025	1.000
	1.000														

[1]Generation Capacity [4]Jobs Creation
[7]Construction Time
[2]Perticulate Matter [5]Compensation Rate
[3]Land Requirement [6]Operational Life

4. Results and Discussions

This work proposes a method to make suitable choice for renewable energy source for energy generation in India. For this, the taken energy sources has been grouped in four main groups, and further divided in fourteen sub groups. Table 2-5, represent technical, environmental, social and economical data respectively. Based on the available data, pair-wise comparison has been done by using 9 point scale as Table 1, where 9 signify most important and 1 signifies equally important. From Table 6, technical category is having most important criterion with weight 0.549 followed by environmental, economical and social with weights 0.3, 0.097 and 0.054 respectively.

From Table 6, within technical group, availability is significant sub-criterion followed by efficiency, generation capacity and capacity. Within environment group, carbon emission is most important sub-criterion comes after particulate matter and land requirements. From the perspective of a social group, job creation is prior than compensation rate. From Economical group, operational life is imperative sub-criterion, whereas construction time, fixed operational and maintenance cost, fuel cost and construction time are at trailing end.

Table 6 presents that biomass is the best renewable energy source with priority weight 0.359, followed by hydro-energy, wind energy and solar energy with priority weights 0.273, 0.260 and 0.108 respectively.

5. Conclusion

Increasing energy demands force the energy producers to think of alternative energy generation sources because the conventional energy sources are very limited. Renewable energy sources are the obvious choice but there is lot of constraints like availability, capital cost, capacity, efficiency etc. AHP technique is used to figure out better alternative source based on priority. Selection criterion is based on the data available in literature. Hence it can be concluded that bio-mass energy is the preferable alternative on overall basis followed by hydro-power, wind energy and solar energy.

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