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Assessment of Appropriate Renewable Energy Resources for India using Entropy and WASPAS Techniques

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Abstract
Energy, a necessary component of the invention, has negative externalities on the health of humans and the environment due to its production and use, which hinders national growth. For this reason, countries should act with two main motivations when choosing energy sources. The first should be economic development by considering the increase in production and efficiency supplied by the source of energy, and the second should be to choose energy resources that will promote the welfare of the people. In this work, conventional and renewable energy sources for the long-term growth of India's energy sector are assessed from a variety of viewpoints including technical, economic, environmental, and social criteria. In the choice model, the thermal, solar, wind, biomass, and hydro-energy options are employed as alternatives. In this study, suitable energy sources are selected for India with the help of the entropy method and the WASPAS (Weighted Aggregated Sum Product Assessment) method, and the relevance of environmental, technical, social, and economic aspects of renewable sources of energy is assessed, and in the second step, a proposal is made about which renewable energy source can be suitable to meet the energy requirement in India through the WASPAS technique. From the results obtained from the WASPAS method, it is found that the renewable energy resources suitable for investment in India are hydro, geothermal, wind, biomass, and solar energy, respectively.

Keywords: *Multi-criteria decision-making, Shannon's Entropy, Renewable energy Assessment, Normalization, WASPAS Techniques.*

1. Introduction

Renewable energy is derived from non-depleting sources that are regenerated on a human timeline. Solar, biomass, wind, hydro-power, and geothermal are some of the most prevalent instances. Non-renewable resources such as petroleum, fossil fuels, coal, nuclear power, and natural gas are not renewable. The sun provides most of the renewable energy, either directly or indirectly. When the sun heats the Earth's surface unevenly, the wind is formed, and the energy is captured by turbines. Light is essential for plants to survive, and the energy they store may be utilized to produce energy from biomass. The Earth's core heat is used in geo-thermal energy; tidal energy is based on the moon's gravitational pull, and hydro-power is based on the stream of water. Renewable energy sources, on the other hand, are good for the environment, and produce fewer emissions than conventional fossil fuels; several of these source materials face technical challenges, intermittent issues that make them difficult to implement on a wide level, and large start-up capital costs. Environmental issues induced by using fossil fuels may be mitigated by using renewable energy with the lowest environmental impacts. Solid hazardous wastes such as heavy metals and other contaminants are generated by petroleum exploration and coal mining and purification. When coal is used to generate electricity, it emits arsenic and carries nitrogen oxides, carbon dioxide, sulfur dioxide, and mercury into the atmosphere along surface waterways, causing ozone layer gas and other gases. Petro-chemicals are eliminated from the products, which cause respiratory diseases and mortality in people. Human generation, of carbon dioxide and other greenhouse emissions, is causing global warming and climate change.

India is always experiencing both a base and peak power shortage. During the 2014-15 calendar year, there are a 5% base power loss, and a 2% peak power loss was observed. The country's energy imbalance harms its economic and industrial growth [20]. India relies heavily on fossil fuels for energy generation, accounting for 70% of the country's total installed capacity [12]. Fossil fuels are imported from nations such as South Africa, Australia, and Indonesia, increasing the Indian economy's economic burden [1]. Aside from the financial cost, the usage of fossil fuels contributes to a significant increase in greenhouse gas emissions. After China and the US, India is the third-largest greenhouse gas emitter [5, 6]. As a result, developing a broad energy strategy and increasing the percentage of utilization of renewable energy resources is critical for the country. Forms of renewable energy should include a resolution that is dependable, less hazardous to the environment, cost-effective, efficient, human health, produces less waste, and is long-term accessible [13, 3].

Energy is a crucial element for economic and social development, causes environmental and economic problems when used incorrectly, and harms the quality of life of the people. Today, many countries develop alternative energy policies to get rid of such damages arising from energy use. Countries consider many constraints when choosing the appropriate alternative energy source to support their sustainable development. For example, while fossil fuels support the competitiveness of countries with their low production costs, the harmful gases released into the environment limit the use of these fuels. Nuclear energy, which is the other alternative, gives the appearance of a suitable energy source due to its high efficiency, while the risks of nuclear accidents arising from energy production, waste emitting high radioactivity, and the costs of their safe storage cause these power plants to pose a threat to sustainable development. Renewable energy sources are the final option for meeting energy demands. The problems that renewable resources had high production costs in the past have been solved with the widespread use of renewable energy, and renewable energy production costs have become competitive with fossil fuels. In addition, there are factors in the preference for these resources by countries, such as preventing foreign trade deficits that may arise due to energy imports and enabling a better-quality environment.

Although many nations invest in renewable energy resources because of their benefits, it is necessary to determine which resource and what size to invest in to increase the benefits of these resources to the nations. All aspects including the investment's payback duration, the potential of renewable energy resources, the number of emissions created by energy production, and the additional jobs offered throughout the installation and operation process must be considered when making an investment choice. Therefore, in this study, renewable energy wellspring considering such and similar criteria it has, the appropriate energy source for India to invest in has been determined. While choosing renewable energy sources, the final decision was reached in two stages. In the first stage, the weights related to the criteria were found with the entropy method. On the other hand, with the help of the objective data of the weights and criteria, the ranking of renewable energy resources is proposed by the Weighted Aggregated Sum Product Assessment (WASPAS) technique. Few studies in the literature have used the WASPAS method to select the appropriate energy source Mardani *et al*. [11]. In this study, WASPAS and Shannon's entropy [16] approaches are used together for the first time in the selection of renewable resources. From the results obtained with the WASPAS method, we find that hydroelectric energy is a suitable choice for India to invest in and the renewable energy resource order is suggested as biomass, solar, hydro, geothermal, and wind energy. We apply the MCDM (multi-criteria decision- making) technique to the renewable energy assessment issue to test the practicality, accuracy, and efficacy of the suggested theory, and the results are compared with the existing methodology. Also covered are various pertinent studies based on the same problem, as well as management implications derived from the computational procedure.

The following is how the paper is structured. Section 2 introduces the Importance of renewable energy investment in demand and some fundamental concepts and theories. In Section 3, we first discuss the methodology used for the evaluation, calculating the weights of the criteria using Shannon entropy and then ranking the different energy sources according to their scores using the Waspass method. Section 4 contains application data as well as sample renewable energy resources for countries, and the selection of suitable renewable energy bases for India. Following that, a sensitivity analysis of various parameters is performed, and a comparison study with the present approach is discussed. Section 5 provides a discussion on future investigations to bring the paper to completion. Lastly, Section 6 provides the conclusion.

2. Importance of renewable energy investment in demand

India is one of the top five clean-energy manufacturers in the world, which is on track to meet its initial goal. By establishing an aspirational goal of 450 GW of renewable electricity production by 2030, the Indian government has shown its commitment to promoting renewable power. India's renewable energy capacity was 90.39 GW in November 2020, with a goal of 175 GW by 2022. According to the strategic blueprint of the Central Electricity Authority, the government aims to generate 57 % of the overall electricity generating capacity from renewables by 2027. India plans to generate 15 GW from nuclear power, 72 GW from hydropower, 275 GW from renewable energy, and over 100 GW from "other zero emission" resources.

India has a tremendous amount of solar generating capacity, and has the greatest solar insulations in the world, collecting around 5,000 trillion kWh annually throughout its total area, with many of these sections getting 4-7 kWh^2/day. Photovoltaic cells, which are comprised of semiconductors, may be used to generate solar electricity for a variety of applications, including illumination, irrigation, telecommunication, and power source in rural regions. As of February 28, 2021, total solar power electricity generation was 38.79 GW, with a goal of 100 GW by 2022. The government of India has set aside 35,000 km^2 of Thar Desert for solar power projects with a capacity of 700 to 2,100 GW. Between 1997 and 2018, the average economic growth rate in terms of Gross Domestic Product (GDP) was 6.51 %, whereas the rate of energy consumption was 6.53% [19]. The country's economic growth is heavily reliant on the country's energy usage [4]. Figure 1 depicts the country's exponential rise in energy demand and GDP from 1997 to 2016.

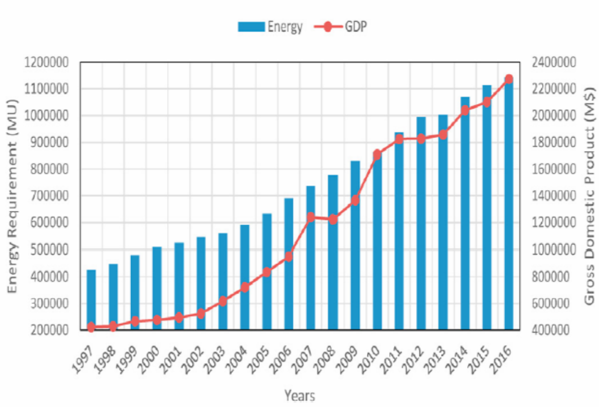

Figure 1. India's energy demand and gross domestic product increase [12, 19].

Wind energy makes up 10% of India's total generation capacity. The deployment of renewable power in India was 38.68 GW as of February 28, 2021, with a goal of 60 GW of energy generated by wind power by 2022. Solar power complements wind power in India since it is produced primarily during the non-monsoon season during the day. India is an excellent climate for biomass production, provided its humid, tropical position, plentiful sunlight, and precipitation. Biomass is a form of renewable energy made from a carbon chain, a waste of natural and human activities. Biomass energy includes waste to energy, biomass gasification, biomass power, bagasse cogeneration, bioethanol, and biodiesel, among other things. Overall electricity generation of bioenergy electricity in India was 10.14 GW on February 28, 2021, above the objective of 10 GW by 2022. A bright and green future beckon both for renewable energy development and employment in such a situation. The renewable energy industry, particularly in rural India, generates employment at all levels. India has an abundance of renewable electricity to bridge the space between the call for and supply, consequently, we ought to hold to make efforts to harness numerous sorts of renewable electricity sources via the use of modern technology to create a safe and clean environment.

Indian electricity generation is the world's largest varied and rapidly increasing energy sector. Energy consumption in India has been steadily increasing in tandem with the country's economic progress, and it is likely to continue to rise in the future as an outcome of government initiatives such as "The Saubhagya Scheme," "24/7 Power for All," and "PM Sahaj Bijli Har Ghar Yojana" [17]. India's installed capacity has expanded nearly 200 times since 1950, from 1713 MW to 349 GW in 2019. Over seventy years, it indicates an aggregate annual growth rate of 9% [12]. The requirement has been growing, with per capita power consumption rising from 18 kWh in 1950 to 1122 kWh in 2017. Six yearly plans, and twelve distinct five-year plans, in the Indian energy industry, flourished and the pace of increase in installed renewable power capability represents the Indian economy's growth tendency. The year-by-year rise in installed energy resource capacity in India is depicted in figure 2.

Today, development economists argue that the high greenhouse gas emissions of fossil fuels that threaten life and cause climate change will be overcome with renewable energy sources that will be substituted for these fuels. The Intergovernmental Panel on Climate Change

(IPCC) held by the United Nations (UN) has recently published its 5th edition. In the evaluation report, attention was drawn to this situation and the negative effects of greenhouse gases on the climate were expressed by IPCC, 2013 [7]. The warming of the global climate is certain, and the observed changes in climate since the 1950s are unprecedented over a millennium time. Every 10 years of the past 30 years have been consecutively warmer on Earth than any decade calculated for global temperature data recorded since 1850. In many regions, ice masses are losing volume, and snow cover is decreasing fossil fuels are responsible for the emergence of these problems and the increase in greenhouse gas emissions. From an economic point of view, it is seen that countries that cannot evaluate their renewable energy potential face the threat of the current account deficit by importing fossil fuels. Increases in fuel prices imported by these countries harm the country's production and national product and jeopardize the energy supply security. The foreign dependency of countries in terms of energy leaves the amount and price control of resources to the initiative of foreign countries. In case of a decrease in the resource, there will be an increase in the price of the resource following the most basic economic rule. Today, it is impossible to sustain the high growth rate that countries want to achieve with high energy prices. Sharma [25], critically analyses the energy from geothermal resources and the breadth of its application in India. Applications of renewable energy sources were given in Assad et al. [26].

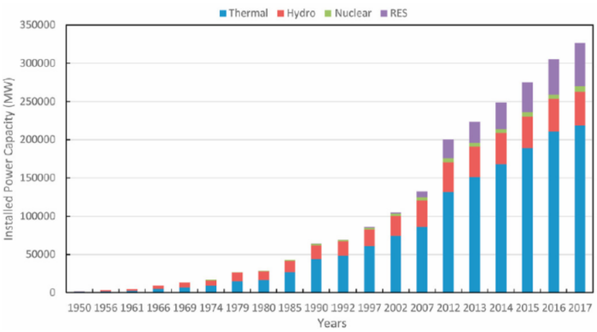

Figure 2. Growth of India's installed electricity generation [12].

Clean, limitless, and more cost-effective energy comes from renewable sources. They vary from fossil fuels primarily in their variety, quantity, and possibility for usage wherever on Earth but most importantly in that, they don't emit any greenhouse gases that contribute to climate change or other harmful emissions. While the general cost trend for fossil fuels is in the opposite direction despite their current volatility, their expenses continue to decrease and at an adequate pace. According to statistics compiled annually by the International Energy Agency (IEA), the expansion of renewable energy sources is invincible. In 2014, when they were the second largest source of electricity in the world, after coal, they accounted for nearly half of all the new power plants set up. The IEA predicts that by 2040, global electricity demand would have grown by 70%, accounting for 24% of total energy consumption, up from 18% at the time. The primary drivers of this growth are the developing economies of South-East Asia, the Middle East, Africa, India, and China. In India, hydro-power technology is advanced and able to concurrently service the needs of both major, centrally located urban regions and distant, decentralised areas. It is designed for meeting both regular usage and demand during peak hours owing of its high power generation effectiveness (up to 90%) and quick power generation. Drinking water, irrigation, drought and flood management, navigation, and additional power supply are a few of the many applications of hydropower. MNRE is undertaking projects in Ladakh and Arunachal Pradesh to reduce dependency on fossil fuels in these regions and to satisfy its electricity needs from local sources of electricity due to the potential for SHP to meet the energy demands of distant locales.

3. Methodology

The significance weights of the assessment criteria are calculated using Shannon's Entropy technique. According to the weights assigned to these criteria in the first step, the ranking of the alternatives is made by the WASPAS technique.

3.1. Entropy method

Shannon's entropy [16] is a notion that is used to quantify the uncertainty due to the random variable. This method is frequently used in many studies since it analyzes criterion weights with objective methods without resorting to subjective value judgments. Although it is commonly combined with fuzzy numbers in the literature, to find the weight of the criteria, generally utilized Shannon's entropy technique. This technique can be summarized in the subsequent steps of Li *et al*. [10]; Wang & Lee [21], and Dwivedi and Sharma [24].

Creating decision matrix: A decision matrix (DM) made up of choice alternatives and criteria is produced in the first stage. The following choice matrix is displayed:

$$\mathbf{DM} = [\mathbf{x_{ij}}]_{\mathbf{m\times n}} = \begin{bmatrix} \mathbf{x_{11}} & \mathbf{x_{12}} & \cdots & \mathbf{x_{1n}} \\ \mathbf{x_{21}} & \mathbf{x_{22}} & \cdots & \mathbf{x_{2n}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{x_{m1}} & \mathbf{x_{m2}} & \cdots & \mathbf{x_{mn}} \end{bmatrix} \quad (1)$$

In equation (1), x_{ij} denotes the performance of i alternative in j criteria. In this decision matrix, there are n criteria and m alternatives.

Normalizing decision matrix: The values in the decision matrix are normalized by (2). The f_{ij} value in (2) shows the normalized value.

$$\mathbf{f_{ij}} = \frac{\mathbf{x_{ij}}}{\sum_{\mathbf{i=1}}^{\mathbf{m}} \mathbf{x_{ij}}} \quad (2)$$

Calculation of entropy value: After the normalization process, the entropy value of each criterion is calculated with the subsequent equation.

$$\mathbf{E_j} = -\frac{\sum_{\mathbf{i=1}}^{\mathbf{m}} \mathbf{f_{ij}} \log \mathbf{f_{ij}}}{\log \mathbf{m}} \quad (3)$$

In the above equation E_j represent the entropy value, and $\log m$ represent the entropy coefficient.

Calculation of entropy weight: Finally, the objective weight (w_j) of each criterion is calculated with the subsequent equation.

$$\mathbf{w_j} = \frac{\mathbf{1 - E_j}}{\sum_{\mathbf{i=1}}^{\mathbf{n}} (\mathbf{1 - E_j})} \quad (4)$$

The w_j the value shown in (4) shows the weight of the criterion. As a result of the entropy method, criterion weights are obtained. The weights obtained from the method are used for scoring within the criteria in different methods such as WASPAS.

3.2. WASPAS method

Zavadskas *et al*. [22] by combining Weighted Sum Method (WSM) and Weighted Product Model (WPM) methods, the WASPAS method has recently become a common method used in MCDM methods proved in their studies that this method achieves more accurate results than other methods. In the literature and several studies, it is seen that the WASPAS technique is combined with fuzzy numbers and grey numbers Mardani et al. [11].

The WASPAS approach is composed of the following steps:

I. In the first stage, in the matrix where the alternatives are scored based on the criteria (shown in equation 1), for benefit criteria, we use (5) and for non-benefit criteria, we use (6), and the values are normalized Zavadskas and Turski's, [23] as follows.

$$\bar{\mathbf{x}}_{\mathbf{ij}} = \frac{\mathbf{x_{ij}}}{\mathbf{max_j}(\mathbf{x_{ij}})} \quad (5)$$

$$\bar{\mathbf{x}}_{\mathbf{ij}} = \frac{\mathbf{min_j}(\mathbf{x_{ij}})}{\mathbf{x_{ij}}} \quad (6)$$

II. The total relative importance value for each alternative is calculated separately according to WSM and WPM. In this calculation, the weights found by the entropy method are included in both processes.

$$\mathbf{WSM} = \mathbf{Q_i^{(I)}} = \sum_{\mathbf{j=1}}^{\mathbf{n}} \bar{\mathbf{x}}_{\mathbf{ij}} \mathbf{w_j} \quad (7)$$

$$\mathbf{WPM} = \mathbf{Q_i^{(II)}} = \prod_{\mathbf{j=1}}^{\mathbf{n}} (\bar{\mathbf{x}}_{\mathbf{ij}})^{\mathbf{w_j}} \quad (8)$$

III. For each alternative, both total relative importance values are combined with the following equation. Thus weighted combined final scores (Q_i) for each alternative are obtained.

$$\mathbf{Q_i} = \mathbf{0.5} \sum_{\mathbf{j=1}}^{\mathbf{n}} \bar{\mathbf{x}}_{\mathbf{ij}} \mathbf{w_j} + (\mathbf{0.5}) \prod_{\mathbf{j=1}}^{\mathbf{n}} (\mathbf{x_{ij}})^{\mathbf{w_j}} \quad (9)$$

Based on equation (10), Saparauskas *et al*. [14], and Zavadskas *et al*. [22], a more generalized equation for estimating the overall relative relevance of the i^{th} the choice is calculated:

$$\mathbf{Q_i} = \boldsymbol{\alpha} \sum_{\mathbf{j=1}}^{\mathbf{n}} \bar{\mathbf{x}}_{\mathbf{ij}} \mathbf{w_j} + (\mathbf{1} - \boldsymbol{\alpha}) \prod_{\mathbf{j=1}}^{\mathbf{n}} (\mathbf{x_{ij}})^{\mathbf{w_j}} \quad \text{where } \boldsymbol{\alpha} \in [\mathbf{0}, \mathbf{1}] \quad (10)$$

In equation (10), the measure Q_i signify the relative significance, based on the WSM and WPM methods, where w_j denotes the weightage of criteria. It was suggested that WASPAS be tested for correctness using initial criteria precision. It has been demonstrated that the accuracy of aggregating approaches is higher than the accuracy of single procedures. As it can be seen, the WASPAS method provides fast results since it does not have complicated processes.

4. Application

Four fundamental criteria and 20 sub-criteria are used to determine the value of renewable energy sources for countries. Table 5 lists the technical, economic, environmental, and social criteria, as well as sub-criteria. All of the characteristics of renewable energy sources were attempted to be understood when determining which criteria to include in the investigation, and the criteria used in the selection of energy sources in the literature were favoured. Kayakutlu and Ercan [8]; Saraswat and Abhijeet [15]; Kenny, Law, and Pearce [9]; and Stein is on page 18. Below is a quick description of these criteria.

4.1. Technical criteria

Renewable energy sources with good precision and potential should be prioritized from a technological standpoint. The technical criteria include the technical characteristics of renewable energy resources and investments and consist of sub-criteria such as the efficiency, potential, and capacity of energy resources. Table 1 shows the data for the sub-criteria constituting the technical criteria.

In table 1, the energy efficiency sub-criterion shows the efficiency obtained from the unit energy source during the production phase. The coefficients show the amount of energy obtained from the 1 MW installed power of each source, based on the 2015 electricity generation data of India. Accordingly, while the energy source that provides the most output with the least input in the production process is geothermal, the energy source with the least efficiency is solar energy. The economic potential data in the table shows how much of the theoretical potential of renewable energy resources in India can be produced with low economic cost. Accordingly, hydroelectric power has been the energy source with the best economic potential, with 140 GW per year. The performance ratio is calculated by dividing the total energy generated by the plant during a certain time by the maximum energy it can generate. Accordingly, the closest production to full capacity is provided by geothermal.

4.2. Economic criteria

Although renewable energy resources have technically optimal features, investments in these resources may not be economically profitable. The maximum effectiveness of the sources to be employed for these expenditures may be lower than the return that would be gained if these resources were put to better use elsewhere. Before deciding to invest in these resources, especially the investment and electricity production costs and the expected payback period from the investment should be compared with other investment options. From this point of view, economic criteria allow the comparison of renewable energy investments in terms of cost and payback period to use the country's resources effectively. Countries prefer energy resources with low investment costs, low operating and maintenance costs, and short payback periods to use their resources effectively and gain competitiveness. As seen in table 2, while the source with the lowest investment cost per kW is biomass, the lowest electricity production cost belongs to geothermal energy. It is seen that wind energy is superior to other renewable resources in repayment of the total capital spent on investment. Source of data of table from 1 to 4 taken from Annual Energy Outlook 2021, [2].

Table 1. Technical criteria.

Type of energy	Wind	Solar	Hydro	Biomass	Geo-thermal
Energy efficiency	3.56	0.96	3.55	5.33	**6.65**
Economic potential (GW/year)	95	86	**150**	10	8
Operating life (years)	30	50	**100**	50	45
Global power capacity (%)	6.5	3.5	**19.8**	2.5	0.5
Capacity factor (%)	35	26.8	38.5	95	**100**

*The bolded numbers represent the best and cost alternative for each criterion.

Table 2. Economic criteria.

Type of energy	Wind	Solar	Hydro	Biomass	Geo-thermal
Investment cost ($/kW)	2000	4800	7000	**450**	3100
Maintenance cost ($/MW-year)	25530	60315	**4550**	88560	183652
Electricity generation cost ($/kW-hour)	0.083	0.132	0.082	0.2	**0.08**
LCOE electricity cost ($/MWh)	35.98	41.02	56.40	86.69	**35.83**
Payback period (year)	**0.9**	2.85	15.9	4.90	8.5

*The bolded numbers represent the best and cost alternative for each criterion.

4.3. Environmental criteria

When evaluated in terms of social welfare, the harm caused by the energy resources to be invested in the environment and human health can prevent the technical and economic benefits of the resource. Therefore, environmental factors show the damage of renewable resources used in energy production to the environment and human health. Table 3 on the environmental impacts of resources shows the relevant data.

Among the external costs seen in the first line of table 4, there are environmental costs such as reduced product yield, and air and water pollution, as well as costs on human health such as premature death, loss of work, and productivity caused by energy production and consumption. Since biomass energy releases more emissions among renewable resources, this resource has more external costs than other renewable resources. The least external cost belongs to wind energy. While solar energy is the renewable resource that provides the most employment in the manufacturing, construction, and installation phases, it is seen that biomass energy creates more employment than other renewable resources during the operation phase. Since it is necessary to collect and transport organic wastes to produce energy with biomass, it is seen that this source provides more employment during the operation phase.

4.4. Social criteria

Within the scope of social criteria, the social effects of renewable energy investments are compared. Because these criteria have a direct influence on public benefit functions, governments factor them into their cost-benefit analyses when deciding on energy policy.

Table 3. Environmental criteria.

Type of energy	Wind	Solar	Hydro	Biomass	Geo-thermal
NOx emissions (g/MWh)	30.85	95.40	20.50	1000	**15.50**
CO2 emissions (gCO_2/kWh)	**15**	45	28	330	40
CO emissions (g/MWh)	40.5	645	**15.5**	1500	25.8
SO2 emissions (g/MWh)	30.5	60.5	12.3	448	**5.15**
Particle emissions (g/MWh)	0.0155	0.0354	0.00625	0.436	**0.00156**
Non-methane compounds (g/MWh)	8.62	38.6	0.655	45.5	**0.544**
Space requirement (m^2/kWh)	0.000932	0.001652	**0.000156**	0.00050	0.000255

*The bolded numbers represent the best and cost alternative for each criterion.

Table 4. Social criteria.

Type of energy	Wind	Solar	Hydro	Biomass	Geo-thermal
External costs	**0.20**	0.8	0.65	3.05	0.5
Manufacturing-installation (per MW)	9.4	**18.9**	6.5	8.2	12.3
Operation-maintenance process (per MW)	0.3	0.5	0.6	**6.51**	0.5

*The bolded numbers represent the best and cost alternative for each criterion.

4.5. Determination of criterion weights by entropy method

The entropy technique is utilized to determine weights, and the criteria for selecting renewable energy sources are separated into benefit and non-benefit/cost categories. As seen in table 5, data on harmful gases and metals and space requirement of each renewable resource show that geothermal energy is superior in 4 criteria and hydropower in 2 criteria. In terms of carbon dioxide emissions, it is seen that wind energy is a more environmentally friendly source with emissions of 11 grams per kWh.

Table 5. Beneficial and cost criteria.

Main criterion	Sub-criteria	Notation	Benefit/Cost
Technical criteria (M1)	Energy efficiency	SC1	Beneficial
	Economic potential	SC2	Beneficial
	Operating life	SC3	Beneficial
	Global power capacity	SC4	Beneficial
	Capacity factor	SC5	Beneficial
Economic criteria (M2)	Investment cost	SC6	Cost
	Maintenance cost	SC7	Cost
	Electricity generation cost	SC8	Cost
	LCOE electricity cost	SC9	Cost
	Payback period	SC10	Cost
	NOx emissions	SC11	Cost
	CO_2 emissions	SC12	Cost
Environmental criteria (M3)	CO emissions	SC13	Cost
	SO_2 emissions	SC14	Cost
	Particle emissions	SC15	Cost
	Non-methane compounds	SC16	Cost
	Space requirement	SC17	Cost
Social criteria (M4)	External costs	SC18	Cost
	Manufacturing-installation	SC19	Beneficial
	Operation-maintenance process	SC20	Beneficial

In the first step of the WASPAS technique, a decision matrix is created from the data in tables 1, 2, 3, and 4. With the help of (5) and (6), the values in the choice matrix are normalized. Table 6 shows the normalized decision matrix, and with the entropy method, objective criterion weights are obtained by using empirical data. We obtained weight by Shannon's entropy (E_j) with the help of (2) and (3) the normalized values are multiplied by the natural logarithm values of these values. By taking the sum of these product values, the weighted values for each criterion are found with the help of (4) and given in the last columns in table 6, and the ranking of the weight represent in figure 3.

As seen in table 6, bolded number represents the global power capacity (SC4) in technical criteria, NOx emissions (SC11) in economic criteria, particle emission (SC15) in environmental criteria, and employment in operation-maintenance process in social criteria have a higher weight compared to other criteria weights.

Table 6. Normalized decision-making matrix and weighted value.

Criteria	Sub-criteria	Wind	Solar	Hydro	Biomass	Geo-thermal	Weighted value
M1	SC1	0.5353	0.1444	0.5338	0.8015	1.0000	0.0414
	SC2	0.6333	0.5733	1.0000	0.0667	0.0533	0.0475
	SC3	0.3000	0.5000	1.0000	0.5000	0.4500	0.0401
	SC4	0.3283	0.1768	1.0000	0.1263	0.0253	**0.0510**
	SC5	0.3500	0.2680	0.3850	0.9500	1.0000	0.0416
M2	SC6	0.2250	0.0938	0.0643	1.0000	0.1452	0.0442
	SC7	0.1782	0.0754	1.0000	0.0514	0.0248	0.0481
	SC8	0.9639	0.6061	0.9756	0.4000	1.0000	0.0398
	SC9	0.9958	0.8735	0.6353	0.4133	1.0000	0.0395
	SC10	1.0000	0.3158	0.0566	0.1837	0.1059	0.0464
	SC11	0.5024	0.1625	0.7561	0.0155	1.0000	**0.0664**
	SC12	1.0000	0.3333	0.5357	0.0455	0.3750	0.0555
M3	SC13	0.3827	0.0240	1.0000	0.0103	0.6008	0.0603
	SC14	0.1689	0.0851	0.4187	0.0115	1.0000	0.0625
	SC15	0.1006	0.0441	0.2496	0.0036	1.0000	**0.0685**
	SC16	0.0631	0.0141	0.8305	0.0120	1.0000	0.0544
	SC17	0.1674	0.0944	1.0000	0.3120	0.6118	0.0458
M4	SC18	1.0000	0.2500	0.8125	0.0656	0.4000	0.0486
	SC19	0.4974	1.0000	0.3439	0.4339	0.6508	0.0397
	SC20	0.0461	0.0768	0.0922	1.0000	0.0768	**0.0587**

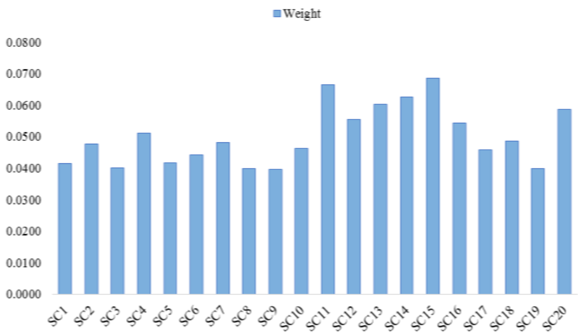

Figure 3. Bar graph representation of sub-criteria weights.

4.6. Alternative energy with WASPAS method

Ranking of resources in the second stage, renewable energy resources were ranked according to their performance in the criteria by using the WASPAS method. The data in the decision matrix used in the entropy method was normalized with equations 7 and 8. Thus the first step of the WASPAS method is realized. Table 7 shows the normalized values. With the help of equation (7) and equation (8), the total relative importance degrees of the normalized values according to WSM and WPM are found. Alternative energy according to WSM. $Q_i^{(I)}$ and WPM according to $Q_i^{(II)}$, figure 4 illustrates the energy rank.

Table 7. Score for WSM and WPM.

Alternative	Score Q_i		Rank	
	WSM $Q_i^{(I)}$	WPM $Q_i^{(II)}$	WSM	WPM
Wind	0.4498	0.3137	3	3
Solar	0.2551	0.1470	5	4
Hydro	0.6272	0.4750	1	1
Biomass	0.2890	0.0894	4	5
Geo-thermal	0.5833	0.3512	2	2

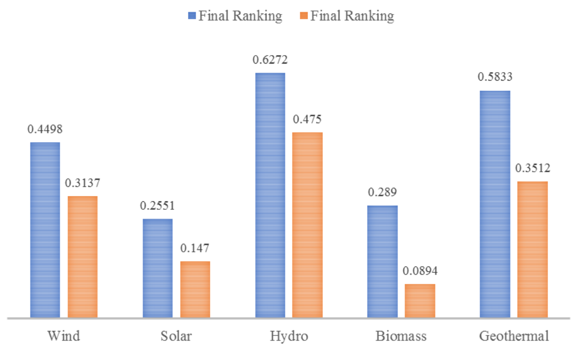

Figure 4. Representation of renewable energy according to achieve the score.

After ranking finally by WSM and WPM, these values are combined with the equation (9) for each alternative energy to obtain the final scores of the alternatives. Table 8 shows the total relative importance and final scores Q_i when WASPAS parameter α = 0, 0.5 and 1 by using equation (10). The WASPAS technique yielded the appropriate renewable energy resource rating for India, which was hydro, geothermal, wind, biomass, and solar. If the sensitivity analysis is done and the criteria weights are taken equal, the weight of each criterion becomes (1/20) = 0.05 since 20 criteria are taken into consideration. When reprocessing is done according to these weights, there is no change in the order of energy sources. If the weight of the "energy efficiency" criterion was increased and the value 0.11 was taken, the weights of the "economic potential, operational life, and global installed capacity" criteria were reduced and the values of 0.04, 0.02, and 0.03 were taken, and the weights of the other criteria were 0.05, were left constant, the order of energy sources would change to geothermal, hydro, wind, biomass, and sun. As can be seen, a change in the criteria weights affects the result. Since objective weights were used instead of subjective weights in the study, no decision-maker affected the results. Figure 5 shows the final WASPAS score of the main criteria taken in the study for α = 0.5, 0,1 as well as the combined renewable energy ranking for α = 0.5 sowing in figure 6.

Table 8. Rank of alternatives when WASPAS parameter α = 0.5, 0, 1.

Alternative	α = 0.5		α = 0		α = 1	
	WASPAS score	Rank	WASPAS score	Rank	WASPAS score	Rank
Wind	0.3817	3	0.3137	3	0.4498	3
Solar	0.2010	4	0.1470	4	0.2551	5
Hydro	0.5511	1	0.4750	1	0.6272	1
Biomass	0.1892	5	0.0894	5	0.2890	4
Geo-thermal	0.4673	2	0.3512	2	0.5833	2

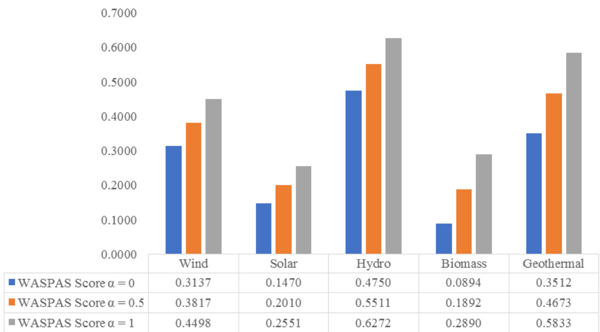

Figure 5. Representation of renewable energy according to WASPAS score.

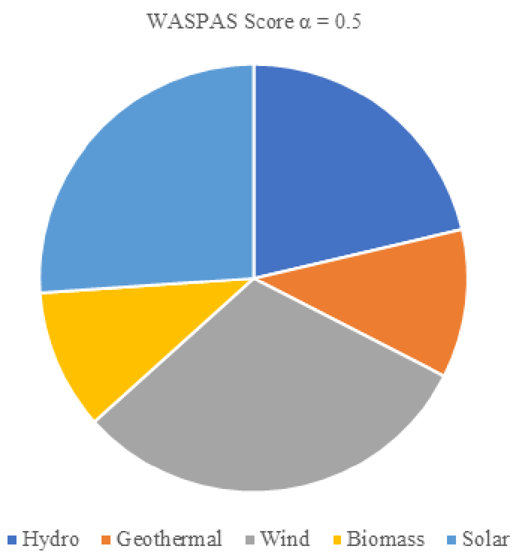

Figure 6. Illustration of renewably ranking of energy alternatives.

5. Discussion

Energy sources, which are of vital importance for countries, as well as also have characteristics that have harmful effects. Studies conducted for the last half-century focus on the environmental and economic damage of fossil fuels and emphasize the importance of countries investing in renewable energy sources. However, at this point, it is an important question that needs to be answered which renewable energy source will lead to additional best outcomes for countries. For this reason, in the study, considering 20 different criteria of renewable energy resources, a suitable renewable energy source to invest in India has been determined. In this study, the appropriate energy source selection in meeting the energy need in India is made through an integrated model by utilizing the combination of WASPAS and Entropy techniques. In the entropy method, criterion weights are found with the help of objective data. These weights are transferred to the WASPAS method and the empirical data whose weights are determined were analyzed with this method and it was calculated which energy source is more suitable for India.

The use of renewable energy is expanding quickly throughout most of the world, and it has been the focus of research at both the doctoral and undergraduate levels as well as of growing social interest. A highly beneficial choice for society is to produce energy from renewable sources, such as electricity and heat, with little harm to the environment. Most nations are tightening their energy regulations, largely to reduce emissions of greenhouse gases and other pollutants. As a result, there is more interest in and support for using renewable energy sources. Engineers and technicians are also required to develop, build, and run renewable energy systems. The renewable energy industry in India has been boosted by the country's thriving fossil fuel markets, the government's supportive policies, technological advancements, and the falling cost of renewable energy sources; as a result, the nation is currently experiencing the world's biggest renewable energy growth programmes with a number of renewable energy initiatives. Due to India's status as the world's third-biggest carbon emitter and the second-most populated nation, such initiatives are now required.

6. Conclusion

Energy use has both positive and negative effects on social welfare. For this reason, countries should plan on a model in which externalities are considered while determining their energy policies. In energy plans where the external costs caused by fossil fuels are not taken into account as a cost element, these fuels are presented above the optimal and there is an increase in environmental, social, and economic problems in the countries. It is possible to prevent these problems with the intervention of the state in the market. It is necessary for the more efficient distribution of resources that the state should tax the production costs of fossil fuels, including the damages to society. It is also possible to apply subsidies to renewable energy sources due to their positive externalities. Because these resources reduce the imports of countries, create new employment areas, and enable production that is more sensitive to environmental quality and human health. Incentives such as tax reductions, convenience in loan interests, and customs exemption can be provided to the renewable energy sector, as well as studies should be carried out to realize the production of materials (wind turbine and parts, etc.) to be used in renewable energy power plants in our country. In this study, on the basis of different energy sources, studied various criteria such as technical criteria, economic criteria, environmental criteria, and social criteria. We calculated the weights of the criteria. Using entropy, it is found that the weight of technical criteria is 0.0510, the weight of economic criteria is 0.0664, the weight of environmental criteria is 0.0685, and the weight of social criteria is 0.0587. Based on these criterias, assessed the energy sources by taking different parameter α = 0.5, 0, 1 and found that at α = 1, hydro energy score is 0.6272, geo-thermal energy score is 0.5833, wind energy score is 0.4498, biomass energy score is 0.2890, and solar energy's score is 0.2551. In this study, according to WASPAS score the hydropower energy is the most suitable renewable energy resource for India.

7. References

[1] Ali, S., The future of Indian electricity demand. https://www.brookings.edu/wp content/uploads/2018/10/The-future-of-Indian-electricity-demand.pdf, 2018.

[2] Annual Energy Outlook (2021). U.S. Energy Information Administration, https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

[3] Cayir Ervural, B., S. Zaim, O.F. Demirel, Z. Aydin, and D. Delen, An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey’s energy planning, Renew. Sustain. Energy Rev. 82 (2018) 1538e1550, https://doi.org/10.1016/j.rser.2017.06.095.

[4] Ghosh, S., Electricity supply, employment and real GDP in India: evidence from cointegration and Granger-causality tests, Energy Pol. 37 (2009) 2926e2929, https://doi.org/10.1016/j.enpol.2009.03.022.

[5] IEA, CO_2 emission from fuel combustion highlights. http://www. indiaenvironmentportal.org.in/files/file/CO_2 Emissions from Fuel Combustion_Highlights_2015.pdf, 2015.

[6] IEA, CO_2 emission from fuel combustion highlights. http://www.indiaenvironmentportal.org.in/files/file/CO2EmissionsfromFuelCombustion_ Highlights_2016.pdf, 2016.

[7] IPCC (2013). Climate Change 2013: The Physical Science Basis, Summary for Policymakers, Technical Summary and Frequently Asked Questions. Intergovernmental Panel on Climate Change.

[8] Kayakutlu, G. and Ercan, S. (2015), “Regional Energy Portfolio Construction: Case Studies in Turkey. In Sustainable Future Energy Technology and Supply Chains”, Springer International Publishing, 107-126.

[9] Kenny, R., Law, C., and Pearce, J.M. (2010), “Towards Real Energy Economics: Energy Policy Driven by Life-Cycle Carbon Emission”, Energy Policy, 38(4), 1969-1978.

[10] Li, X., Wang, K., Liu, L., Xin, J., Yang, H. and Gao, C. (2011)” Application of the entropy weight and TOPSIS method in safety evaluation of coal mines.” Procedia Engineering, 26: 2085-2091.

[11] Mardani, A., Nilashi, M., Zakuan, N., Loganathan, N., Soheilirad, S., Saman, M. Z. M., and Ibrahim, O. (2017) “A systematic review and meta-Analysis of SWARA and WASPAS methods: Theory and applications with recent fuzzy developments.” Applied Soft Computing, 52: 265-292.

[12] Ministry of Power, Government of India, https://npp.gov.in/.

[13] Onat, N., H. Bayar, the sustainability indicators of power production systems, Renew. Sustain. Energy Rev. 14 (2010) 3108e3115, https://doi.org/10.1016/ j. rser.2010.07.022.

[14] Saparauskas, J., Zavadskas, E.K., and Turskis, Z., 2011. Selection of facade’s alternatives of commercial and public buildings based on multiple criteria. Int. J. Strateg. Prop. Manag. 15 (2), 189–203.

[15] Saraswat, S.K. and Abhijeet K. Digalwar (2021). Evaluation of energy alternatives for sustainable development of energy sector in India: An integrated

[16] Shannon’s entropy fuzzy multicriteria decision approach, Renewable Energy 171 (2021) 58-74. Shannon, C. E. “A mathematical theory of communication Bell Syst. Tech. J., Vol. 27, No. 3, pp. 379-423, 1948.

[17] Srikanth, R., India's sustainable development goals e glide path for India's power sector, Energy Pol. 123 (2018) 325e336, https://doi.org/10.1016/ j. enpol.2018.08.050.

[18] Stein, E.W. (2013), "A Comprehensive Multi-Criteria Model to Rank Electric Energy Production Technologies", Renewable and Sustainable Energy Reviews, 22, 640-654. https://e3garden.com/wpcontent/uploads/2013/10/RSER2418_Stein.pdf, (10.05.2017)

[19] The World Bank, https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2018&locations=IN&start=1961&view=chart, 2019.

[20] Tripathi, L., A.K. Mishra, A.K. Dubey, C.B. Tripathi, P. Baredar, Renewable energy: an overview on its contribution in current energy scenario of India, Renew. Sustain. Energy Rev. 60 (2016) 226e233, https://doi.org/10.1016/ j. rser.2016.01.047.

[21] Wang, T. C. and Lee, H. D. (2009) "Developing a fuzzy TOPSIS approach based on subjective weights and objective weights." Expert Systems with Applications, 36(5): 8980-8985.

[22] Zavadskas, E.K., Turskis, Z., Antucheviciene, J., and Zakarevicius, A., 2012. Optimization of weighted aggregated Sum Product assessment. Electron. Electr. Eng. 6, 122 3–6.

[23] Zavadskas, E. K. and Turskis, Z. (2010) "A new additive ratio assessment (ARAS) method in multicriteria decision-making. "Technological and Economic Development of Economy, 16(2):159-172.

[24] Dwivedi, P.P., Sharma, D. K. Application of Shannon Entropy and COCOSO techniques to analyze performance of sustainable development goals: The case of the Indian Union Territories, Results in Engineering, Volume 14, 2022,100416, https://doi.org/10.1016/j.rineng.2022.100416.

[25] Sharma, R.C. Energy from Geothermal Resources and Scope of its Utilization in India,Volume 4, Issue 2 ,145-157 https://doi.org/10.22044/rera.2022.12359.1175.

[26] Mamdouh El Haj Assad, Mohammad Alhuyi Nazari, Marc A. Rosen, Chapter 1 Applications of renewable energy sources, Design and Performance Optimization of Renewable Energy Systems, Academic Press, https://doi.org/10.1016/B978-0-12-821602-6.00001-8.