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Research Article

Sustainable Transportation: Economics Driving Towards Environmental Solutions

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ARTICLE INFO	ABSTRACT

Energy demand rises along with global population growth and urbanization. Fossil fuels provide a large portion of the world's energy supply, and these sources are quickly being depleted at the current usage rate. Sustainability and social acceptability are fulfilled through an alternative source of energy. Renewable energy sources have been motivated by expanding global energy demand and growing environmental concerns. Renewable energy technologies may help reduce greenhouse gas emissions, improve energy security, and promote rising economies. A review of previous evaluations determines the existing costs of renewable energy relative to other sources of energy and rates the squabble based on past and present prices of renewable energy, providing the cost measurement analysis of available several renewable energy sources.

Keywords: *Renewable resources, Cost analysis, LCOE, Solar, Wind*

Introduction:

Urbanization and population growth worldwide increase the need for energy, which drives energy demands. The world's energy supply is primarily derived from fossil fuels and industrialization, which are rapidly occurring at the current use rate. Greenhouse gas emissions from the use of fossil fuels, urban areas, and industry are another factor contributing to the rise of insistence energy. Hence, renewable energy offers applied and sustainable responses in this direction[1]. The developing world is concerned about people's willingness to get more renewable energy sources for social acceptability. India, the fourth-largest greenhouse gas emitter in the world, has often acknowledged the significance of moving toward sustainable energy[2]. Burning of coal and oil releases particulates that contaminate the land, water, and atmosphere. Many of these particles are released into the air; some are captured and placed aside[3]. Fossil fuel combustion also throws off Earth's "carbon budget," which balances carbon in the atmosphere, ocean, and land. These energy sources take millions or even thousands of years to produce, and we will run out of them in decades. Hence, the generation of renewable energy may be a suitable alternative[4]. Compared to coal, oil, or gas, renewable energy sources like wind and solar are typically more affordable, widely available, and have minimal greenhouse gas emissions. Currently, some developing countries are apprehensive about the social acceptability of renewable energy. India, the world's fourth-largest greenhouse gas emitter, has frequently recognized the importance of transitioning towards sustainable energy[5, 6]. India has made significant progress in utilizing renewable energy, ranking sixth in the world in grid-connected capacity by the Ministry of New and Renewable Energy in 2006. Prominence, understanding, and the adoption of renewable energy technology continue to encounter many challenges despite their efforts. To overcome these ambiguities, a number of research programs have attempted to address public views concerning certain energy supplies, considering social, industrial, economic, and environmental issues[7].

The world's rising energy demand and growing environmental concerns prompted a shift to renewable energy sources. Potential corrections for lowering greenhouse gas emissions, enhancing energy security, and boosting emerging economies can be found through renewable energy technology. Contrarily, researchers have also pointed out recent research on producing low-cost, improved renewable energy. The publication has drawn attention to the problems with intermittency, storage, and investment costs[8 9]. Most of the capital and infrastructure of contemporary economic systems still rely on fossil fuels; however, significant changes in governmental regulations are required to expedite the transition to improved production of renewable energy resources. Like other energy sources, renewable energy must be cost-effective in order to provide adequate returns to investors. Many Western European countries, as well as China and India, have similarly used subsidies to promote renewable energy, and the development and cost of renewable energy resources in Vietnam have been observed by[10]. The national electricity utility adjusts electricity prices to ensure fair returns for private investors in renewable energy; these adjustments are based on regional cost conditions. Given these challenges, it is necessary to assess the production costs of renewable energy to determine whether prices are viable enough for long-term use. Prior research on renewable energy has focused on the overall approach to different climate conditions and produced negligible reports on the costs of renewable resources. In contrast, the expenses associated with using these resources to support the green transition are associated with low-cost renewable energy production. To approach these challenges, it is necessary to review the production costs of renewable energy and set up specific policies and regulatory frameworks for clean energy development that do not overburden consumers. Past research has been conducted on promoting renewable energy[11], but it tends to focus on the Vietnamese government's overall approach to climate change policy rather than the costs of renewable energy[12]. The purpose of this paper is to review past analyses, calculate the present costs of renewable energy relative to other sources of energy, and assess the squabble based on the past and present prices of renewable energy. The present article depicts a cost measurement analysis of various renewable energy sources through the levelized cost of energy (LCOE) model, a recent measurement method tool that may be useful for sustainable and profitable energy production[13]. WWF-India carried out a renewable energy survey. The web platform used for the poll was designed with general internet users in mind. Social media and bulk emailing were used to target the respondents. The poll was conducted over a month. There were 28 straightforward questions on the form, split between open-ended and closed-ended options. These surveys covered a wide range of topics, including applicable regulations and incentives, awareness levels, knowledge platforms, current products and technologies, cost and financing choices, technological and business model advancements, and potential solutions. Additionally, the surveys make an effort to evaluate some of the critical elements of renewable energy, including its acceptability, dependability, availability of pertinent data, gaps in current understanding, and other financial and technological impediments.

Renewable Energy and Its Potential

Solar Energy associated with the country's dense population, which prioritizes residential, agricultural, and industrial sectors, means that land availability for solar programs will probably be limited[14]. Therefore, rooftop photovoltaic systems may help offset the need for more acreage for solar power. Numerous studies demonstrate that rooftop photovoltaic systems may significantly augment grid electricity, and states such as West Bengal and Kerala are promoting their adoption. The utilization of roof space is hampered by several factors, including competing usage for other services, issues with solar-water heating systems, and the lack of suitable roof space that complies with building construction bylaws. Because of the abovementioned obstacles, rooftop photovoltaic potential is unlikely to be fully realized; nonetheless, innovative methods can maximize rooftop photovoltaic efficiency. The primary concerns that persist are the comparatively elevated expenses and the limited capacity factor (sporadic functioning), which result in elevated expenses for electricity production and necessitate suitable grid supervision, energy storage, or backup power in off-grid setups. While grid authorities get ready to handle more and more renewable intermittent capacity (storage), the Indian government and several state governments provide financial incentives for Photovoltaic electricity generation in an effort to achieve cost reductions through implementation. The basic principle behind solar energy is the conversion of sunlight into electricity. It is achieved primarily through photovoltaic cells, also known as solar cells. There are two main types of solar power technologies. Solar Photovoltaic (PV) systems convert sunlight directly into electricity, while solar thermal systems convert sunlight into heat energy, and then the heat is converted to electricity. Uttarakhand boasts significant solar potential due to its abundant sunshine. It receives an average of 4-7 kWh/m2 of solar radiation per day, with 280-300 sunny days annually. This translates to a high electricity generation potential [10]. The state's diverse climate zones, ranging from semi-moderate plains to cold and sunny mountains, offer suitable conditions for solar energy utilization[15]. Likewise, wind Energy, as given on the map, makes evident that five states account for over 95% of the country's potential for wind energy: Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, and Gujarat. Karnataka has the most incredible total resources, whereas Tamil Nadu has the best quality (speed) resources. In India, the average capacity of wind turbines is currently 20%, with projections indicating a 30% growth by 2031. From 14%, this has significantly improved during the last ten years. Similarly, hydropower is a renewable resource that has social and environmental effects. The construction of dams is a necessary component of large hydroelectric projects. Dams store water and release it (either through generation or spill), usually under controlled conditions, drastically altering an otherwise free-flowing river. While basic machinery has not seen a major breakthrough in decades, advancements in computer technology have resulted in considerable improvements in many areas, including protection, control, monitoring, and diagnostics. However, Geothermal Energy is a vast and underutilized source of heat and power; geothermal energy is clean, dependable (with an average system availability of 95%), import-independent (meaning it reduces reliance on foreign oil), and highly effective in both on- and off-grid developments. It is beneficial in rural electrification projects.

Report on the status of Renewable Energy Technologies Used in India

Many states in India use various renewable energy technologies to fulfill their energy demands. Solar PV systems, solar water heating systems, and solar cookers are common in the Andaman and Nicobar Islands, as are small wind turbines and micro hydro systems[4, 16, 17]. Similarly, states such as Arunachal Pradesh, Assam, and Jammu and Kashmir use solar technology in conjunction with tiny wind turbines, hydro projects, and biogas facilities. Some states, such as Bihar, Chandigarh, and Goa, rely heavily on solar technology and biogas plants due to the unavailability of wind and hydropower technologies, as shown in Fig 1

Fig.1 Reports on renewable resources in various states of India

On the other hand, states like Gujarat, Himachal Pradesh, and Madhya Pradesh have a mix of solar, wind, and small hydro projects (Table 1). While states like Maharashtra and Rajasthan concentrate on solar and large hydro projects, others like Tamil Nadu and Odisha rely on solar and wind energy. Each state's renewable energy mix is tailored to its geographical, climatic, and resource availability, showcasing the diverse strategies employed nationwide to harness clean and sustainable energy sources [18,19].

Cost of Different Renewable Energy Technologies Used in India and its Economic Prospective

In India, various states utilize a range of renewable energy technologies to meet their energy needs. In the Andaman and Nicobar Islands, solar PV systems, solar water heating systems, and solar cookers are prevalent, along with small wind turbines and micro hydro systems. Similarly, states like Arunachal Pradesh, Assam, Jammu, and Kashmir also employ solar technologies, small wind turbines, small hydro projects, and biogas plants. Some states like Bihar, Chandigarh, and Goa focus primarily on solar technologies and biogas plants due to the absence of wind and hydropower technologies. On the other hand, states like Gujarat, Himachal Pradesh, and Madhya Pradesh have a mix of solar, wind, and small hydro projects. While states like Maharashtra and Rajasthan concentrate on solar and large hydro projects, others like Tamil Nadu and Odisha rely on solar and wind energy. Each state's renewable energy mix is tailored to its geographical, climatic, and resource availability, showcasing the diverse strategies employed nationwide to harness clean and sustainable energy sources. The cost of various forms of renewable energy technology used in India has been elucidated in Table 1.

Table 1: Reports on the expense of a variety of renewable energy technology utilized in India

State	**Solar PV (INR/kWh)**	**Wind (INR/kWh)**	**Hydro (INR/kWh)**	**Geothermal (INR/kWh)**
Andaman and Nicobar Islands	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Andhra Pradesh	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Arunachal Pradesh	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Assam	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Bihar	₹4.00 - ₹6.00	₹3.50 - ₹5.50	₹4.00 - ₹6.50	₹5.00 - ₹7.00

Chandigarh	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Chhattisgarh	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Dadra and Nagar Haveli and Daman and Diu	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Delhi	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Goa	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Gujarat	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Haryana	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Himachal Pradesh	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Jammu and Kashmir	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Jharkhand	₹4.00 - ₹6.00	₹3.50 - ₹5.50	₹4.00 - ₹6.50	₹5.00 - ₹7.00
Karnataka	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Kerala	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Ladakh	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Lakshadweep	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Madhya Pradesh	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Maharashtra	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Manipur	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Meghalaya	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Mizoram	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Nagaland	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Odisha	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Puducherry	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Punjab	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Rajasthan	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Sikkim	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Tamil Nadu	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Telangana	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Tripura	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
Uttar Pradesh	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50
Uttarakhand	₹5.00 - ₹7.00	₹4.50 - ₹6.50	₹5.00 - ₹8.00	₹6.00 - ₹8.00
West Bengal	₹4.50 - ₹6.50	₹4.00 - ₹6.00	₹4.50 - ₹7.00	₹5.50 - ₹7.50

Economics of Renewable Energy

In general, the cost of electricity from diverse sources of energy fails to include all external costs, that is, the expenses faced indirectly by society as a whole as a result of using the energy source. Each energy source's pricing should include all of its societal costs. Various studies of energy externalities imply that if externality costs were reflected in the pricing of all energy sources, the transition to renewable would be much simpler.

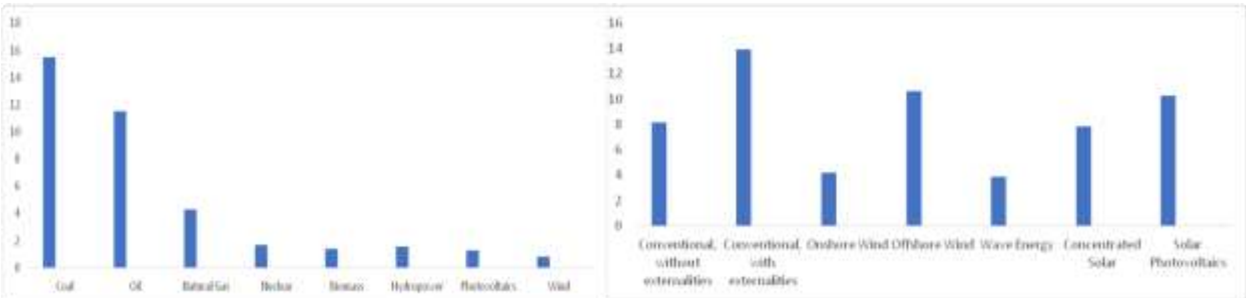

Fig: 2 (A) Various electricity-generated methods and their cost (Y-axis are in Eurocents)
(B) Electricity from various renewable sources (Y-axis represents %/kilowatt-hour.)

The costs and consequences of renewable energy are substantially lower, at less than one Eurocent per kilowatt hour. So, while fossil fuels may now have an economic advantage over renewable based only on market prices, if factors have been considered, some renewable energy sources, notably onshore wind, geothermal, and biomass energy, will likely become the most economical. As a result, this suggests that the inability to account for externalities is the most significant impediment to the transition to renewable energy. Factoring in externalities costs and setting 'correct' pricing would strongly message companies and consumers that relying on fossil fuels is poor economics.

An estimated comparison of the cost of electricity generation in 2020 by utilizing traditional fossil fuel methods and various renewable alternatives has been demonstrated in Fig. 2 B. Based only on production costs, the renewable sources of onshore wind, wave energy, concentrated solar, and potentially offshore wind are all expected to be cost competitive with fossil fuels. Once the effect of externalities is included, all renewable sources are less expensive than fossil fuels. These results imply good economic reasons to promote a transition towards renewable.

Financial Viability Assessment:

The Financial sustainability research analyses an organization's ability to fulfill functioning commitments, respond to industry-wide difficulties and unpredictability, and stay financially viable. Moreover, Levelized cost of energy (LCOE) is a measurement used to assess and compare alternative methods of energy production. The LCOE of an energy-generating asset is the average total cost of building and operating the asset per unit of total electricity generated over an assumed lifetime.
The formula of LCOE:

$$LCOE = \frac{Io + \sum_{t=1}^{n} \frac{At}{(1+i)^t}}{\sum_{t=1}^{n} Mt,el/(1+e)^t}$$

LCOE Levelized cost of electricity in EUR/kWh
Io Investment expenditure in EUR
At Annual total cost in EUR per year, t
Mt,el Produced amount of electricity in kWh per year.
i Real interest rate in %
n Economic lifetime in years
t Year of lifetime (1,2, ...n)

If the LCOE is lower than the power cost the plant can accomplish, the venture can possibly turn a benefit. If the LCOE is higher than the power cost, the venture will likely be non-profitable. LCOE is important as it enables us for the comparisons between different energy-producing technologies. As a result comparisons are possible, regardless of unequal life ranges, contrasting capital costs, measures of the ventures, and different threats related to each project. This is possible because LCOE gives the per-unit cost of electricity generated, and the risk of each project is an implication of the specific discount rate used for each power-generating asset. ROI: Investors need to figure out the expected ROI of their investments. Renewable energy projects will most likely involve a more extended repayment period; however, they can provide a stable cash flow over the long term. In the direction of renewables becoming competitive, their costs should drop to the discounted power cost or the cost at which fossil-fuel control plants offer power to the network.

The pattern of cost analysis for Renewable resources:

It is the sum of the numerous fixed and variable expenditures that comprise a company's total expenses. Cost structure is used by businesses to determine pricing and find areas where expenditures may be decreased. The costs for externalities associated with renewable energy are considerably lower than one Eurocent per kilowatt-hour. So, while fossil fuels may have a cost advantage over renewable energy based solely on market prices if the externalities were included, several renewable energy sources would likely become the most affordable, mainly onshore wind, geothermal, and biomass energy. So, this advocates that the main factor currently hindering the change towards renewable energy is the failure to account for externalities. Factoring in the externalities cost and making the prices' right' would give a clear message to businesses and consumers that dependence on fossil fuels is bad economics. An estimated comparison of the cost of electricity generation in 2020 by utilizing traditional fossil fuel methods and various renewable alternatives has been shown in Fig. 3.

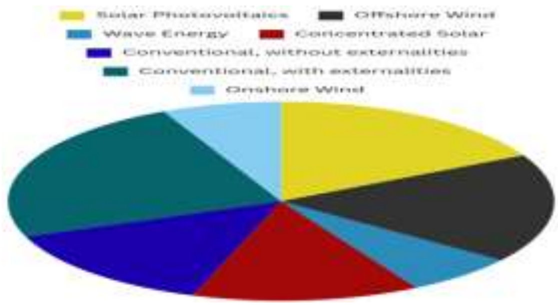

Fig: 3 Cost of electricity generated from various sources

Based only on production costs, the renewable sources of onshore wind, wave energy, concentrated solar, and potentially offshore wind are all expected to be cost-competitive with fossil fuels. Once the effect of externalities is included, all renewable sources are less expensive than fossil fuels. These results imply that there are good economic reasons to promote a sustainable transport transition towards renewable[20]. Solar panels and inverters constitute the significant cost component. Prices have been steadily decreasing, making solar more accessible[21]. Installation and labor costs can vary depending on project size and location, with hilly regions potentially incurring higher expenses[22-25].

Discussion

Low-temperature solar thermal systems collect solar radiation to heat air and water for industrial applications, whereas high-temperature solar thermal systems: use mirrors and other reflective surfaces to concentrate solar radiation. Solar water heating is already financially competitive with fossil fuels in many climates. Solar space heating is also possible, but the challenge is that solar space heating systems almost always require some supplemental heat source. LCOE Solar thermal systems, which use sunlight to generate heat, have higher LCOEs than solar PV due to higher installation and maintenance costs. Similarly, wind turbines are installed on land and range in size from small turbines used for individual homes or businesses to large wind farms that supply power to the grid (Fig 4). Onshore wind farms are more common and have been in use for a longer period. They are often located in areas with consistent and robust wind patterns. However, like all energy sources, wind power has its externalities. The main ones of concern are the aesthetic impact of the wind turbines, which are commonly over 400' in height; noise related to wind in turbine blades, which can be troublesome close to wind turbines; and bird mortality from collisions with turbine blades.

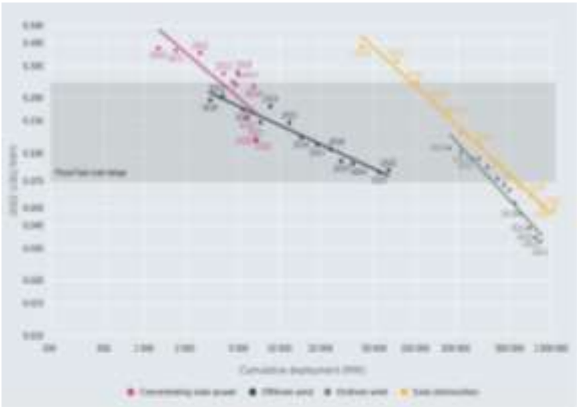
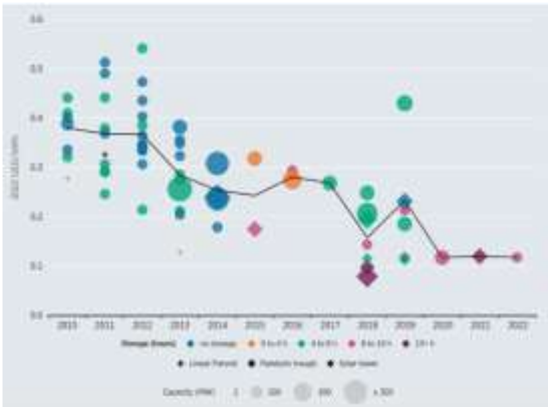

Fig. 4 (A) LCOE analysis of solar resource (B) LCOE analysis of wind resource

Onshore wind and solar PV generally have the lowest LCOEs among renewable energy sources, making them highly competitive with conventional fossil fuel generation (Fig 5 A). Offshore wind, hydroelectric power, and biomass energy have higher LCOEs due to varying factors such as resource availability, technology costs, and geographical constraints. The ROI in Solar PV and onshore wind are attractive and widely deployed due to mature technology and favorable economics. They have relatively shorter payback periods, making them attractive investment options for both small-scale and large-scale projects. Offshore wind, large-scale hydro, and biomass energy projects require higher upfront investment and longer payback periods due to operational complexities and, thus, have relatively low ROI (Fig 5 B). Solar PV and Wind Power energy sources generally offer lower LCOE and shorter ROI, making them widely adopted and economically viable options for renewable energy generation. Likewise, hydroelectric power has competitive LCOE. Its longer ROI and environmental considerations can impact its overall economic attractiveness. Similarly, Biomass and Geothermal sources have higher LCOE and longer ROI due to resource constraints, technology costs, and other factors, making them less competitive compared to solar and wind power.

Conclusion:

India's solar energy capacity has grown significantly, increasing from 1.60 GW in 2013 to 63.15 GW in 2022. Solar power, including rooftops, accounted for about 49.1% of renewable power sources' total installed generation capacity in 2022. In FY 2022, the share of solar power in India's total electricity generation was 5%. Similarly, wind power accounts for 36.73% of the installed grid-interactive renewable power capacity. The wind energy potential in India is very high, estimated at 695.5GW at 120m in height. Likewise, according to the Central Electricity Authority (CEA) estimates, India has 145 GW of Hydroelectric potential, of which just 29% has been constructed. A similar kind of report has also been observed by Ilja Pawel in 2014[16]. The share of hydropower has declined from 29% in India's electricity production in 1985 to just 9% today. In contrast, India's geothermal energy has huge potential to become a leading contributor to generating ecofriendly and cost-effective geothermal power. However, the current utilization of geothermal energy in India is relatively low. Based on the analysis and research, solar energy seizes significant financial viability in Uttarakhand as the state has abundant sunshine, government incentives, and decreasing costs create a favorable economic outlook[22]. While initial investment costs and specific project challenges exist, careful planning, utilizing subsidies, and considering technological advancements can significantly enhance the project's feasibility. As solar technology continues to evolve and policies become more supportive, the state is the potential to harness clean and sustainable solar energy for significant growth and utility.

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