# Cost of Power Generation Technologies: An Overview of LCOE Metric

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**Abstract**
Transition to a cost-effective and low-carbon energy technology is necessary for achieving sustainable development goals in this modern era. High economic and storage costs of renewable energy are the key hindrances to the country's consistent and sustainable electricity supply. Although conventional sources are more cost-competitive than renewables, they are limited in amount, pose environmental threats, and depend on other countries for import are the key concerns. Studies revealed that renewable energy sources with storage requirements are more cost-competitive than conventional ones. This study critically examines the LCOE metric used for checking the feasibility of electricity generation technologiesfor 20 to 40 years.Levelized electricity cost of power generation technologies will decrease if we move to 100% renewable energy adoption. Following the introduction, we discussed assumptions made for estimation, parameters involved in the metric, and the cost components ignored by this metric. Most studies considered producer cost for comparing the electricity generation technologies ignoring the additional consumer and external costs with societal implications, which is inadequate for decision and policy-making. Previous studies also ignored critical components such as inflation rate, integration, and system costs for comparing the electricity generation technologies feasibility. However, there is no agreement on this opinion due to the wide disparity in factors influencing electricity costs of technologies (LCOE) across nations. The additional costs integration (storage cost, external cost) would result in a more comprehensive evaluation of power-generating projects and the system. Therefore, there is a need to modify the LCOE metric by incorporating other significant components.
***Keywords*:** Power generation, Levelized cost, Renewables energy technologies, Sustainability, Conventional sources.

**Introduction**

Electricity distribution has become a necessary aspect of the country's progressive development. A stable, abundant, and affordable electrical supply underpins many human activities. The electricity production in the energy grid using fossil fuelscontribute significantly to the generation of greenhouse gases. Other environmental consequences produced by the power sector are water contamination, health hazards, and land degradation, which calls for the decarbonization of the electricity sector. India depends on fossil fuels for more than 60% of its electricity generation (CEA (Central Electricity Authority)2021). The country's electricity demand increased from 612 TWh to 1158 TWh between 2009 and 2019, making it the world's third-largest electricity market. The projected power demand of India will increase at a rate of 5% per year by 2040, which would triple global power demand (IEA (International Energy Agency)2020). In 2021, India's total electricity generation capacity was 3,90,791MW, of which 2,34,024MW from fossil fuels and 1,56,347MW from renewable energy sources. The country's power supply is 8,17,816 MU; still, there is demand for 8,21,705 MU of energy (MoP (Ministry of Power)2021).National Electricity Plan has prepared a ten-year action plan to deliver electricity to citizens effectively at an affordable cost in the country(NEP (National Electricity Plan)2016). The plan reaffirms the administration's obligation toward modernizing the power industry, suspending 48.3 Gigawatts of old coal plants, with a primary objective of raising the share of renewable power in the coming decade. In 2017, the plan predicted the shutdown of 22.7 Gigawatts of coal plants due to the insufficient area meant for FGDs equipment up to 2022 (IEEFA (Institute of Energy Economics and Financial Analysis)2021). Integrating renewables in power generation is significant in maintaining energy security andreducing carbon emission, for this target of installing 450 GW of renewable power have been made by 2030. However, because of the Covid-19 pandemic, improvement stalled in 2021.Several countries changed their power policy to mitigate global warming and increase the security of the energy supply. United Nations Framework Convention on Climate Change (UNFCCC)is committed to reducing greenhouse gas emissions under the Kyoto Protocol by providingincentives to encourage renewable energy sources. Consequently, many countries have made goals for boosting the proportion of sustainable sources for the power industry. The emphasis on renewable power generation will benefit the environment, energy security, and availability.

A study on the co-benefits of intense emission reduction policies asserted that emissions reduction policies could prevent 36000 premature deaths annually from 2016 to 2030 and implied that the avoided deaths would exceed the climate benefits of these policies (Shindell et al.,2018). Many corporations have announced theirrenewable energy goals for fulfilling these eleven different power generatorsand have committedto India's 301 GW of energy generation.However, renewable energy growth necessitates storage technologies in the power system. According to a Brookings study, renewable energy with a storage system may be comparable with new coal facilities but not existing coal plants. The study estimated thatthe storage requirement of India will be roughly 220 GW by 2028, slightly more than the 2022 aim but far lower than the recently announced 500 GW target. These findings show that energy production may struggle to replace coal power since rising storage costs for renewables may erode cost advantages over coal.It can be said that comparingenergy generation costs from various sources is difficult because of adding more renewable power sourcesto the grid.This research examines numerous energy production cost evaluations to discover variations in techniques and underlying assumptions to understand the reason for widely disparate cost estimates in the literature. These distinctions are examined in detail, emphasizing several significant factors impacting the claimed electricity production costs.The cost of wind and solar PV has fallen over the decade, indicating the future competitiveness of renewables over conventional power sources, as shown in Fig.1.

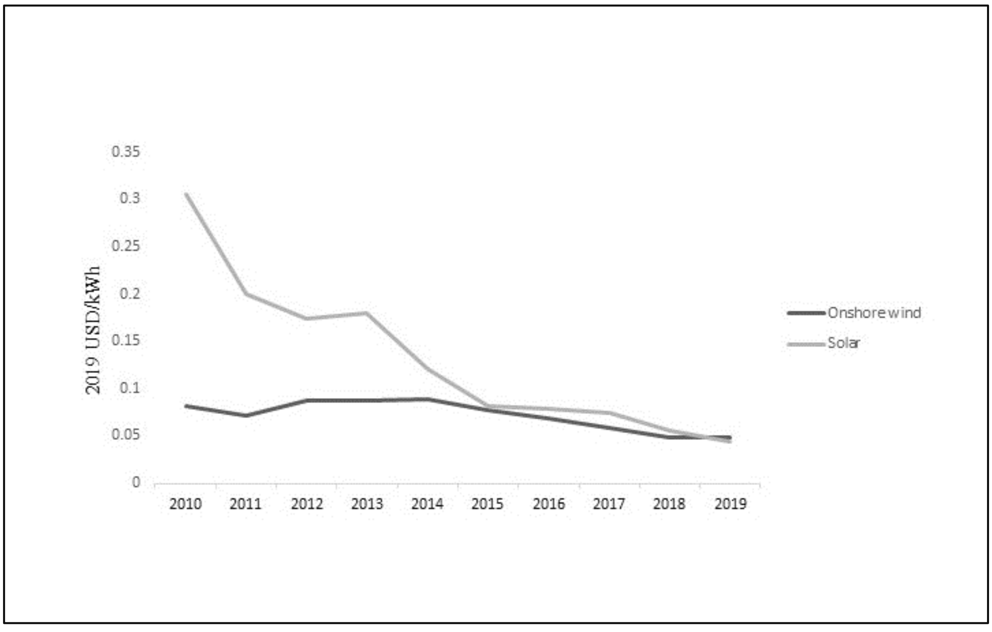


*Figure 1. Technology-wise levelized cost in India (2019 USD/kWh). (Ourworld data)*

### *1.1 Installed capacity and electricity generation in India*

Over the years, the installed capacity of India has increased; till 2010, it was 173626 MW,now it has been increased to 407796.67 MW. The share of renewable power generation has increased in the last decade, as shown in Table1.

**Table 1. Sources of installed capacity and power generation in India**

| Year | Installed capacity (MW) | Total electricity generation (BU) | Conventional Sources (BU) | Renewablesources (BU) |
|---|---|---|---|---|
| 2010-11 | 173626 | 850.387 | 811.142 | 39.245 |
| 2011-12 | 199877 | 928.113 | 876.887 | 51.226 |
| 2012-13 | 223344 | 969.506 | 912.057 | 57.449 |
| 2013-14 | 248554 | 1,020.200 | 967.15 | 53.050 |
| 2014-15 | 274904 | 1,110.392 | 1,048.673 | 61.719 |
| 2015-16 | 305163 | 1,173.603 | 1,107.822 | 65.781 |
| 2016-17 | 326833 | 1,241.689 | 1,160.141 | 81.548 |
| 2017-18 | 344002 | 1307.76 | 227.95 | 101.839 |
| 2018-19 | 356100 | 1375.95 | 261.65 | 1,114.3 |
| 2019-20 | 370106 | 1389.12 | 294.09 | 1,095.03 |
| 2020-21 | 382151 | 1381.86 | 297.55 | 1,084.31 |
| 2021-22 | 399496 | 1491.9 | 321.02 | 1,170.88 |

***CEA (2022).***

## 2.Theoretical background

Levelized electricity cost (LCOE) is a frequently used metric to estimate the power plant's cost, facilitating comparison between generation sources.Larsson et al. (2014) emphasized that the typical levelized electricity cost model is based on the producer perspective, ignoring the consumer perspective and societal impacts.Every year,the international agency Lazard provides a global report on LCOE, as shown in Fig.2. In this metric, prices are standardized to include investment cost, maintenance cost, capacity factor, and fuel cost.The value of LCOEdepends on whether the power plant is new or old; that is why the cost of newly installed solar power plants is higher than that of an old coal-fired power plant. Based on current economics, coal is a more cost-effective option than renewables. Renewable power may struggle to displace existing coal assets, particularly near coal mines.According to Brookings's estimate (2018), the LCOE of the newly installed solar plant without storage is lower than the new coal-fired power plant in India. Tran and Smith (2018) evaluated the levelized electricity cost of energy technologies and checked the effects of input variables using the Monte Carlo approach.(IRENA (International Renewable Energy Agency)2012) reported that capital cost, discount rate, operating and maintenance cost, interest rate, inflation rate, the level of solar irradiation, cost of finance, administrative expenses, taxes, dismantling cost, and thesolar cells' efficiency influence the power generation cost of a photovoltaic system. Solar electricity generation costs are mostly determined by capital expenditure (equipment, module, and installation). Among these factors, module cost covers almost half the entire cost, which leads to higher investment in solar photovoltaic plants. Solar power plants work without fuel, withvery little maintenance, and have an average lifespan of 20 to 25 years.

Besides the factors mentioned above, solar irradiance isthe most influential factorin the energy yields of PV systems(Bertrand et al., 2018; Gurturk et al., 2018).Parrado et al. (2016) calculated LCOE andexamined the suitable options among photovoltaic power plants, concentrated solar power plants, and hybrid PV-CSP plants of different capacities for continuous energy supply.Results of the study reported that PV-CSP power plants are a practical choice for the ongoing supply of sustainable electricity. Allouhi et al. (2019) examined three varieties of on-grid PV systems to analyzetheir energetic, economic, and environmental effects. The study revealed that installing on-grid PV systems is economical and mitigates environmental effects.Ross et al. (2016) examined the role of enterprises in utilizing solar PV systems to reduce their reliance on their sole electricity source and reported thatsolar PV systems' feasible energy generation cost should be between Rs. 0.91 and Rs. 2.07 per kWh. Zhao et al. (2016) calculated the cost of thermal, nuclear, hydropower, natural gas, wind, and biomass power plants using the LCOE model. In this study,they observed thatthe overall cost of the biomass power plant wasthe maximum, while the total electricity generation cost of the hydropower facility wasthe least. Hernandez-Moro and Martinez-

Duart(2013)projected that solar electricity costs for CSP will decline dramaticallybut at a much slower rate, and the cost reductions for PVwould be low initially; however,over time, they might surpass those for CSP. Sklar-Chik et al. (2016) investigated the cost competitiveness of 20 megawattsof concentrated solar power and photovoltaic power plants. They showed that the PV plant is economically competitive compared to the CSP plant. Bano and Rao (2016) analyzedthe effect of different parameters onthe levelized cost of electricity. Theyfound that LCOE rises with an increase inthe inflation rate, plant life, capacity factor,and interest rates. Gioutsos et al. (2018)determined that the levelized costof electricityreducesas renewable energy penetration increases but upto acertain. Sharma et al. (2018) examined that the annual electricity generation varies significantlydue to differences insolar radiation intensity, resulting in levelized cost differences.Prakash et al. (2020) revealedthat supercritical and ultra-supercritical technologies imbibe less cost for minimizing carbon emissions from coal power plants.Kamal et al. (2021) found thatPV, wind, battery, and diesel provide the lowest cost to electrify the remote community in the proposed location compared to other energy systems. In contrast,Wehbe (2020) evaluated thatthe LCOE of natural gas turbines and hydropower plants would be the least, followed by waste-to-energy plants and onshore wind plants in 2030. Breyer and Gerlach (2013) stated that photo voltaicpower generation wouldbecome cost-competitive to conventional energy sources. Januar (2017) examined that photovoltaics are economically competitive compared to solar thermal plants.Ouyang and Lin (2014) suggested that renewable energy feed-in tariffs should be modified based on the levelized electricity cost to promote renewable development. Hansen (2019) found thatby substituting nuclear power with variable renewable sources, carbon dioxide($CO_2$) emissions may increase in some conditions due to a temporal disparity in demand and supply, promotingfossil-based power generation.Even though the levelized cost (LCOE) is a valuable metric, its valueis affected by input variables. Sensitivity analysis determines the most important input variables for calculating the cost of power generation and checks the effect of input variables on theoutput cost. Capital expenditure impacts power generation technologies' levelized cost (LCOE), followed by the discount rate, fuel cost, and economic life (Lee and Ahn,2020). The National Renewable Energy Laboratory's standard formula for calculating lifecycle costs is provided below (NREL):

$$LCOE = \left\{ {(Co * CRF + Fix.O\&M\ Cost}/{8760 * CF)} \right\} (F * HR) + Var.O\&M\ Cost$$

In the above equation, $C_0$ is overnight capital cost, CRF is Capital Recovery Factor, CF is Capacity Factor, Fis Fuel cost, and HRis Heat Rate.

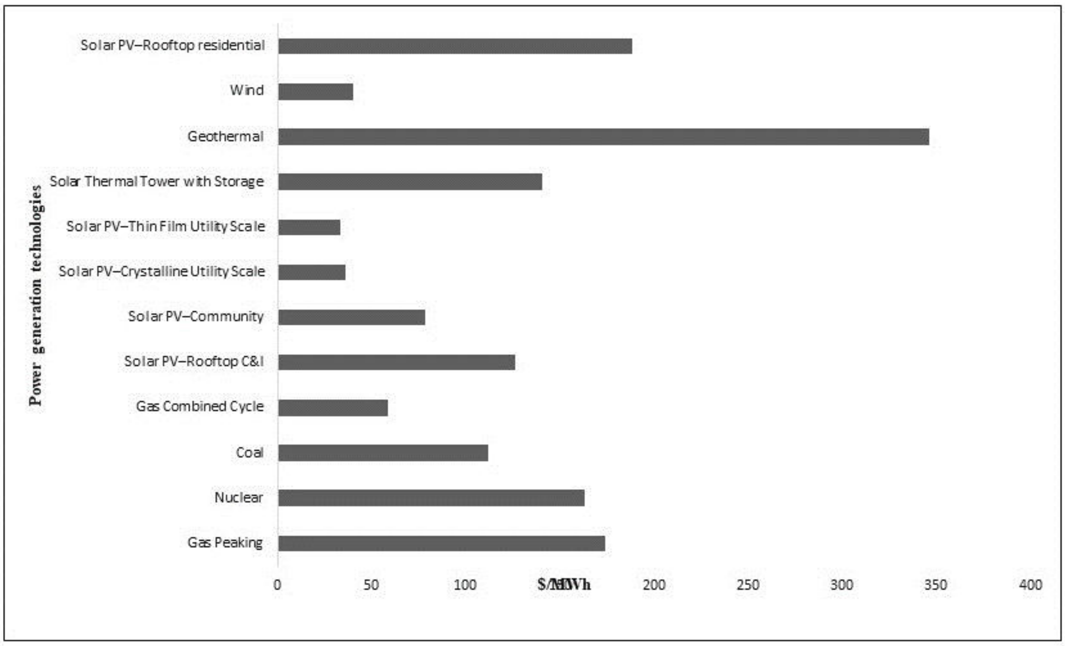


*Figure 2.Global LCOE of power generation technologies. (Lazard,2020).*

### *2.1. Parameters used in LCO Ecalculation*

The Levelized Cost of Energy (LCOE) calculation involves several key parameters, each crucial in determining the overall cost efficiency. These factors include capital cost, fuel cost, auxiliary consumption, generation efficiency, land cost, operation and maintenance cost, degradation factor, and discount rate. The social perspective of parameters not integrated with the LCOE metric is illustrated in Fig.3.Among these parameters, capital cost stands out as a significant influencer on LCOE output. Numerous studies have focused on calculating the total capital cost of photovoltaic (PV) systems, with some examining module prices and other component costs separately. The breakdown of PV capital costs often includes module cost, land acquisition expenses, general works, mounting structures, power conditioning units, decommissioning costs up to the interconnection point, and preliminary expenses (Ayompe et al., 2010; Fraunhofer ISE, 2018; Breyer and Gerlach, 2013). Another component, Fuel cost, is a vital in the levelized cost calculation, but it does not apply to renewable technologies, excluding Biomass, as they do not rely on traditional fuels (Prakash et al., 2020).

Auxiliary consumption is a critical aspect of energy management, encompassing the energy used for system operations such as fans, air conditioning, and lighting. This consumption, which bridges the gap between gross generation and energy export, plays a vital role in optimizing fuel usage while maintaining electricity generation within a given plant configuration.Another key determinant in the levelized cost of energy (LCOE) is generation efficiency, representing the proportion of energy produced relative to the input energy supplied to the plant. Factors influencing the module efficiency of photovoltaic (PV) plants include the site's orientation, angle, solar irradiation, shade, load, and temperature (Saleem et al., 2019). Notably, shading from nearby structures and trees emerges as a critical factor impacting the efficiency of solar panels.Estimating land cost, also a challenging task dependent on location, is crucial in the context of photovoltaic installations. Typically requiring 10–50 square kilometers per gigawatt less than coal power plants (IEA, 2004), land cost estimation also considers country-specific inflation rates when adjusting the present value of the land.Operating and maintenance costs for utility-scale PV systems vary significantly based on size, type, local climate, and season. Projections by the European Commission (2005) suggest a 0.5 to 1 percent decrease in the initial investment rate of solar technology by 2030. Maintenance costs are often considered 1.5 percent of the capital cost, covering module cleaning, supervision, and replacement of associated components (Hernandez-Moro &Martinez-Duart,2013). Other studies, such as those by Bano and Rao (2016), Kohle and Joshi (2002), and Bhandari and Stadler (2009), assume a 1% operating and maintenance cost of the original investment.

The degradation factor, indicating the decline in the conversion efficiency of a power plant over time, is another crucial parameter. Solar PV modules experience reduced performance due to exposure to ultraviolet (UV) rays, with a system typically considered failed when its initial efficiency drops by 20%. Studies indicate degradation rates of 0.6% and 0.7% per year for PV modules (Branker et al., 2011; Jordan & Kurtz, 2012). Manufacturers can enhance procedures to minimize early module failures and reduce uncertainty in system degradation rates.The discount rate is pivotal in LCOE calculations, accounting for inflation rates and technological risks. Lee and Ahn (2020) underscore its significance, attributing 18% of the variance in cost estimation to the discount rate. Zweibel et al. (2008) noted thatthe private sector favors higher discount rates for short-term profit maximization, such rates may be excessively high to capitalize on the long-term benefits fully. Consistently considering these parameters is crucial in accurately assessing and optimizing the levelized cost of energy for photovoltaic systems. The period of operation (Lifetime) is a significant factor in calculating the LCOE of every power plant.Concerning this, Fig.4. depicts the phases in the power plant's lifecycle. The Solar PV plant life is generally taken as 25 years in many studiesasa warranty is providedfor 20–25 years by manufacturersofthe solar PV system (Dunlop et al.,2005; Pacca et al.,2007; Hernandez-Moro and Martinez-Duart,2013; Bearley,2009).

Capacity Utilization Factor (CUF)orCapacity FactororLoad factor would be the ratio of the actual output of the power plant compared to theelectricity generated if it runs continuously at its rated capacity over a year.It assesses the reliability of different power plants.The plant location and technology type are highly affected by capacity factors(Horner& Clark,2013). Lazard,an international organization,does not considerthe difference between CUF and CAF and terms it as 'CF.'The CUF does not account for environmental factors such as irradiance variations from year to year or panel degradation.Finally, the Capital Recovery Factor (CRF) amortizes an initial capital investment over time. It is the nominal periodic amount required to repay an initial loan plus interest (NREL,2020). According to Sahu (2015), the expenditures must be spread out and updated over the predicted years of operation to assess the plant's annual expenses.

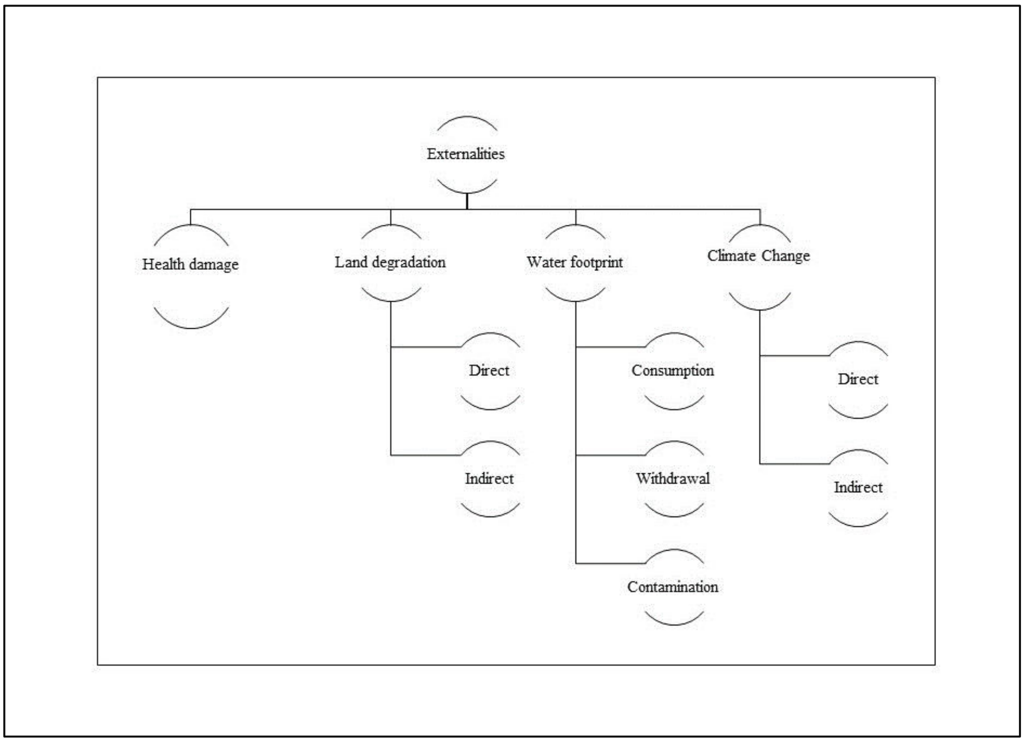


***Figure 3.Components not included in typical LCOE metric***

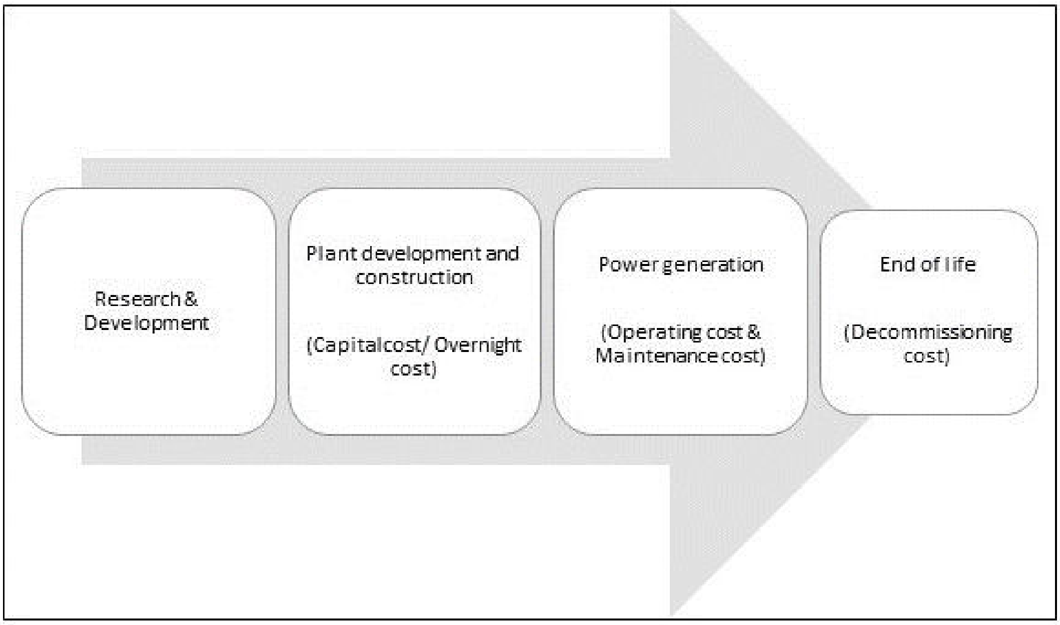


*Figure 4. Lifecycle cost components of power plants.*

**3.Methodology adopted**

A comprehensive review was conducted using Web of Science, Scopus, and Science Direct databasesto identify core concepts of the levelized cost methodology and variables used to calculate the power generation. Boolean search strings such as 'Cost of electricity' OR 'Economic cost of power generation' OR 'Levelized cost of electricity' OR 'Levelized electricity cost' OR 'Power generation cost of coal' OR 'Cost of solar power generation' OR 'Impact of power generation' OR 'Levelized electricity cost' OR 'Electricity generation through thermal power plants' AND 'Social cost of energy generation' OR 'Social cost of solar PV system' OR 'Coal power plants' OR 'External cost of electricity generation' were used for searching the available literature. We retrieved articles containing the abstract, title, and keyword search queries. The search aimed to locate existing literature in various areas: such as social science, energy fuels, environmental science, energy sustainability, energy economics, and environmental studies.

**4. Conclusion**

This study delves into the widely adopted and utilized Levelized Cost of Electricity (LCOE) metric within global electricity projects. A comprehensive examination of prior research on power generation systems forms the basis of our inquiry. The existing LCOE methodology primarily concentrates on the costs associated with power generation. However, in the strategic planning of sustainable electricity systems, it becomes imperative to extend assessments beyond the immediate generation costs and account for external costs and system-wide influences.The profound impact of country-specific variables on cost outcomes underscores the necessity to approach power generation costs at a country-specific level. Moreover, costs exhibit location-specific characteristics, susceptible to changes in input parameters, and display dynamic trends over time. To draw accurate conclusions, cost assessments must maintain transparency, considering the contextual scenarios in which they are applied.Assumptions regarding discount rates, fuel prices, and heat credits vary significantly, introducing notable fluctuations in the production cost estimates of various power generation technologies. Consequently, caution is warranted against generalizing power generation costs to represent specific technologies. To enhance the effectiveness of the LCOE metric, it becomes imperative to incorporate additional essential components, thereby refining its applicability and relevance in the complex landscape of power generation assessments.

**Declaration of interests**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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