Energy
Volume 259, 15 November 2022, 124905

Levelized Full System Costs of Electricity

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https://doi.org/10.1016/j.energy.2022.124905
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Highlights

- Levelized Costs of Electricity ignore the cost of intermittency of renewables.
- Including storage to balance them increases the costs of variable renewables.
- Levelized Full System Costs of Electricity include the cost of balancing.
- Combining wind and solar with a firm resource reduces costs significantly.

Abstract

Different electricity generating technologies are often compared using the Levelized Costs of Electricity (LCOE), which summarize different ratios of fixed to variable costs into a single cost metric. They have been criticized for ignoring the effects of intermittency and non-dispatchability. This paper introduces the Levelized Full System Costs of Electricity (LFSCOE), a novel cost evaluation metric that compares the costs of serving the entire market using just one source plus storage. Like LCOE, and in contrast to alternatives such as System LCOE, LFSCOE condense the cost for each technology into one number per market. The paper calculates LFSCOE for several technologies using data from two different markets. It then discusses some refinements, including the LFSCOE-95 metric that require each technology to supply only 95% of total demand.

Introduction

The lifetime costs of an investment are key measures for decision-making. This is true for investment decisions in electricity markets as well, where the most popular measure to compare different technologies for generating electricity are the Levelized Costs of Electricity (LCOE). To calculate the LCOE, the expected lifetime generation of an electricity generating plant and the expected costs to generate the lifetime electricity are calculated. After dividing total costs by total generation, the final number (usually in USD/MWh) is derived. Input assumptions like capacity costs, maintenance, marginal operating costs, or average capacity factor, which is particularly relevant for renewable sources of electricity, are crucial for the calculation and vary by study.[1] For example, Lazard estimates the LCOE of coal between 66 and 152 USD/MWh and onshore wind between 28 and 54 USD/MWh, whereas the U.S. Energy Information Agency (EIA) derives LCOE for coal of 76 USD/MWh and LCOE for wind of 40 USD/MW [1], [2]. Many recent studies indicate that the LCOE are the lowest for onshore wind and utility-scale solar using photovoltaic cells (hereafter referred to as “solar PV” or “solar”), findings frequently cited by proponents of a fast transition towards renewable electricity. Nevertheless, if it is the cheapest source while not emitting CO2, why are countries still investing heavily in new gas and coal power plants? Is it just because coal generation may employ more people in politically sensitive regions of the country, or are there financial reasons not reflected in the LCOE?

Critiques of LCOE are not scarce. Joskow is one of the first to point out that LCOE ignore the costs associated with intermittency [3]. It is easy to see the fundamental misunderstanding in LCOE: The LCOE describe the costs of generating electricity. However, the function of supply in electricity markets is not to generate electricity but to provide a specified amount of electricity to a specific place at a particular time. The locational aspect adds significant additional costs to renewables that are generally less flexible about where they can be sited than fossil fuel plants. As a result, a larger grid is required to transport the electricity from, e.g., hydropower plants to the demand in urban areas. These transmission costs are partly taken care of in some LCOE estimates when a transmission cost adder is included in the LCOE. But the timing aspect turns out to be even more crucial and the focus of this paper. Many renewables (like wind and solar) are intermittent and non-dispatchable (hereafter referred to just as "intermittent" unless further specified), and some that are not intermittent (like run-of-river-hydro) are often not fully dispatchable.[2] As long as the share of intermittent generation is low, sufficient dispatchable generation capacity will usually be available to step in and replace missing intermittent generation output. Economically, the fact that intermittent generation has no obligation to meet the demand can be seen as a hidden subsidy. One can even go one step further and argue that intermittent generation is of zero value if it cannot be made available to consumers who demand a steady electricity flow. To do that, however, supply and demand on the network must always be in balance. In effect, the ability to schedule other generators to continuously maintain that balance is necessary to give value to renewable output. The dispatchable generators thus raise the value of renewable generation, but the subsidy is "hidden" because the latter does not have to pay for it. Once the share of intermittent generation increases to a certain level (and dispatchable capacity is shut down), efforts have to be taken to maintain system reliability. But who should be responsible for these costs? How can the cost of integrating renewables into the system (which increases significantly with their market share) be included in the evaluation of their cost?

Ueckerdt et al. address the cost of integrating renewables into a network by introducing the "System LCOE" [4]. The System LCOE of an intermittent source are defined as the sum of the (marginal) generation costs (the LCOE) and the (marginal) integration costs, where integration costs can be split up into balancing costs, grid costs, and profile costs — see Section 2 for further information of System LCOE. Unlike conventional LCOE, the System LCOE of renewable sources of electricity depend highly on their market share. If the share of wind (resp. solar) generation increases, the generation costs (i.e., the LCOE) remain constant, while the integration costs increase significantly. In their calculation, the System LCOE for wind in Germany increase from 60 EUR/MWh to almost 100 EUR/MWh if the share increases from 0% to 40%.

The System LCOE seem to be state of the art and reasonably accurate (see Reichenberg for further refinement), but are apparently too complicated and "not catchy" enough to be used by a non-academic audience [5].[3] However, there is a high necessity of a cost measure that includes the costs of intermittency and is accessible to a broader audience. Since the transition of electricity generation towards zero-carbon sources became a crucial topic in public debates and politics, the LCOE have become the most popular measure to evaluate investment decisions and market developments in electricity generation. As politicians and policymakers fail to understand the limitations and flaws of this measure and spread the idea that solar PV and wind are the cheapest sources of electricity, there is a need for a cost measure that addresses the limitations of LCOE yet remains accessible to a broader audience by being catchy and straightforward.

This paper introduces a novel method to evaluate the costs of electricity that is catchy and includes the costs of intermittency: The Levelized Full System Costs of Electricity (LFSCOE). The LFSCOE are defined as the costs of providing electricity by a given generation technology, assuming that a particular market has to be supplied solely by this source of electricity plus storage.[4] Methodologically, the LFSCOE for intermittent or baseload technologies are the opposite extreme of the LCOE. While the latter implicitly assume that a respective source has no obligation to balance the market and meet the demand (and thus demand patterns and intermittency can be ignored), LFSCOE assume that this source has maximal balancing and supply obligations. This paper shows that in both Germany and the region of the Electricity Reliability Council of Texas (ERCOT), the LFSCOE of wind and solar PV are higher than the most expensive dispatchable technology examined in this paper.[5] Simulating the effect of decreasing storage costs, we observe that although the LFSCOE for wind and solar drop significantly, even a storage cost reduction of 90% is insufficient to make wind or solar PV competitive on an LFSCOE basis.[6] Allowing for losses in the charging and discharging process, it is interesting to see the small magnitude of economic effects of even significant storage losses in such a system. Last, we extend the LFSCOE to

LFSCOE-95, which assume that only 95% of the system must be supplied by a certain technology plus storage. While the LFSCOE-95 are only slightly lower than the LFSCOE for dispatchable technologies, they are about 50% lower for intermittent sources, which challenges the economic sanity of 100% intermittent renewable targets.[7]

This paper is structured as follows: Section 2 introduces the method for calculating LFSCOE and concludes with the cost evaluations for the markets in ERCOT/Texas and Germany. Section 3 examines different changes in the model assumptions (such as storage losses), follows up with an analysis of significant decreases in storage costs, and concludes with introducing the LFSCOE-95. Section 4 discusses potential model extensions and concludes.

To my knowledge, the cost measure and evaluation methodology introduced in this paper are new. However, studies have been conducted that address the cost of intermittent renewables or baseload technologies when they are responsible for meeting the market demand. Becker et al. examine the requirements of a fully renewable system in the U.S., whereas Hartley those of a wind-only market in Texas [8], [9]. Denholm combine renewables and nuclear with storage [10]. For the market in Germany, Sinn discusses economic challenges by pointing out the large curtailment and storage requirements in a wind and solar market in Germany (using existing storage in Norway), while Zerrahn et al. conclude that electrical storage would rather not limit the transition to renewable energy [11], [12]. It is important to note that the motivation of this paper is to introduce a novel methodology of calculating costs and then use this methodology to examine some relevant counterfactuals. Given the simplifying assumptions, the numbers should not be seen as definitive.

Section snippets

Levelized full system costs of electricity

This section first introduces the concept of the Levelized Full System Costs of Electricity and compares 5 dispatchable technologies (biomass, ultra-supercritical coal (USC), natural gas combined cycle (CC) and combustion turbine (CT) as well as nuclear) with wind, utility scale solar PV (called “solar” from now on), and an optimal combination of wind and solar. …

Counterfactual: Impact of falling storage costs.

Using the initial model as described above, LFSCOE can be determined if the costs for storage decrease significantly.

Fig. 3 supports the intuition: Technologies that require large storage facilities (like wind and solar) benefit from a significant decrease in storage costs, whereas the effect on the LFSCOE for dispatchable technologies (like nuclear and natural gas) is barely noticeable. A reduction in costs of storage capacity by even 95% would still not make the LFSCOE of wind, solar, or …

Conclusion

Intermittency of generation makes the cost comparison between different generation technologies much more difficult. While being a good measure to evaluate the cost to generate electricity, the most popular cost measure, the Levelized Costs of Electricity, fails to include the costs associated with meeting the demand and providing usable electricity. On the other hand, the System Levelized Costs of Electricity by Ueckerdt et al. include the cost of integration and balancing, but do not seem to …

CRediT authorship contribution statement

Robert Idel: Study conception and design, Data collection, analysis and interpretation of results, Manuscript preparation. …

Acknowledgments

I am grateful to two anonymous reviewers for their helpful comments. Thanks are also due to Peter Hartley, Olivera Jankovska, Kenneth Medlock, Kelly Neill, and the participants of the OSWEET conference in October 2020 for insightful discussions and comments. All errors and omissions are my responsibility. …

Declaration of competing interest

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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