Major Discussions on the Life Cycle Cost of Electricity Generation Systems

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Abstract. The aim of this paper was to discuss the use of Life Cycle Cost (LCC) in the assessment of electricity generation systems. To that end, it was conducted a systematic literature review. EndNote, Mendeley and Excel spreadsheets were used to manage references, while the VOSviewer and Microsoft Power Business Intelligence software tools were used to create visual maps. Europe seemed to stand out regarding the number of studies, while there was a lack of LCC studies in America, Asia and Oceania. Concerns seem to have switched from being only about the source for producing electricity to how to diversify the energy system including renewable energy in the energy mix. Overall, there seems to be a shortage of recent studies regarding the LCC of electricity generation systems, which requires further contributions to enable better decision-making.

1. Introduction
In order to analyze the financial feasibility, it is possible to use the Life Cycle Cost (LCC) method, which enables measuring the acquisition, operation, maintenance and final disposal costs of a given system. In LCC, different cost categories can be defined according to the study’s scope. Several studies involving LCC, as in the interest of this article, can be found in the existing literature, including comparisons of different energy production strategies, among other approaches.

Studies found in the literature, such as [1, 2, 3] used methods and tools, such as figure of merit (FM), net present cost (NPC), and levelized cost of electricity (COE) to characterize the performance of electrical systems and establish a relationship between the current net present cost of electricity and future energy sales. Therefore, it is possible to obtain more accurate estimates of the payback time and compare costs and sales prices if different renewable sources were applied.

The focus of this review is to analyze qualitative and quantitative characteristics of studies on LCC of electricity systems. To the best of the authors’ knowledge, this is one of the first reports on the existing literature on LCC of electricity systems. Thus, the present study assists in organizing, summarizing and pointing out future paths on this aspect. Therefore, the aim of this paper was to discuss the use of Life Cycle Cost in the assessment of electricity generation systems.

This study is structured as follows. This first section presented the initial considerations on the topic and stated the objective of this article. Section 2 presents the methods used to conduct this research. Section 3 unveils the main considerations on the LCC of electricity generation systems, as well as the bibliometrics on the field. Section 4 draws on this study’s final considerations, as well as limitations and suggestions for future research.
2. Methods
The investigation in this study was based on a systematic literature review, which was conducted in steps.

Step 1: Definition of keywords
The set of keywords, and their combinations, was defined using BOOLEAN operators and wildcards. The reference query for the search was: ("Life Cycle Cost*" OR LCC) AND ("electric* grid" OR "electric* mix" OR "electric* system" OR "electric* product*" OR "electric* generat*" OR "electric* energy").

Step 2: Search and document collection
The base query was used to conduct searches in the ScienceDirect, Scopus, and Web of Science databases, seeking to capture all available literature fitting the query up to January 13, 2020. The reference query was then adapted to the particularities of each database. The EndNote software tool, Mendeley, and Excel spreadsheets were used to manage the references. Therefrom, a series of filters were applied to select the relevant studies.

Step 3: Portfolio Selection
The searches returned a considerable number of documents. The assessment of all studies would be impractical time- and resource-wise. Thus, the following filters were used to select the most relevant studies:

- Excluding duplicates: all duplicate entries were excluded;
- Excluding grey literature: only articles from peer reviewed journals were kept, thus documents from all other sources were ruled out;
- Title, keywords and abstract: all titles, keywords and abstracts of all articles were read, and the documents not fitting this study’s scope were excluded;
- Full-reading: the remaining articles were read in full and only the studies closely related to this study’s scope were kept, the non-related articles were ruled out.

Therefore, 17 articles remained to be fully analysed in this article.

2.1. Visual Maps
The Microsoft Power Business Intelligence (BI) and the VOSviewer software tools [4] were used to create visual maps. Using Microsoft Power BI, a graph showing publications per year and per journal (Figure 1) was created. Using VOSviewer, the co-occurrence of terms map (Figure 2) was created based on text data, using the following settings: source: bibliographic data; type of analysis: co-occurrence; unit of analysis: keywords; counting method: full counting; threshold: 3.

3. Major Discussions on Life Cycle Cost of Electricity Generation Systems
The Sustainable Development Goals (SDG) bring in their goal nº 7 “Ensure access affordable, reliable, sustainable and modern energy for all”. This requires efforts in different areas such as technology, private and public investments and an increase in the access to renewable energy [5]. Therefore, without studies about the ways to produce clean energy, achieving this objective becomes difficult.

The studies addressing LCC mainly conduct comparisons between LCCs of different electricity generation sources. The sources include wind, biomass, diesel, and others. The studies were developed in many countries, thus, under different economic, environmental and social scenarios.

With two studies, Spain stands out. Research in the country includes investigating costs of melting aluminium for energy generation [6], comparing the potential impacts of three scenarios in the furnace: natural gas and alternating current power, natural gas and direct current power, and direct current. In turn, [7] conducted an LCC and assessed the economic feasibility of floating offshore wind farms.

The remaining contributing countries produced one study each, showing a lack of studies in the American and Asian continents. Hence, it can be noted the need for further studies in different areas and locations in order to increase the knowledge around the costs involved with different electricity generation sources, to allow more solid decision-making.

In the Netherlands, [8] excluded tax from their calculations and showed that using ethanol is more economically feasible than using gasoline, due to oil prices. On top of it, both studies of [9, 10] defended considering the costs of capital, operations and maintenance in their calculations.
[11, 12] used financial indicators as Present Value (PV) and Return on Investment (ROI) to analyze the economic feasibility of energy production from wind, solar power, hydrogen and other sources. The authors detected some elevated costs to these renewable energy pathways. Indicators as Internal Rate of Return (IRR) and Payback were used in the study of [7] to compare wind in different areas of Galiza, Spain. Some authors combined these indicators to some boundaries to their studies as Well-to-Tank (WTT), Tank-to-Wheel (TTW) and Well-to-Wheel (WTW). An example can be found in [12] comparing wind-hydrogen systems to generate electricity.

The study [13] analyzed three configurations in order to compare net present cost, energy cost and operating cost with the sales price, to estimate the payback times. The study by [2] point out that electricity production from biomass is important, making it possible to reduce government costs with organic waste and job implementation. In India, [1] showed that even with a positive economic and environmental performance of solar panels in different locations on the planet, it is still necessary to study each case, as the climate variable differs considerably from region to region. The work by [14], in China, addressed an analysis of the economic viability of the Solar Dish/Stirling (SDS) that uses solar energy. On an island belonging to Italy, in the Mediterranean, [3], discussed the economic feasibility of establishing an area dedicated to solar panels with the purpose of desalinating sea water, making it drinkable.

It can be seen, thus, many ways to conduct an LCC, with each study considering the local conditions. However, capital, operation, maintenance and final disposal costs, in most cases, are considered by the pieces of research. The lifetimes of the alternatives are also taken into consideration, the values range from 10 to 12 years depending on the energy source.

LCC studies have addressed different issues depending on when they seemed relevant. Therefore, Figure 1 shows the number of studies published per year, per journal and their respective impact factor.

![Figure 1. Number of LCC-related publications per year, per journal and their respective impact factors.](image)

Applied Energy, which has the second greatest impact factor, showed four publications related to LCC. These are related to photovoltaic panel systems [15], combustion systems [16], thermal energy storage systems [17] and the economic feasibility of using solar panels to desalinate sea water [3]. Similarly to the journal Applied Energy, Energy also published four papers [10, 18, 7, 13].
The most recent studies analyzed transportation, installation, operation and maintenance costs comparing energy from diesel generators to energy from photovoltaic systems [9] and costs of melting aluminium for energy generation in European countries [6]. The study of [19] reinforces the awareness of the characteristics and economics of photovoltaic panels on roofs, being vital for the implementation of renewable energy. Nevertheless, there seems to be a shortage of recent studies regarding the LCC of electricity generation systems, which requires for further and greater contributions in order to enable better decision-making. Thus, a more specific analysis could offer further insights on this literature body; therefore, Figure 2 shows a term co-occurrence map of the LCC studies in the final portfolio.

![Figure 2. Co-occurrence of keywords in LCC-related studies.](image)

Analyzing the term co-occurrence map and the afore discussion, the interest in studies of scenarios, technologies, electricity mixes, and economic feasibility have increased in the last few years. Concerns have switched from being only about the source for producing electricity to how to diversify the energy system including renewable energy in the energy mix. The methods to evaluate the feasibility have changed. The studies started combining economic indicators with LCA methods, but there is a lack of these studies in the literature yet. In the future, it is expected that analysis that evaluate the environmental and social impacts together with the economic dimension be conducted.

4. Final Considerations
This study aimed to discuss the use of Life Cycle Cost in the assessment of electricity generation systems, from which a few conclusions could be reached and some recommendations be drawn.

On the economic dimension, indicators are identified to evaluate a system of electricity production, as well as some boundaries were used by the authors to carry out their analyses. Depending on the scenario, in the long-term renewable energy sources are more economically feasible than the traditional ways of producing electricity. It is important to emphasize that each country has different characteristics according to where it is located.

The results in this study can be used to foment public policies towards more sustainable energy generation, as it could be seen that less environmentally impacting energy sources seem to also have positive economic results. On top of governmental implications, it enables practitioners and researchers to engage in partnerships towards the development of further research and technology by showing the main countries and institutions developing research on the subject worldwide.

This study contributes to knowledge generation on more sustainable practices towards electricity matrices/mixes, bringing out the knowledge of previous studies on the economic assessment of said systems. Such results present the scientific community with what has already been studied, as well as point out best practices on the economic dimension of electricity generation systems.
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