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Review article

A bibliometric review of grid parity, energy transition and electricity cost research for sustainable development

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ABSTRACT

As the topic of sustainable development continues to prominence in global affairs, the case for renewable energy has never been stronger. To be regarded as a perfect alternative to conventional (non-renewable) energy sources in many climes, renewable energy, such as solar and wind, shows promise when considering concepts like grid parity. A significant number of studies have been devoted to understanding the concept. However, only a few studies have committed themselves to analysing the research activity carried out on it. This paper will present a bibliometric and empirical review of worldwide grid parity, energy transition, and electricity cost research. To situate the progress in this research area, a detailed search of Scopus was used to identify and situate research development in the field from 1965 until 2021. Using the data extracted from Scopus and VOSviewer for analysis, we explore different aspects of the publications, such as the volume, growth rate, and coverage of published documents, the most influential research papers and journals in this research area, and the most studied research themes in recent years. We also discuss Governmental policies in developed and developing economies that have accelerated the attainment of Grid parity in certain countries. Also, an empirical review of top-down, bottom-up, and artificial neural network approaches to evaluating grid parity was conducted. The study revealed a steady increase in the research articles focused on grid parity, energy transition, and electricity cost research from 2006. The geographic distribution of the publications shows that most of the publications on the subject originated from the USA, Germany, China, United Kingdom, and Spain, raking in 42.2% of the publications. Also, the top 7 authors with the highest document count from Scopus are from Finland, which coincidentally is one of the countries making significant progress in Grid parity attainment. Of the total document count from Scopus, only 0.02% are papers published from African Countries. Could this reluctance to publish research findings on energy transition be one of the reasons for the slow progression of sustainable energy for all in Africa? Therefore, it is imperative now more than ever for more research focusing on the attainment of grid parity, energy transition, and electricity costs for developing countries to be brought to the fore. This article provides a review of state-of-the-art research on the attainment of grid parity and energy transition with a focus on the Levelized Cost of Electricity (LCOE) models of renewable energy sources.

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1. Introduction

Energy poverty is the lack of reliable access to modern energy sources. Billions of people live without electricity worldwide [1–4]. Most of these people live in developing countries in sub-Saharan Africa and South Asia [5]. Therefore, improving access to energy is a constant challenge for governments and non-governmental organizations [6]. In light of growing concerns over climate change and the persistent use of non-renewable energy sources with high carbon footprints, governments are trying to further promote Renewable Energy Sources (RES). Grid parity is considered an essential milestone to be achieved [7]. Grid parity is a benchmark for evaluating the competitiveness of RES with conventional energy systems [8,9].

There is no single definition for grid parity [10–13]. In a broad sense, grid parity is defined as the threshold at which the price of electricity from a RES, e.g., a photovoltaic (PV) system, is equal to or lower than the electricity generated by conventional grids. Grid parity can also be determined as the time point when a KiloWattHour (kWh) of renewable energy generation cost becomes equal to a kWh of electricity generation from the grid [14]. Grid parity is also a point where an alternative energy source can generate power at a Levelized Cost of Electricity (LCOE) less than or equal to the cost of obtaining power from the power grid. It is usually calculated from the viewpoint of the consumer or the utility. It mainly involves reducing the cost of the alternative generation source so that it can compete with conventional grid-supplied electricity [15].

The notion of grid parity is related to the market competitiveness of solar PV units with conventional energy systems. This establishes grid parity as a trending topic in the modern literature on renewable energy. In an article published by J. Ellsmoor in late 2018, grid parity ranked fourth out of six key renewable trends to watch out for in 2019. In Ref. [7], grid parity is identified as the "third PV diffusion" phase. Residential energy markets around the world are experiencing grid-parity events. In 2011 and 2012, Germany was one of the first countries to attain grid parity for utility-scale and rooftop solar PV. At least nineteen (19) countries achieved grid parity in March 2014 for solar PV systems. Similarly, some areas in Europe attained grid parity for wind power in the mid-2000s. A study by Ref. [9] shows that the concept of grid parity has a relatively long history with roots in psychology. According to the concept of the study, the grid parity concept can be traced back to the experience curve. However, it was not until 2005 that the first source related to the concept of grid parity surfaced as an article in the magazine "Frontiers, the BP magazine of technology and innovation," which related grid parity to making solar PV units competitive [9,16]. From that moment on, the concept of grid parity has received growing attention, especially in the energy industry-where the fossil fuel energy market has l experienced an inevitable disruption from cost and commercially competitive clean energy alternatives.

Currently, grid parity is a key indicator of market competitiveness for the PV industry [8,9].

However, it is worth noting that researchers have held divergent opinions regarding the importance of Grid parity. Some studies, like reference [7,17–20,22] believe that grid parity is a tipping point for solar dominance in the energy market. The belief is that if consumers are offered renewable-generated electricity at a price equal to or lower than the price of electricity fossil-based generation, they would opt for renewable energy systems. In contrast, the reference [23] believe that - grid parity, when scrutinized in light of electricity pricing dynamics, lacks the sufficient substance required for it to be considered a key indicator of market competitiveness for the PV industry.

Grid parity attainment is also necessary to achieve a successful energy transition. In light of the global objective of Sustainable Energy for all in 2030 (SDG Goal 7), Grid parity attainment and Energy transition studies are intertwined. Energy transition is the gradual change in primary energy supply from a predominantly fossil-based generation and consumption to low or zero-carbon sources to reduce carbon emissions. Furthermore, two studies [24,25] discussed using LCOE to evaluate and compare the cost of various energy-generating technologies, including renewable energy sources.

The race to achieve sustainable energy for all by 2030 has spurred many Governments of many countries to institute policies that would increase clean energy generation and the gradual phase-out of fossil-based generation. While some countries and regions are making significant progress, little has been made and/or documented in certain countries and regions. This study seeks to shed light on the research progress and activities in this area, hoping that developing countries can make more progress by modifying or adopting some of the ideas from other regions.

The contribution of this paper is as follows: (1) a bibliometric study to situate the progress in grid parity, energy transition, and electricity cost research was used to identify and situate research development in the field and (2) an empirical study of Levelized Cost of Electricity (LCOE) models used in grid parity research, with a discussion of papers supporting and criticizing the use of LCOE models for assessment of grid parity. This study also seeks to answer the following research objectives (RO).

RO1 – What are the volume, growth rate, and coverage of published documents across countries, types of publications, and research methods used to evaluate grid parity and energy transition?
RO2 – What authors, journals, and research papers have significantly influenced this research area?
RO3 – What has been the most frequently studied research theme in grid parity and energy transition research in recent years?

Bibliometric analysis is becoming more popular for analyzing and exploring large volumes of scientific and research data [26]. Bibliometric techniques identify leading authors in various research topics, disciplines and fields [27]. By analyzing the citations, we can identify journals, organizations, and countries that may significantly impact different research fields [28]. Bibliometric methods are an important addition to the research landscape because they complement meta-analysis and structured literature reviews for reviewing and evaluating scientific literature [29].

The structure of the remaining parts of the paper is as follows. Section 2 provides the methodology and search parameter considerations for the bibliometric review; Sections 3 and 4 provide the results and discussion, respectively. This section evaluates the results from the bibliometric search and the empirical review of grid parity, energy transition, and electricity methodologies. Finally, Section 5 concludes the study with a summary, recommendations, and conclusions.

2. Methodology

This review aims to bridge the gap by conducting a bibliometric analysis of global research output on grid parity and energy transition research. To situate the progress in grid parity and energy transition research, a detailed search of one of the widely used databases, Scopus, was carried out; Scopus was used to identify and curate research development in the field. Elsevier developed Scopus in 2004, although its coverage period started in 1996 [30]. Scopus is the database of the choice of bibliometric analyzes due to the many advantages listed in Refs. [31–34]. The Scopus database was searched using the article title, abstract, and keyword fields. All documents relating to grid parity, energy transition and electricity costs focusing on solar power from 1965 – to 2021 were selected for this study. The publications reviewed in the article were exported on February 26, 2022. The search strategy went thus:

(TITLE-ABS-KEY ("Grid parity") OR TITLE-ABS-KEY ("Energy transition") OR TITLE-ABS-KEY ("Electricity costs") AND TITLE-ABS-KEY (solar*))

While searching for a relevant document, the authors chose to be unspecific concerning the start year of publication, satisfying this criterion; this allowed for flexibility in the resulting output from Scopus. The relevant documents include articles, conference papers, reviews, book chapters, book notes, conference reviews, and short surveys.

The bibliometric information related to these documents was extracted using Scopus and analyzed using excel, google sheets, and VOSviewer [35]. Some analyses are descriptive statistics, citation and co-citation analysis, social network analysis, and keyword co-occurrence analysis [29].

This literature review utilizes the bibliometric method to evaluate research output on grid parity, energy transition, and electricity costs research. It should be noted that compared with the traditional approach to research review, the bibliometric method does not provide detailed findings of the studies. Instead, bibliometric review documents and synthesizes broad research trends that report the research area's research landscape, composition, and intellectual structure [36].

3. Results of bibliometric review of grid parity research

3.1. *Volume, growth rate, and coverage of grid parity, energy transition, and electricity costs research in literature*

A total of 2249 documents were identified in Scopus. The documents comprise 1425 journal articles, 545 conference papers, 119 review articles, 106 book chapters, 16 Books, and 13 Notes. The remaining 38 documents are distributed between conference reviews, short surveys, editorials, erratum, data papers, and an undefined paper. The first document on this topic emerged in 1964 [37]; however, no author name was provided; hence the first major publication emerged in 1965 [38]. Based on the data synthesis, it can be summarized that the publication output in this area has seen three evolutionary stages. (1) Pre-2000s – During this phase, only 49 documents were published (2) 2000 to 2014 – during this stage, 469 documents were published. The rise in publications in this research area began in the 2000s; this could be congruent with the fact that in the year 2000, the Millennium Development Goals (MDGs) was signed in September 2000 by the United Nations. (3) Post MDGS; 2015 to 2022 - The last seven years of the Sustainable Development Goals (SDGs) area has produced 1731 documents as shown in Fig. 1.

Numerous authors from over 107 countries have contributed to research regarding grid parity, energy transition, and electricity

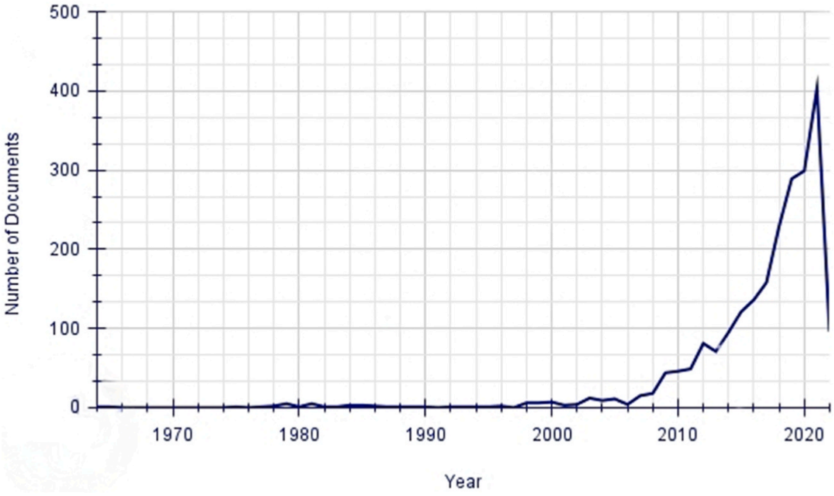

Fig. 1. Growth rate of the grid parity, energy transition, and electricity costs research development, 1964–2022 (n = 2249).

costs. According to the authorship map in Fig. 2, most scholars from the United States, Germany, China, the United Kingdom, Spain, and Australia have produced over 100 documents, resulting in 42.2% of the published articles. Other authors from Italy (93 documents), the Netherlands (93 documents), France (86 documents), and India (85 documents) have also contributed heavily to the research area, with more than 80 documents each resulting in another 11.8% of the published articles. Notably, only 63 documents (0.02%) have been published in African countries.

3.2. Most influential authors, journals, and research papers

Secondly, this paper seeks to identify the most influential authors published in this research field, how these contributions have been distributed across different journals and which research papers have been the most prominent.

Among the research publications in this research sample, 91 authors satisfy the minimum threshold of 5 documents. These items were further subjected to direct citation analysis. Documents with the highest number of citation links were selected. The largest set of connection documents number 71 items. The 71 items were classified into 8 clusters, as seen in Fig. 4. The constituent and research topics of each cluster are provided in Table 2. The number of clusters is evaluated in VOSviewer using pre-defined parameters as detailed in Table 1.

In Table 2, the clusters are ranked from highest to lowest. The first cluster consisting of 28 authors, discussed energy master plans, energy law, energy transition for rural and developed economies, the economic potential of solar thermal power plants, and pathways to decarbonization. The second cluster of 12 authors discussed grid parity analysis, solar energy transitions, sustainable energy planning for cities, climate change for sustainable development, building integrated photovoltaic projects (BIPV), and grid-connected PV systems. The third cluster of 8 authors focuses on life-cycle carbon emissions, low carbon transitions, and energy storage. The fourth cluster of 7 authors discussed topics on energy transition pathways, solar-driven net-zero emission studies, and battery and water storage. The fifth cluster of 5 authors researches solar thermal power plants, micro gas-turbine design, and optimal gas turbines. The sixth cluster of 4 authors discussed grid-connected and grid-interactive systems, PV and pumped hydro storage systems, solar-assisted pump water heating systems, and PV and ground water pumped hydro storage. The seventh cluster of 4 authors discussed the techno-economic evaluation of biogas-integrated parabolic trough. Finally, the eight clusters of 3 items consist of global energy transition roadmaps, the role and demand of storage technologies in energy transition, and a comparative assessment of solar PV-Wind hybrid energy systems.

Table 3 details the most highly cited authors based on Scopus rankings in this research area. The citation analysis reveals the contributions of Breyer (1179 citations), Bogdanov (673), Aghahosseini (563) and Caldera (357). Incidentally, all these authors are from the same University and research laboratory in Finland - Lappeenranta-Lahti University of Technology (LUT).

Co-citation analysis of authors was also performed in addition to direct citation analysis. Co-citation analysis is important because it captures citations from other documents beyond the review [39]. Many scholars believe that co-citation analysis is a better representation of scholarly influence when compared to direct citation analysis [40]. The full counting method was used for co-citation analysis. Full counting means the same weight is assigned to each co-authorship, co-occurrence, and bibliographic coupling. The minimum number of citations of an author was defined as 20. A total of 1202 authors satisfied this threshold. Table 4 presents the results of the co-citation analysis. The result revealed sixteen (16) additional unidentified authors using the direct con analysis. Incidentally, these authors appear in the Top 50 list from the direct citation analysis. These authors include Gratzel M (191 citations), Zhang Y (263), Zhang J (200), Wang Y (301), and Wang J (260), ranked by total link strength. Thus, the two analyses' results are required to obtain the best overview of influential authors. Fig. 3 shows the network analysis of Top cited authors in the research area.

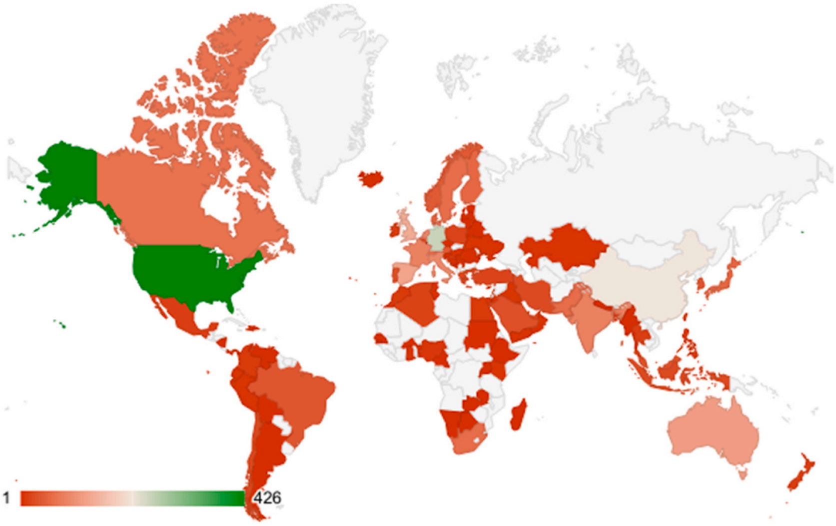

Fig. 2. Map showing the geographical distribution of publications in grid parity, energy transition, and electricity cost.

Table 1
VOSviewer parameters.

Parameter	Value/Characteristics
Minimum number of citations of a document (network analysis)	0
Minimum number of a citation for co-citation analysis	20
Minimum number of documents per author	5
Normalization method	Association Strength
Layout	Attraction- 2; Repulsion −0
Clustering	Resolution – 1.00; Minimum cluster size – 10

Table 2
Research Clusters of core authors in the Grid Parity, Energy Transition, and Electricity Cost research area.

Cluster Number/ Number of authors	Authors	Topics
Cluster 1/28 authors	Cao Y, Chen X, Davies P.J., Eck M, Feldhoff J.F., Kammen D.M., Li W, Li Y, Li Z, Liu J, Liu X, Reddy K·S., Sun Y, Trieb F, Van Sark W.G.J.H.M., Wang J, Wang L, Wang M, Wang S, Wang X, Wang Y, Wu Y, Xu Y, Yang Y, Zhang Y, Zhao Z	Energy master plan, Energy law, Energy transition for rural and Developed economies, Economic potential of solar thermal power plants, Pathways to decarbonization.
Cluster 2/12 authors	Bhandari R, Byrne J, Duic N, Fan Y, Kim J, Li H, Liu W, Ruther R, Wang Z, Zhang H, Zhang J, Zhang X	Grid parity analysis, Solar energy transitions, Sustainable energy planning for cities, Climate change for sustainable development, Building integrated photovoltaic projects (BIPV), Grid-connected PV systems.
Cluster 3/8 authors	Fthenakis V, Hook A, Hunag P, Kwon S, Liu Y, Martiskainen M, Sovacool B·K., Stock R	Life-cycle carbon emissions, Low carbon transitions, Energy storage.
Cluster 4/7 authors	Aghahosseini A, Bogdanov D, Breyer C, Caldera U, Munoz-Ceron E, Oyewo A.S, Ram M	Energy transition pathways, Solar driven net zero emission studies, Battery and Water storage
Cluster 5/5 authors	Buck R, Fransson T, Laumert B, Pitz-Paal R, Spelling J	Solar thermal power plants, Micro gas-turbine design Optimal gas-turbines
Clusters 6/4 authors	Han X, Kusakana K, Li X, Wu Z.	Grid-connected and grid-interactive systems, PV and pumped hydro storage systems, Solar-assisted pump water heating system, PV and ground water pumped hydro storage.
Cluster 7/4 authors	Dabwab Y·N, Li J, Mokheimer E.M.A., Zhao B	Techno-economic evaluation of biogas integrated parabolic trough
Cluster 8/3 authors	Gulagi A, Jr, Ocon J.D	Global energy transition roadmaps, the role and demand of storage technologies in energy transition, Comparative assessment of solar PV-Wind hybrid energy systems.

The geographical distribution of co-cited authors reveals that these authors are from economically developed countries.

The topical theme of the Top cited documents revolve around the following areas: Critical reviews papers on grid parity and energy transition research [21,41–48], City wide analysis of grid parity and energy transition issues [49,50], global case studies [51,52], and country-wide analysis of grid parity attainment issues [11,14,53–62] as seen in Table 5. Table 6 provides details of the highest co-cited documents. This information provides details of other documents that may not have garnered high citations but has very strong links, making them important in this research area.

Next, we investigated the most active journals and research articles publishing grid parity, energy transition, and electricity cost research. The summary is provided in Table 7 and Fig. 5. A total of 887 journals fulfil the threshold of 1 journal paper and 0 citations set in VOSviewer. This shows that a wide range of publishers are documenting progress in Grid parity attainment, energy transition, and electricity cost research.

Key: ENS – Environmental Science: Management, Monitoring, Policy and Law, ENE - Energy: General Energy, ENG – Engineering, MAS – Materials Science: General Materials Science, SOC – Social Sciences: Social Sciences (miscellaneous), MAT – Mathematics: Control and Optimization, PHA – Physics and Astronomy: Condensed Matter Physics, BMA – Business, Management, and Accounting: Strategy and Management, COS – Computer Science: General Computer Science, PSY – Psychology: Applied Psychology, EEF: Economics, Econometrics, and Finance: Economics and Econometrics.

3.3. Most studied theme in recent years for grid parity, energy transition, and electricity cost research area

The final research question identifies the most studied research themes in the grid parity, energy transition, and electricity cost research area. The co-word analysis process was used to identify the research themes. There are two main types of co-word analysis: (1)

Table 3
Most highly cited authors in Grid Parity, Energy Transition and Electricity Cost research area ranked by Scopus Citations, 1964–2022.

Rank	Author	Country	Documents	Scopus Citations	Total Link Strength
1	Breyer C.	Finland	35	1179	521
2	Bogdanov D.	Finland	21	673	394
3	Aghahosseini A.	Finland	14	563	336
4	Caldera U.	Finland	10	357	195
5	Ram M.	Finland	6	184	171
6	Oyewo A.S.	Finland	6	191	170
7	Gulagi A.	Finland	8	437	167
8	Munoz-Ceron E.	Spain	7	126	86
9	Dabwan Y·N.	Yemen	10	163	46
10	Mokheimer E.M.A	Saudi Arabia	6	132	36
11	Kammen D.M.	United States	8	593	25
12	Yang Y.	China	10	233	24
13	Li J.	China	6	44	20
14	Li Y.	China	7	132	17
15	Sovacool B·K.	Denmark	11	257	17
16	Spelling J.	United Kingdom	16	331	16
17	Laumert B.	Sweden	14	201	14
18	Liu Y.	China	7	182	14
19	Ocon J.D.	Philippines	5	46	14
20	Fthenakis V.	United States	5	36	13
21	Eck M.	Germany	9	394	12
22	Fransson T.	Netherlands	9	152	11
23	Hook A.	United Kingdom	5	138	10
24	Wu Z.	China	5	286	10
25	Zhao B.	China	5	14	10

Table 4
Top 25 co-cited authors in Grid Parity, Energy Transition and Electricity Cost research area ranked by Scopus Citations, 1964–2022.

Rank	Author	Country	Citations	Total Link Strength
1	Breyer C.	Finland	891	78,656
2	Bogdanov D.	Finland	500	48,670
3	** Gratzel M.	Switzerland	191	37,044
4	Li Y.	China	295	25,722
5	Aghahosseini A.	Finland	234	25,531
6	** Zhang Y.	China	263	24,798
7	** Zhang J.	USA	200	24,630
8	** Wang Y.	China	301	24,308
9	Yang Y.	China	217	23,403
10	Sovacool B·K.	Denmark	439	22,502
11	** Wang J.	China	260	22,048
12	** Chen H.	China	108	21,384
13	** Zhang X.	Sweden	233	20,924
14	Li J.	China	209	20,737
15	** Wang X.	China	242	20,633
16	Liu Y.	China	191	20,405
17	** Liu X.	China	125	20,311
18	** Liu Z.	China	118	19,964
19	** Liu J.	China	168	19,426
20	** Li X.	USA	168	19,352
21	Gulagi A.	Finland	174	17,644
22	** Zhang H.	China	139	17,347
23	** Nassereddine M.K.	United Arab Emirates	82	16,970
24	** Bella F.	Italy	28	16,734
25	** Liu H.	China	113	16,528

Frequency of keyword occurrence and (2) temporal co-word analysis [35,36].

VOSviewer was used to generate a list revealing the most frequently adopted keywords. Also, a temporal co-word map was generated using overlay visualization, as seen in Fig. 6. The first analysis evaluated the frequency of research themes in the grid parity, energy transition, and electricity cost research area. After excluding grid parity, energy transition, and electricity cost from the results, the other frequently used themes in this research area are Renewable with 224 occurrences, Solar Energy (144), Photovoltaic and Photovoltaics with a combined occurrence of 134, Energy Storage (61), Solar (46), and Smart Grid (40). A comprehensive list of the top 25 keywords is provided in Table 8.

Regarding temporal co-word analysis, the size of the nodes shown in Fig. 6 reflects the frequency of the keyword occurrence, while the colour shows its recency of use. The software assigns lighter colours to keywords based on the times it has been used in recent years.

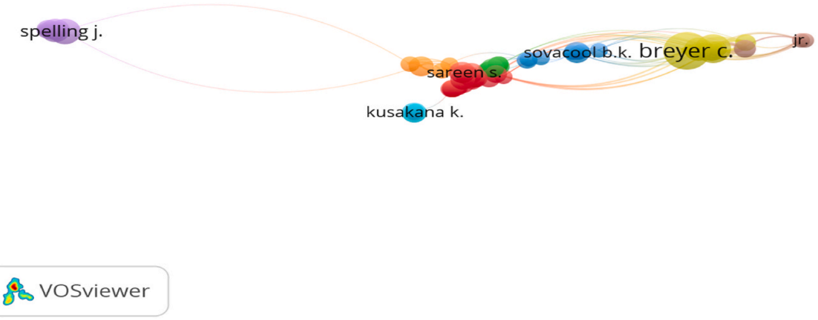

Fig. 3. Direct Citation Analysis of Grid Parity, Energy Transition and Electricity Cost publication between 2000 and 2022 (using network visualization; weight links). Source: Author's study. Data from Scopus and analyzed with VOSviewer (March 7, 2022).

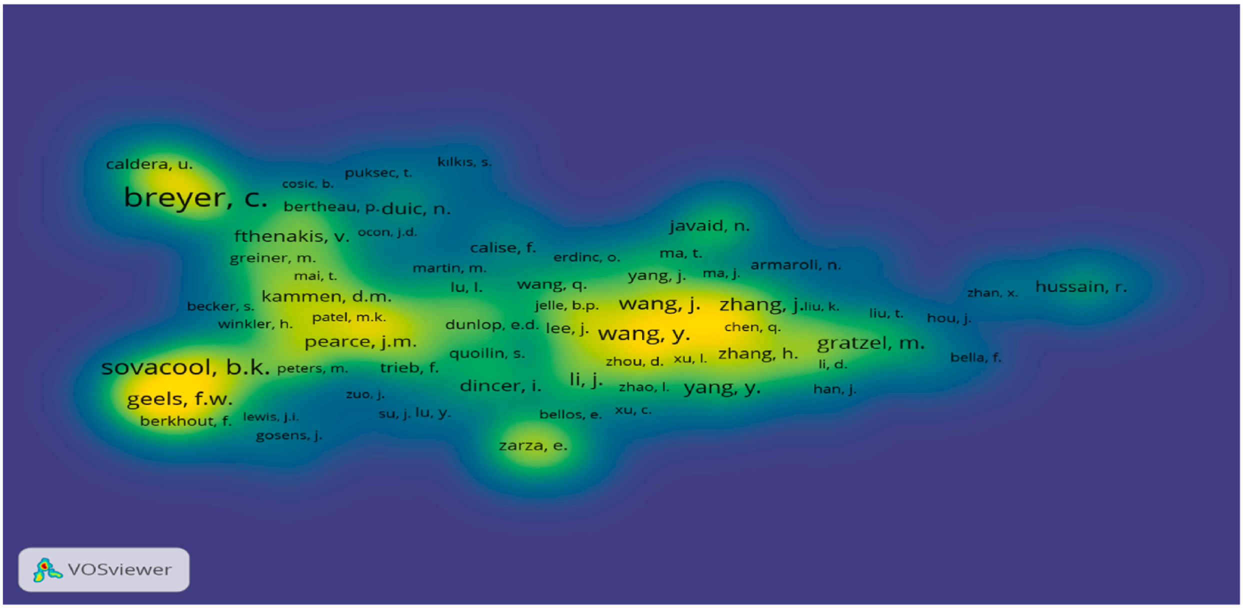

Fig. 4. Network analysis showing Top cited authors in grid parity, energy transition, and electricity cost research.

The result of the temporal co-word analysis was generated using the author keyword selection in VOSviewer; the minimum occurrence of a keyword was set to 5. Of the 5143 keywords generated – 240 keywords meet this threshold. Next, the themes with the lighter shade were grouped in order of recency. Three main clusters emerged as the most discussed topics of 2020 and 2021.

The first cluster, energy management for sustainable development, focuses on research relating to appliance scheduling, demand response, and demand-side management. The keywords under the cluster can be further grouped into research focusing on (1) Optimization using mixed-integer linear programming, stochastic programming, and machine learning techniques, (2) research focused on integrating renewable energy, distributed generation, electric vehicles, and energy storage.

The second cluster, sustainable energy transitions, consists of topics relating to climate change mitigation – carbon footprint, GHG emissions, and energy security topics. Other topics of note here are community energy studies in Africa, India, and Portugal.

The third cluster, grid integration studies, details the role of wind and solar energy in energy transition and sustainable development. Bio-fuels, fossil fuels, and their role in creating a decarbonized future are also discussed.

4. Discussion

4.1. Discussion of research on grid parity

The body of work of Rohatgi A revolves around developing solar cells with higher efficiency than those existing in the commercial market [88]. In Ref. [88], the authors developed 20% solar efficient cells using Spin-on based simultaneous diffusion and dielectric anneal. While developing this solar cell, the authors suggest that using a similar cell structure could increase solar cells' efficiency by over 20% on thin wafers. The author [89] developed solar cells with a large surface area using diffusion, oxidation, and screen printing

Table 5
Top Cited documents.

Rank	Authors and Article title	Year	Paper Type	Scopus Citations	Links
1	Bhandari, R. and I. Stadler, Grid parity analysis of solar photovoltaic systems in Germany using experience curves. Solar Energy [14].	2009	Empirical	116	24
2	Yan, J. et al., City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China. Nature Energy [49].	2019	Empirical	122	21
3	Breyer, C. et al., On the role of solar photovoltaics in global energy transition scenarios. Progress in Photovoltaics: Research and Applications [51].	2017	Empirical	160	21
4	Yenneti, K., R. Day, and O. Golubchikov, Spatial justice and the land politics of renewables: Dispossessing vulnerable communities through solar energy mega-projects. Geoforum [50].	2016	Empirical	110	21
5	Ram, M., A. Aghahosseini, and C. Breyer, Job creation during the global energy transition towards 100% renewable power system by 2050. Technological Forecasting and Social Change [52].	2020	Empirical	76	20
6	Osorio-Aravena, J.C. et al., The impact of renewable energy and sector coupling on the pathway towards a sustainable energy system in Chile. Renewable and Sustainable Energy Reviews [53].	2021	Empirical	5	18
7	Yang, C.J., Reconsidering solar grid parity. Energy Policy [21].	2010	Review	80	18
8	Breyer, C. et al. Solar Photovoltaic Capacity Demand for a fully sustainable Transport Sector - How to fulfil the Paris Agreement by 2050 [41].	2018	Empirical	119	17
9	Zhang, M. and Q. Zhang, Grid parity analysis of distributed photovoltaic power generation in China. Energy [54].	2020	Empirical	19	15
10	Reichelstein, S. and M. Yorston, The prospects for cost competitive solar PV power. Energy Policy [42].	2013	Review	169	15
11	Lund, P.D., Boosting new renewable technologies towards grid parity - Economic and policy aspects. Renewable Energy [43].	2011	Empirical	51	15
12	Manjong, N·B., A.S. Oyewo, and C. Breyer, Setting the Pace for a Sustainable Energy Transition in Central Africa: The Case of Cameroon. IEEE Access [55].	2021	Empirical	1	14
13	Sareen, S. and H. Haarstad, Bridging socio-technical and justice aspects of sustainable energy transitions. Applied Energy [44].	2018	Review	61	14
14	Kittner, N., F. Lill, and D.M. Kammen, Energy storage deployment and innovation for the clean energy transition. Nature Energy [45].	2017	Empirical	355	14
15	Zou, H. et al., Large-scale PV power generation in China: A grid parity and techno-economic analysis. Energy [56].	2017	Empirical	55	14
16	Biondi, T. and M. Moretto, Solar Grid Parity dynamics in Italy: A real option approach. Energy [11].	2015	Empirical	52	14
17	Orioli, A. and A. Di Gangi, The recent change in the Italian policies for photovoltaics: Effects on the payback period and levelized cost of electricity of grid-connected photovoltaic systems installed in urban contexts. Energy [57].	2015	Empirical	45	14
18	Sareen, S. and S.A. Wolf, Accountability and sustainability transitions. Ecological Economics [46].	2021	Review	0	13
19	Horn, M., H. Führing, and J. Rheinländer, Economic analysis of integrated solar combined cycle power plants A sample case: The economic feasibility of an ISCCS power plant in Egypt. Energy [58].	2004	Empirical	105	13
20	Oyewo, A.S. et al., Just transition towards defossilised energy systems for developing economies: A case study of Ethiopia. Renewable Energy [59].	2021	Empirical	5	12
21	Kamran, M. et al., Solar photovoltaic grid parity: A review of issues and challenges and status of different PV markets. International Journal of Renewable Energy Research [47].	2019	Empirical	11	12
22	Khalilpour, R. and A. Vassallo, Leaving the grid: An ambition or a real choice? Energy Policy [48].	2015	Empirical	97	11
23	Oyewo, A.S. et al., Pathway towards achieving 100% renewable electricity by 2050 for South Africa. Solar Energy [60].	2019	Empirical	18	11
24	Inderberg, T.H.J., K. Tews, and B. Turner, Is there a Prosumer Pathway? Exploring household solar energy development in Germany, Norway, and the United Kingdom. Energy Research and Social Science [61].	2018	Review	41	11
25	Mokheimer, E.M.A., Y.N. Dabwan, and M.A. Habib, Optimal integration of solar energy with fossil fuel gas turbine cogeneration plants using three different CSP technologies in Saudi Arabia. Applied Energy [62].	2017	Empirical	94	11

technologies. The fabricated cells have an efficiency ranging from 18.5% to 19.7% for 62cm2 and 4cm2 cells. The authors improved the efficiency of 4cm2 cells to 20% using screen-printing technology and Ultra Violet (UV) laser for rear dielectric removal [90,91]. The streamlined ion-implantation process also improved the efficiency from 18.3 to 19.1% [92]. The author considered the influence of light-induced degradation based on the efficiency of solar cells. The results reveal that Solar Cells doped with boron could reduce efficiency over prolonged use. The author suggests that n-type silicon cells that do not reduce efficiency over time should be the industrial standard to facilitate grid parity attainment [93]. The author also developed different empirical models to evaluate LCOE [94,95] and test the model on commercial-scale roof-top solar installations [95].

Ruther R worked primarily on Building-Integrated PV Solar Generators in Brazil [96,97] and investigated the influence of BIPV projects proposed in Brazil on the attainment of Grid Parity. In Ref. [117], the authors make a case for extending the reach of Solar PV installations in Brazil to Grid-Connected PV installations. They noted that Grid Connected renewable energy systems are more common in developed than developing countries. The authors encouraged the governments of developing countries to ramp up capacities to include Grid connections. The authors also evaluated the grid parity attainment time of BIPV projects in Brazil [98,99].

In reference to Refs. [100,101], the authors focused on net-metering policies as an alternative to Feed-in-tariff to achieve grid parity in the Mediterranean region. This is because the cost of solar power compared to grid power is reducing worldwide, and net-metering policies may be the next suitable alternative for Governments and investors [102]. Besides that, the author also assesses the suitability

Table 6
Top Co-cited documents.

Rank	Authors and Article Title	Year	Paper Type	Scopus Citations	Total Link Strength
1	Marzolf, N·C. et al., A unique approach for sustainable energy in Trinidad and Tobago. 2015: Inter-American Development Bank Washington, DC [63]	2015	Review	4	2468
2	Allcott, H. and M. Greenstone, Measuring the welfare effects of residential energy efficiency programs. 2017, National Bureau of Economic Research [64]	2017	Empirical	6	2334
3	Boomhower, J. and L.W. Davis, A credible approach for measuring inframarginal participation in energy efficiency programs [65]	2014	Empirical	6	2334
4	Fennell, L.A. and R.H. McAdams, Fairness in Law and Economics: Introduction. Fairness in Law and Economics [66]	2013	Empirical	5	1950
5	Chivers, D., Renewable Energy: Cleaner, fairer ways to power the planet [67]	2015	Review	3	1854
6	Humpert, M. and R. Espinosa, Energy Dossier: Trinidad and Tobago [68]	2016	Policy Document	3	1854
7	Goss, B., Choosing Solar Electricity: A Guide to Photovoltaic Systems [69]	2010	Review	3	1854
8	Horta, A. et al., Socio-technical and cultural approaches to energy consumption: an introduction [70]	2014	Review	3	1854
9	Ince, D. and B. Haynes, Barbados National Energy Policy (2017–2037) [71]	2018	Policy Document	3	1854
10	Rogers, T., K. Chmutina, and L.L. Moseley, The potential of PV installations in SIDS–an example in the island of Barbados [72]	2012	Empirical	3	1854
11	Alberini, A., A. Bigano, and M. Boeri, Looking for free riding: energy efficiency incentives and Italian homeowners [73]	2014	Empirical	4	1564
12	Klass, A.B., Public Utilities and Transportation Electrification [74]	2018	Review	4	1564
13	Raskin, D.B., The regulatory challenge of distributed generation [75]	2013	Review	4	1564
14	Jacobs, S·B., The energy prosumer [76]	2016	Review	4	1564
15	Rossi, J., Federalism and the net metering alternative. The Electricity Journal [77]	2016	Review	4	1564
16	Train, K.E., Estimation of net savings from energy-conservation programs. Energy [78]	1994	Empirical	4	1564
17	Davies, L.L. et al., Energy Law and Policy. Energy Law and Policy [79]	2020	Policy education	4	1564
18	Boyd, W. and A.E. Carlson, Accidents of federalism: ratemaking and policy innovation in public utility law [80]	2016	Review	4	1564
19	Bass, S. and D.B. Dalal-Clayton, Small island states and sustainable development: strategic issues and experience [81]	1995	Policy document	2	1238
20	Bauner, C. and C.L. Crago, Adoption of residential solar power under uncertainty: Implications for renewable energy incentives [82]	2015	Empirical	2	1238
21	Beerepoot, M. and N. Beerepoot, Government regulation as an impetus for innovation: Evidence from energy performance regulation in the Dutch residential building sector [83]	2007	Review	2	1238
22	Blechinger, P·F.H. and K.U. Shah, A multi-criteria evaluation of policy instruments for climate change mitigation in the power generation sector of Trinidad and Tobago [84]	2011	Empirical	2	1238
23	Daghfous, N., J.V. Petrof, and F. Pons, Values and adoption of innovations: a cross-cultural study [85]	1999	Empirical	2	1238
24	Dorf, R.C., Managerial and economic barriers and incentives to the commercialization of solar energy technologies [86]	1984	Empirical	2	1238
25	Egmond, C., R. Jonkers, and G. Kok, One size fits all? Policy instruments should fit the segments of target groups [87]	2006	Empirical	2	1238

of solar panels and balance of scale systems [103,104].

Guerrero-Lemus et al. [105] analyzed the techno-economic feasibility of siting a silicon-based solar production factory in West Africa or China. According to the results, the Canary Islands, China, Morocco, Ghana, Cape Verde, Senegal, Cameroon, The Gambia, Mauritania, and Benin ranked 1 through 10 as the most feasible sites for a solar production factory [106]. The authors also developed an empirical model to model the evolution of Solar electricity costs [107,108]. The model developed is suitable for Solar PV and CSP projects. The author has also contributed to reviewing the impact of the Spanish energy legislation on the attainment of Grid parity for an islanded system [109] and the possibility of grid energy attainment for off-grid villages far away from the national grid [110].

Lughi V. et al. [111] have worked significantly on Italy's grid parity events. Beginning with [111], the authors accessed the attainment of grid parity in the Italian residential energy market. In Ref. [112], the authors focused on attaining grid parity in the Italian commercial and industrial energy market. These two research happened at the heels of Italy attaining grid parity. The author has also conducted research focusing on the economic rate of return on investments for PV projects for residential and commercial energy consumers at different time intervals [113,114].

From Table 9, it can be summarized that Country and Regional assessments of Grid parity events are some of the more discussed issues. Also, research on developing energy-efficient PV cells to facilitate grid parity attainment is a popular research area among the top authors.

4.2. Discussion of research on energy transition

Renewable Energy Frameworks to support both local and regional incentives for energy transition have been adopted by several

Table 7
Top 25 active journals publishing grid parity, energy transition, and electricity cost research.

Rank	Journal	Document Count	Scopus Citations	Total Link Strength	Subject Area	Scopus Quartile
1	Energy Policy	80	2560	161	ENS, ENE	95th
2	Renewable and Sustainable Energy Reviews	65	4474	137	ENE	97th
3	Renewable Energy	67	1490	135	ENE	88th
4	Applied Energy	74	2698	133	ENE, ENG, ENS	99th
5	Solar Energy	44	2632	121	MAS, ENE	87th
6	Energy	64	1891	119	MAT, ENG, ENE	98th
7	Energy research and Social Science	68	1097	68	SOS, ENE	98th
8	Energies	84	678	58	MAT, ENG, ENE	85th
9	Energy conversion and management	35	1031	49	ENE	97th
10	Progress in Photovoltaics: Research and Applications	20	775	46	ENG, PHA, MAS	97th
11	Sustainability	40	371	38	SOS, ENS	84th
12	Nature Energy	6	576	33	ENE, MAS	99th
13	Geoforum	7	156	31	SOS	94th
14	Journal of Cleaner production	27	523	30	BMA, ENS, ENG, ENE	98th
15	IEEE Access	19	218	27	ENG COS, MAS	87th
16	Energy Procedia	39	779	27	ENE	77th
17	Technological Forecasting and Social Change	5	169	19	BMA, PSY	97th
18	Journal of Energy Storage	12	225	18	ENE, ENG	81st
19	Energy Economics	10	257	18	EEF, ENE	96th
20	Joule	15	652	18	ENE	99th
21	Energy for sustainable development	17	377	15	SOS, ENS	96th
22	Energy Strategy reviews	5	915	15	ENE	85th
23	Global environmental change	3	93	15	SOS, ENS,	99th
24	Current Opinion in environmental sustainability	1	0	13	SOS, ENS	99th
25	International Journal of Renewable energy research	5	29	13	ENE	69th

countries. For instance, in Austria, the Federal Green Electricity Act was implemented in 2003; this resulted in an annual PV installed capacity of 6.5 MW. By 2008, the cumulative capacity of PV installation had risen to 32.4 MW [117]. China has evolved in a fascinating pattern in the renewable energy landscape. First, China was the leading manufacturer of PV modules, manufacturing about 67% of the world's consumption [118]. The adoption of Feed-In-Tariffs (FiTs) for grid-connected systems in 2011 increased the installation profile for China significantly [119]. Before 2012, PV FiT in China clocked at USD 0.18/kWh; after 2012, it reduced to USD 0.15/kWh [47,120]. In 2015, China surpassed the long-time global cumulative PV capacity leader – Germany [47]; by November 2017, China announced the development of a 1089 MW and 250 MW concentrated solar power (CSP) plant, respectively. In 2018, China's first large-scale development of a commercial CSP plant, 50 MW, connected to the national grid. According to its 13th Five-Year Plan, it was estimated that by the year 2020, 5 GW of Concentrated Solar Power (CSP) plants would be installed. China estimates to generation 118 GW of CSP in 2050 [121]. However, despite the significant strides the Chinese Government has made in attaining grid parity - especially for large-scale projects; the Government plans to phase out subsidies relating to PV generation in the coming years [122]. Hence, the authors evaluated the impact of this decision on the attainment of grid parity. The results reveal that most regions would attain grid parity by 2030, and more than half would attain grid parity by 2022. Rather than removing subsidies for PV generation, the authors suggested that PV developers should be given access to low-cost financing, reduced investment costs, and favourably profit-sharing mechanisms [122,123].

Historically, many European Countries ramped up Renewable Energy production and Investments by engaging in FiT policies [113,117]. However, many Countries discontinue the policy adoption after attaining Grid Parity. In some European countries like Denmark, Germany, Spain, Italy, Cyprus, Malta, and Portugal, grid parity is the status quo even without a Feed-In Tariff subsidy [124]. Spain, Italy, and Germany have also attained grid parity, even for small PV installations [124,125]. Hence, a great debate on the necessity of FIT schemes ensues. Rather than implementing FIT schemes which may not be sustainable, the researchers in Ref. [126] suggest that small PV plants installed by household owners can be bought and sold under a VAT exemption scheme [127].

Regarding small PV installations, Indonesia, Malaysia, the Philippines, Singapore, and Thailand recently developed policy frameworks to encourage investments in Solar PV rooftop systems. However, Thailand, the Czech Republic, and Malaysia discontinued their FIT schemes to reduce the financial implications of feed-in tariff schemes. Malaysia, the Philippines, and Indonesia opted for a net

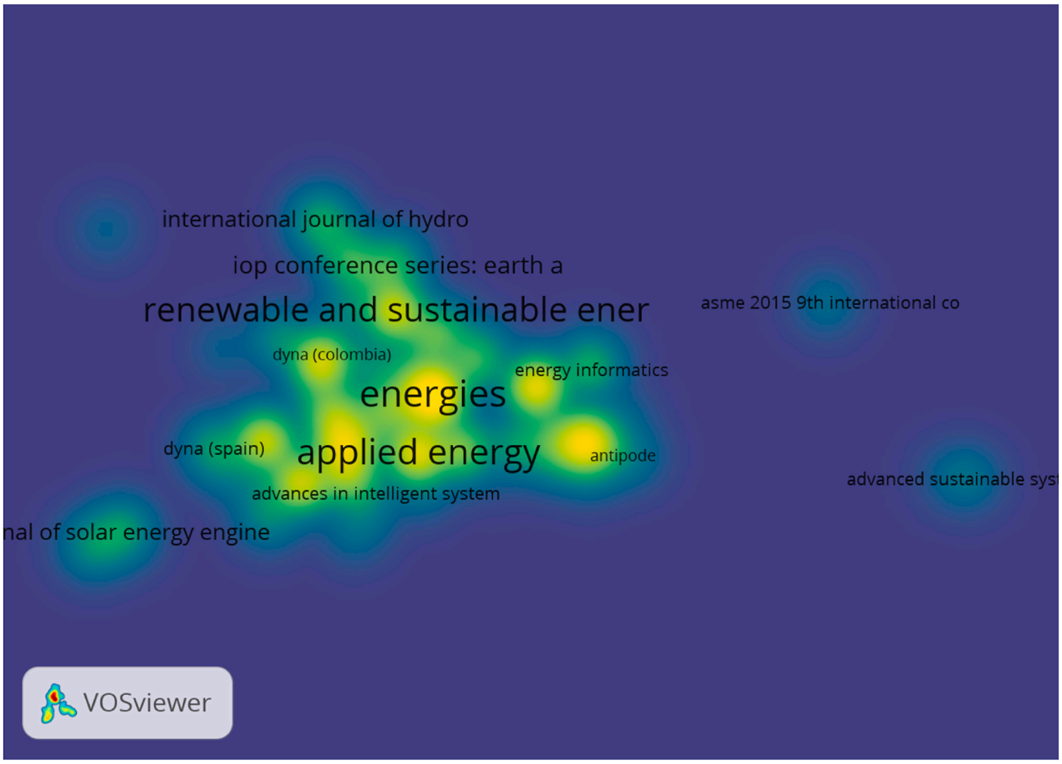

Fig. 5. Citation per journal density visualization for grid parity, energy transition, and electricity cost research area.

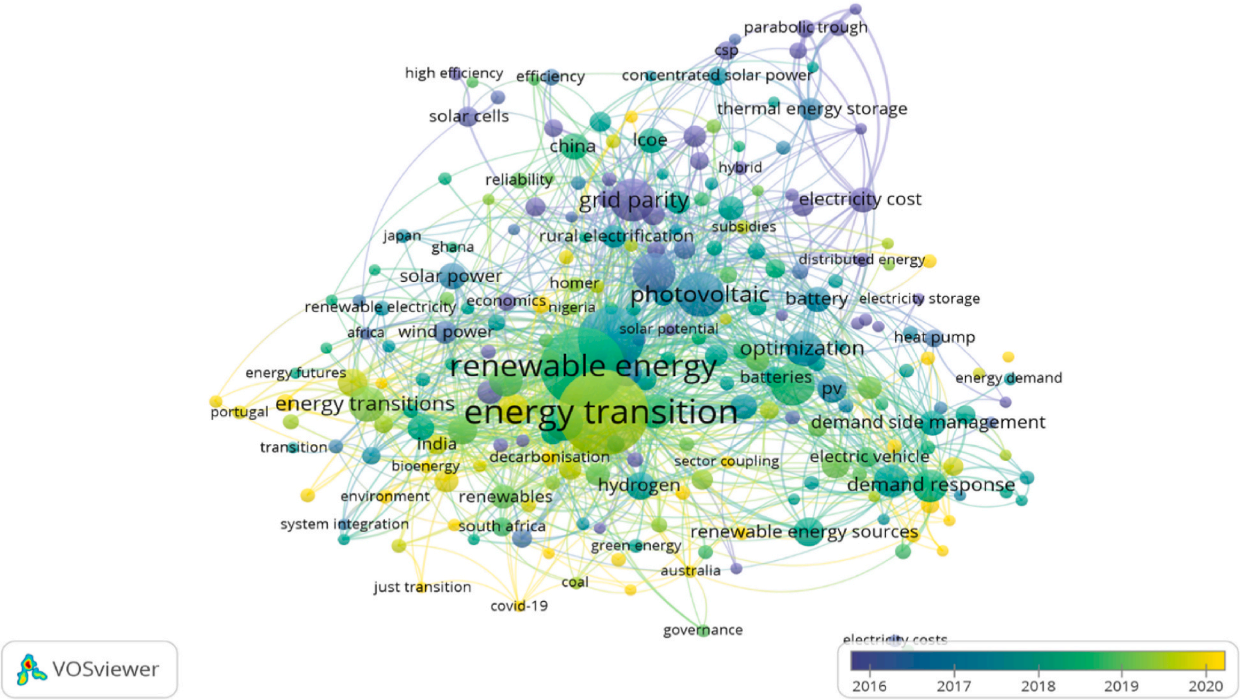

Fig. 6. Overlay visualization of the Co-word map of grid parity, energy transition and electricity cost research.

Table 8

Top 25 Keywords in the grid parity, energy transition and electricity cost research area.

S/N	Keyword	Occurrences	Total Link Strength
1	Renewable Energy	224	453
2	Solar Energy	144	298
3	Photovoltaic	76	141
4	Photovoltaics	58	117
5	Energy Storage	61	116
6	Solar	46	106
7	Smart Grid	40	93
8	Wind Energy	31	87
9	Demand response	40	84
10	Optimization	44	81
11	Climate Change	29	79
12	Solar PV	42	79
13	Sustainability	36	77
14	Energy Policy	34	70
15	Hydrogen	29	66
16	Electricity Cost	24	60
17	100% renewable energy	20	59
18	Wind Power	19	58
19	Biomass	17	57
20	Renewables	22	56
21	Battery	23	55
22	PV	29	54
23	Solar Power	26	54
24	Self-Consumption	21	53
25	Energy Management	26	50

Table 9

Summary of top authors' research in grid parity.

Summary of Research Findings	No of documents	References
Papers relating to development of PV cells to facilitate Grid Parity attainment	7	[88–91,93,105,106]
Mathematical Modelling	3	[95,108,115]
Testing of Model on Residential and Commercial buildings	5	[95,99,111–113]
BIPV and PV-Battery Storage Systems	4	[96,97,103,109]
Country and Regional Assessment of Grid Parity	8	[96,97,101,102,110–112,116]
Grid Connected Systems	3	[98,114,116]
Field Projects	2	[100,104]

metering framework, while Thailand adopted a self-consumption policy [127]. Malaysia is an example of a country sticking with the long-term solar energy implementation plan despite policy revisions and is poised to attain grid parity [128]. Spain also introduced a FiT policy in 2005 [117,129] but discontinued the policy in 2013 [130] following a successful renewable energy investment by the private sector and a USD 26 billion energy tariff debt.

Other considerations for grid parity attainment include research conducted in Brazil which compared the cost of generating on-grid solar power with the national grid. The researchers discovered that most of the sites had attained more significant grid parity in the research study sites than the national grid [131,132]. Another factor that can accelerate the attainment of Grid parity is high electricity prices, as seen in Germany, Australia, Italy, Denmark, and Spain [47]. These Countries were able to attain Grid parity before 2012. Denmark's portfolio of PV installations included rooftop solar and BIPV applications, a cumulative 3.3 MW in 2008. Denmark's residential energy sector achieved Grid Parity before 2020 due to high electricity tariffs [117]. However, for Countries like Russia, China, India, and Saudi Arabia, where the cost of grid electricity is significantly lesser than solar power, more incentives must be given to attain grid parity.

In reference [18], about 20% of the electricity demand in the Middle East and North Africa (MENA) region was beyond grid parity in the 2010s. Regions with high solar irradiation and high electricity prices first attained grid parity, followed by regions with moderate solar irradiation and high electricity prices. Reference [18] also suggested that PV would be the most preferred option for on-grid rooftop systems in many parts of the MENA region.

On the other side, in Europe, large residential markets attain grid parity events first, followed by the Asia-Pacific region and the Americas [7]. In Ref. [133], the cost associated with BIPV Systems is included in the model to evaluate grid parity. It has been discovered that most countries in the European Union (EU) have attained Grid Parity except for Bulgaria, Croatia, Czechia, Estonia, Finland, Hungary, Latvia, Lithuania, Netherlands, Norway, Poland, Romania, and Slovakia. These countries would require incentive programs focused on BIPV to reach grid parity with this technology. This is why in 2010, the UK government introduced the FIT incentive program to accelerate PV investment [117]. Furthermore, the UK FIT policy was revised in 2011, and the FIT rates were reduced from 43.3 p/kWh in 2011 to 14.90 p/kWh, and the tariff lifespan was reduced from 25 years to 20 years for new installations

[134]. However, despite these reductions, the UK still ranked in the Top 10 highest countries for PV demand in 2012 [134].

In the USA, reference [135] reflects that the States close to attaining Grid Parity do so only because they have good solar irradiance and high electricity prices, e.g., California. Otherwise, they have government incentives and high electricity prices, e.g., Massachusetts and New York State. However, to ensure that grid parity is attained easily in the USA, the US energy department set a target to reduce the cost of Solar PV to USD1/Watts (USD 0.06/kWh) by 2020 [47].

In Africa, most countries attained grid parity in the early 2010s, possibly because electricity prices are notoriously higher than Solar PV costs. However, larger markets like South Africa (USD 9 billion) and Egypt (USD 15 billion) subsidized their energy market heavily [7] and will attain grid parity no less than 2020. Other Countries in the MENA region are also experiencing delays in attaining grid parity because of heavy energy subsidies: Iran (USD 56 billion) and Saudi Arabia (USD 25 billi on) [18]. Reference [7] states that Grid parity for residential and industrial market segments is typically the easiest to attain in the following African Countries: Seychelles and Madagascar, The Gambia, Burkina Faso, Senegal, Mali, and Chad. These Countries have the best combination of high electricity prices compared to the solar cost and high solar irradiance. Table 10 summarizes FIT schemes by several Governments to encourage energy transition.

4.3. Discussion of research on electricity cost

4.3.1. Discussion of Levelized Cost of Electricity (LCOE) models

Reference [14] used the experience curve analysis to calculate the future prices of solar PV units. The experience curve analysis talks about how the cost of technology is reduced with cumulative production and use. Cumulative production approximates the experience of producing and/or using the technology. It assumes that the cost reduces at a fixed percentage, with each doubling of the total number of units produced. The authors imposed a growth rate of 75–90% in addition to the experience curve analysis. They calculated the cost of kWh PV generation for the coming years using local market parameters and module price data. The learning curve is given by Eqs. (1) and (2).

Table 10
Start and End Year of Feed-In Tariff (FiT) policies by some Government.

Countries	FIT Start	FIT End	FIT details	References
Brazil	2002	2010	They used FIT only for the First half of the 2000s and transitioned into an auction system	[91,92]
Ecuador	2000	Still in force	The FIT policy was revised in 2002,2004,2006,2013,2014	[91–95]
Nicaragua	2005	Still in force	Still in effect	[91,92]
Argentina	2006	Still in force	FIT is still in effect. However, other schemes like the Net Billing scheme was introduced by law in 2017	[91,92] [96, 97],
Peru	2010	Still in force	FIT is for only off-grid applications	[91,92]
Thailand	2013	Still in force	The FIT policy took over from the Adder program launched in 2007	[98,99]
Uganda	2007	Still in force	The FIT adoption consists of three phases starting in 2007	[98]
Spain	1994	Still in force	Spain was the first country to adopt a FIT subsidy mechanism to promote the development of the CSP generation industry [54].	[100]
Germany	1990	2021	Renewable energy auctions started in 2017. The last phase of the 20-year-long FIT scheme ended on January 1, 2021	[101] [102],
Cyprus	2013	Still in force	With concerted efforts, Cyprus achieved their 2020 visions forecasts in 2018	[47]
Denmark	1993	Still in force	Denmark has invested a significant amount on the Research and development of Wind Energy related patents	[104]
Japan	2012	Still in force	Japan also has a renewable energy auctions policy	[105]
South Africa	2009	Still in force	South Africa also has a renewable energy auctions policy	[93,106]
Kenya	2008	Still in force	Kenya also has a renewable energy auctions policy	[93]
Algeria	2004	Still in force	Algeria was the first country in Africa to introduce FITs in 2004. However, details of the FIT implementation was provided in the No. 13–218 of 2013 decree	[107]
Mauritius	2010	Still in force	Mauritius also has a renewable energy auctions policy	[93,108]
Tanzania	2003	Still in force	Tanzania also has a renewable energy auctions policy	[93,106]
UK	2010	Still in force	Did a review of their FIT scheme in 2011 from 43.3 p/kWh in 2011 to 14.90 p/kWh. However, this decrease did not affect the demand for Solar PV negatively because in 2012. The UK was still one of the top countries with the highest PV demand in 2012	[68,88]
Malaysia	2011	2016	Transitioned to Net-Metering in 2016	[82]

$$C(x_t) = C(x_t)\left(\frac{x_t}{x_o}\right)^b \tag{1}$$

$$LR = 1 - 2^b \tag{2}$$

Here: Xt = cumulative installed PV unit capacity at year t, Xo = cumulative installed PV unit capacity at an arbitrary starting year, b = learning parameter or rate of innovation, C (Xt) = PV unit cost per kWh at year t, C (Xo) = PV unit cost at an arbitrary starting year, LR = Learning Rate.

The authors in Ref. [14] also extensively analyzed net present value (NPV). Net Present Value is defined as the total cost of the current PV unit, initial BOS, replacement cost of the BOS, and variable cost. The total cost of the life cycle of a PV unit is given in Eq. (3). Substituting values for C_{mt}, C_{BOS}, C_{BOSrep}, and C_V as shown in Ref. [14] results in Eq. (4). Eq. (5) is given as the module price reduction factor.

$$C_t = C_{mt} + C_{BOS} + C_{BOSrep} + C_v \tag{3}$$

Where:

$$C_t = C_m P_{peak}\left[\begin{array}{l}\left\{\sum_{n=1}^{n=N}\frac{1+i(N-n+1)}{N(!+d)^n}\right\}+\left\{\sum_{n=1}^{n=N_r}\frac{1+i(N_r-n+1)}{N_r(!+d)^n}\right\}\\ +k\left\{\frac{K_{BOS}K_{Bosrep}}{(1+d)^{(N_r)}}\right\}+k_v(1+k_{BOS})\left\{\sum_{n=1}^{n=N}\frac{1}{(!+d)^n}\right\}\end{array}\right] \tag{4}$$

$$k = \frac{C_{m(n+N_r)}}{C_{m(n)}} \tag{5}$$

Where: C_t = total PV unit cost (€),

C_{mt} = current cost associated with PV unit (€$_{2009}$),
C_{BOS} = current cost associated with initial investment on BOS (€$_{2009}$),
C_{BOSrep} = current BOS replacement cost (€$_{2009}$),
C_v = current the total variable cost (€$_{2009}$),
GHG_{EF} = the greenhouse gas emission factor.

The present value of total revenue (R_t) from the system during its useful lifespan is given as the sum of current revenue generated from the PV electricity on-site and the present value of revenue exported to the grid as shown in Eq. (6). The net present benefit (B) of the PV system is given in Eq. (7).

$$R_t = P_{peak}\,Q\frac{G_m}{I_{STC}} * \left[P_{el,im}E_{on}\sum_{n=1}^{n=N}\frac{(1+nr_{im})(1-s)^{n-1}}{(1+d)^n} + P_{el,ex}(1-E_{on})\sum_{n=1}^{n=N}\frac{(1+nr_{im})(1-s)^{n-1}}{(1+d)^n}\right] \tag{6}$$

Therefore:

$$\text{Net present benefit } (B) = R_t - C_t \tag{7}$$

The authors also stated that the Experience curve analysis for Balance of Systems (BOS) had been studied less than PV units.

Reference [37] performed a techno-economic analysis of three small PV systems in different Peru cities.

Reference [38] suggested the computation of LCOE be used among other standard economic evaluation criteria for several configurations, namely fixed, horizontal one-axis, and two-axis tracking, where local technical and economic factors are utilized. The authors argue that optimization methods should be identified based on technological, economic, and financial characteristics and that electricity prices should be included as a strategic component in the study.

Reference [136] analyzed the grid parity for grid-connected systems. The authors determined that learning or experience curves, progress ratios, and performance ratios influence the rate systems attain grid parity. In this paper, the learning curve is evaluated as stated in Eq. (2). The authors stated that investing in a system is much more beneficial An NPV greater than zero indicates that an investment is profitable. The key assumptions in this study are that the current feed-in tariff (applicable throughout the life of the PV unit) and the CO2 emissions due to the embodied energy are ignored.

In [15], the authors discussed the methodologies and approaches used to calculate the LCOE. They discussed a tool called Solar Buzz, which attempts to give a dynamic LCOE rather than the usual static results in the LCOE calculations. The typical formula for LCOE is provided in Eq. (8), also used in Ref. [137], to determine the residential PV grid parity for 11 cities in Colombia. The authors posit that if LCOE will be used to determine the future cost of PV units, it is essential to include more costs like initial investment, maintenance, and operating costs, as shown in Eqs. (9) and (10).

$$\mathrm{LCOE}=\frac{\sum_{t=0}^{T}\frac{C_t}{(1+r)^t}}{\sum_{t=0}^{T}\frac{E_t}{(1+r)^t}} \tag{8}$$

$$\mathrm{LCOE}=\frac{\sum_{t=0}^{T}\frac{(I_t+O_t+M_t+F_t)}{(1+r)^t}}{\sum_{t=0}^{T}\frac{E_t}{(1+r)^t}} \tag{9}$$

$$\mathrm{LCOE}=\frac{\sum_{t=0}^{T}\frac{(I_t+O_t+M_t+F_t)}{(1+r)^t}}{\sum_{t=0}^{T}\frac{S_t\ (1-d)^t}{(1+r)^t}} \tag{10}$$

Where: T = Life of the project (years), T = Year, t, Ct = Net cost of the project for t ($), Et = Energy produced for t ($), It = Initial investment/cost of the system including construction, installation, Mt = Maintenance costs for t ($), Ot = Operation costs for t ($), Fr = Interest expenditure for t ($), r = Discount rate for t (%), St = Yearly rated energy output for t (kWh/year), D: Degradation rate (%).

The authors stated that some of the major misconceptions and assumptions that influence the LCOE calculations are; the choice of the discount rate, the average system price, the financing method employed, the lifetime of the average system, and the degradation of energy generation over the lifetime of the system. (Further explanations of the discrepancies can be found in this paper). They also provided a numerical example for Ontario using simplified and improved methods. To achieve grid parity, the residential solar cost would need to be between $0.06/kWh and $0.17/kWh.

Reference [138] concludes that both PV and wind technology could be the technologies required to influence the global energy supply in the coming years. In this paper, the author says that the most appropriate method for evaluating PV units' cost is the (LCOE model provided in Eqs. (11)–(13):

$$\mathrm{LCOE}=\frac{\mathrm{Capex}}{Y_{\mathrm{ref}}\times \mathrm{PerfR}}\times\left(\frac{\mathrm{WACC}\times(1+\mathrm{WACC})^N}{(1+\mathrm{WACC})^N-1}+k\right) \tag{11}$$

$$\mathrm{WACC}=\frac{E}{E+D}\times k_E+\frac{D}{E+D}\times k_D \tag{12}$$

$$k=k_{\mathrm{ins}}+k_{\mathrm{O\&M}} \tag{13}$$

Where: Capex = Capital Expenditures;

Y_{ref} = Yield for specific PV unit at a specific site;
PerfR = Performance ratio; WACC = Weighted Average Cost of Capital;
N = Lifetime of the PV System;
Opex = Annual operation and maintenance expenditures;
k = Annual cost of Opex in percent of Capex; E = Equity; D = Debt; k_E = Return on equity;
k_D = cost of debt; k_{ins} = Annual insurance cost in percent of Capex;
$k_{\mathrm{O\&M}}$ = Annual Opex in percent of Capex.

The authors used an analytical approach to determine grid and fuel parity based on mathematical formulae. In this work, the authors consider the critical input parameters to be the progress ratio of PV, the growth rate of the global PV industry, and both key drivers of the experience curve and the electricity price trends.

The experience curve is the empirical law used for cost reduction in industries. The experience curve refers to the stable decrease experienced by each doubling in the cumulative output or production. The specific cost often decreases by a nearly stable percentage, as shown in Eqs. (14)–(17).

$$C_x=C_o\times\left(\frac{P_X}{P_o}\right)^{\frac{\log\ \mathrm{Progress\ ratio}}{\log\ 2}} \tag{14}$$

$$P_X=\sum_{t=0}^{T}P_t \tag{15}$$

$$P_t=P_{t-1}\times(1+GR_t)\ \text{for}\ t\geq 1 \tag{16}$$

$$P_X=P_o\times\prod_{t=0}^{T}(1+GR_t) \tag{17}$$

Grid parity has been analyzed for up to 150 countries [139]. The method and details are described in the above reference. In this paper, the author ascertains the values used for each variable and the ranges also considered. The model developed here ascertains the first markets to reach residential grid parity; the markets are Cyprus, Italy, the Caribbean, and West Africa. It is worth noting that the authors made an exception for Africa because more than 60% of Africa's energy generation can be traced back to South Africa and Egypt, and these countries have benefited from energy subsidies.

Following this paper [140], discussed four (4) historical phases of PV spread; the first stage deals with powering satellites, the second deals with off-grid applications, the third deals with grid parity of on-grid rooftop systems, and the fourth deals with fuel parity of PV power plants. This paper focuses on determining the grid parity of PV units in the MENA regions. The critical input parameters used are the Progress ratio (unity minus learning rate) of PV, the growth rate of the global PV industry, and the electricity price trends. The model used in this paper is the same as that used here [138]. They developed a dynamic model representing grid parity, specifically, PV LCOE and electricity cost for end-users in the MENA region's residential and industrial market segments. In conducting this research, the authors did not consider subsidies for PV; only the real cost was considered.

In [141], the authors used the LCOE calculation expressed in (Eq. (18)), where CAPEX is defined as capital expenditure (investment cost), OPEX is operating and maintenance cost, EP is the electricity produced, and NPV is the net present value. The LCOE is determined by some predefined input parameters in the paper; they also provided a breakdown of how to achieve Grid Parity. In addition to grid parity, the authors evaluated the breakeven point. The model developed for the breakeven point was adopted by the National Renewable Energy Laboratory (NREL) under the United States Department of Energy (DOE) for the SAM software developed by the NREL to evaluate the LCOE for a residential and commercial project (Eq. (19)).

$$LCOE = \frac{CAPEX + NPV(OPEX)}{NPV(EP)} \tag{18}$$

$$LCOE = \frac{NPC + \sum_{n=1}^{N}\frac{LP}{(1+d_r)^n} + \sum_{n=1}^{N}\frac{AO}{(1+d_r)^n} - \sum_{n=1}^{N}\frac{RV}{(1+d_r)^n}}{\left\{\sum_{n=1}^{N}\frac{E_n * \ (1-d_s)^n}{(1+d_s)^n}\right\}} \tag{19}$$

Where: AO = Annual operation expenditures; NPC = Net Project Cost; LP = Annual loan reimbursement; En = Net-energy output first year; RV = Residual value for the solar system; ds = Degradation rate; dr = Discount rate.

In [142], the authors used a simple formulation for the LCOE given by Eq. (20):

$$\frac{\sum_{t=1}^{n}\frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+r)^t}} \tag{20}$$

Where: I_t = Investment and financing expenditure in year t;

M_t = Operation and maintenance expenditure in year t;
F_t = Fuel expenditure in year t; E_t = Electricity generation in year t;
r = discount rate; n = lifetime of the system .

In [143], the authors developed a mathematical closed-form evaluation to evaluate the LCOE for CSP electricity between 2010 and 2050. They considered this for the parabolic trough CSP.

The LCOE was calculated based on four (4) different approaches: the life-cycle cost method, the net present values, the discounted cash flow technique, and the learning curve approach. The authors modelled LCOE using ten (10) independent variables and justified the choice of the range of each variable. The ten (10) variables are total cost of systems installed in a certain year (this depends on the cost of the systems in 2010), learning rate LR, cumulative installed capacity, land cost, discount rate, operations and maintenance costs, insurance costs, solar resource, tracking factor, performance factor, lifetime of CSP systems, and degradation factor.

They derived a new Eq. for LCOE given as Eq. (21):

$$\mathrm{LCOE} = \sum_{i=0}^{T}\left[\frac{C_i + L_i + O\&M_i + I_i}{(1+d)^i}\right] \Bigg/ \sum_{i=0}^{T}\left[\frac{C_i}{(1+d)^i}\right] \tag{21}$$

Where: C_i = Expenditures due to the cost of the system; L_i = Land cost; $O\&M_i$ = Operations and Maintenance Cost; I_i = Insurance Costs.

In 2013, the authors [107] updated the model they created in Ref. [143] by adding two (2) new variables, thus making a total of 12 variables, as shown in Eq. (22):

$$\mathrm{LCOE} = \left(C(O)\left(\frac{Q(t)}{Q(O)}\right)^{\frac{\log(1-LR)}{\log\ (2)}} + L + \sum_{n=1}^{N}\frac{(OPEX+1)\times C(O)(Q(t)/Q(O))^{\frac{Log\ (1-LR)}{Log\ (2)}}}{(1+r)^n}\right) \Bigg/ \left(\sum_{n=1}^{N}\frac{S\times TF\times \vartheta \times (1-d)^n}{(1+r)^n}\right) \tag{22}$$

Where: C(o) = Cost of the system installed in 2010; Q(o) = Cumulative installed capacity in 2010; Q(t) = Cumulative installed capacity in a year t; LR = Learning rate; L = Land cost; r = Discount rate; O&M = O&M cost; I = Annual Insurance rate; S = Solar resource; TF = Tracking factor; η = Performance factor; N = Lifetime of the systems; d = Annual output degradation rate.

In [137], the authors considered the residential PV Grid Parity for 11 cities in Colombia. They also developed a financial model that can be used to determine the feasibility of a solar technology cost. The LCOE cost was used, given by Eq. (23):

$$LCOE = \frac{\sum_{t=0}^{n} c_t / (1+r)^t}{\sum_{t=0}^{n} E_t / (1+r)^t} \tag{23}$$

4.3.2. Discussion of papers skeptical of Levelized Cost of Electricity (LCOE) calculations

The article [47] talks about determining the factors that affected the achievement of grid parity in isolated systems located in Cyprus. The authors note that, rather than the 2016–2020 time frame predicted by research, grid parity was attained earlier in some regions in Cyprus. According to them, this could be due to rapid downward price changes. They examined the conditions to reach grid parity by reviewing the following: manufacturing cost ranges, the selling price of the energy produced, and the performance of the PV systems. The analysis was performed on a 1 MW PV plant installed in Cyprus.

Furthermore, the authors considered the internal rate of return on investment (IRR). The IRR helps to give a clear picture of the profitability of the investment for the installer. It gives the present value when all future cash flows equal the initial investment. A project may be profitable when the IRR is a positive value, as seen in Eq. (24).

$$\mathrm{NPV} = \sum_{i=1}^{n} \frac{\mathrm{P_i}}{(1+\mathrm{IRR})^{\mathrm{i}}} \tag{24}$$

This study made some assumptions: NPV = 4% (to stakeholders), Leverage loans = 70%; no leverage loans, Interest rate = 6.5% (constant), Maturity = 10 years; financial analysis was performed for a 20-year period. The characteristics of the 1 MW system reviewed are Polycrystalline, static mount, 60 cells, Panel efficiency = 15%, Transformerless string inverters, and Running cost = 1% of total equipment cost.

The authors used PVSyst to calculate the average annual energy yield. A performance ratio of 80% and a deterioration rate of annual energy yield loss of 0.55% were assumed. Profit before taxes was given by Eq. 25

$$\mathrm{P_i} = \mathrm{I_i} - \mathrm{OC_i} - \mathrm{L} - \mathrm{D} \tag{25}$$

Where: $\mathrm{I_i}$ = Annual Income; $\mathrm{OC_i}$ = inflated operating and maintenance expenses; L = Loan interest; D = Depreciation of materials; 20 years .

$$OC_i = (Saf \times In \times Main \times NfE) \times (1 + IR)^{(i-1)} \tag{26}$$

Where: Saf = Safety annual expenses; In = annual Insurance fee; Main = maintenance and annual expenses; Nfe = Non-foreseen expenses.

Other considerations in the calculations include calculating net income after tax, dividends to the shareholders, 10% corporate tax, 20% defense contribution to the net income, and special defense contribution imposed on income earned by Cyprus enterprises.

In reference [8], the authors stated that determining grid parity based on LCOE costs can be misleading because LCOE does not consider the systematic changes within the electric power ecosystem. Some of these changes are the balance of electricity demand, the demand pattern, and the characteristics of renewable energy technology. To solve this concern, the authors decided to introduce the bottom-up energy system model and compare the result of this methodology with the LCOE cost to show the variations in the results. Although the bottom-up methodology was tagged as the authors' preferred methodology, they stated that some of the methodology's drawbacks included the fact that it required a large amount of data on technology characteristics such as efficiency, maximum capacity factor, and cost of each generation technology. The bottom-up energy system model consists of two types: the optimization model and the accounting model. The optimization model works by analyzing different technology variants and energy sources and determining the most efficient cost, given a set of demands. The accounting model uses a scenario approach to determine a possible form of a target system. Some examples of commercial products of optimization models and accounting models are given in Tables 11 and 12. The authors used TIMES but did not use any accounting model since it cannot capture the effect needed. Also, many studies and international agencies have used the TIMES model. They concluded that the grid parity point of an electric power system depends on the RE technology, the time of introduction, and the system's circumstances. In Ref. [144], the authors focused on the whole life cost model for offshore WIND farms. To assist in determining the profitable long-term investment in wind energy generation for farm operators and investors.

The authors embarked on a study to develop a Whole life Cost (WLC) analysis framework for an offshore wind farm throughout its operational years (~25 years). The analysis was performed by evaluating the cost breakdown structure of the system (CBS).

The methods used include identifying key cost drivers and evaluating costs associated with the five phases of offshore wind projects.

Table 11
Commercial products for energy accounting models.

Model	Developer
Long-Range Energy Alternative Planning Model (LEAP)	Stockholm Environment Institute
Modele d'Evolution de la Demande d'Energie (MEDEE)	IIASA

Table 12
Commercial products of Energy Optimization Models.

Model	Developer
Regional Energy Scenario Generator (RESGEN)	Resource Management Associates
Market Allocation Model (MARKAL)	International Energy Agency (IEA) Energy Technology Systems Analysis Program (ETSAP)
The Integrated MARKEL-EFOM system (TIMES)	IEA ETSAP
Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE)	International Institute for Applied System Analysis (IIASA) Used a lot by the International Panel on Climate Change (IPCC) and the International Atomic Energy Agency (IAEA)

1. Predevelopment and consenting (P&C).
2. Production and acquisition (P&A).
3. Installation and commissioning (I&C.
4. Operation and Maintenance (O&M).
5. Decommissioning and disposal (D&D).

Other critical factors such as geographical location, meteorological conditions, rated power, wind turbine capacity factor, reliability of subsystems, and availability and accessibility of transportation were analyzed. The operation and maintenance (O&M) costs (from data available from failure databases, fault logs and O&M reports, and data supplied by inspection agencies) include the cost of renewable and replacement, the cost of lost production, and the cost of skilled workers maintenance labour, and logistics cost.

The quantified current values of future cash flows – Net Present Value (NPV) were used. The bottom-up estimation technique was used. The authors calculated the Life Cycle Cost (LCC) of the Wind project. LCC is a process of evaluating economic performance over its entire life span. They tested their developed model on an offshore 500-MW baseline wind farm project. The results from this model were compared to experimental values already reported in the literature. They discovered that the Whole Life Cost (WLC) cost is the largest proportion of the capital cost of wind turbines, installation, and O&M costs. Also, a sensitivity analysis was conducted to identify the factors having the most significant impact on LCOE. At the end of the analysis, the factors that significantly influence LCOE are the installed capacity of a wind farm, distance from shore, and fault detection capability of the condition monitoring system.

4.3.3. Artificial neural network and grid parity research

In [145], the authors used the feed-forward backpropagation learning algorithm while considering three (3) different variants: Levenberge Marquardt (LM), Scaled Conjugate Gradient (SCG), and Pola-Ribiere Conjugate Gradient (CGP). This was done to determine the best prediction approach and techno-economic optimization for a parabolic trough solar thermal power plant (PTSTPP) integrated with a fuel backup and thermal energy storage. The authors used the following as input parameters, namely design ambient temperature (34 OC), Solar Radiation at design (850 W/m2), Row Spacing between Parallel collectors (23 m), Solar multiple (1.7), and the number of hours for the storage system (2.5 h) (Full load hours of the thermal energy system). The output parameters are annual power generation (PGnet) and LCOE.

The authors used SAM (Solar Advisor Model) for Modelling and Simulation. SAM uses the TRNSYS software and the Solar Thermal Electric Components (STEC) model library. They also used EBSILON professional 10.06 to evaluate and simulate the Power Cycle. Using this software, they evaluated the overall thermal efficiency values and incorporated this as INPUTS into SAM. The parameters used for this analysis are detailed in the paper. SAM was then used to simulate the whole plant's techno-economic performance, including the SF, TES, FBS, PB, and heat rejection system. SAM was also used to perform the economic assessment (LCOE) using parameters provided in the article. The LCOE calculated by SAM uses the model:

$$LCOE = \frac{crf * \ C_{inv} + C_{o\&M} - C_{env}}{PG_{net}} \tag{27}$$

Where: crf $=$ Capital Recovery Factor; $\mathrm{C_{inv}}$ $=$ total investment cost (US\$);

$\mathrm{C_{o\&M}}$ $=$ Annual Operating and maintenance costs (US\$);
$\mathrm{C_{env}}$ $=$ Environmental cost according to CO2 rejected (US\$);
$\mathrm{PG_{net}}$ $=$ Annual net power generation (KWh).

$$crf = \frac{k_d * \ (k_d + 1)^N}{\left[(k_d + 1)^N - 1\right]} \tag{28}$$

Where: $\mathrm{k_d}$ $=$ Annual discount rate; N $=$ depreciation operation time (years).

They discovered that using LM with 38 neurons in the ANN predicted annual power generation and LCOE. They also used the weights obtained from the ANN to compute the LCOE and determine the optimum system. They decided that the new weights could obtain a minimum LCOE of 8.88 cents/kWh. The dataset they used was 1024 records long. The authors also used the Solar Thermal Electric Components dataset.

In another paper [146], they used different types of plants, the ones that used oil and the ones that used salt. Also, instead of five (5)

Table 13
ANN methods for Solar Power Forecasting.

Reference	Methods
[148]	Machine learning-based approach
[149]	Neural Network based approach for short-term forecasting (PV units
[150]	Neural Network based approach for short-term forecasting (Storage Systems)
[151]	Support Vector Machine for Solar Forecasting
[152]	A hybrid methodology using machine learning techniques (self-organizing maps, support vector regression, learning vector quantization network, fuzzy logic)
[153]	Forecasting for Smart grid management

variables, as in the first one, they used 6 as INPUTS and one output, in this case, LCOE. The inputs are ambient temperature, solar radiation at design, solar multiple, row spacing between parallel collectors, full load hours of the thermal energy system, and maximum temperature of each plant's working fluid.

In [147], the authors aimed to develop a methodology to help detect solar panels' underperformance, malfunction, and ageing. They proposed a moving-window-based machine learning approach. Data were collected at 1 per minute for three (3) years. This aims to help predict the energy production from a solar farm accurately. Other benefits of this proposed methodology are the ability to monitor the performance yields of solar farms, the identification of operational problems, and the degradation of solar panels due to ageing.

They tested their idea by modelling a 1.2 MW system in a tropical country with six different PV technologies of 200 KW each. The measurements from the Solar Panels are panel voltage (DC), panel current (DC), inverter voltage (AC), inverter current (AC), DC & AC power, and frequency. The weather parameters are direct normal irradiance (DNI), diffused horizontal irradiance (DHI), ambient temperature, wind speed, and humidity. Tables 13 and 14 lists some research papers on ANN methods for solar power forecasting and ANN for farm condition monitoring.

5. Summary, recommendation, and conclusion

In this study, a good deal of data relating to the global contributions to grid parity, energy transition, and electricity costs research from 1965 to 2021 has been brought to light. A detailed search of one of the most widely used databases, Scopus, was used to identify and situate research development in the field. A total of 2249 documents were identified in Scopus. This comprises 1425 journal articles, 545 conference papers, 119 review articles, 106 book chapters, 16 Books, and 13 Notes. The remaining 38 documents are distributed between conference reviews, short surveys, editorials, erratum, data papers, and an undefined paper.

Based on the data synthesis, it can be summarized that the publication output in this area has seen three evolutionary stages. (1) Pre-2000s – During this phase, only 49 documents were published (2) 2000 to 2014 – during this stage, 469 documents were published. The rise in publications in this research area began in the 2000s, and this could be congruent with the fact that in the year 2000, the Millennium Development Goals (MDGs) were signed in September 2000 by the United Nations. (3) Post MDGs; 2015 to 2022 - The last seven years of the Sustainable Development Goals (SDGs) area have produced 1731 documents.

Using VOSviewer, the citation analysis reveals the contributions of Breyer (1179 citations), Bogdanov (673), Aghahosseini (563), Caldera (357), and Ram M (184) as the five most prolific authors in the field. Meanwhile, regarding the distribution of publications and citations in these research areas, all these authors are from the same University and research laboratory in Finland - Lappeenranta-Lahti University of Technology (LUT).

Regarding the distribution of publications, scholars from the United States, Germany, China, the United Kingdom, Spain, and Australia have produced over 100 documents, each resulting in 42.2% of the published articles. Other authors from Italy (93 documents), Netherlands (93 documents), France (86 documents), and India (85 documents) have also contributed heavily to the research area, with other 80 documents each resulting in another 11.8% of the published articles. Sixty-three documents (0.02%) have been published from African countries combined.

Furthermore, key subject categories such as "energy," "engineering," "environmental sciences," and "social sciences" have had considerable influence on the structure and development of this research and aid in connecting the distinct aspects and concepts in the research field. High-impact journals such as Energy Policy, Applied Energy, Renewable energy, Renewable and Sustainable Energy Reviews, and Energy have published significant findings in grid parity research with publications of 80, 74, 67, 65, and 64,

Table 14
ANN for farm condition monitoring (analytical and data-driven methodologies).

Reference	Methods
[154]	Comprehensive analysis of a 100 KWp solar power plant
[155]	Long term degradation analysis for PV units
[156]	Fault detection (comparison between expected and actual production)
[157]	Statistical Analysis
[158]	Artificial Neural Networks
[159]	Using the I–V curve of the PV unit and voltage measurements to estimate plants power output

respectively. Also, papers from non-English authors were excluded, as only English publications were considered in this study.

With theories on power systems and grid parity calculations and research output mostly focusing on power generation in developed nations, it is imperative for research in developing countries to focus on the following areas: determination of the key driving forces that are responsible for cost reduction in RETs for developing countries thereby facilitating the achievement of grid parity; development of an optimized model suitable for calculating LCOE for RETs for developing countries considering cross country peculiarities; visualization of grid parity attainment markers based on energy policy planning for sub-Saharan countries. Also, research in grid parity events for other types of Renewable energy sources needs to the ramped up. Most of the research on grid parity focuses on Solar power. A summary of the input parameters regularly used in the LCOE model is provided in Appendix A. The most widely used parameters are system life (in a year), annual performance degradation, performance ratio, operation and maintenance cost, discount rate, and interest rate.

In conclusion, it is important to note that as sustainable development continues to gain importance [64–67], concepts such as grid parity and energy transition will consequently be subjected to the thorough significance and validation tests. In this regard, this study predicts that the global increase in the awareness of climate change and the need for renewable energy alternatives will be accompanied by the growing global popularity of the concept of grid parity and energy transition and a more uniform worldwide geographic distribution of research in the field.

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Appendix A

Table A.1
Input parameters used in LCOE methodology

LCOE input parameter groups	LCOE input parameters	Ref [46]	Ref [41]	Ref [18]	Ref [19]	Ref [43]	Ref [28]	Ref [47]	Ref [48]	Ref [30]	Ref 42]
Solar systems	Irradiation (March region) kWh/m2 - monthly	**									
	Peak Power (kW)/kWp	**	**	**							
	Electricity produced in the first year (kWh/year)	**			**			**			
	Azimuth (Angle degree)	**									
	Tilt (Angle degree)	**									
	System life (Year)	**		**	**	**	**	**		**	
	Initial year (Year)				**						
	Global radiation (kWh/m2 yr)		**	**							
	Standard radiation (kW/m2)		**	**							
	Yield for specific PV unit at a specific site (Yref)					**					
	Land Cost								**	**	
	Cost of the system installed in a particular year C (o)									**	
	Cumulative installed capacity in 2010 Q(o)									**	
	Cumulative installed capacity in year t									**	
	Solar resource (kWh/m2/yr)									**	

(continued on next page)

Table A.1 (*continued*)

LCOE input parameter groups	LCOE input parameters	Ref [46]	Ref [41]	Ref [18]	Ref [19]	Ref [43]	Ref [28]	Ref [47]	Ref [48]	Ref [30]	Ref 42]
	Capacity - total initial electricity that can be produced for the PV unit										**
	Tracking factor									**	
	Charge factor										**
	Annual performance degradation (percent)	**	**	**	**					**	**
General system losses	Inverter (percent)	**									
	Shading (percent)	**									
	Reflection (percent)	**									
	Circuit (percent)	**									
	Temperature (percent)	**									
	Incoherence performance (percent)/ Performance ratio	**	**	**						**	
PV unit Cost	Crystalline silicon (c-Si) modules – (Euro 2010/ kW)/(Euro 2009/KWp)	**	**	**							
	Inverter (Euro 2010/kW)	**									
	BOS cost factor (Percent)	**	**	**							
	BOS replacement cost factor (%)		**	**							
	BOS Component lifetime (Year)		**	**							
	Annual operation cost (Percent)	**									
	Variable Cost Factor (%)		**	**							
	Net cost of the project ($)				**						
	Energy produced ($)				**						
	Maintenance costs ($)				**						
	Operations cost ($)				**	**	**				
	Capital Expenditure					**	**		**		
	Interest expenditure ($)				**						
	Weighted Average of Cost of Capital (WACC)					**	**				
	Annual cost of Opex in percent of Capex (k)					**					
	Annuity factor (Enet)						**				
	Investment and Financing expenditure in year t							**			
	Operation and Maintenance Cost in year 1 t							**	**	**	
	Operation and Maintenance Cost in year 2 t										
	Fuel expenditure in year t							**			
	All expenditures associated with the solar system										**
	Installed cost (Euro 2010/kW)	**			**						
Financial parameter	Annual growth rate for end-user electricity price (percent)	**									
	Discounting rate (percent)	**	**	**	**			**		**	**
	Interest rate (percent)	**	**	**							
	Financing term (Year)	**									
	VAT (percent)	**									
	PACE policy interest rate (percent)	**									
	Performance ratio					**	**				**
	Equity (€)					**	**				
	Debt (D)					**	**				
	Return on equity (Ke)					**	**				
	Cost of debt (Kd)					**	**				
	Annual insurance cost in percent of Capex (Kins)					**	**				
	Insurance Costs								**	**	
	Annual Opex in percent of Capex (Ko&m)					**					
	Learning rate									**	
	PACE policy financing term (Year)	**									
Electricity Price	The electricity price based on Italian Energy Authority data (average rate for 2700 kW h/year consumption) - (Euro 2010/kW)/Base year grid-supplied electricity price/Base year wholesale electricity price	**	**	**							
	Base year electricity export price (feed-in tariff) (Euro 2009/kWh)/Base year household (end-user) electricity price		**	**							
	Annual growth rate of grid-supplied electricity price (%)/Annual growth rate for wholesale price		**	**							
	Annual growth rate of feed-in tariff % (Euros 2009)/Annual growth rate for end-user electricity price		**	**							
	Percentage of on-site electricity use (%)		**								

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