Zaidi, Abdelhamid

Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Zaidi, Abdelhamid (2024). Utilisation of deep learning (DL) and neural networks (NN) Algorithms for energy power generation : a social network and bibliometric analysis (2004-2022). In: International Journal of Energy Economics and Policy 14 (1), S. 172 - 183.
https://www.econjournals.com/index.php/ijeep/article/download/15161/7660/35606.
doi:10.32479/ijeep.15161.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(1), 172-183.

Utilisation of Deep Learning (DL) and Neural Networks (NN) Algorithms for Energy Power Generation: A Social Network and Bibliometric Analysis (2004-2022)

Abdelhamid Zaidi*

Department of Mathematics, College of Science, Qassim University, P.O. Box 6644, Buraydah 51452, Saudi Arabia.
*Email: a.zaıdı@qu.edu.sa

Received: 10 September 2023 **Accepted:** 11 December 2023 **DOI:** https://doi.org/10.32479/ijeep.15161

ABSTRACT

The research landscape on the applications of advanced computational tools (ACTs) such as machine/deep learning and neural network algorithms for energy and power generation (EPG) was critically examined through publication trends and bibliometrics data analysis. The Elsevier Scopus database and the PRISMA methodology were employed to identify and screen the published documents, whereas the bibliometric analysis software VOSviewer was used to analyse the co-authorships, citations, and keyword occurrences. The results showed that 152 documents have been published on the topic comprising conference proceedings (58.6%) and articles (41.4%) between 2004 and 2022. Publication trends analysis revealed the number of publications increased from 1 to 31 or by 3,000% over the same period, which was ascribed to the growing scientific interest and research impact of the topic. Stakeholder analysis revealed the top authors/researchers are Anvari M, Ghaderi SF and Saberi M, whereas the most prolific affiliation and nations actively engaged in the topic are the North China Electric Power University, and China, respectively. Conversely, the top funding agency actively backing research on the topic is the National Natural Science Foundation of China (NSFC). Co-authorship analysis revealed high levels of collaboration between researching nations compared to authors and affiliations. Hotspot analysis revealed three major thematic focus areas namely, Energy Grid Forecasting, Power Generation Control, and Intelligent Energy Optimization. In conclusion, the study showed that the application of ACTs in EPG is an active, multidisciplinary, and impact area of research with potential for more impactful contributions to research and society at large.

Keywords: Deep Learning, Neural Networks, Machine Learning Energy Power Generation, Sustainable Energy Generation, Bibliometric Analysis
JEL Classifications: C4, C5, R3

1. INTRODUCTION

Globally, the rapid growth in population, urbanization and living standards have exacerbated the energy demand (Razmjoo et al., 2020, Hashmi et al., 2021). Likewise, the outlined dynamics have prompted the search for affordable, reliable, and sustainable supplies of energy (United Nations, 2015). The upward trajectory of energy demand has also necessitated the design, development, and operation of efficient systems for power generation, storage, and distribution (Kyriakopoulos and Arabatzis, 2016, Soroush and Chmielewski, 2013). In response to this imperative, the global energy industry is seeking to integrate advanced computational tools such as machine learning, deep learning, and neural networks among others into energy generation, and distribution systems. This paradigm shift according to many analysts could profoundly transform the way humanity generates, distributes, and consumes energy across the globe.

Owing to this, the utilisation of numerical simulations, machine/deep learning algorithms, data analytics, and other computational tools has become commonplace in the energy and power generation sector (Munir et al., 2022, Siavash et al., 2021, Azad et al., 2021, Sharifzadeh et al., 2019). Advanced computational tools are largely used to model and analyse complex energy systems, and conduct performance optimization, as well as in the design, development, and operation of novel solutions for the energy and power sector. Numerous researchers and studies in the literature have also shown that advanced computational tools such as machine/deep learning, and neural networks among others have the potential to shape the future of electric power generation. This dynamic is critical to global initiatives to nurture and integrate renewable energy technologies (RETs) into conventional energy grids. According to numerous analysts, this shift will greatly enhance the global phase-out of fossil-based energy supplies as well as help to curb or mitigate global warming and climate change.

The review of the literature shows that the integration and utilisation of advanced computational tools in the electric power generation sector is largely focused on the design, development, analysis, operation, management, maintenance, and optimization of such systems. The objective has been generally to enhance energy grid forecasting, power generation and control, as well as intelligent optimization. Various studies demonstrated the potential of utilising ACTs in forecasting or predicting RETs (Siavash et al., 2021, Peiris et al., 2021) as well as greenhouse gas emissions (Bakay and Ağbulut, 2021), and faults, accidents or operational issues (Tan and Lim, 2004, Bae et al., 2006, Aslan, 2012) in energy grid systems. The versatility of ACTs applied in EPGs also spans the areas of power generation and control as demonstrated by various studies in the literature (Sharifzadeh et al., 2019, Lin et al., 2011, Singh et al., 2014, Lawan et al., 2017). The findings revealed that ACTs such as artificial neural networks (ANNs), machine/deep learning methods, support vector regression, and Gaussian process regression have the potential to enhance power generation as well as control the operations of EPG systems. ACTs like ANNs and related algorithms have also been adopted to assess the performance, adequacy, and generation capacity of various EPG systems based on RETs such as wind (Ak et al., 2018, Azadeh et al., 2007).

Despite their potential, RETs such as solar and wind are hampered by their intermittent production and supply of energy (Notton et al., 2018), as such studies have been carried out by various groups to optimise their operations (Jahangoshai Rezaee and Dadkhah, 2019, Panta et al., 2007, Yilmaz and Sen, 2022). In addition to performance optimization, the thermo-economic, techno-economic, and energy consumption aspects of EPG from RETs have also been optimised by various researchers in the literature. Yilmaz and Sen (2022) performed optimisation of the simultaneous production of hydrogen and energy from geothermal and solar energy generation technologies, whereas (Panta et al., 2007) examined the optimal economic dispatch for power generation using ANN. NNs have also been employed to examine the power generation and desalination potentials of a solar chimney, as reported in the literature (Azad et al., 2021), whereas Jahangoshai Rezaee and Dadkhah (2019) used NNs to ascertain the optimal energy consumption from electric power generation.

Based on the foregoing, the topic of the Utilisation of Advanced Computational Tools for Electric Power Generation has gained traction over the years. The publications data from Elsevier Scopus shows that publications on the topic date back to 1987 with over 6,877 mentions of the keywords in the database. However, to date, there has been no study that critically examines the research landscape on using ACTs for EPG or comprehensively explores the pivotal role that computational tools have played in shaping the electric power generation landscape. Therefore, this study examines the research landscape on the innovative applications of advanced computational tools for electric power generation, forecasting, operation, and optimization using publication trends and bibliometric analyses. The significance of this work resides not only in its computational tool analysis but also in its application of bibliometric techniques to evaluate the scholarly landscape. This study uses bibliometric analysis to provide a novel viewpoint on the development and influence of research on sophisticated computational tools for electric power generation. Bibliometric analysis is a powerful tool for analysing publication patterns, identifying important authors, and institutions as well as comprehending the research landscape on a specific topic (Donthu et al., 2021). Numerous studies have effectively implemented the methodology in examining the research landscape of various fields and disciplines and climate change (Ajibade et al., 2023b), smart cities (Zaidi et al., 2023), renewable energy (Ajibade et al., 2023a), plastics (Wong et al., 2020b), agrowaste valorisation (Nyakuma et al., 2021), food products (Lee et al., 2023), solid wastes (Wong et al., 2020a), among others.

2. METHODOLOGY

The research landscape on the utilisation of advanced computational tools for electric power generation was examined through publication trends and bibliometrics data analyses. The PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) technique was adopted to identify, screen, and examine the published documents on the topic indexed in the Elsevier Scopus database from 2004 to 2022. The Scopus database is one of the largest collections of scientific abstracts and citations on published documents in various disciplines (Khudzari et al., 2018).

The first stage of the methodology involved the identification of related published documents on the use of advanced computational tools for electric power generation (hereafter termed ACT-EPG) Research. Consequently, a suitable search string containing related keywords was designed to identify and screen related published documents (or publications) on the topic in the Scopus database. The search string TITLE ((“artificial intelligence” OR “AI” OR “machine learning” OR “deep learning” OR neural AND network*)) AND “power generation” OR “energy power generation” OR “energy production”)) AND PUBYEAR > 2003 AND PUBYEAR < 2023 AND (LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (EXCLUDE (LANGUAGE, “Japanese”)).

The search results returned 152 published documents, which were subsequently examined through publication trends and bibliometric data analyses. The general publication trends were examined to determine the growth trajectory of publications on the topic, source titles, top cited publications, sources, and subject areas. Next, the stakeholders analysis was examined to elucidate the top funding agencies, authors, countries, and affiliations actively engaged in the research landscape from 2004 to 2022. The VOSviewer software was subsequently adopted to examine the co-authorships, research hotspots, and literature review on the topic in the literature.

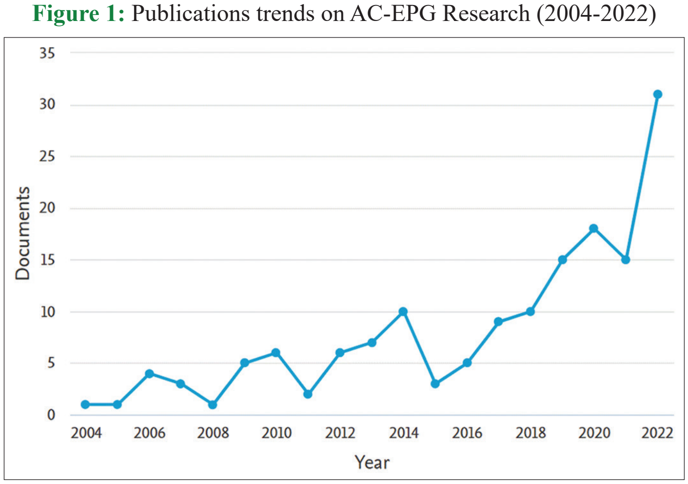
3. RESULTS AND DISCUSSION

3.1. Publication Trends

Figure 1 shows the publication trends on ACT-EPG Research. The plot of the publications against publication year shows that the number of published documents increased from 1 to 31 between 2004 and 2022. The distribution of document types shows that 89 or 58.6% of the publications are Conference Papers, whereas 63 or 41.4% are Articles. Further analysis showed that 45 publications are Open Access, whereas 29 (Gold), 14 (Green), 10 (Bronze), and 2 (Hybrid Gold).

The subject areas analysis revealed that publications on ACT-EPG are indexed in 17 categories with the top 5 being Engineering (84), Energy (60), Computer Science (58), Mathematics (25), and Environmental Science (21). The findings show that ACT-EPG research cuts across various STEM (science, technology, engineering, and mathematics) and HASS (humanities, arts, and social sciences) areas. The subject areas of Engineering, Energy, Computer Science, Mathematics, and Environmental Science all contribute significantly to the use of AI and neural networks in electric power generation. While energy professionals utilise AI for demand management and renewable energy integration, engineers build and optimise power infrastructure. Additionally, the mathematics discipline provides modelling and optimisation tools, whereas computer scientists create algorithms and manage data. Environmental scientists prioritise evaluating renewable energy sources and reducing emissions. Together, these industries work to improve the effectiveness, dependability, and sustainability of the power generation process by utilising AI to manage resources, detect breakdowns, optimise operations, and lessen environmental impact. The advancement of computational tools in the energy sector depends on these interdisciplinary initiatives.

Figure 1: Publications trends on AC-EPG Research (2004-2022)



3.2. Source Titles

The specialised nature of the subject areas in ACT-EPG research has given rise to thematic sources of publications for the findings on the topic. Table 1 presents the top 10 sources titles or medium for publications on the topic in the Scopus database. The number of publications from each of these sources within a particular dataset is disclosed by this data source, enabling comprehension of the relative contributions of these sources to the overall body of literature in the relevant domains. This information can be used by researchers and analysts to evaluate the acceptance, importance, or prevalence of publications from many sources within a specific setting or field of study.

As observed, the top 10 source titles comprising journals, and conference proceedings from various publishers, including Elsevier, Frontiers and MDPI among others, account for 36 publications or 23.68% of the TP on the topic. The top source titles on the topic are Journal of Physics Conference Series, Energies, and Lecture Notes in Electrical Engineering. A deeper investigation reveals that the Journal of Physics Conference Series publishes conference proceedings from physics and related subfields. On the other side, research on energy-related topics, such as renewable energy, energy efficiency, and sustainable energy systems, is covered in Energies, a peer-reviewed open-access journal published by MDPI (Switzerland). Last but not least, the Lecture Notes in Electrical Engineering series is a collection of lecture notes, publications, and conference papers on various facets of electrical engineering.

3.3. Benchmark Publications

Table 2 shows the top 10 most cited publications on ACT-EPG research in the Scopus database. Data analysis showed that these publications have been cited between 48 and 289 times (or 103 on average) over the years. The analysis of highlighted cited publications provides critical information on the research landscape on any given topic, as high citations indicate that such publications have been critical to the growth and development of the field. In the field of ACT-EPG research, the top cited publication is "Neural-network-based MPPT control of a stand-alone hybrid power generation system" by Lin et al. (2011) 289 publications published in the IEEE Transactions on Power Electronics. In second place is "Machine-learning methods for integrated renewable power generation: A comparative study of artificial neural networks, Support Vector Regression, and Gaussian Process Regression" by Sharifzadeh et al. (2019) published in Renewable and Sustainable Energy Reviews with 153 citations. Lastly, the study by Bakay and Ağbulut (2021) titled "Electricity production-based forecasting of greenhouse gas emissions in Turkey with deep learning, support vector machine and artificial neural network algorithms" is in third place with 95 citations.

Overall, the top publications on the topic have focused on the use of artificial intelligence tools and neural network algorithms such as machine learning and deep learning to design, develop, operate, and manage integrated renewable (e.g., solar, PV, and wind) and

Table 1: Top sources titles for ACT-EPG research

Source Titles	Total publications (TP)	Percentage Total Publications (%TP)
Journal of physics conference series	8	5.26
Energies	5	3.29
Lecture notes in electrical engineering	5	3.29
Advanced materials research	3	1.97
Frontiers in energy research	3	1.97
IET renewable power generation	3	1.97
IOP conference series EES	3	1.97
Applied energy	2	1.32
Energy	2	1.32
Energy procedia	2	1.32

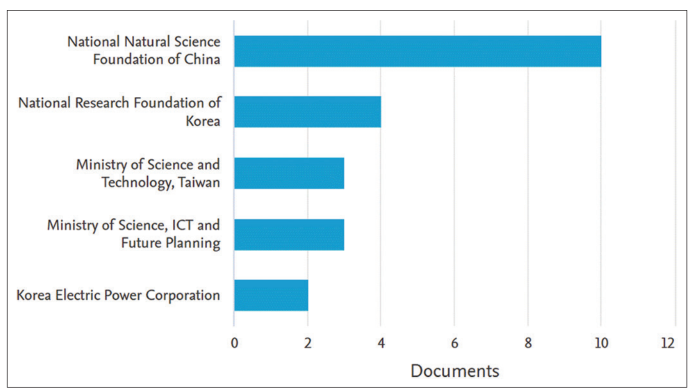
*EES - Earth and Environmental Science

Table 2: Top 10 most cited publications on ACT-EPG research

References	Title	Cited by
Lin et al. (2011)	Neural-network-based MPPT control of a stand-alone hybrid power generation system	289
Sharifzadeh et al. (2019)	Machine-learning methods for integrated renewable power generation: A comparative study of artificial neural networks, support vector regression, and Gaussian Process Regression	153
Bakay and Ağbulut (2021)	Electricity production-based forecasting of greenhouse gas emissions in Turkey with deep learning, support vector machine and artificial neural network algorithms	95
Sitharthan et al. (2019)	An improved radial basis function neural network control strategy-based maximum power point tracking controller for wind power generation system	85
Yang et al. (2020)	A novel competitive swarm optimized RBF neural network model for short-term solar power generation forecasting	84
Kardakos et al. (2013)	Application of time series and artificial neural network models in short-term forecasting of PV power generation	76
Singh et al. (2014)	Neural network controlled grid interfaced solar photovoltaic power generation	74
Azadeh et al. (2007)	Performance assessment of electric power generations using an adaptive neural network algorithm	72
Tan and Lim (2004)	Application of an adaptive neural network with symbolic rule extraction to fault detection and diagnosis in a power generation plant	54
Zhong et al. (2018)	Prediction of photovoltaic power generation based on general regression and back propagation neural network	48

conventional power generation systems (Kardakos et al., 2013). Others have sought to comparatively examine the deployment of such advanced technologies and tools to forecast/predict generation (Sitharthan et al., 2019), analyse performance, capacity utilisation (Singh and Sharma, 2011), as well as greenhouse gas emissions (Bakay and Ağbulut, 2021). Lastly, some studies have explored the use of ACT for fault detection, troubleshooting and diagnosis in energy and power generation plants worldwide (Tan and Lim, 2004). The impact of such studies on the overall growth and development of global energy production and utilisation has prompted significant investments through research and development funding. Section IV will examine the impact of such financial investments and support on the research landscape of ACT-EPG.

Figure 2: Top research funding agencies on ACT-EPG research



3.4. Funding Agencies

Figure 2 shows the top 5 research funding agencies on ACT-EPG research worldwide. Funding organisations play an important role in nurturing and developing research across the globe (Wong et al., 2020a, Ajibade and Ojeniyi, 2022). The financial and non-material resources from such funding bodies provide an avenue for the purchase of equipment, and materials (Nyakuma et al., 2021), as well as the necessary funds for research travels and collaborations (Ajibade et al., 2023a). In this study, the most active research funding organization is the National Natural Science Foundation of China (NSFC) with 10 publications which have been cited 148 times. The NSFC has been critical to funding research and development efforts in the People's Republic of China to the tune of over \$4 billion annually (NSFC, 2022). In second place is the National Research Foundation of Korea (NRFK), with a budget of \$5.24 million for the year 2019 (NRFK, 2019), which has funded 4 publications which have gained 34 citations. The NRF of Korea caters to research and development efforts aimed at promoting Korean researchers at home and abroad. In third place are the Ministry of Science and Technology of Taiwan and the Ministry of Science, ICT and Future Planning each with 3 publications.

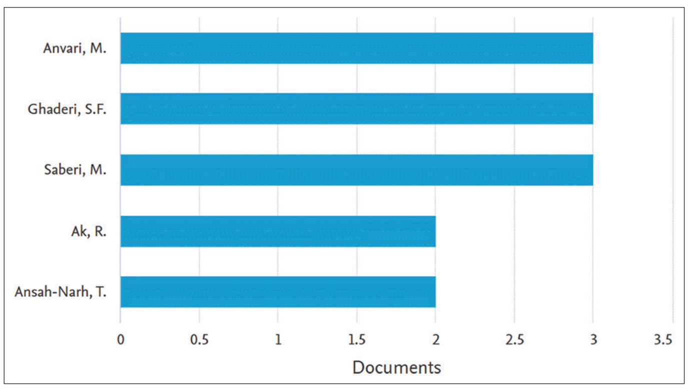
The findings indicate that the top 5 funders of research on ACT-EPG are based in China and Korea. Both countries have invested significant resources in ACT for EPG to ensure they become global leaders in the field. Furthermore, analysts opine that nations with a clear lead in AI technologies will be global shapers of research and technologies needed for sustainable growth and technological development. Hence, both nations have made enormous efforts to lead the race to attain top-class AI tools, algorithms, and technologies by investing the R&D as well as researchers, and institutions in their countries.

3.5. Stakeholder Analysis

3.5.1. Authors/researchers

Stakeholder analysis is an integral aspect of examining the research landscape in any given field of research (Syed et al., 2023). The researchers, affiliations and countries actively involved in any subject area provide insights into the research impact, collaborative networks, and future directions (Nyakuma et al., 2023). The top researchers on ACT-EPG research from 2004 to 2022 as deduced from the Scopus database are presented in Figure 3. The top researcher position on the topic is split three ways among Anvari M, Ghaderi SF and Saberi M each with 3 publications. Other notable researchers in the top 5 bracket are Ak R, and Ansah-Narh T with 2 publications each. Figure 4 shows the overlay visualisation map for researchers-based co-authorships on ACT-EPG research.

Figure 3: Top researchers on ACT-EPG research (2004-2022)



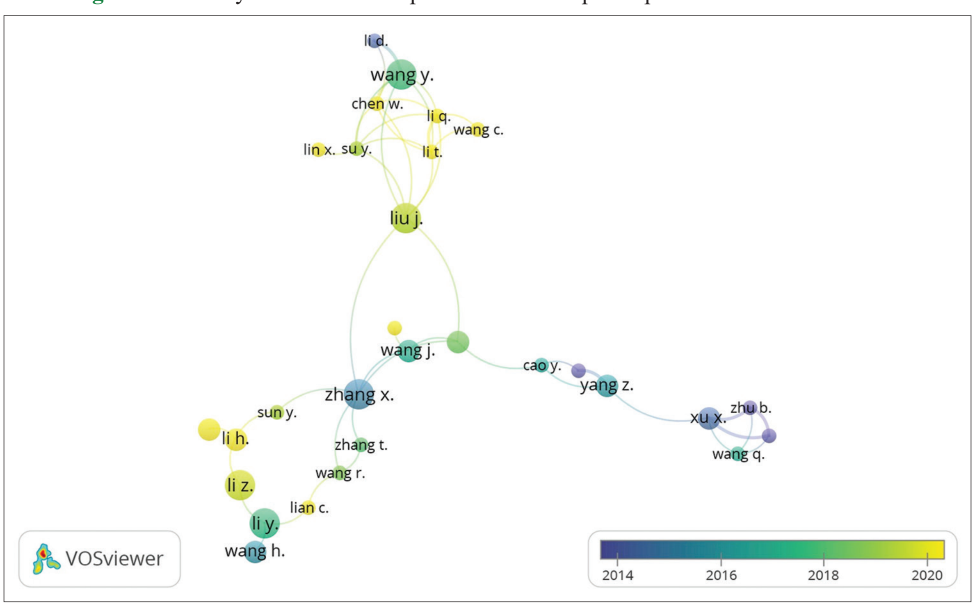
The overlay visualisation map in Figure 4 shows 5 clusters comprising 2-10 authors. The results of the co-authorship analysis show that out of the possible 64 authors, only 29 authors have co-authored 2 or more publications on the topic. Based on the foregoing, it can be surmised that only 45.31% of the authors are productive co-authored papers on the topic, indicating the collaboration has not significantly impacted the researcher-based productivity of ACT-EPG as also evident in the low number of links (48), total link strength (TLS, 55). Hence, analysis of the top countries and their collaborations was examined in the study. Nonetheless, the highest number of co-authored publications was reported for Wang Y, Liu J, and Zhang X, whereas the authors with the highest cited documents are Hong CM (316); Yang Z (93), and Anvari M (92).

3.5.2. Nations/countries

Figure 5 shows the top 5 nations/countries actively involved in ACT-EPG research worldwide. As observed the list includes nations such as China, Iran, India, Malaysia, and the United States.

The most prolific nation in the field is China with 67 publications which have been cited 476 times over the years. The productivity of China is large due to the works of Ma X, Ni C, and Xiu J who are largely based at institutions such as the North China Electric Power University, Ministry of Education (China), Southeast University, *Hohai* University, and Beijing Institute of Technology, among others. In second place is Iran with 11 publications and 219 citations to date largely due to the productivity of researchers such as the University of Tehran, Bu-Ali Sina University, and Islamic Azad University, Hamedan Branch. The spot for third place is tied among India, Malaysia, and the United States each with 9 publications on the topic over the years. The higher productivity observed among nations compared to the authors shows that

Figure 4: Overlay visualisation map for co-authorship of top researchers on ACT-EPG



collaboration is more active or pronounced at the national level. To further examine this submission, VOSviewer was used to examine the level of co-authorships among countries, as shown in the overlay visualisation map in Figure 6.

The map shows that 22 out of the 25 countries with 2 or more publications are linked suggesting the existence of active collaborations between the nations. The links and nodes indicate that there are 7 clusters (comprising 2-5 countries) on the ACT-EPG research landscape. China was adjudged the nation with the most co-authored and co-cited publications compared to other nations notably Iran, India, Taiwan, and the United States, as depicted in Figure 6. Similarly, China showed the highest total link strength among the top nations actively engaged in ACT-EPG research. Overall, the findings indicate China is not only the most prolific but most influential in terms of publications and citations. In an effort to modernise its economy and have a smaller negative impact on the environment, China is actively integrating artificial intelligence (AI) into the energy generation industry. Investment in smart grids, optimum integration of renewable energy sources, increased energy efficiency, monitoring of carbon emissions, and promotion of infrastructure for charging electric vehicles were some of the key components of AI policies. AI was also used in data analysis for policymaking and energy management systems. The government promoted worldwide collaborations and provided financial support for AI research and development. Remember that these regulations may have changed, so for the most recent details on China's AI-related energy generation programmes, check with current sources. In general, the dominance of the outlined nations is largely due to the productivity and collaborative efforts of their researchers (Figures 3 and 4) but also their affiliation (universities, research institutions, and centres of research/excellence). Figure 7 shows the plot of the most active research affiliations engaged in ACT-EPG research between 2004 and 2022.

As seen, the most prolific affiliation is North China Electric Power University (China) with 4 publications, whereas the University of Tehran (Iran) and Bu-Ali Sina University (Iran) both have 3 publications to take up 2nd and 3rd places, respectively. Other notable contributions have been from the IEEE and the *Università degli Studi di* Padova each with 2 publications. The data also shows that the top 5 spots are occupied by universities in China, Iran, and Italy, which could suggest that institutions in these countries have strong research groups currently engaged in the field. Globally institutions have in place research policies and framework strategies that seek to create knowledge centres, technological incubators or scientific zones based on specific thematic areas as well as to deploy resources towards addressing societal needs or national interests. Consequently, such institutions and ultimately their nations become the epicentres of research, growth, and development.

3.6. Hotspots Analysis

Keywords co-occurrence analysis is typically used to examine the various research hotspots or thematic areas in any field of science or research endeavour (Lis and Tomanek, 2020). It can also be used to beam a searchlight on the current trending topics as well as predict future directions on various subject areas (Lee et al., 2023). In this paper, the VOSviewer software was used to examine the current research hotspots or thematic areas on the ACT-EPG research landscape. Figure 8a and b presents the network visualisation map and overlay visualisation map for the co-occurrence analyses of related keywords on ACT-EPG. The maps show all the keywords that occurred at least 10 times during the search and analysis in VOSviewer. A total of 26 keywords out of 1487 satisfied the search criteria, which resulted in 3 clusters comprising between 4 and 10 keywords. The largest cluster consists of keywords like forecasting, meteorology, and solar energy among others, whereas the smallest has "power generation" and "neural networks" among others. Table 3 shows the resulting keywords from the keywords co-occurrence analysis after eliminating duplicate keywords and terms from the lists in the software.

Based on the findings in Table 3, the highest occurring keywords which also incidentally have the highest total link strengths are Neural networks (93 times, TLS = 357),

Figure 5: Top nations/countries on ACT-EPG research

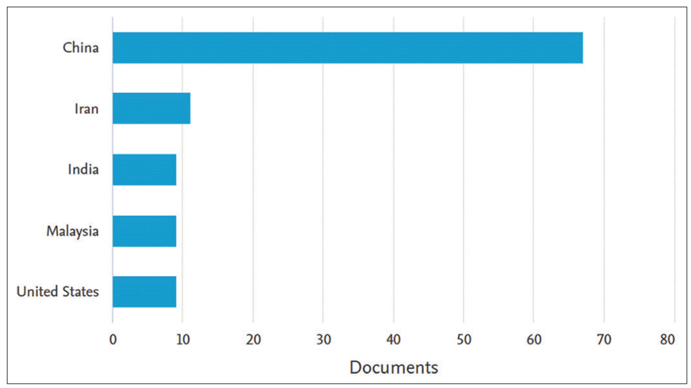


Figure 6: Overlay visualisation map for co-authorships among countries in ACT-EPG research

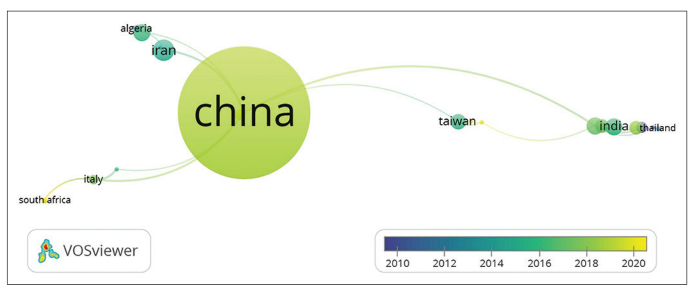


Figure 7: Top affiliations engaged in ACT-EPG research (2004-2022)

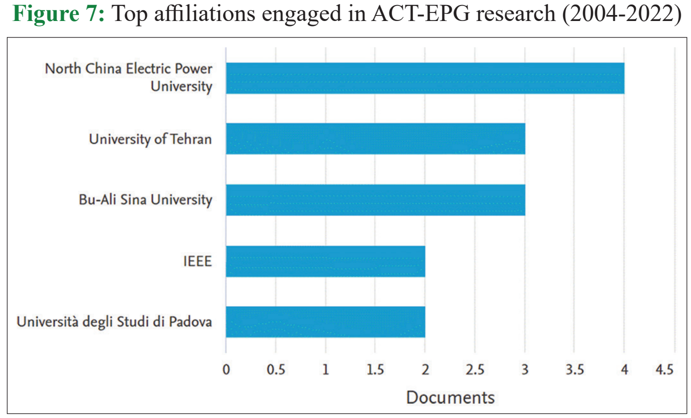


Figure 8: Keywords co-occurrence analyses of ACT-EPG (a) Network visualisation map (b) Overlay visualisation map

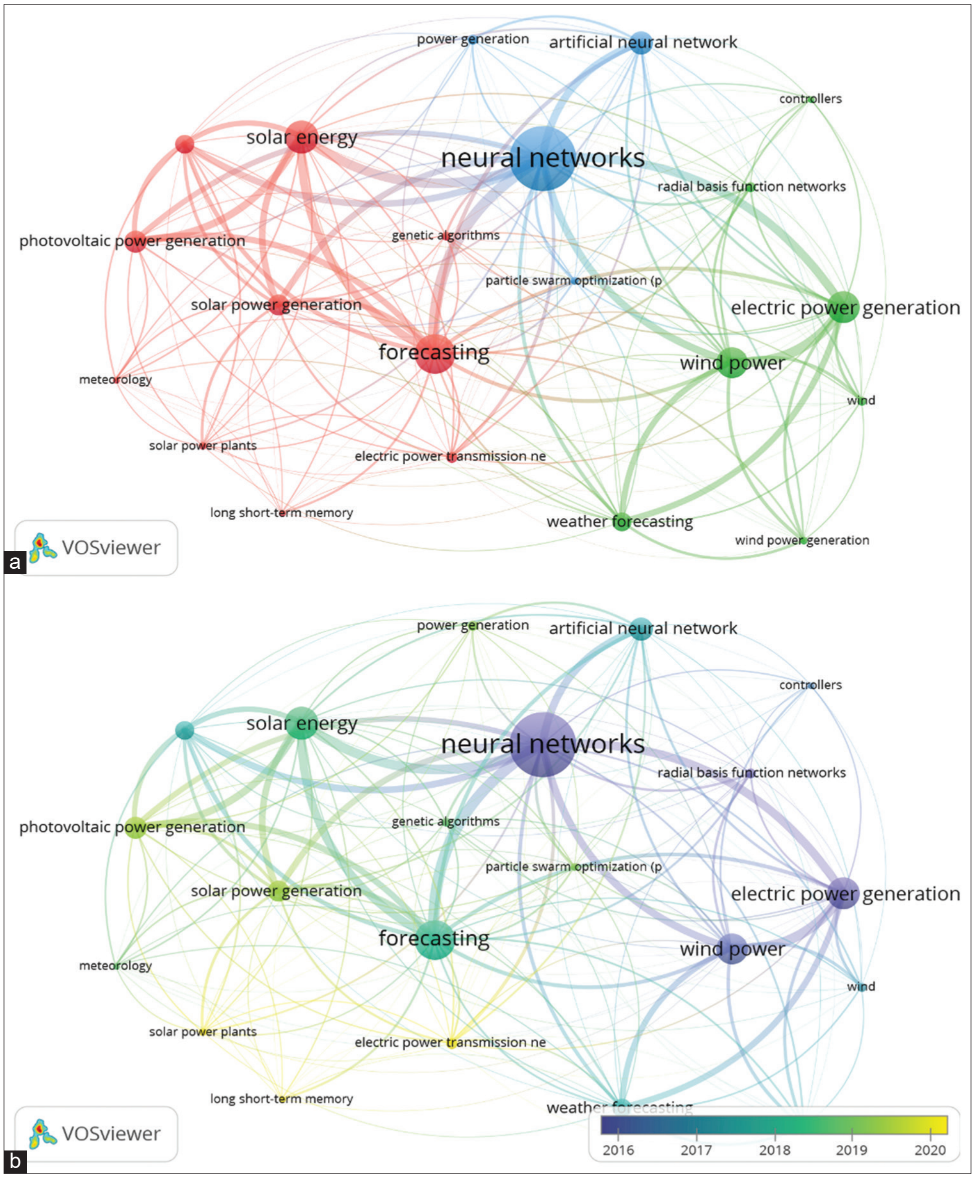


Table 3: Cluster keywords for ACT-EPG research

	Clusters		
S. No	**1**	**2**	**3**
1	Electric power transmission	Controllers	Artificial intelligence
2	Forecasting	Electric power generation	Neural networks
3	Genetic algorithms	Radial basis function net	Particle swarm optimization
4	Long short-term memory	Weather forecasting	Power generation
5	Meteorology	Wind	
6	Photovoltaic cells	Wind power	
7	Photovoltaic power generation	Wind power generation	
8	Solar energy		
9	Solar power generation		
10	Solar power plants		

Forecasting (58 times, TLS = 264), and Solar Energy (48 times, TLS = 225). Based on the cluster analysis, it can be concluded that ACT-EPG research is characterised by three hotspots or thematic areas of research namely; (i) Energy Grid Forecasting, (ii) Power Generation Control, and (iii) Intelligent Energy Optimization.

3.7. Literature Review

3.7.1. Energy grid forecasting (EGF)

EGF is a data-driven approach for predicting the future patterns of electricity demand and supply within a power system (Barkh et al., 2022). It helps grid operators maximize energy generation and distribution by using historical data, weather predictions, and sophisticated algorithms to predict when and where energy demand will peak. By considering the intermittent nature of renewable energy sources, this forecasting facilitates effective resource allocation, lowers the danger of blackouts, and encourages their integration. In addition to improving energy sustainability and lowering costs for both consumers and providers, it is essential to maintain a stable and reliable electrical system (AlHaddad et al., 2023).

Over the years, EGF has gained importance due to the growing need for renewable energy technologies (RETs) integration into and the decentralization of conventional grid energy from distributed resources. Furthermore, EGF has become a critical aspect of energy dynamics due to its potential to improve energy efficiency and facilitate demand-side management (Chang et al., 2018, Verma et al., 2016). On the whole, it has the potential to bolster grid resilience against the twin scourges of global warming and climate change using data and technological advancements. In addition, EGF helps engineers, scientists, and policymakers manage the changing energy landscape, improve grid dependability, and make the switch to efficient and sustainable energy systems (Munir et al., 2022, Oudjana et al., 2012). Accurate forecasting is necessary to create an energy grid that is more resilient and responsive by balancing supply and demand, cutting waste, and aligning with global sustainability goals (Dong et al., 2017).

Given these dynamics, many researchers have critically examined the potential of EGF in electric power generation worldwide. De Aquino et al. (2009) examined the application of Wavelet and Neural Network models for forecasting wind speed and power generation in an experimental wind park. Similarly, Salgado and Afonso (2013) investigated the use of hybrid fuzzy clustering for forecasting power generation from wind energy using neural network models. In the study by Zhang et al. (2015) similar day and Elman neural networks were utilised for short-term forecasting of power generation from wind energy installations. On the other hand, Chang et al. (2018) proposed the use of a novel type of radial basis function-based neural network to forecast the power generation capacity of wind energy. Recently, Wang et al. (2022) explored the nonparametric probabilistic forecasting of wind power generation using a quadratic slope quantile function and an autoregressive recurrent neural network. The proposed approach outperforms advanced benchmarks by at least 6% in terms of CRPS, demonstrating its high-quality probabilistic wind power forecasting.

Other studies in the literature have also examined the use of neural networks to forecast energy generation and production from solar energy. For example, Chaouachi et al. (2010) highlighted the potential of utilising neural networks for the short-term forecasting of the power generation potential of ensemble-based solar. Similarly, Oudjana et al. (2012) examined the use of neural networks to forecast short-term power generation in photovoltaics. Yang et al. (2014), developed a generic algorithm and BP neural network-based models for forecasting the power generation capacity of photovoltaic arrays. Verma et al. (2016) examined the power generation capacity of a solar system using neural networks and regression models. Rogier and Mohamudally (2019) estimated the power generation of a photovoltaic system using an IoT-based nonlinear autoregressive neural network. More recently, Yang et al. (2020) examined the prospects of short-term solar power generation using a novel competitive swarm optimized RBF neural network model. Munir et al. (2022) examine the simplified 1-day ahead forecasting of solar photovoltaic energy generation using artificial neural networks. The analysis revealed that two combinations the first includes temperature, dew point, relative humidity, and cloud cover, and the second includes all six characteristics are the most accurate for predicting the generation. Other studies have also utilised neural networks to estimate water consumption (Hussin et al., 2017) and forecast greenhouse gas emissions around the world (Bakay and Ağbulut, 2021) using artificial neural networks-BAT, deep learning, and support vector machine algorithms.

Overall, these studies have looked into the use of neural network models to forecast power generation, particularly for wind and solar energy. These studies use a variety of methods, including deep learning, radial basis functions, fuzzy clustering, genetic algorithms, and wavelets. They have a focus on short-term forecasting, which includes projecting the production of solar and wind energy using historical trends and weather data. Forecasting loads and greenhouse gas emissions are also covered in many studies. Overall, this research focus area aids in the creation of precise and effective models for predicting the production of renewable energy sources and the power demand.

3.7.2. Power generation control (PGC)

PGC uses artificial intelligence tools and algorithms such as neural networks, to better manage and optimize the production of electrical power (Kumar, 1998, Farooq et al., 2022). Neural networks can assist in integrating renewable energy technologies as well as forecasting future demand for generated energy. In addition, the NN can be used to efficiently optimize and maintain power schedules and monitor the stability of grids (Sitharthan et al., 2019, Singh and Sharma, 2011, Chao et al., 2013). PGC and NNs can also be used to fine-tune power plant operations, detect equipment faults, assist in demand response, and enable real-time grid management. It is widely reported that applying ACTs such as NNs in power generation enhances efficiency, reduces costs, and ensures grid reliability (Sitharthan et al., 2019, Singh and Sharma, 2011). However, successful implementation necessitates robust data collection, model training, and seamless integration with existing systems for safety and reliability. PGC with neural network algorithms has the potential to change how the power generation sector operates. The integration of neural networks into PGC enables precise demand forecasting, effective maintenance planning, and real-time grid stability management (Yao et al., 2010). In addition, it allows for the seamless integration of renewable energy sources as well as the optimization of power plant operations. Moreso, it can be used to swiftly detect faults and equipment problems which aid in demand response, operation of grids, and cost savings.

Given these opportunities, numerous studies have been conducted on PGC worldwide. For example, Wang et al. (2009) examined various fuzzy neural network-based synthesised power and frequency management methods for wind power production systems. The results of the simulations demonstrated that, even in the presence of varying system characteristics and load torque disturbances, the suggested method could still operate with good dynamic performance and control precision. Yao et al. (2010) examine a self-tuning PID pitch control using RBf neural networks for wind power generation. The findings showed that the proposed controller outperformed the traditional PID controller under a random wind speed. Lin et al. (2011) demonstrated the prospects of control of an independent hybrid power system (comprising solar, wind, diesel engines, and intelligent power controllers) using neural networks. Singh and Sharma (2011) examined the potential of utilising neural network-based voltage and frequency controllers for remote control of wind power generation. Chao et al. (2013) developed an innovative cerebellar model articulation controller neural network to analyse the faults of a photovoltaic power generating system. The findings showed that the proposed strategy requires less training time and takes less time to train. In addition, the diagnosis system's detection tolerance was improved, and the fault diagnosis accuracy rate was greatly raised. Similarly, Singh et al. (2014) examined neural networks to control power generation in solar photovoltaics with grid interface.

The implementation of NNs in wind-based power generation has also been extensively examined in the literature. Sitharthan et al. (2019) proposed an enhanced maximum power point tracking controller for wind power generation systems using the radial basis function neural network control approach. Lu et al. (2019) examined the potential to control integrated offshore wind and wave power generation systems using a recurrent wavelet-based Elman neural network and a modified gravitational search method. The results showed that the proposed control scheme improved the real power regulation and dynamic performance of a combined wind and ocean wave energy scheme over a wide range of operating conditions. Shanmugam et al. (2020) examined the potential application of an event-triggered neural network control system to wind power generation systems and its stabilization. Siavash et al. (2021) combined artificial neural networks and multiple linear regression to predict the power production and rotor angular speed of a tiny wind turbine fitted with a controlled duct. The findings showed that for both rotor speed estimation and the estimate of the turbine power curve, the created neural network model was found to perform better than the regression model. The Betz limit, which increases the wind flow through the rotor plane, may typically be exceeded by shrouding a wind turbine. The turbine's performance will be strongly influenced by the shrouding angle at higher wind speeds.

3.7.3. Intelligent energy optimization (IEO)

IEO aims to utilize neural networks to reduce energy use across various applications. NNs enable data-driven decisions by learning from both historical and current data, which can be used to predict energy demand, manage loads, integrate renewables efficiently, and enhance industrial processes (Sri and Divya, 2020). In grid management, IEO using NNs aids forecasting and demand response which ultimately helps to ensure grid stability. Energy efficiency is improved as NNs identify savings opportunities and cut costs. This approach fosters sustainability by reducing environmental impact (Kim et al., 2019, Shalaby et al., 2022). In essence, NNs-driven IEO offers adaptive, data-centric solutions to improve efficiency, lower costs, and promote sustainability in various energy-related sectors (Donohoo, 2012, Pedram et al., 2023). Owing to its potential researchers worldwide have actively researched various ways to implement NNs-based IEO in the energy sector. Liu (2012) examined the integration of particle swarm optimization (PSO) and RBF neural networks for optimizing wind power generation. The study showed that the SO algorithm can effectively be utilised to optimize connection weights, radial basis function centres, and widths for wind power generation prediction, with a hybrid model showing better prediction ability than the BP neural network. Similarly, Heydari and Keynia (2015) Particle swarm optimization and an Elman neural network are combined to predict the amount of wind energy that will be produced (El-PSO).

Assareh et al. (2016) employed an advanced hybrid RBF neural network coupled with the HGA-GSA optimization method to optimize the power generation of wind energy in low wind speed zones in the southwest of Iran. The finding revealed that the wind potential at the location is insufficient for power generation as such a proportional and integral (PI) control system integrated to vary the wind turbine torque to significantly enhance the power generated by the generator even at low wind speeds. In the proposed model, the net acquired gains of the PI controller were modified by the RBF neural network to maximize the generator's output power. Lastly, the HGA-GSA, a hybrid genetic algorithm and gravitational search algorithm, were utilized to educate and train the neural network. Overall, the authors showed that NNs could used to optimise power generation in wind energy systems for efficient performance. Similarly, Yu and Tao (2020) employed PSO and NN-based algorithms to examine the complementary power generation capacity of a wind water and solar system. The findings showed that NN successfully predicted and optimised the output of wind and solar energy over the short-term period examined in the study. It was also observed that the system effectively controlled energy consumption at different periods to achieve complementary results and maintain system stability.

NNs have also been used to optimise the power generation potential of standalone or hybrid-based solar and photovoltaic systems across the globe. Azad et al. (2021) employed an NN algorithm to perform multi-objective optimization of an innovative solar chimney for simultaneous water desalination and generation of energy. A perceptron neural network with two hidden layers was used to determine the total power and condensed water by predicting the average temperature on the collector's surface and the average air velocity at the turbine intake. The genetic algorithm was applied for optimization, whereas the Pareto frontier was used to solve the operational problem. Based on the NN-based optimisation, the values for total energy production and freshwater production that correspond to the optimum level are 719 kW and 14.28 kg/s, respectively. Yilmaz and Sen (2022) developed an innovative artificial neural network-based genetic (Field Programmable Gate Array) algorithm to optimise and thermo-economically examine to optimize a hybrid system that combines geothermal and solar energy for simultaneous hydrogen production and power generation. The findings showed that at a geothermal energy temperature of 200 C, hydrogen could be produced via water electrolysis at an exergy efficiency of 38.4% and production cost of US$1.088/kg of H_2. The payback time and net work done by the system were optimally observed to be 7.98 MW and ~4.1 years, respectively.

4. CONCLUSIONS

The paper examined the research landscape on the utilisation of advanced computational tools such as neural network algorithms for electric power generation was examined through publication trends and bibliometrics data analyses. The PRISMA identified over 152 published documents comprising articles (41.4%), and conference proceedings (58.6%), after extensive screening of records from the Elsevier Scopus database between 2004 and 2022. Further analysis showed that the number of publications on the topic increased by 3,000% from 2004 to 2022, which indicates significant scientific interest in the topic due to the growing impact of the topic globally. Further analysis revealed that ACT-EPG is a multidisciplinary area of research with the potential to transform the dynamics of current energy mixes as well as curb/mitigate the impacts of global warming and climate change. Stakeholder analysis revealed the research landscape on ACT-EPG is characterised by active research output by several authors, affiliations, and nations due to ample funding from various funding bodies worldwide. The most notable researchers on the topic are based in China, Iran, and India which suggests ACT applications in EPG are a top feature of the research priority and national policies of these nations. As a result, large resources in the form of financial support for research infrastructure among others have been invested in these nations which has resulted in high numbers of publications, particularly in high-impact journals over the years. Bibliometric analysis showed a high rate of collaboration between the top nations, which indicates research in this area seeks to address not only national interests but also international issues such as global warming and climate change caused by extensive fossil fuel pollution. Hotspot analysis revealed three major themes or focus areas on the topic namely; Energy Grid Forecasting, Power Generation Control, and Intelligent Energy Optimization. Based on the foregoing, we predict that future studies on the topic could include extensive research into the cybersecurity of such EPG systems particularly in the wake of numerous malware, phishing, and other intrusion attacks on the energy and grid infrastructure worldwide.

5. ACKNOWLEDGEMENT

Researchers would like to thank the Deanship of Scientific Research, Qassim University for funding publication of this project.

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