Water Practice & Technology

IWA PUBLISHING

Water Practice & Technology Vol 17 No 10, 2071 doi: 10.2166/wpt.2022.116

Bibliometric analysis of artificial intelligence algorithms used for microbial fuel cell research

Luis Erick Coy-Aceves and Benito Corona-Vasquez*
Departamento de Ingeniería Civil y Ambiental, Universidad de las Américas Puebla, Ex-Hacienda Santa Catarina Mártir S/N, San Andrés Cholula, Puebla 72810, México
*Corresponding author. E-mail: benito.corona@udlap.mx

LEC-A, 0000-0002-1737-9155; BC-V, 0000-0003-0538-2741

ABSTRACT

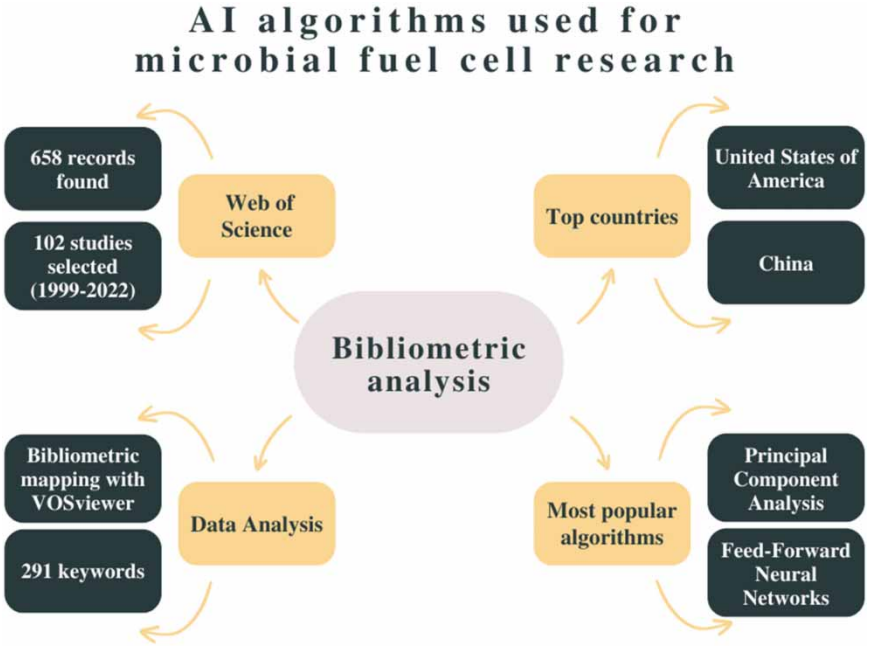
Research regarding microbial fuel cells has been stimulated to reduce the operating costs and energy consumption of conventional wastewater treatment, and increase its profitability. However, these devices are challenging to study due to their complexity and sensitivity to both internal and external factors. Artificial intelligence (AI) has been used to analyze microbial fuel cells as an effective alternative to the use of mathematical models, which are still in development. In this study, the main goals were to perform the first bibliometric analysis of AI applied to microbial fuel cell research and to find the most popular algorithms used to date. Using the Web of Science database, a total of 102 articles published between 1999 and 2022 were retrieved. The cumulative number of articles has greatly increased over the past 10 years. About 55% were contributed by researchers from China and USA, leading among 20 countries. Some 50 algorithms were used, with principal component analysis and feed-forward neural networks being the most popular used to study and optimize microbial fuel cells.

Key words: artificial intelligence, artificial neural network, bibliometric analysis, bioelectrochemical systems, machine learning, microbial fuel cell

HIGHLIGHTS

- The first bibliometric analysis of applied to microbial fuel cell research was performed.
- The number of publications has grown exponentially since 2013.
- 102 articles were published between 1999 and 2022.
- 50 AI algorithms have been used in microbial fuel cell research.
- The most popular algorithms are principal component analysis and feed-forward neural networks.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Developing countries treat insufficient wastewater because conventional treatment has high operating costs and energy consumption, and low economic returns (Vazquez-Alvarez & Buchauer 2015). To solve this, wastewater treatment technologies have been developed with lower operating costs or the ability to obtain subproducts from wastewater that can generate a profit. Some of these are designed to harness the chemical energy contained in wastewater, as it can be between 6 and 13 times greater than that required for conventional wastewater treatment (Barroso-Soares *et al.* 2017; Beegle & Borole 2018).

Bioelectrochemical systems, such as microbial fuel cells, have been widely researched because they can treat wastewater and generate electricity, hydrogen, or valuable chemical compounds simultaneously (Zou & He 2018). Microbial fuel cells can achieve up to 90% removal of chemical oxygen demand (COD) (Tsekouras *et al.* 2022), making them similar to conventional activated sludge treatment technologies (Christian *et al.* 2008). They can also treat wastewater without requiring aeration (Huggins *et al.* 2013) so they transform organic pollutants into green energy while reducing energy consumption and operating costs significantly compared to conventional aerated activated sludge.

Microbial fuel cell optimization has been a topic of research and discussion for many years. Microbial fuel cells are highly sensitive to both environmental and internal parameters; their microorganism biomes are diverse consortia inoculated from sludge and their substrate is domestic wastewater with variable chemical content. Their optimization is typically done experimentally, modifying one or more parameters systematically while monitoring the system's behavior. As this approach can consume large amounts of time and resources, efforts have been made to create mathematical models for fuel cell diagnosis and optimization. The reliability of such models has not been high enough, however, and they are still in development (Gadkari *et al.* 2018).

An alternative method for modeling complex non-linear systems such as microbial fuel cells is to use artificial intelligence (AI). AI algorithms are trained with experimental operating data. If sufficient data are input, the model generated can be reliable enough to study and optimize the devices that produced the data (Garg *et al.* 2014; Garg & Lam 2017). Many AI algorithms are available and it can be a significant challenge to choose one that is suitable.

The main objectives of this paper are to present the first bibliometric analysis of AI applied to microbial fuel cell research, including authors' contributions, preferred journals, and leading countries; highlight common terminology and research topics, and identify the most popular algorithms.

2. METHODS

A bibliometric analysis is a mechanistic approach to understanding trends, based on outputs from academic literature. This differentiates it from review papers, which focus on the latest progress, challenges, and future research directions (Md-Khudzari *et al.* 2018). Also, a bibliometric analysis provides a descriptive analysis of the available literature involving regions, periods, and disciplines. It can also provide evaluation analysis, within which literature usage is counted, involving references and citations. Both types of analyses enable evaluation of research output in particular disciplines and observation of research trends, as well as researchers' preferences for publication output (Blažun-Vošner *et al.* 2017).

2.1. Data source and search strategy

Web of Science, one of the most popular databases for scientific literature, is a useful source for high-quality and standardized papers. Data mining for this study was conducted between July 1, 2021, and June 7, 2022, using the Web of Science database. The main theme was research articles containing the most used terms for microbial fuel cells, as well as several AI algorithms in all fields. The query strings used were structured as (ALL = (Bioelectrochemical system$ OR Microbial Fuel Cell$ OR Microbial Electrolysis Cell$ OR Microbial Desalination Cell$)) AND ALL = (…). The suspension points represent a wide variety of classification, regression, neural network, anomaly detection, dimensionality reduction, ensemble, clustering, association rule analysis, regularization, and time series analysis algorithm names used for several query strings. The data collection methodology for queries is summarized in Figure 1.

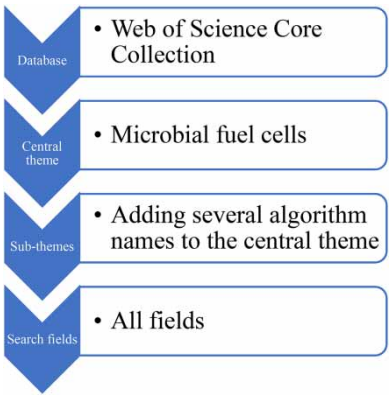


Figure 1 | Data search and collection flowchart for central and sub-themes.

The initial search results from the queries were refined to eliminate duplicates and the remaining record titles were screened to exclude those not related to microbial fuel cell research. the abstracts of the remaining academic articles were then read to exclude those not using AI algorithms. As the searches were made in all fields, the results could include papers related to microbial fuel cells that mentioned the use of AI algorithms in their main text, but not in their titles or abstracts. Thus, as a final assessment, articles unrelated to the central and/or sub-themes were removed using a full-text screening.

2.2. Bibliometric mapping

Bibliometric mapping is a quantitative approach that helps visualize several aspects of scientific publications (Blažun-Vošner *et al.* 2017). Author keywords, and bibliographic and citation information for the articles included were exported to VOSviewer version 1.6.18, a software tool used to build and visualize bibliometric maps (van Eck & Waltman 2022). VOSviewer finds the frequency of each term analyzed – e.g., author keywords or countries – and the connections between all terms (also called 'links' in the software). Links are represented by positive numbers, and the higher the number, the stronger the link. In co-authorship analysis, the link strength between any pair of countries represents the number of papers co-authored by the same authors. For co-occurrence analysis, however, the link between keywords represents the number of records in which both keywords are included as author keywords.

2.3. Data analysis

All the bibliometric data downloaded from the Web of Science database were exported to a Microsoft Excel spreadsheet and preprocessed using built-in Excel functions to create figures, graphs, and tables. In the co-authorship analysis, the countries identified were included, and the largest set of co-authoring countries was identified and illustrated with VOSviewer. Analysis of the co-occurrence of author keywords involved 291 keywords from 102 articles and, before importing them into VOSviewer, synonymic single words and congeneric phrases were analyzed. For example, artificial neural network, neural network algorithms, neural networks, and ANN were counted as one and relabeled as artificial neural network. These would otherwise be counted as different keywords making their bibliometric mapping unnecessarily complex.

VOSviewer can analyze items that occur a preset number of times. As the number of keywords in this study is small due to the number of included articles, the minimum keyword occurrence was set at 1 to enable a complete analysis of all available information. Overlay and density visualization modes were selected to view the average publication year, the number of occurrences, and the link strength of keywords, and identify kernel keywords.

Once the full text of a record had been retrieved, it was analyzed to obtain the names of the algorithms applied, to determine which were used most frequently, as well as the number of algorithms used by each author. VOSviewer was also used to analyze these data, using the overlay visualization mode.

3. RESULTS AND DISCUSSION

The 15 searches recovered 658 publications. The process for article identification, screening, and selection is outlined in Figure 2. After duplicate removal and screening, it was determined that 102 articles written in the past 23 years addressed the application of AI algorithms to microbial fuel cell research.

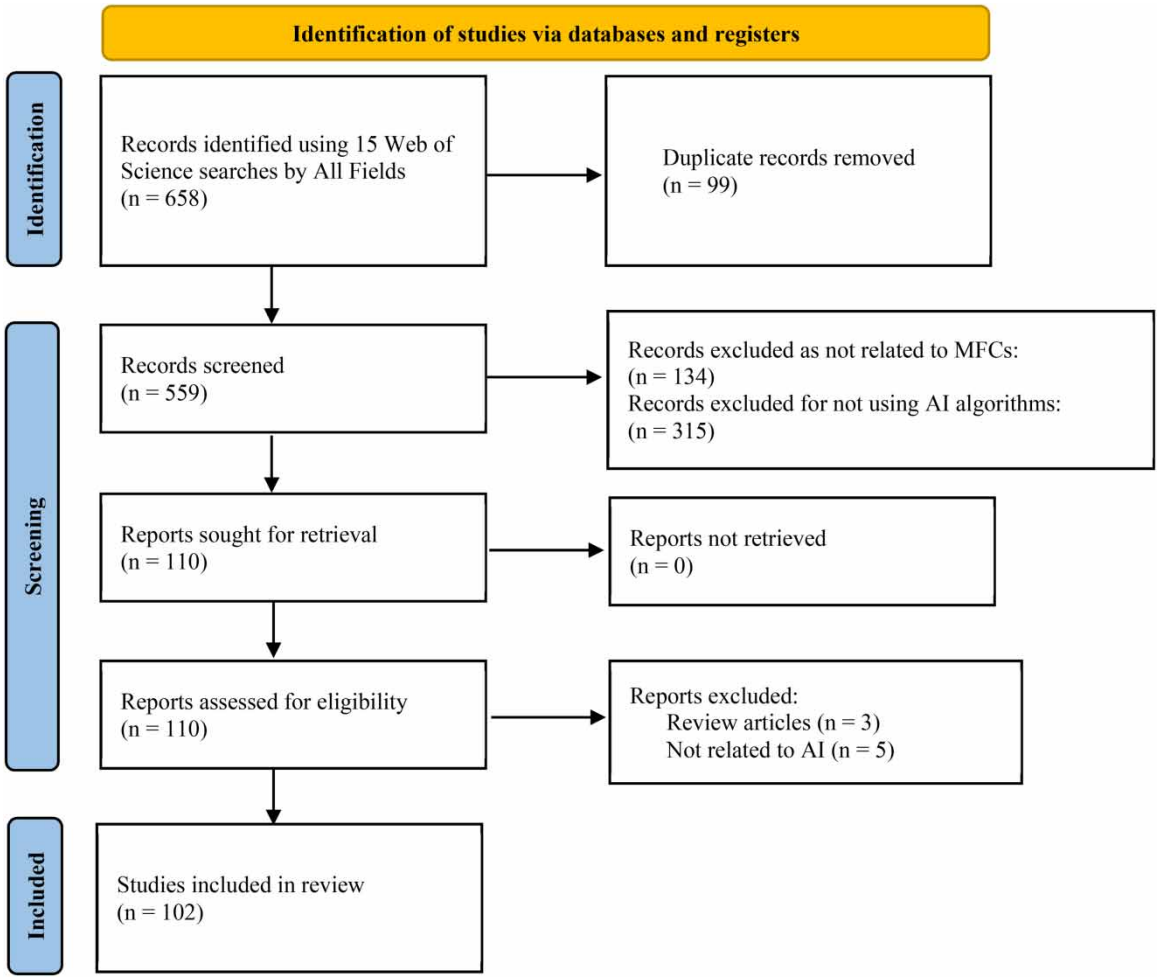


Figure 2 | Publication screening and selection. (Adapted from the PRISMA statement and reporting guideline (Page *et al.* 2021)).

3.1. Publication output and growth of research interest (Page *et al.* 2021)

The number of research articles published is a relevant research discipline or topic trend indicator (López-Carril *et al.* 2020). From 1999 to 7 June 2022, some 102 papers were published on AI algorithms applied to microbial fuel cell research. Only one article was published in 1999, and no other subject-related research was reported until 2010. Figure 3 shows the publication distribution over time, starting in 1999. As can be seen, the topic was addressed only a couple of times before 2013, since when there has been an exponential increase.

Price's law says that the growth of a scientific field has four phases: (1) precursor – a few groups begin to publish research on an unexplored field; (2) exponential growth – expansion of the field appeals to more researchers and more areas of research opportunity are identified; (3) consolidation of knowledge – the number of published articles decreases, and (4) domain breakdown – significant reduction in the volume of publications (López-Carril *et al.* 2020). Given the results observed in this study, the area of AI applied to microbial fuel cell research is currently in its second phase.

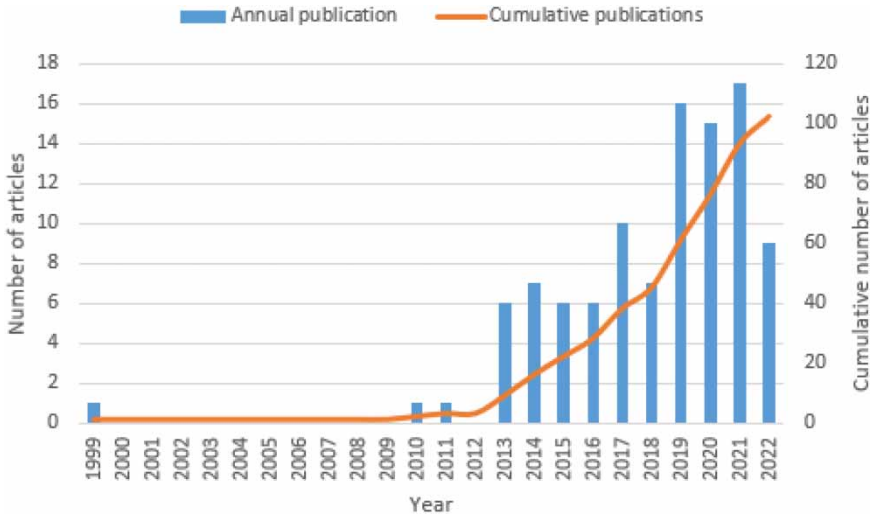


Figure 3 | Publication of articles from 1999 to 2022 related AI application to the analysis of microbial fuel cells, as reported in Web of Science.

3.2. Preferred journals

Sixteen journals with two or more publications were identified in data mining, and the top five in terms of relevant articles published and impact factors are listed in Table 1. Their impact factors (IFs) range from 5.816 to 11.236. Journals in environmental science have an average IF of 2.72 and the top 40% have at least 2.35 (Joannah 2022). All of the top five journals that published articles on the topic of this study are in the top 40% in the environmental science category. Table 1 also shows the SCImago Journal Rank (SJR) and their source normalized impact per article (SNIP) indicators. SJR and SNIP are commonly used to estimate both the value of a citation and a journal's impact, SJR reflecting scientific prestige and SNIP measuring the contextual citation impact. It is generally accepted that high index values reflect a high-quality journal. CiteScore (CS), a new metrics standard, also measures a journal's impact, using the Scopus database, and is very similar to the impact factor, the differences being that it is calculated using data from the previous three years instead of two, and that it includes all document types, rather than only papers and reviews (Kim & Chung 2018).

Table 1 shows that none of the top journals focuses on ML, AI, data science, or computer science. This suggests that most researchers are using AI algorithms as tools to study and model experimental data, rather than using microbial fuel cells' outputs and parameters to study algorithms themselves.

3.3. Most cited articles

The scientific performance, impact, influence, or utility of a research article can be measured objectively by its total citation count (Sureka *et al.* 2020). The most influential articles among those included in this study are listed in Table 2. The most cited – 'Nanoparticle decorated anodes for enhanced current generation in microbial

Table 1 | Top five journals with articles related to AI application to microbial fuel cell analysis

Source title	No. articles	IF	SJR	SNIP	CS
Bioresource Technology	9	9.642	2.489	2.073	14.8
Water Research	5	11.236	3.099	2.640	15.6
International Journal of Hydrogen Energy	5	5.816	1.212	1.335	9.0
Science of the Total Environment	4	7.963	1.795	2.015	10.5
Applied Energy	3	9.746	3.035	2.696	17.6

Table 2 | Top 5 most cited articles among those analyzed in this study

Article title	Journal	Authors	Year	Times cited
Nanoparticle decorated anodes for enhanced current generation in microbial electrochemical cells	*Biosensors & Bioelectronics*	Fan, Yanzhen; Xu, Shoutao; Schaller, Rebecca; Jiao, Jun; Chaplen, Frank; Liu, Hong	2011	108
Discovery of commonly existing anode biofilm microbes in two different wastewater treatment MFCs using FLX Titanium pyrosequencing	*Applied Microbiology and Biotechnology*	Lee, Tae Kwon; Doan, Tuan Van; Yoo, Kyuseon; Choi, Soojung; Kim, Changwon; Park, Joonhong	2010	67
Start-up process modelling of sediment microbial fuel cells based on data driven	*Mathematical Problems in Engineering*	Ma, Fengying; Yin, Yankai; Li, Min	2019	59
Surface modification of microbial fuel cells anodes: approaches to practical design	*Electrochimica Acta*	Li, Baitao; Zhou, Jun; Zhou, Xiuxiu; Wang, Xiujun; Li, Baikun; Santoro, Carlo; Grattieri, Matteo; Babanova, Sofia; Artyushkova, Kateryna; Atanassov, Plamen; Schuler, Andrew J.	2014	57
Performance evaluation of microbial fuel cell by artificial intelligence methods	*Expert Systems with Applications*	Garg, A.; Vijayaraghavan, V.; Mahapatra, S. S.; Tai, K.; Wong, C. H.	2014	49

electrochemical cells' – uses only linear regression, which belongs to a subset of AI algorithms known as supervised machine learning models (Murphy 2012). Of the 108 articles that cite the work by Fan *et al.* (2011), none addresses the use of any AI algorithms as verified in the Web of Science database, meaning that the article is popular because of the experimental results and methodology rather than the Linear Regression model used.

The other four articles used more complex algorithms such as hierarchical clustering, principal component analysis, multi-gene genetic programming, and support vector regression, as well as radial basis function, back-propagation, and extreme learning machine neural networks to model their experimental data.

3.3.1. Citation analysis

The most widely cited articles found are not the most popular in this new area of AI research. A citation analysis must be done to find the most popular articles. It is the best method because the number of times that the included papers cite each other is counted. Of the 102 publications analyzed in VOSviewer, 43 have zero link strength – i.e., they neither cited nor were they cited by any of the other publications included – and the largest connected set of documents contains 43 papers (Figure 4).

The citation analysis helps highlight the papers that have been the most influential in this research area (Table 3). As the links in VOSviewer are undirected – i.e., no distinction is made as to which paper at the end of a link contains the citation – the most cited articles are found by counting the number of linked articles that were published after any item. For example, the item with the highest link strength is that published by Tsompanas *et al.* (2019). Only two of its 10 linked articles were published after 2019, however, meaning that

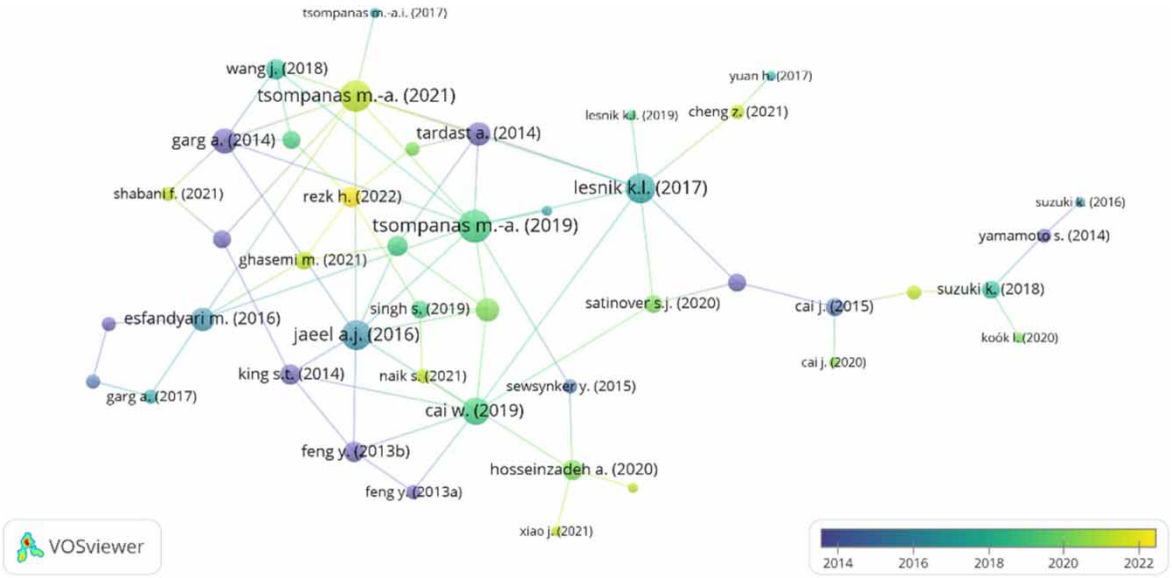


Figure 4 | Citation analysis of 43 of the papers analyzed. The lines connecting elements are the links, the size of each item representing its link strength. (This image can be downloaded at its highest resolution from: https://bit.ly/3H1jj62).

Table 3 | Top 5 most influential articles in the field of AI applied in microbial fuel cell research

Article title	Journal	Authors	Year	Times cited*
Performance evaluation of microbial fuel cell by artificial intelligence methods	*Expert Systems with Applications*	Garg, A.; Vijayaraghavan, V.; Mahapatra, S. S.; Tai, K.; Wong, C. H.	2014	6
Predicting microbial fuel cell biofilm communities and bioreactor performance using artificial neural networks	*Environmental Science & Technology*	Lesnik, Keaton Larson; Liu, Hong	2017	6
Use of artificial neural network for the prediction of bioelectricity production in a membrane less microbial fuel cell	*Fuel*	Tardast, Ali; Rahimnejad, Mostafa; Najafpour, Ghasem; Ghoreyshi, Ali; Premier, Giuliano C.; Bakeri, Gholamreza; Oh, Sang-Eun	2014	5
Prediction of sustainable electricity generation in microbial fuel cell by neural network: Effect of anode angle with respect to flow direction	*Journal of Electrochemical Chemistry*	Jaeel, Ali J.; Al-wared, Abeer I.; Ismail, Zainab Z.	2016	5
Neural network and neuro-fuzzy modeling to investigate the power density and Columbic efficiency of microbial fuel cell	*Journal of the Taiwan Institute of Chemical Engineers*	Esfandyari, Morteza; Fanaei, Mohammad Ali; Gheshlaghi, Reza; Mahdavi, Mahmood Akhavan	2016	4

*Cited in articles in the same area studied in this work.

it was only cited twice. On the other hand, six of the eight links for the paper written by Lesnik & Liu (2017) were published after it, meaning that it was cited six times and was, therefore, more influential.

The titles of the most influential articles contain keywords related to AI such as 'artificial neural network' or 'artificial intelligence methods', which make them easier to find through search engines when researchers look for information about algorithms used for microbial fuel cell research. This is important because other papers report the use of AI algorithms, but this is not mentioned in their titles or keywords, making them harder to find. One example is the publication by Liu *et al.* (2021) that reports the use of a back-propagation neural network – a variation of the interconnected groups of artificial nodes or neurons called neural networks – titled 'High efficiency in-situ biogas upgrading in a bioelectrochemical system with low energy input'. Use of this computational

method is mentioned in the article's abstract, but the absence of any related keywords in its title may dissuade others from looking into it when looking for related applications.

3.4. Leading countries, top institutions, and international collaboration

Figure 5 shows those countries that have contributed to the growth of the application of AI to microbial fuel cell research worldwide. Approximately 55% of the articles selected were written in China and USA, indicating that these two lead in this research area. China is currently the leader with 36 publications, 35.2% of total global records.

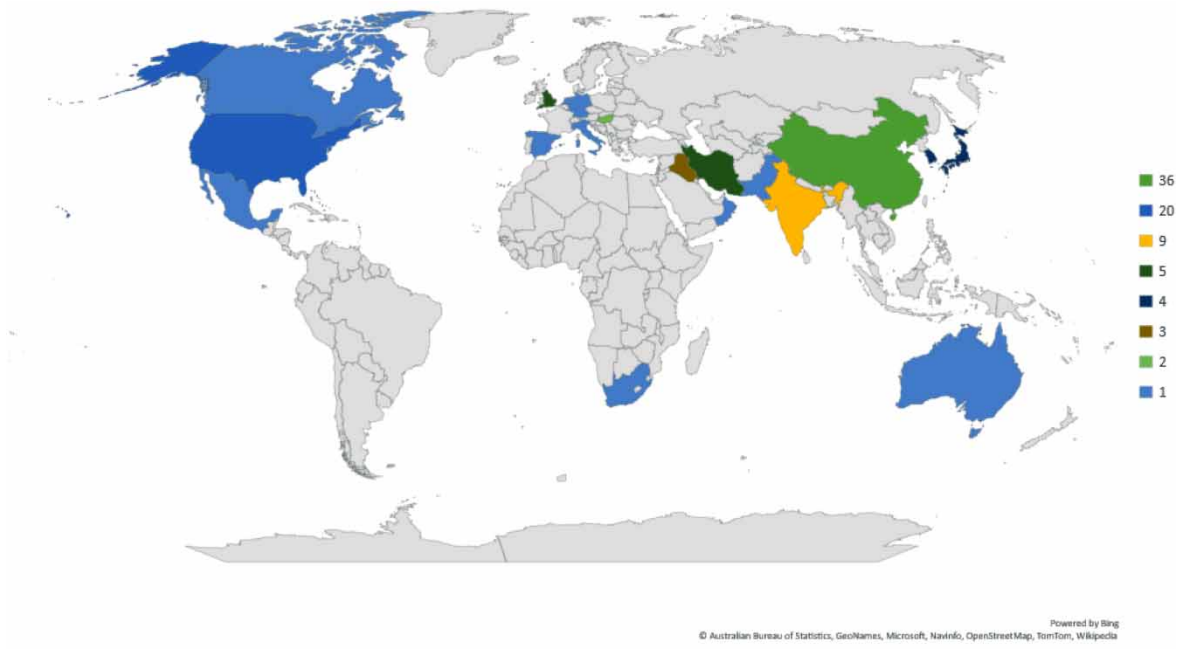


Figure 5 | Article publications by country.

Country co-authorship is shown in Figure 6. China was the most affiliated country, linked to 13 others while collaborating in 25 articles. The USA came next, with six links and 13 co-authorships, followed by the United Kingdom with eight links and 16 co-authorships, and India with six links and seven co-authorships. It was also shown that 26 (83.8%) of the countries listed had been involved in international collaborations.

Co-authorship in Iraq and Mexico is not connected to the set shown in Figure 6 since their publications were made without international collaboration. Germany published one paper with Austria and another with the Netherlands, forming a small subset of co-authorships not connected with the larger set. As this research area is still developing, it is quite likely that more countries will begin research independently, and find collaboration opportunities through review articles and bibliometric analysis, making the co-authorship set even larger than that found in this study.

Many factors can contribute to international collaboration dynamics, including the diversity of research partners, the proportion of foreign students and/or visiting scholars, and research funding. It is important to maintain a flexible research policy to encourage international collaboration (Md-Khudzari *et al.* 2018).

3.5. Leading authors

Table 4 lists the top five authors who have published research articles related to AI applied to bioelectrochemical systems. The most prolific authors on this topic are affiliated with China (4 authors) and the UK (1).

3.6. Author keywords

Author keywords are essential to reveal research trends and of proven significance for monitoring scientific development. They are usually written to express a researcher's main research interests, goals, and solutions (Chen *et al.* 2021). Author keywords are analyzed from three different perspectives – statistically to identify popular

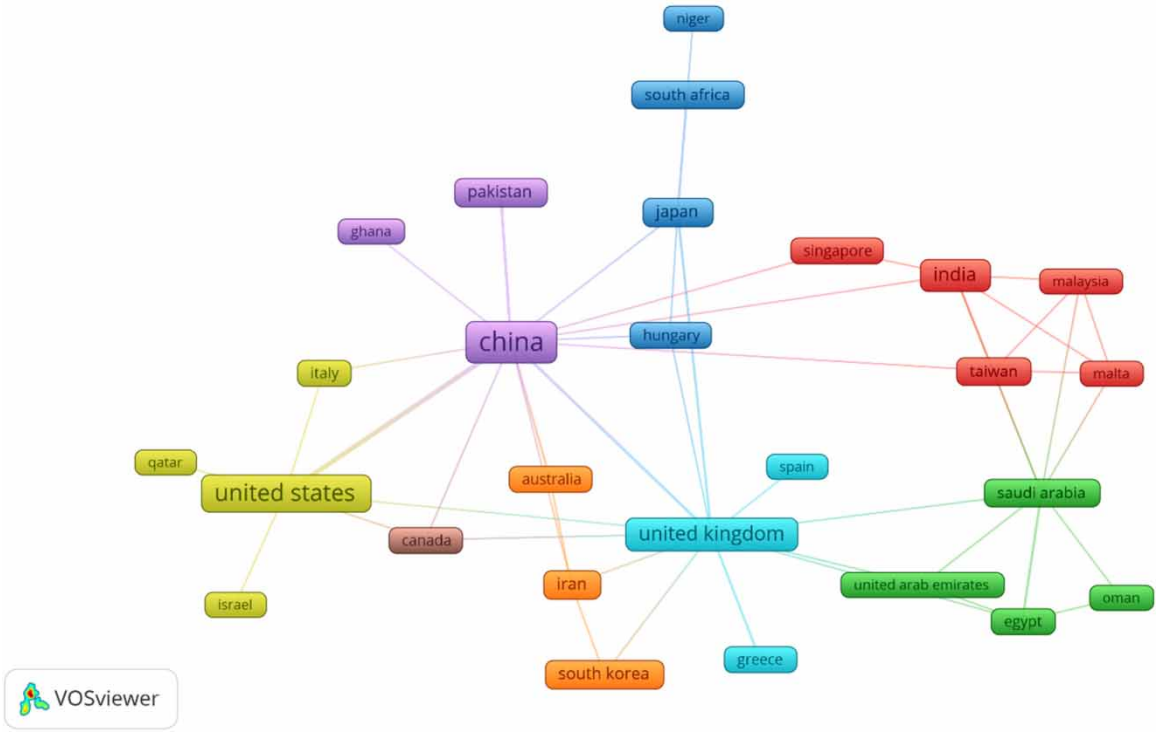


Figure 6 | Article co-authorships by country.

Table 4 | The five most prolific authors in the field of AI applied to microbial fuel cell research

Author	Affiliation	Country	RP	TP
Tsompanas, Michail-Antisthenis I.	University of the West of England	UK	4	38
Ma, Fengying	Hunan University	China	3	113
Cai, Jing	Beijing Forestry University	China	3	54
Feng, Yinghua	Sixth Peoples Hosp Kaifeng City	China	3	9
Garg, A.	Huazhong University of Science & Technology	China	2	145

RP, relevant publications; TP, total publications.

keywords, to illustrate popularity and quantity, and to show them as clusters to help researchers identify relationship groups according to different kernel keywords.

After initial exploratory analysis, relabeling of synonyms, etc., some 291 keywords were identified, of which 255 (87.63%) were used only once, 15 (5.15%) twice, 10 (3.44%) thrice, and 11 (3.78%) more than three times. Figures 7 and 8, show that the largest set of co-occurring author keywords contains 247 elements and includes the most commonly used.

Keywords tend to change over time as research evolves. Figure 7 explores the hidden changes in author keywords over time, as well as their co-occurrences. The size of each circle represents the frequency of use of each term and its color indicates how close it is to the present day.

Expressing keyword clusters and their relationship with colors can help in understanding their interconnections. Figure 8 shows several author keyword clusters. The largest that can be identified is that with the 'microbial fuel cells' keyword, which contains most of the smaller clusters, as well as general terms such as 'artificial intelligence', 'computational intelligence', and 'classifier'. The second largest cluster is that containing the keyword 'artificial neural network', indicating that artificial neural networks are some of the most popular algorithms used currently to study bioelectrochemical systems.

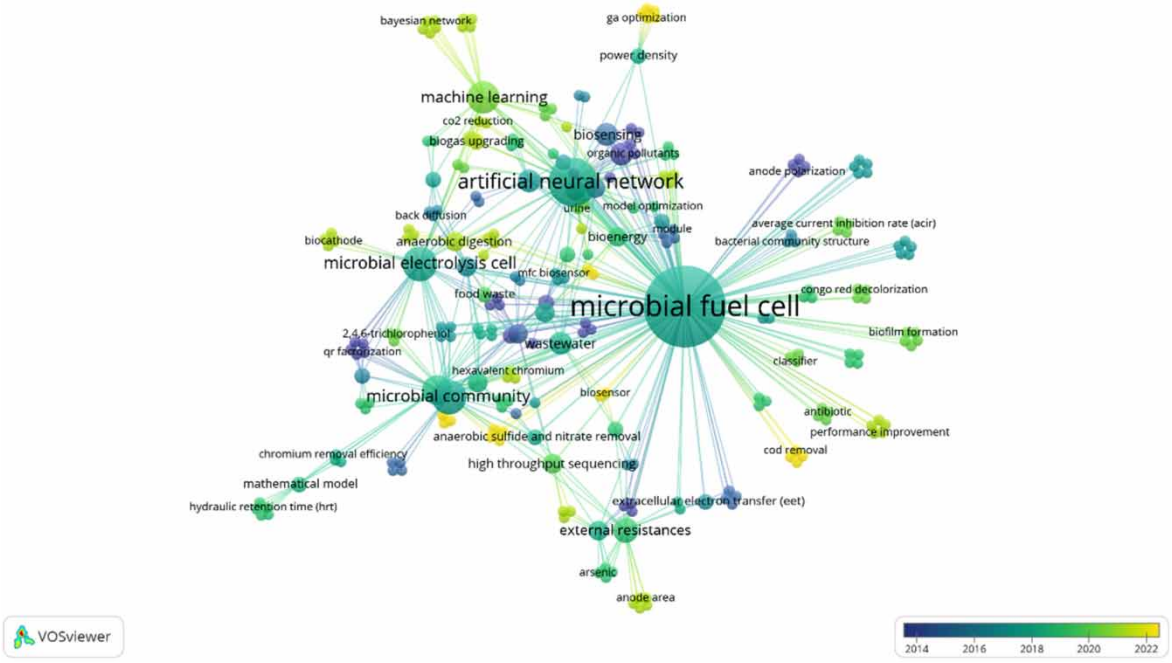


Figure 7 | Author keywords co-occurrence (overlay visualization mode in VOSviewer). This image can be downloaded at its highest resolution from: https://bit.ly/3H285yk.

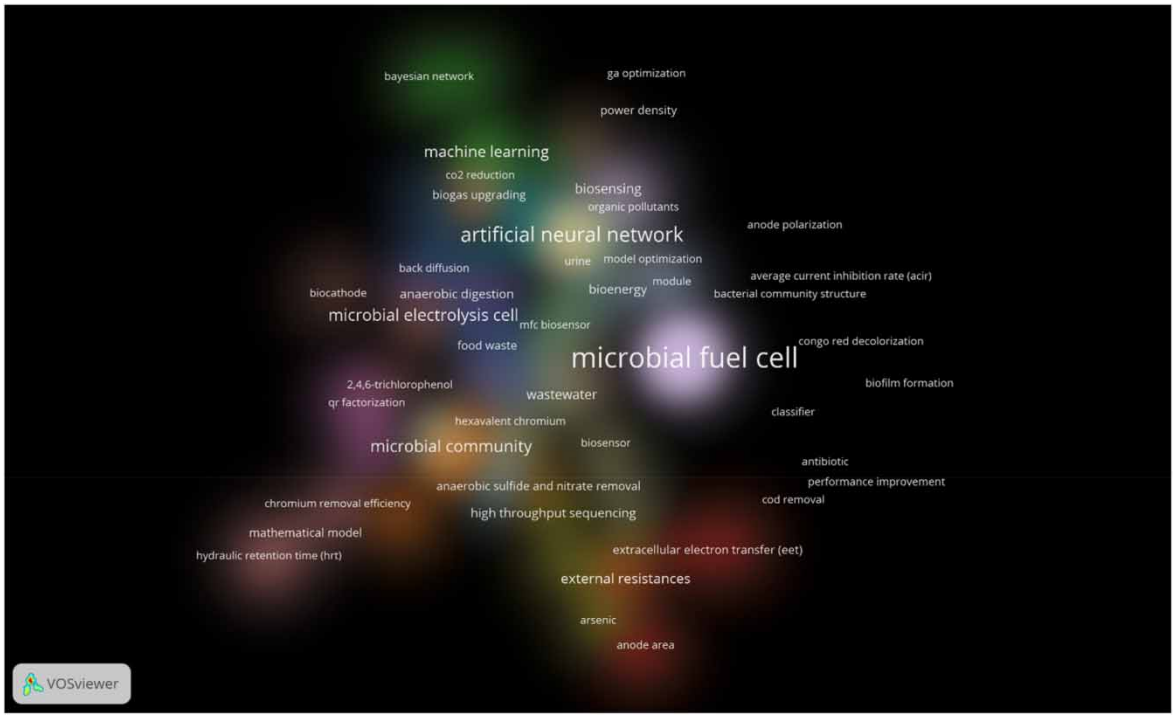


Figure 8 | Author keyword co-occurrence with density clusters (visualization mode in VOSviewer). This image can be downloaded at its highest resolution from: https://bit.ly/3znodbM.

3.6.1. Terminology and concepts

As shown in Figure 7, 'microbial fuel cell', the most frequently used keyword, occurs 50 times with 205 links to other keywords. Some general terms such as 'bioelectrochemical systems' (7 occurrences and 34 links), 'microbial electrolysis cell' (9 and 41), and 'biofuel cells' (1 and 4) were also found.

The most popular keyword related to AI algorithms is 'artificial neural network', with 18 occurrences and 69 links – see Figure 7. Related keywords include 'machine learning' (8 occurrences and 31 links) and 'modeling' (4 and 15). Terms such as 'computational intelligence' (1 occurrence and 5 links) and 'artificial intelligence' (1 and 5) co-occur with the most popular keyword 'microbial fuel cell'.

Microbial fuel cell-related keywords predominate clearly across the results, which is to be expected as the central theme of these research reports is microbial fuel cell development. No mention is made of the use of AI in the titles, abstracts, or keywords of some articles, making them hard to find.

3.7. Frequently used algorithms

Of the 102 articles selected, 78 (76.5%) related to the training of a single algorithm with their datasets, 14 (13.7%) the training of two, five (4.9%) three, and five (4.9%) more than three algorithms.

Some 50 AI algorithms were used in the studies included, 27 (54%) were used only once, six (12%) twice, and 17 (34%) at least thrice. Principal component analysis, a multivariate statistical analysis method that classifies samples into groups (Babanova *et al.* 2014) was the most used algorithm (25 times); followed by feed-forward neural network (15), back-propagation neural network (13), linear regression (7), and K-nearest neighbors (6).

3.8. Study limitation

As the main theme of the search queries included only the most popular keywords such as 'bioelectrochemical systems', 'microbial fuel cell', and 'microbial electrolysis cell', the results might not cover all relevant MFC-related studies available, because some researchers might not refer to their systems as microbial fuel cells. This also applies to the AI sub-themes. As there are numerous algorithms, many of which are not widely known, it is possible that some were used in microbial fuel cell research studies but were not found using this search strategy.

4. CONCLUSIONS

This was the first bibliometric analysis of AI algorithms applied to microbial fuel cell research. It was based on 102 relevant publications, published from 1999 to 2022, found through the Web of Science database. The number of publications has grown rapidly since 2013 and is likely to continue to rise, following the second phase of Price's Law, due to the widespread interest in AI.

Most of the reports included were published in China and USA, and many of them involved international collaboration.

A keyword analysis showed that author keywords are related predominantly to topics surrounding microbial fuel cells, with a much smaller proportion related to AI algorithms. Full-text analysis revealed that 50 different algorithms have been applied in microbial fuel cell research, with principal component analysis and feed-forward neural networks among the most used.

The results confirm that this new research field is beginning to consolidate, and can help research teams to study and optimize microbial fuel cells through AI.

ACKNOWLEDGEMENTS

Gratitude goes to Universidad de las Américas Puebla (UDLAP) and the Consejo Nacional de Ciencia y Tecnología (CONACYT) for assistance rendered in this study, especially for granting a Ph.D. scholarship to the lead author.

FUNDING

Funding for a scholarship was provided partially by both UDLAP and CONACYT.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OneDrive at https://bit.ly/3Bvhldj, in an Excel file with all the Web of Science data downloaded for the 102 articles that were analyzed.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Babanova, S., Bretschger, O., Roy, J., Cheung, A., Artyushkova, K. & Atanassov, P. 2014 Innovative statistical interpretation of Shewanella oneidensis microbial fuel cells data. *Physical Chemistry Chemical Physics* **16**(19), 8956–8969.

Barroso-Soares, R., Santos-Memelli, M., Pereira-Roque, R. & Franci, G. R. 2017 Comparative analysis of the energy consumption of different wastewater treatment plants. *International Journal of Architecture, Arts and Applications* **3**(6), 79–86.

Beegle, J. R. & Borole, A. P. 2018 Energy production from waste: evaluation of anaerobic digestion and bioelectrochemical systems based on energy efficiency and economic factors. *Renewable and Sustainable Energy Reviews* **96**, 343–351.

Blažun-Vošner, H., Bobek, S., Sternad, S. & Kokol, P. 2017 Openness and information technology: a bibliometric analysis of literature production. *Kybernetes* **46**(5), 750–766.

Chen, W., Ahmed, M. M., Sofiah, W. I., Isa, N. A. M., Ebrahim, N. A. & Hai, T. 2021 A bibliometric statistical analysis of the fuzzy inference system-based classifiers. *IEEE Access* **9**, 77811–77829.

Christian, S. J., Grant, S. R., Singh, K. S. & Landine, R. C. 2008 Performance of a high-rate/high-shear activated sludge bioreactor treating biodegradable wastewater. *Environmental Technology* **29**(8), 837–846.

Fan, Y., Xu, S., Schaller, R., Jiao, J., Chaplen, F. & Liu, H. 2011 Nanoparticle decorated anodes for enhanced current generation in microbial electrochemical cells. *Biosensors and Bioelectronics* **26**(5), 1908–1912.

Gadkari, S., Gu, S. & Sadhukhan, J. 2018 Towards automated design of bioelectrochemical systems: a comprehensive review of mathematical models. *Chemical Engineering Journal* **343**, 303–316.

Garg, A. & Lam, J. S. L. 2017 Design of explicit models for estimating efficiency characteristics of microbial fuel cells. *Energy* **134**, 136–156.

Garg, A., Vijayaraghavan, V., Mahapatra, S. S., Tai, K. & Wong, C. H. 2014 Performance evaluation of microbial fuel cell by artificial intelligence methods. *Expert Systems with Applications* **41**(4 PART 1), 1389–1399.

Huggins, T., Fallgren, P. H., Jin, S. & Ren, Z. J. 2013 Energy and performance comparison of microbial fuel cell and conventional aeration treating of wastewater. *Journal of Microbial & Biochemical Technology* **S6**, 1–5.

Joannah, W. 2022 *What's a Good Impact Factor (Ranking in 27 Categories)*. Available from: https://www.scijournal.org/articles/good-impact-factor (accessed 07 June 2022).

Kim, K. & Chung, Y. 2018 Overview of journal metrics. *Science Editing* **5**(1), 16–20.

Lesnik, K. L. & Liu, H. 2017 Predicting microbial fuel cell biofilm communities and bioreactor performance using artificial neural networks. *Environmental Science and Technology* **51**(18), 10881–10892.

Liu, C., Xiao, J., Li, H., Chen, Q., Sun, D., Cheng, X., Li, P., Dang, Y., Smith, J. A. & Holmes, D. E. 2021 High efficiency in-situ biogas upgrading in a bioelectrochemical system with low energy input. *Water Research* **197**, 1–9.

López-Carril, S., Escamilla-Fajardo, P., González-Serrano, M. H., Ratten, V. & González-García, R. J. 2020 The rise of social media in sport: a bibliometric analysis. *International Journal of Innovation and Technology Management* **17**(6), 1–29.

Md-Khudzari, J., Kurian, J., Tartakovsky, B. & Raghavan, G. S. V. 2018 Bibliometric analysis of global research trends on microbial fuel cells using Scopus database. *Biochemical Engineering Journal* **136**, 51–60.

Murphy, K. P. 2012 *Machine Learning: A Probabilistic Perspective*, 1st edn. MIT Press, Cambridge, Massachusetts, USA.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuiness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P. & Moher, D. 2021 The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *The BMJ* **372**, 1–9.

Sureka, R., Donthu, N. & Kumar, S. 2020 Three decades of the journal of teaching in international business: a bibliometric overview. *Journal of Teaching in International Business* **31**(3), 259–285.

Tsekouras, G. J., Deligianni, P. M., Kanellos, F. D., Kontargyri, V. T., Kontaxis, P. A., Manousakis, N. M. & Elias, C. N. 2022 Microbial fuel cell for wastewater treatment as power plant in smart grids: Utopia or reality? *Frontiers in Energy Research* **10**, 1–36.

Tsompanas, M. A., You, J., Wallis, L., Greenman, J. & Ieropoulos, I. 2019 Artificial neural network simulating microbial fuel cells with different membrane materials and electrode configurations. *Journal of Power Sources* **436**, 1–7.

van Eck, N. J. & Waltman, L. 2022 *VOSViewer: Visualizing Scientific Landscapes*. Available from: https://www.vosviewer.com (accessed 20 June 2022).

Vazquez-Alvarez, V. & Buchauer, K. 2015 *East Asia and Pacific, Wastewater to Energy Processes: A Technical Note for Utility Managers in EAP Countries*. Report ACS13221, The International Bank for Reconstruction and Development, The World Bank, Washington, USA.

Zou, S. & He, Z. 2018 Efficiently 'pumping out' value-added resources from wastewater by bioelectrochemical systems: a review from energy perspectives. *Water Research* **131**, 62–73.

First received 23 June 2022; accepted in revised form 25 September 2022. Available online 29 September 2022