

A Bibliometric Comparative Analysis on the Applications of AI, IoT, and Big Data to Energy Efficiency

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Abstract

Artificial intelligence (AI), the Internet of Things (IoT), and Big Data are playing important roles in improving or upgrading energy efficiency. Furthermore, their roles in energy efficiency are expected to become more and more essential. This study conducted a bibliometric comparative analysis on the features in the articles on the AI, the IoT, and the Big Data in energy efficiency by using the Web of Science database and compared the features in their trends in article publications, citations, countries, research areas, journals, and funding agencies from 2012 to 2022. This study attempted to make significant contributions by shedding new light on the following features. Among the AI, the IoT, and the Big Data in energy efficiency, the most articles were published and the most article citations were received in the AI in energy efficiency. China was found out to be the most leading country. Engineering and computer science were revealed to be the first research area. IEEE Access and IEEE Internet of Things were ranked with first journal. National Natural Science Foundation of China was the first research funding agency concerning the articles published in the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022.

Keywords: *Energy Efficiency; Artificial Intelligence; IoT; Big Data*

1. Introduction

The purpose of this article is to reveal and compare the features in the articles on AI, IoT, and Big Data in energy efficiency. The applications of AI, IoT, and Big Data to improving energy efficiency are becoming more and more important [1-3]. Nowadays, they are playing crucial roles in forecasting energy [4, 5]. They are effectively used to monitor energy [6-8]. Furthermore, they are applied to control energy [9-11]. Existing studies, however, concentrate on the topics concerning some of the AI, IoT, and Big Data although they can work effectively to increase energy efficiency based on their convergence [12]. Therefore, this study conducted a bibliometric comparative analysis on the features in the articles on the AI, the IoT, and the Big Data in energy efficiency by using the Web of Science database. This study compared the features in their trends in publications, citations, countries, research areas, journals, and funding agencies from 2012 to 2022. This study

attempted to answer the following research questions:

- (1) Which application of technology produces the most article publications in energy efficiency among AI, IoT, and Big Data?
- (2) Which application of technology receives the most article citations in energy efficiency among AI, IoT, and Big Data?
- (3) What country is the most productive in publishing the articles on energy efficiency concerning the applications of AI, IoT, and Big Data?
- (4) What is the research area in which the most articles are published in regard to the applications of AI, IoT and Big Data to energy efficiency?
- (5) What journal publishes the most articles in energy efficiency concerning the applications of AI, IoT, and Big Data to energy efficiency?
- (6) What research funding agency funds the most articles regard to the applications of AI, IoT and Big Data to energy efficiency?

This study consists of five parts, including this introductory part, The second part explains the materials and methods used for the bibliometric analysis in this study. The third part reports the results from the analysis. The fourth part discusses the findings from this study and the last part provides the conclusion from them.

2. Research Methods

This study took the three steps to perform a rigorous bibliometric analysis on the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022, as illustrated in Figure 1.

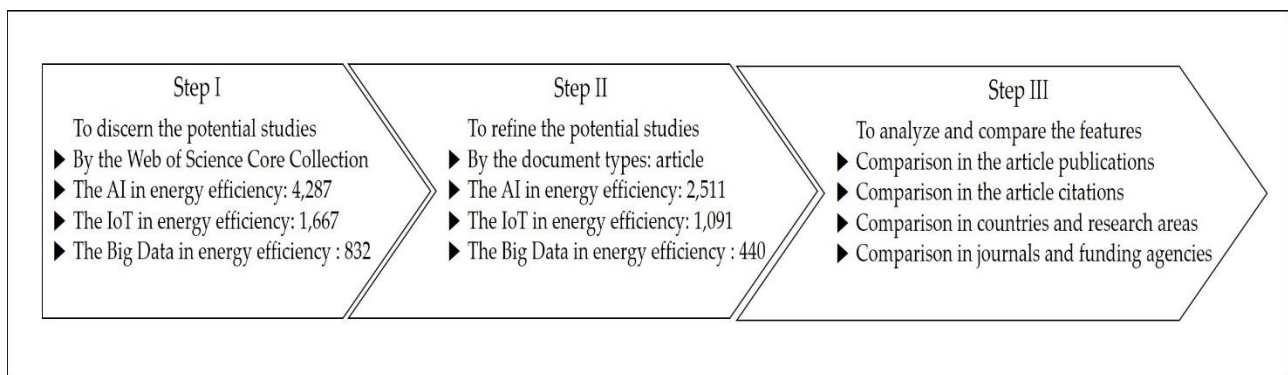


Figure 1. Research flow in this Study

The first step was to discern the potential studies by using the Web of Science database. This research made an advanced search of the Web of Science Core Collection for studies of which titles, abstracts, or keywords contained the following key phrases. In the search of the potential studies on AI and energy efficiency, this study covered various aspects of them by using the key phrases such as ‘machine learning’, artificial

intelligence', 'AI', 'deep learning', 'artificial neural network', 'artificial neural networks' for AI and 'energy efficiency', 'energy saving', 'energy reduction', 'energy decrease', 'energy conservation', and 'energy optimization for energy efficiency'. The search for the AI in energy efficiency was made from the combination of the key phrases in both AI and energy efficiency. In the similar way, the search for potential studies for the IoT and the Big Data in energy efficiency was made by combining the key phrases in the IoT and the Big Data with those in energy efficiency. In the first step, 4,287 potential studies were identified for the AI in energy efficiency, 1,667 for the IoT in energy efficiency, and 832 for the Big Data in energy efficiency. Table 1 shows key phrases used to discern the potential studies in the first Step.

Table 1. Key phrases used to discern the potential studies in the first Step

AI	IoT	Big Data	Energy Efficiency
machine learning, artificial intelligence, AI, deep learning , artificial neural network, artificial neural networks	IoT, Internet of Things,	big data	energy efficiency, energy saving, energy reduction, energy decrease, energy conservation, energy optimization

The second step is to refine the potential studies resulting from the first step by the document types. The 4,287 potential studies were filtered into 2,511 studies in the AI in energy efficiency, the 1,667 potential studies into 1,091 studies in the IoT in energy efficiency, and the 832 potential studies into 440 studies in the Bid Data in energy efficiency which matched the article type in the document types classified by the Web of Science database.

The third step was to analyze and compare articles on the AI, the IoT, and the Big Data in energy efficiency by the trend in publications, citations, countries, research areas, journals, and funding agencies.

3. Results

3.1 Comparison in the Trend in Publications

The total number of article publications in AI and energy efficiency from 2012 to 2022 is much more than those of the IoT and the Big Data in it. It amounted to 2,511 with average per year of 228.27. The total number of article publications in the IoT in energy efficiency amounted to 1,091, and their average per year was 99.18. The total number of article publications in the Big Data in energy efficiency were 440 with average per year of 40.

The article publications in the AI energy efficiency show a rapid increasing trend since 2017. They amounted to 76 in 2017 and increased to 802 in 2022 with the compound annual growth rate (CAGR) of 60.2%. The article publications in the IoT in energy efficiency also indicate a rapid increasing trend since 2017. They amounted to 47 in 2017, and increased to 291 in 2022 with the CAGR of 44%. The articles publications in the Big Data in energy efficiency show a rapid increasing trend from 2012 to 2018 but a up and down trend since 2019. They were 0 in 2012 but increased to 15 in 2015, and amounted to 71 in 2018. Their CAGR from 2013 to 2018 was 104%. They, however, decreased to 59 in 2020 and increased to 78 in 2021. Figure 2 summarizes and compares the trends of article publications in terms of the AI, the IoT, and the Big Data in energy efficiency

from 2012 to 2022.

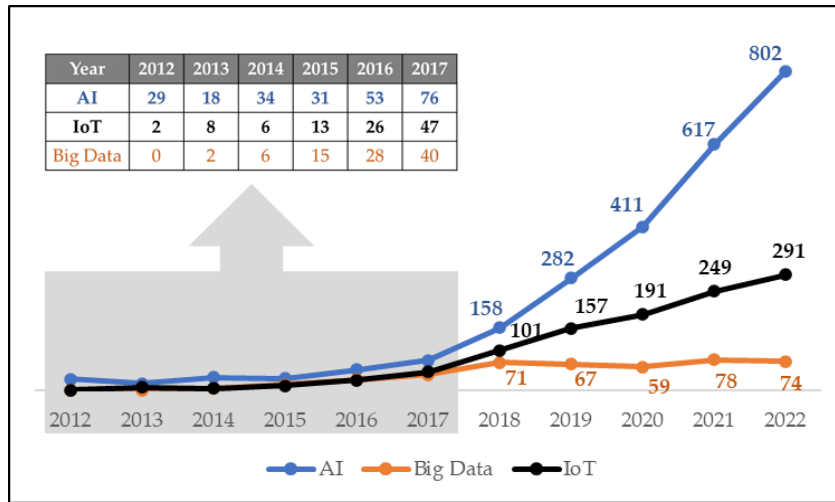


Figure 2. Trends in the article publications in the AI, Big Data, and IoT in energy efficiency

3.2 Comparison in Citations

In terms of the number of citations of articles published in the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022, the articles published in AI in energy efficiency received the most citations. Their numbers of publications and citations were 2,511 and 54,821, respectively, showing the average citation per article of 21.83. The articles published in the IoT in energy efficiency were cited the second most. Their publications and citations were 1,091 and 24,183, indicating the average citation per article of 22.17. The article publications of the Big Data in energy efficiency were 440 but their citations were 10,597, showing the highest average citation per article of 24.08 among the citations of articles published in the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022. Figure 3 summarizes and compares the number of publications and citations of the articles in the AI, the IoT, and the Big Data from 2012 to 2022.

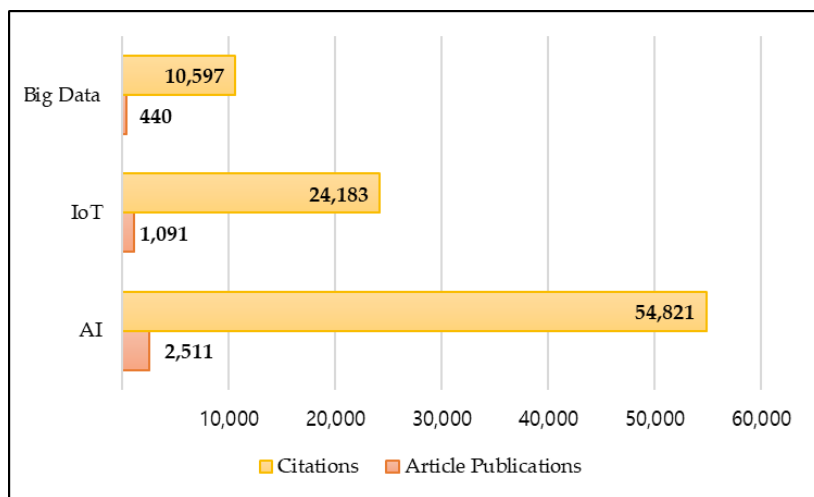


Figure 3. Article citations concerning the AI, IoT, and Big Data in energy efficiency from 2012 to 2022

3.3 Comparison in Countries

China was ranked as the first country in terms of its portion in article publications across all the domains of the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022. Concerning the portion of article publications in the domain of the AI in energy efficiency, USA was ranked as the second, South Korea as the third, India as the fourth, and England as the fifth country. In regard to the portion of article publications in the domain of the IoT in energy efficiency, India was ranked as the second, USA as the third, South Korea as the fourth, and Saudi Arabia as the fifth country. In terms of the portion of article publications in the domain of the Big Data in energy efficiency, USA was ranked as the second, India as the third, South Korea as the fourth, and England as the fifth country. Table 1 summarizes and compares the top 5 countries in regard to their portions of the article publications in the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022.

Table 1. Top 5 countries in the AI, IoT, and Big Data in energy efficiency¹

AI in Energy Efficiency	IoT in Energy Efficiency	Big Data in Energy Efficiency
China (1st, 29.19%)	China (1st, 30.16%)	China (1st, 41.14%)
USA (2nd, 21.43%)	India (2nd, 17.69%)	USA (2nd, 19.77%)
South Korea (3rd, 9.12%)	USA (3rd, 14.02%)	India (3rd, 8.18%)
India (4th, 8.36%)	South Korea (4th, 10.45%)	South Korea (4th, 5.91%)
England (5th, 6.57%)	Saudi Arabia (5th, 8.34%)	England (5th, 5.46%)

¹ The percentage (%) indicates the portion of each country in the total number of articles in each domain.

3.4 Comparison in Research Areas

Looking into the research areas in the articles published in the AI, IoT, and big Data in energy efficiency from 2012 to 2022, engineering, computer science, energy fuels, and telecommunications composed the top 3 areas in them. In term of the portion of the research areas of the article publications in the AI in energy efficiency, engineering was ranked as the first, computer science as the second, energy fuels as the third, telecommunications as the fourth, and science technology other topics as the fifth research area. In regard to the portion of the research areas of the article publications in the IoT in energy efficiency, engineering was ranked as the first, computer science as the second, telecommunications as the third, instruments instrumentation as the fourth, and chemistry as the fifth research area. Concerning the portion of the research areas of the article publications in the Big Data in energy efficiency, computer science was ranked as the first, engineering as the second, telecommunications as the third, energy fuels as the fourth, and science technology other topics as the fifth research area. Table 2 summarizes and compares the top 5 research areas in the articles published in the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022.

Table 2. Top 5 research areas in the AI, IoT, and Big Data in energy efficiency¹

AI in Energy Efficiency	IoT in Energy Efficiency	Big Data in Energy Efficiency
Engineering (1st, 54.00%)	Engineering (1st, 64.71%)	Computer Science (1st, 51.59%)
Computer Science (2nd, 34.13%)	Computer Science (2nd, 63.61%)	Engineering (2nd, 46.14%)
Energy Fuels (3rd, 19.32%)	Telecommunications (3rd, 55.82%)	Telecommunications (3rd, 21.36%)

Telecommunications (4th, 17.28%)	Instruments Instrumentation (4th, 8.52%)	Energy Fuels (4th, 12.50%)
Science Technology Other Topics (5th, 10.00%)	Chemistry (5th, 7.42%)	Science Technology Other Topics (5th, 11.82%)

¹ The percentage (%) indicates the portion of each research area in the total number of articles in each domain. The research areas were categorized with the standards in the research areas of Web of Science.

3.5 Comparison in Top 5 Journals

IEEE Access is the first journal in terms of having published the most articles in both the AI and the Big Data in energy efficiency from 2012 to 2022. IEEE Internet of Things Journal is the first journal in terms of it in the IoT in energy efficiency. Concerning the portion of journals having published the articles in the AI in energy efficiency, Energies was ranked as the second, Energy and Buildings as the third, Applied Energy as the fourth, and Sensors as the fifth journal. With regard to the portion of journals having published the articles in the IoT in energy efficiency, IEEE Access was ranked as the second, Sensors as the third, IEEE Transactions on Green Communications and Networking as the fourth, and IEEE Transactions on Industrial Informatics as the fifth journal. In terms of the portion of journals having published the articles in the Big Data in energy efficiency, Future Generation Computer Systems (The International Journal of Escience) was ranked as the second, IEEE Communications Magazine as the third, Energies as the fourth, and Journal of Cleaner Production as the fifth journal. Table 3 reports and compares the top 5 journals having published the articles in the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022.

Table 3. Top 5 journals in the AI, IoT, and Big Data in energy efficiency¹

AI in Energy Efficiency	IoT in Energy Efficiency	Big Data in Energy Efficiency
IEEE Access (1st, 5.38%)	IEEE Internet of Things Journal (1st, 17.78%)	IEEE Access (1st, 4.77%)
Energies (2nd, 4.02%)	IEEE Access (2nd, 10.63%)	Future Generation Computer Systems (The International Journal of Escience) (2nd, 2.73%)
Energy and Buildings (3rd, 3.58%)	Sensors (3rd, 6.60%)	IEEE Communications Magazine (2nd, 2.73%)
Applied Energy (4th, 2.71%)	IEEE Transactions on Green Communications and Networking (4th, 2.66%)	Energies (4th, 2.50%)
Sensors (5th, 2.51%)	IEEE Transactions on Industrial Informatics (5th, 2.02%)	Journal of Cleaner Production (5th, 2.27%)

¹ The percentage (%) indicates the portion of each journal in the total number of articles in each domain.

3.6 Comparison in Funding Agencies

National Natural Science Foundation of China is the first funding agency with regard to funding the most articles across the AI, IoT, and Big Data in energy efficiency from 2012 to 2022.

Related to the funding agencies for the articles in the AI in energy efficiency, National Science Foundation was ranked the second, National Research Foundation of Korea as the third, European Union as the fourth, and National Key Research and Development Program of China as the fifth funding agency.

Concerning the funding agencies for the articles in the IoT in energy efficiency, National Research Foundation of Korea was ranked as the second, National Science Foundation as the third, National Key Research and Development Program of China as the fourth, and Fundamental Research Funds for the Central Universities as the fifth funding agency.

With regard to the funding agencies for the articles in the Big Data in energy efficiency, National Science Foundation was ranked as the second, Fundamental Research Funds for the Central Universities as the third, European Union as the fourth, and National Research Foundation of Korea as the fifth funding agency. Table 4 summarizes and compares the top 5 funding agencies having funded the articles in the AI, the IoT, and the Big Data in energy efficiency from 2012 to 2022.

Table 4. Top 5 funding agency in the AI, IoT, and Big Data in energy efficiency¹

AI in Energy Efficiency	IoT in Energy Efficiency	Big Data in Energy Efficiency
National Natural Science Foundation of China (1st, 16.45%)	National Natural Science Foundation of China (1st, 19.62%)	National Natural Science Foundation of China (1st, 22.73%)
National Science Foundation (2nd, 6.89%)	National Research Foundation of Korea (2nd, 4.03%)	National Science Foundation (2nd, 6.59%)
National Research Foundation of Korea (3rd, 3.70%)	National Science Foundation (3rd, 3.76%)	Fundamental Research Funds for the Central Universities (3rd, 6.14%)
European Union (4th, 3.03%)	National Key Research and Development Program of China (4th, 3.30%)	European Union (4th, 2.73%)
National Key Research And Development Program Of China (5th, 2.63%)	Fundamental Research Funds for the Central Universities (5th, 2.57%)	National Research Foundation Of Korea (4th, 2.73%)

¹ The percentage (%) indicates the portion of each funding agency in the total number of articles in each domain.

4. Discussion

AI, IoT, and Big Data are playing important roles in improving or upgrading energy efficiency [13-15]. Moreover, their roles in it are expected to become more and more essential. This study performed a bibliometric comparative analysis on the applications of AI, IoT, and Big Data to energy efficiency from 2012 to 2022. It reveals the following implications resulting from the comparisons in the trend in article publications, citations, countries, research areas, journals, and funding agencies.

First, in the comparison in the trend in article publications, the articles publications of the AI in energy efficiency were much more than those of the IoT and the Big Data in it. The total number of article publications of the AI, the IoT and the Big Data in energy efficiency were 2,511, 1,091, and 440, respectively, from 2012 to 2022. the articles publications of the AI and the IoT in energy efficiency show a rapidly increasing trend

since 2017. Those of the Big Data in energy efficiency indicates rapidly increasing trend from 2012 to 2018 but a fluctuating trend since 2019.

Second, in the comparison in citations, the articles published in the AI in energy efficiency received the most citations, which amounted to 54,821. The articles in the IoT and the Big Data in it received the citations of 24,183 and 10,597, respectively. In terms of the average citation per article, however, the Big Data in energy efficiency was ranked as the first, receiving the average citation per article of 24.08. The IoT and the AI in energy efficiency received the average citation per article of 22.17 and 21.83, respectively.

Third, in the comparison in countries, China was found out to be the first country across the AI, the IoT and the Big Data in energy efficiency with regard to its portion in article publications. USA, South Korea, India, England, and Saudi Arabia were the major countries which composed the top 5 countries in the articles published in the AI, the IoT and the Big Data in energy efficiency.

Fourth, in the comparison in research areas, engineering was revealed to be the first area in both the AI and the IoT in energy efficiency but computer science was found out to be the first area in the Big Data in energy efficiency in terms of their portion of each research area in the total number of articles published from 2012 to 2022. Energy fuels, telecommunications, chemistry, instruments instrumentation, and science technology other topics were the major areas that composed the top 5 research areas in the AI, the IoT and the Big Data in energy efficiency.

Fifth, in the comparison in top journals, IEEE Access was ranked the first journal that published the most articles in the AI and the Big Data in energy efficiency from 2012 to 2022. IEEE Internet of Things was ranked as the first journal in the IoT in energy efficiency. Energies, Future Generation Computer Systems (The Internal Journal of Escience), Energy and Buildings, Sensors, IEEE Communications Magazine, Applied Energy, IEEE Transactions on Green Communications and Networking, IEEE Transactions on Industrial Informatics, and Journal of Cleaner Production were the major journals that composed the top 5 journals in the AI, the IoT, and the Big Data in energy efficiency.

Sixth, in the comparison in funding agencies, National Natural Science Foundation of China was found out to be the first funder having supported the most articles published in the AI, the IoT, and the Big Data from 2012 to 2022. National Science Foundation, National Research Foundation of Korea, Fundamental Research Funds for the Central Universities, European Union, and National Key Research and Development Program of China were the active funding agencies composing the top 5 funding agencies in the AI, the IoT, and the Big Data in energy efficiency.

5. Conclusion

Nowadays, the application of AI, IoT and Big Data is becoming more and more important [16, 17]. This study is expected to make the following significant contributions by performing the bibliometric comparative analysis on the applications of AI, IoT, and Big Data from 2012 to 2022:

First, this study illuminates which application of technology produced the most article publications and citations in energy efficiency among AI, IoT, and Big Data.

Second, this research reveals what country produced the most articles on energy efficiency concerning the applications of AI, IoT, and Big Data and what the research area was in which the most articles were published in regard to the applications of AI, IoT and Big Data to energy efficiency.

Third, this paper sheds new light on what journal published the most articles concerning the applications of AI, IoT, and Big Data to energy efficiency and what research funding agency funded the most articles concerning the applications of AI, IoT, and Big Data to energy efficiency.

Acknowledgement

This work was supported by the 2022 Yeungnam University Research Grant.

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