Bibliometric Analysis and Mapping: Research Trends on Leachate as Renewable Energy (2012 – 2022)

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Bibliometric Analysis and Mapping: Research Trends on Leachate as Renewable Energy (2012 – 2022)

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Abstract. The utilization of leachate as a source of renewable energy is a strategic step in providing solutions to the development of alternative power plants. Leachate is a liquid from landfill that is exposed to rainwater and then enters the ground. Several studies on the conversion of leachate as the electrical energy from various disciplines have been carried out, but research development during the last period has decreased. The bibliometric analysis method was applied in this study to assess research trends related to leachate as renewable energy. Over the last ten years, it was found 317 documents related to the topic. Metadata is mined from the Scopus database using VosViewer. From data filtering using Open Refine and Thesaurus, several collaboration groups in field of study were detected, and 1093 authors were used for bibliometric data analysis. The analysis results show that research related to leachate as renewable energy is classified as research that was not widely carried out. The country that produced the most documents on the topic of leachate as a renewable source of electrical energy was the US, with a total of 52 documents, followed by China and Germany. From the bibliometric visualization using VosViewer, a prominent collaboration was found in the aquifer group in the field of hydrogen energy research using the Microbial Fuel Cell (MFC) method. This finding is a bright prospect for future implementation, namely hydrogen production using a single photo-fermentation process and landfill leachate as a substrate using a batch bio-reactor and anaerobic conditions.

Keywords: Bibliometrics, Leachate, Renewable Energy, Aquifer, Electrical Energy.

1. Introduction

Renewable energy is an alternative energy source that is widely available in nature and can also be used sustainably. There are many renewable energy sources available in nature, such as solar thermal energy, water energy, wind energy, and energy derived from waste like biogas, biomass, and leachate. This renewable energy can later be converted into other forms of energy, such as electrical energy.

Leachate is a liquid produced from heaps of garbage that are exposed to rainwater, in which the water enters the soil and contaminates the aquifer system. Leachate is very dangerous for the environment because it contains high organic, inorganic, and metal compounds (Raghab *et al.*, 2013). Negi *et al.* (2018) examined several parameters related to the level of leachate contamination in an aquifer, such as temperature, electrical conductivity, COD, and others. Their study was conducted in the landfills located in 3 densely populated cities in India. The results showed that the hazardous content of leachate produced from landfills in the three cities had polluted groundwater. Therefore, groundwater quality in those areas decreased and was not suitable for human consumption. Research conducted by Mehdi *et al.* (2019) even indicated that the leachate concentration which reflects the chemical characteristics of the leachate can be influenced by the climate of an area. Piles of garbage that produce leachate in areas that have a tropical climate with low levels of rainfall have the potential to pollute the environment compared to areas that have high levels of rainfall.

Sachs (2001) stated that a country with a tropical climate is a developing country with a fairly dense human population. This fact undoubtedly will further exacerbate the level of environmental pollution by leachate due to the large volume of waste generated by the population and the slow rate of decomposition of waste because of the tropical climate.

Behind the losses caused, the volume of leachate that is available in abundance can be used as a source of renewable electrical energy that is sustainable and environmentally friendly. The enormous benefits of leachate processing as a source of renewable electrical energy should be considered to make a strategic step to present solutions to the development of leachate power plants. Research addressing this topic is very important to do. Studies on the conversion of leachate into renewable electrical energy from the point of view of various disciplines have been carried out and published for decades ago. Mithran & Harshan (2016) conducted a study on leachate to test the level of electricity productivity resulting from leachate as an electrolyte in Microbial Fuel Cell technology. By varying the pH and concentration of the substrate, the results indicated that the leachate has the potential to produce a source of electrical energy with a certain amount of voltage. Microbial Fuel Cell technology that is used to convert leachate into a source of electrical energy can also be applied to reduce contaminants in the leachate content. Research by Elmaadawy *et al.* (2020) showed that microbial fuel cells can remove hazardous chemical components in leachates, such as carbon, nitrogen, and phosphorus. This is surely good news in leachate processing in a landfill because the level of leachate pollution to the environment will be minimized while leachate can be converted into electrical energy with the same technology, namely Microbial Fuel Cell.

For this reason, a bibliometric study to analyze publications related to the topic of leachate as a source of renewable electrical energy is deemed important to do. Bibliometrics is a study of literature and information about a document, whether written or not, with a statistical approach. Ellegaard & Wallin (2015) argued that the bibliometric method has been established as an integral part of the research evaluation methodology, especially in the scientific and applied fields. Recent studies have also succeeded in empowering bibliometric methods. One of the benefits is being able to find out up-to-date publications and conventionality in international research collaborations.

2. Materials and Methods

To map research trends related to leachate as renewable energy, the researchers in this study applied bibliometric analysis methods using VosViewer (VV1.6.17). Metadata was mined from the Scopus database on January 27, 2022. The keywords used were leachate, aquifer, and renewable energy. From the results of the bibliographic visualization or data set containing the

document bibliography field, the researchers performed a network analysis based on the co-authorship, co-occurrence, and citation. The following is a flowchart of this study, which is divided into four phases with a description for each phase.

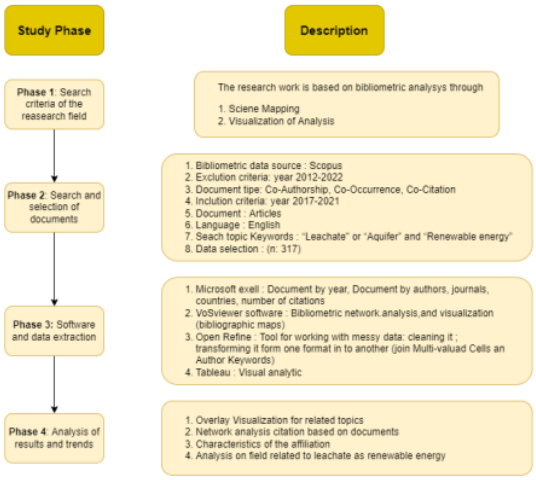

Fig 1. Research Flowchart

From the metadata mined from Scopus, the researchers found data that were still raw and disordered. It could be seen that several keywords having the same meaning or term appeared repeatedly. The researchers overcame this problem by filtering these keywords using OpenRefine and Thesaurus to obtain accurate visualization results, thereby making the data more solid and neat. The following is a list of Thesaurus keywords applied in this study before and after conducting the data cleaning process.

Table 1. List of Keywords in the Data Cleaning Process

No	Keywords	Replacement
1	Aquifers	Aquifer
2	Bioreactors	Bioreactor
3	Compressed Air Energy Storages (CAES)	Compressed Air Energy Storage
4	Energy Resources	Energy Resource
5	Fossil Fuels	Fossil Fuel
6	Gases	Gas
7	Greenhouse Gases	Greenhouse Gas
8	Ground Water	Groundwater
9	Land Fill	Landfill
10	Landfill Leachates	Landfill Leachate
11	Leachates	Leachate
12	Municipal Solid Waste (MSW)	Municipal Solid Waste
13	Renewable Energies	Renewable Energy
14	Renewable Energy Resources	Renewable Energy Resource
15	Waste Disposal Facilities	Waste Disposal Facility
16	Shallow geothermal Energies	Shallow geothermal Energy
17	Aquifer Thermal Energy Storage (ATES)	Aquifer Thermal Energy Storage

From the results of the data cleaning process, the researchers successfully sorted documents using features available in VosViewer to display the visualization results, which included the analyses of co-authorship, co-occurrence, and citation. The results of these analyses were displayed on a bibliometric visualization map.

3. Results and Discussion

In the span of approximately the last 10 years (i.e., from 2012 to early 2022), the researchers by carrying out a metadata search found 317 documents with 25 authors and 1093 keywords that appeared related to leachate. Based on its quantity per year, studies related to the topic of problems were mostly carried out from 2017 to 2021. The following describes the mapping of the distribution of research documents in the form of networks based on year, affiliation, country/region, level of author productivity and collaboration, research topics based on keywords, and the number of documents per year based on data source.

3.1 Distribution of Documents by Year

Documents related to topics investigated were mostly carried out in 2017, totaling more than 40 documents. As seen in Figure 2, the number of documents related to renewable energy seems to have decreased sharply from 2021 to 2022. This is due to the influence of the pandemic conditions during the last 2 years. At that time, research trends can also be said to have shifted. Moreover, publications both nationally and internationally are dominated by those focusing on the issue of handling the pandemic.

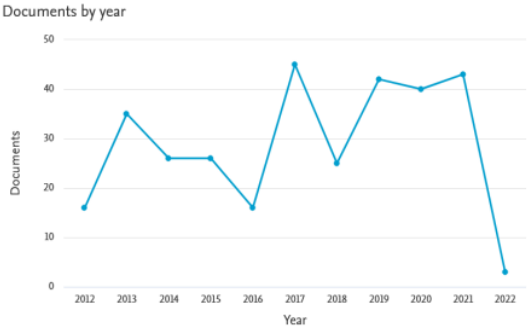

Fig 2. Distribution of Documents by Year

3.2 Distribution of Documents by Affiliation

In this study, the researchers also carried out an analysis of the affiliation of the authors. Author affiliations were then grouped by type and institution name. Based on the type of the author's institution, all of the authors come from the university or college level. These institutions are the main pillar in producing technological research and innovation. The results of the analysis showed that 10 institutions made the largest contribution to research on leachate as a source of renewable electrical energy. The largest number of documents came from Christian-Albrecht University (CAU) of Kiel, totaling 22 documents over the period determined in this study, followed by Université Kasdi Merbah Ouargla in the second place. Details of the author's affiliation can be seen in Figure 3.

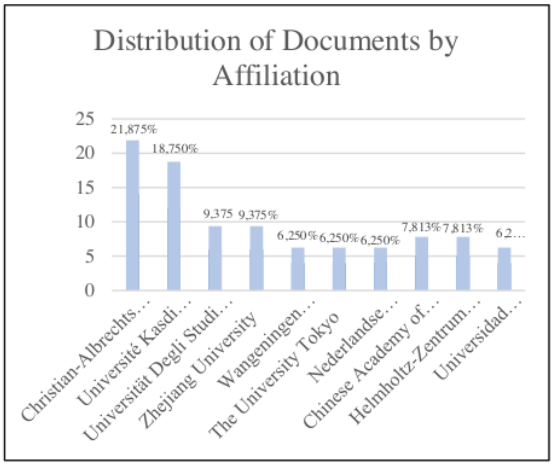

Fig 3. Distribution of Documents by Affiliation

One of the most recent studies is from the Chinese Academy of Geological Sciences, entitled "*The promise and challenges of utility-scale compressed air energy storage in aquifers*" written by Guo C., Li C., Zhang K., Cai Z., Ma T., Maggi F., Gan Y., El-Zein A., Pan Z., and Shen L. The study was conducted in 2021 and presented a selective review of theoretical and numerical modeling studies and field tests along with efficiency and economic analysis to assess the feasibility of the emerging technology for further utilization of leachate.

3.3 Distribution of Documents by Country or Territory

The researchers carried out an analysis of the author's characteristics in terms of country of origin to determine the dominance of the author's country in the topic investigated (Figure 4). The researchers found 23 countries that at least had 5 documents related to the topic investigated. The following Figure 4 presents 10 countries that produced the most documents on the topic of leachate as a source of renewable electricity. The USA occupies the first place with a total of 52 documents, followed by China and Germany in the second and third places.

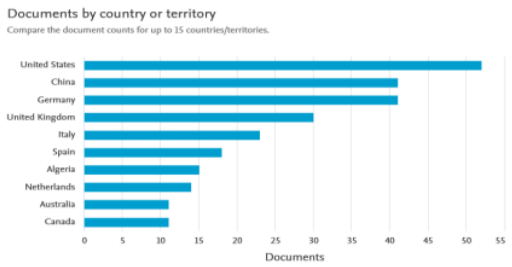

Fig 4. Distribution of Documents by Country or Territory

By analyzing the collected documents using VosViewer, the researchers found that the author's country of origin can be classified into 4 clusters. Cluster 1 consists of 12 countries with a total of 151 documents, mostly from the European continent. Moreover, cluster 2 consists of 9 countries with 172 documents. Cluster 2 shows the diverse country distribution, such as the USA from the American continent, Australia from the Australian continent, some countries from the Asian continent, and others. Apart from that, cluster 3 only classifies documents originating from Japan while cluster 4 only classifies documents originating from Poland, as shown in Figure 5 below.

Fig 5. The Author's Countries of Origin by Cluster

3.4 Author Productivity Levels and Collaboration Distribution

In the co-authorship analysis, the researchers analyze the author's network which will later be able to provide further information and identify the researchers who lead the research. Figure 6 shows that Rabbel W is the author who produced the highest number of documents throughout the last 10 years related to the topic investigated in this study.

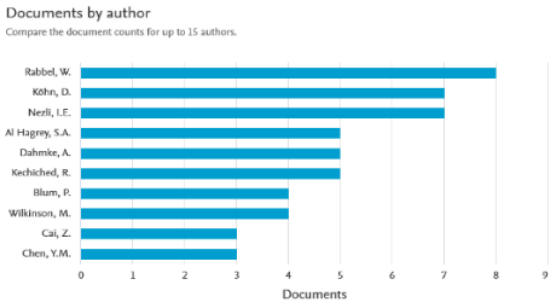

Fig 6. Distribution of Documents by Author

Table 2 below presents data on the 10 largest groups of authors who collaborate in the research related to leachate as renewable energy. Some of the researchers presented in detail are Cai Z., Blum P., Guo C., Wilkinson M., Abdelali A., Nezli I. E., and Benhamida A. S. The distribution of documents by the author as shown in Figure 6 noted Nezli I. E. as the author who collaborated the most in publishing journal papers although his name occupies the third rank as the person who carried out the research related to leachate as renewable energy. The papers published by Nezli I. E. are mostly about geochemistry and groundwater. In his papers, he discussed the geothermal potential of the Continental Intercalaire (C.I.) aquifer which is recommended to be utilized as a renewable energy source that can be applied to heat greenhouses and/or generate electricity.

Table 2. Top 10 Cited Articles related to Leachate and Renewable Energy

Authors	Title and Total Cites	Journal and Year	Publisher
Luo J., Qian G., Liu J., Xu Z.P.	Anaerobic methanogenesis of fresh leachate from municipal solid waste: A brief review on current progress (33 cites)	Renewable and Sustainable Energy Reviews (2015)	Elsevier Ltd
Al Hagrey S.A., Köhn D., Rabbel W.	Geophysical evaluations of renewable gas energy in geologic pore storage - Numerical study (14 cites)	Society of Exploration Geophysicists International Exposition and 84th Annual Meeting SEG (2014)	SEG
Liu X., Novak J.T., He Z.	Synergistically coupling membrane electrochemical reactor with Fenton process to enhance landfill leachate treatment (12 cites)	Chemosphere (2020)	Elsevier Ltd
Romero De León L.A., Quinto Diez P., Tovar Gálvez L.R., Alvarado Perea L., López Barragán C.A., García Rodríguez C.A., Reyes León A.	Biochemical methane potential of water hyacinth and the organic fraction of municipal solid waste using leachate from Mexico City's Bordo Poniente composting plant as inoculum (5 cites)	Fuel (2021)	Elsevier Ltd
al Hagrey S.A., Schäfer D., Köhn D., Wiegers C.E., Chung D., Dahmke A., Rabbel W.	Monitoring gas leakages simulated in a near surface aquifer of the Ellerbek paleo-channel (4 cites)	Environmental Earth Sciences (2016)	Springer Verlag
Abdelali A., Nezli I.E., Kechiched R., Attalah S., Benhamida S.A., Pang Z.	Geothermometry and geochemistry of groundwater in the Continental Intercalaire aquifer, southeastern Algeria: Insights from cations, silica and SO4–H2O isotope geothermometers (4 cites)	Applied Geochemistry (2020)	Elsevier Ltd
Guo C., Li C., Zhang K., Cai Z., Ma T., Maggi F., Gan Y., El-Zein A., Pan Z., Shen L.	The promise and challenges of utility-scale compressed air energy storage in aquifers (cites)	Applied Energy (2021)	Elsevier Ltd
Hei K., Chang Z., Chen G., Ye X., Zhang Y.	Characteristic of leachate distribution at profile in straw anaerobic digestion with high solid content (2 cites)	Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering (2017)	Chinese Society of Agricultural Engineering
Benhamida S.A., Nezli I.E., Kechiched R.	Sources of chemistry of the albian water under arid conditions. Application to the western regions of the Algerian Sahara (1 cites)	Energy Procedia (2017)	Elsevier Ltd
Bettahar A., Nezli I.E., Kechiched R.	Evolution and Mineralization of Water Chemistry in the Aquifer systems of the Terminal Complex of the Wadi Righ Valley (1 cites)	Energy Procedia (2017)	Elsevier Ltd

The quite large number of research collaborations shown in Table 2 indicates that it has become imperative in recent times to find new sustainable and renewable energy sources. It is carried out to avoid dependence on traditional non-renewable energy resources. In this case, renewable energy is needed to help overcome the depletion of natural resources for energy production. One of the findings from those studies is hydrogen production using a single photo-fermentation process and landfill leachate as a substrate by utilizing a batch bio-reactor and anaerobic conditions.

3.5 Distribution of Documents by Keywords

In the co-occurrence network visualization shown in Figure 7, the researchers identified 4 interconnected clusters. The first covers groundwater, geothermal energy, and others (highlighted in green color). The second is about leachate, consisting of landfill leachate, leachate treatment, and others (highlighted in red color). The third discusses renewable energy, electric energy storage, and others (highlighted in blue color). At last, the fourth covers the topic of environmental impact (highlighted in yellow color). Related to these clusters, the researchers detected 254 interconnected items as seen from the line connecting one keyword to another.

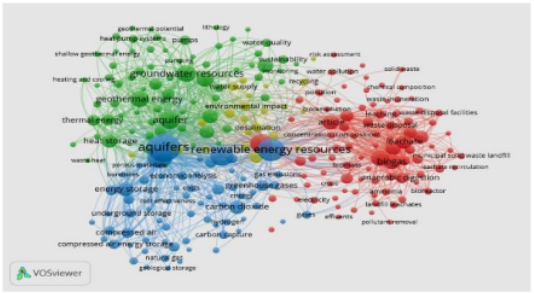

Fig 7. Visualization of Interconnected Topics based on Keywords

The visualization shown in Figure 7 can be used to find out parts of research that are rarely carried out or have few publications. As shown in Figure 7, the topics interconnected with leachate are solid waste, waste incineration, municipal solid waste landfill, and others. On the topic of the aquifer, Nezli I. E. is recorded as the author with the most collaborations (by publishing 7 journals). Specifically, his research is mostly about geochemistry and groundwater, which discusses the geothermal potential of the CI (Continental Intercalaire) aquifer. In his papers, he suggested the use of a renewable energy source that can be applied in heating greenhouses and/or generating electricity.

3.6 Citation Analysis by Number of Documents

The analysis by year shows that a large number of citations for research related to leachate occurred between 2013 and 2016 (Figure 8). The larger the circle that appears on VosViewer is, the greater the number of citations made by other researchers on a certain publication will be. There are several authors whose publications have been cited many times, such as Tarkowski R. (2019) with a paper entitled "*Underground hydrogen storage: Characteristics and prospects*" published by the journal *Renewable and Sustainable Energy Reviews*, followed by Hahnlein S. (2013) and Al-Thyabat S. (2015).

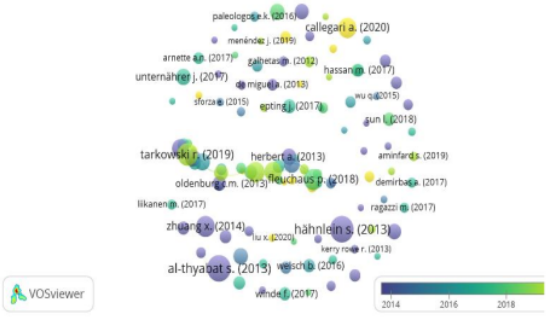

Fig 8. Visualization of Citation based on the Number of Documents

This is in line with the results of the citation analysis that has been carried out previously, in which the publication of Tarkowski R. in 2019 was the publication with the most citations throughout the last 10 years. Two of the papers he published are entitled "*Perspectives of using the geological subsurface for hydrogen storage in Poland* (2016)" and "*Some aspects of underground hydrogen storage* (2017)". His papers present prospective areas for various options for underground hydrogen storage.

3.7 The Number of Documents by Year

In the last 10 years, the number of publications on the topic of leachate as a source of renewable electrical energy in the field of waste management has decreased from 3 documents in 2012 to 1 document in 2013-2016. It then increased to 2 documents in the following year but decreased again in 2021 (only 1 document in this year). In the field of renewable energy, it can be seen that the number of publications fluctuates from year to year, starting from 2015 to 2021, as shown in Figure 9.

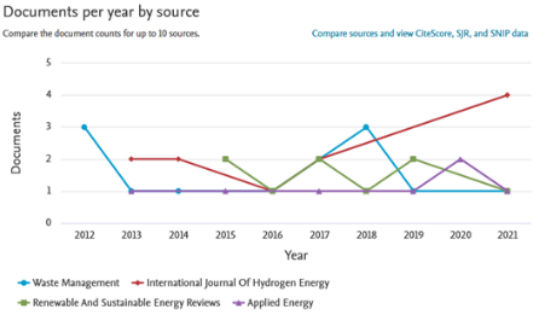

Fig 9. Graph of Documents per Year by Source

This shows that, in the applied energy field, high research interest in leachate has not been seen in the last 10 years. Figure 9 above indicates that the number of documents, especially related to research on leachate, is highly limited. The opposite occurs in the trend of publications in the *Journal of Hydrogen Energy* which has increased from 2016 to 2021. The *Journal of Hydrogen Energy* is an international journal with research coverage related to innovation and technological developments. Furthermore, research in the field of hydrogen energy covers many aspects, including the study of fuel cells. The research related to the potential of leachate as a source of renewable electrical energy is included in the scope of the *Journal of Hydrogen Energy* with a focus on the utilization of leachate as a substrate for microbial fuel cell reactors. A study conducted by Sonawane *et al.* (2017) in the *Journal of Hydrogen Energy* presented that leachate from landfills is a promising raw material for microbial fuel cells (MFC). In other words, the chemical energy produced can be converted into electrical energy. Despite having potential, the maximum voltage observed during the study was 1.29 volts. The relatively small voltage of this MFC system is certainly still a challenge in research on leachate as a source of renewable electrical energy. Many factors are presumed to be the cause of the low level of electricity productivity from leachate even though it possesses great potential. A study conducted by Yaqoob *et al.* (2021) provided several recommendations that can be applied in further research on the application of MFCs in generating electrical energy from leachates, such as improving electrode material and increasing research on microbial mechanisms and their characteristics during MFC observations.

Outside 10 major institutions shown in Figure 3, the researchers found Bandung Institute of Technology

(Indonesian: *Institut Teknologi Bandung* (ITB)) and Diponegoro University (Indonesian: *Universitas Diponegoro* (UNDIP)) as institutions that study leachate as renewable energy. However, the papers were only published in Indonesian journals. One of the papers was entitled "*Challenges and opportunities of microbial fuel cells (MFCs) technology development in Indonesia*" by Surya Ramadan in 2017. In his paper, he stated that microbial fuel cell (MFC) is a potential source of electrical energy from waste rich in organic materials, such as leachate. The bacteria in MFCs can be used to generate electricity as long as the leachate from the waste is available to be consumed by the bacteria.

4. Conclusions

Based on the results of a bibliometric study of articles addressing the topic of "*Global Trends in Research related to Leachate as Renewable Energy*", we may conclude several things, namely as follows.

1. The number of publications related to leachate shows that there are not many studies addressing this topic during the years 2012-2022. Many factors are presumed to be the cause of the low level of electricity productivity from leachate even though it has great potential. However, there has been an increase recently in the publication trend in international journals since 2016. The topic related to the potential of leachate as a source of renewable electrical energy is included in the scope of the study that must be developed. Due to the recent conditions, especially the pandemic that has hit the world, the publications on the topic of leachate as renewable energy have declined.
2. Most of the research activities addressing leachate as a source of electrical energy have been consistently carried out in collaboration by several authors. The author with the highest number of research collaborations is Nezli I. E. In addition, the researchers found 6 other authors produced at least 5 publications, in which the highest level of productivity is awarded to Rabbel W, having a total of more than 8 documents. Furthermore, based on its country, most of the documents are produced by the USA (52 documents).
3. The most frequently cited documents with 10 or more citations were dominated by publications published from 2013 to 2021. The paper produced by Tarkowski R. *et al.* (*Renewable and Sustainable Energy Reviews*) in 2019 became the most cited paper in the last 10 years.
4. The field that most raises the topic of leachate as a source of renewable electrical energy is the field of hydrogen energy which covers many aspects, especially the study of fuel cells. Research related to the potential of the leachate is included in the scope of the journal with a focus on the use of leachate as a substrate for a microbial fuel cell (MFC) reactor. The bacteria in MFCs are considered to be able to generate electricity as long as the leachate from the waste is available to be consumed by the bacteria.

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