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Optimization of Geothermal Binary Cycle Technology: an Review

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Abstract
Geothermal energy is mostly stored in the earth's interior, cost-effective and reliable compared to other sustainable energies, such as solar, wind and nuclear energy. Geothermal energy or geothermal energy is a competitive alternative energy because it is available in very large potential, can be used in the long term, and is environmentally friendly. This research uses descriptive quantitative methods with a data analysis and mapping process approach. The articles used in this research were articles published in the 2018-2023 range, totaling 50 articles. The articles are collected and then saved in *.ris format. Next, researchers used VOSviewer. Furthermore, this application suggests that the use of applications using Vosviewer is an application that is widely used to search for the latest research. Therefore, in this research the topic of optimization and zeotropic mixture.
Keywords: Optimization, Geothermal, Binary Cycle Technology

Introduction
In recent years, environmental problems such as ozone layer depletion and global warming have become energy policy considerations for a country (Kolahi, 2018). The change from fossil fuel energy to renewable energy fuels is becoming increasingly important in the development of sustainable energy due to the need to reduce carbon emissions. One of the benefits provided is reduction of greenhouse gases, energy self-sufficiency, and so on. Therefore, renewable energy such as bioenergy, solar, wind or geothermal is widely used today, but its use has not yet reached its full potential (Syaiful Alim et al., 2023). Among these resources, geothermal energy is the only renewable resource that is not affected by external weather conditions with a wide temperature range between 50 to 350oC (Başoğul, 2021). Geothermal energy is mostly stored in the earth's interior, cost-effective and reliable compared to other sustainable energies, such as solar, wind and nuclear energy (Lei et al., 2019).

Geothermal is a promising renewable resource and can reduce fossil fuels and environmental impacts (Lee, 2019). Therefore, geothermal energy is a competitive alternative energy because it is available in very large potential and can be used in the long term and is environmentally friendly (Wijayanti, 2023). Additionally, geothermal energy is gaining strong interest from both the private and public sectors. Analysts predict that its use will grow rapidly in the next few decades in many places (Zwaan & Longa, 2019). The development of geothermal resources at the world level requires regional information regarding geothermal potential that can be accessed by developers. Heat flow was an important parameter in early reconnaissance work to indicate areas where large amounts of heat release occurred (Prol-Ledesma & Morán-Zenteno, 2019). There are two groups of geothermal systems: 1) geothermal systems with low enthalpy, and 2) geothermal systems with high enthalpy. Regarding the first type, these are geothermal systems characterized by fluids at temperatures below 90oC, not suitable for electricity production, but useful for thermal purposes, that is, for all applications aimed at the direct use of geothermal heat, from room air conditioning to heat supply in large industrial processes, pay attention to Figure 1.

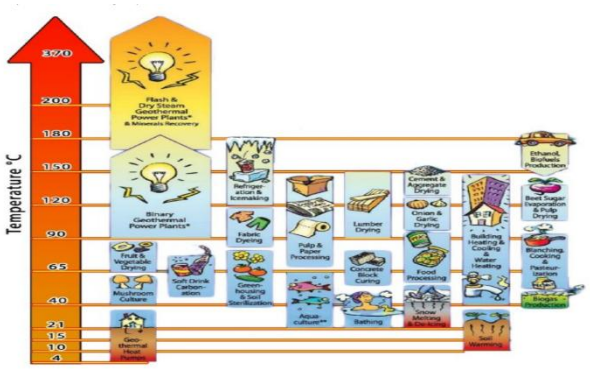


Figure 1. Lindal Diagram: Schematically Depicts the Use of Geothermal Energy Based on System Temperature

Next, regarding geothermal systems with high enthalpy. In this type it is possible to produce electricity starting from around 90oC. Geothermal energy can provide basic services and can play a role of "flexibility" in a sustainable electricity system in the future (Zwaan & Longa, 2019). However, for electricity generation, a higher temperature power source is needed, around 100-1500C or higher (Aghahosseini, 2020). Geothermal power plants can only be built around tectonic plates where high temperatures from geothermal sources are available near the surface. Developments and improvements in drilling and extraction technology have expanded the reach of developing geothermal power plants from nearby tectonic plates (Meilani & Wuryandani, 2010). Drilling technology makes it possible to access the earth's crust and extract geothermal energy for power generation. Conversion of geothermal energy into electricity is promising due to its efficiency and higher load factor. In 2016, geothermal capacity grew at an annual rate of 3.4% (440 MW) to reach 13.4 GW (BP, 2017) (Zhang & Hu, 2018).

Globally, many regions have large geothermal resources so that they can be utilized more optimally and produce electricity continuously at low capital costs. According to Bertani (2016) (in Başoğul, 2021) due to increasing interest in geothermal electricity production lines and lowering costs, existing systems need to be repaired or replaced with new designs. With this goal, the total world installed power will reach 12,640 MW. Of the installed power, 5,079 MW comes from single flash cycle, 2,863 MW from dry steam, 2,544 MW from reverse pressure cycle and hybrid cycle. Currently, all geothermal power plants being built utilize the binary cycle, where geothermal energy is used as a heat source for the Organic Rankine Cycle. Binary geothermal power plants have several advantages over flash-based power plants, including the use of low-quality heat sources and, as a result, longer equipment life, less equipment contact with corrosive geothermal water (Cetin et al., 2020). However, binary GPP with ORC is preferred for generating electricity from geothermal sources with low enthalpy due to recent advances in technological development (Zheng et al., 2015).

The use of ORC technology for geopower production (i.e. binary power generation) has become a well-established solution worldwide. At the end of 2014, the geothermal sector numbered 279 binary units (46% of the total geothermal in the world) with an installed capacity of around 1700 MWel (14% of the total geothermal word) (C et al., 2019). Organic Rankine Cycle (ORC) has been proven to be one of the most efficient ways to utilize low-level geothermal energy, due to its compact structure, stable operation and easy maintenance (Zhao et al., 2021). One of the main challenges in ORC power generation systems is the high rate of exergy destruction in the condenser and evaporator (due to the temperature difference between hot and cold streams) (Almutairi et al., 2021). A modified ORC, namely binary-flashing cycle (BFC), is proposed with incomplete evaporation characteristics for the working fluid in the evaporator. By dividing the traditional evaporation process into two stages, namely incomplete evaporation and flash evaporation, more working fluid is evaporated, resulting in more power production. BFC is proven to be an efficient technology to achieve full utilization of geothermal brine (Wang et al., 2021).

Based on the information presented above, it is clear that geothermal-based energy systems provide good results and are environmentally friendly, making them a viable alternative to replacing fossil fuels. The integration of geothermal energy with other heat sources in combined structures has demonstrated superior performance, especially in terms of economic feasibility and environmental impact. Inspired by these promising results, this research was motivated to carry out the design and analysis of a new geothermal-based system, coupled with the utilization of flue gas from a trigeneration power plant (Xiao et al., 2023).

Materials & Methods

This research uses descriptive quantitative methods with a data analysis and mapping process approach. The article data used in this research is research data from articles that have been published in journals that have been indexed by Scopus. In this research, we used an additional application in the form of Sci.hub to get access to paid journals for free. The reference management application used in this research is Publish or Perish. Publish or Perish is used in conducting a literature review of the theme used. Each article's data must be indexed by Scopus and in the type of journal article and be in accordance with the search for the themes needed in this research in a file that is used in VOSviewer.

In this research, each article was filtered, and the author only took those related to the keywords "binary cycle technology and Geothermal" to obtain 200 articles. However, the data selected is only from journal articles with 91 citations. The articles used in this research are articles published in the 2018-2024 range. The articles are collected and then saved in *.ris format. Next, researchers used the VOSviewer application to visualize and analyze it in the form of a bibliometric map. We mapped article data from prepared database sources. Apart from that, we also filter terms that will

be included in the VOSviewer network mapping visualization.

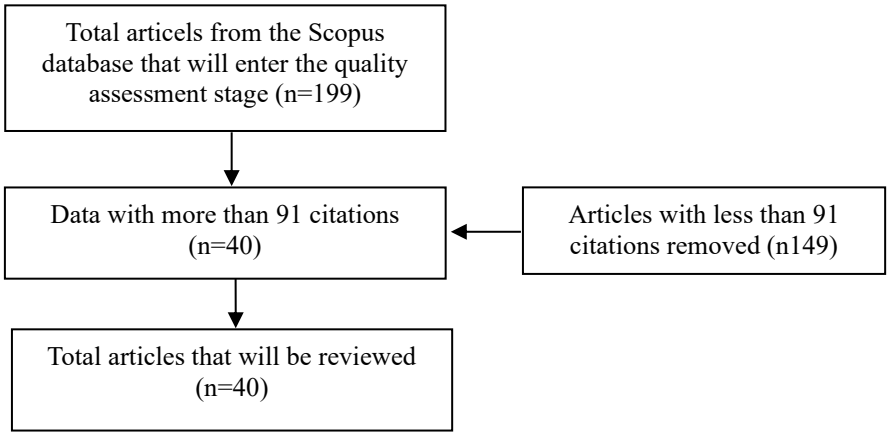
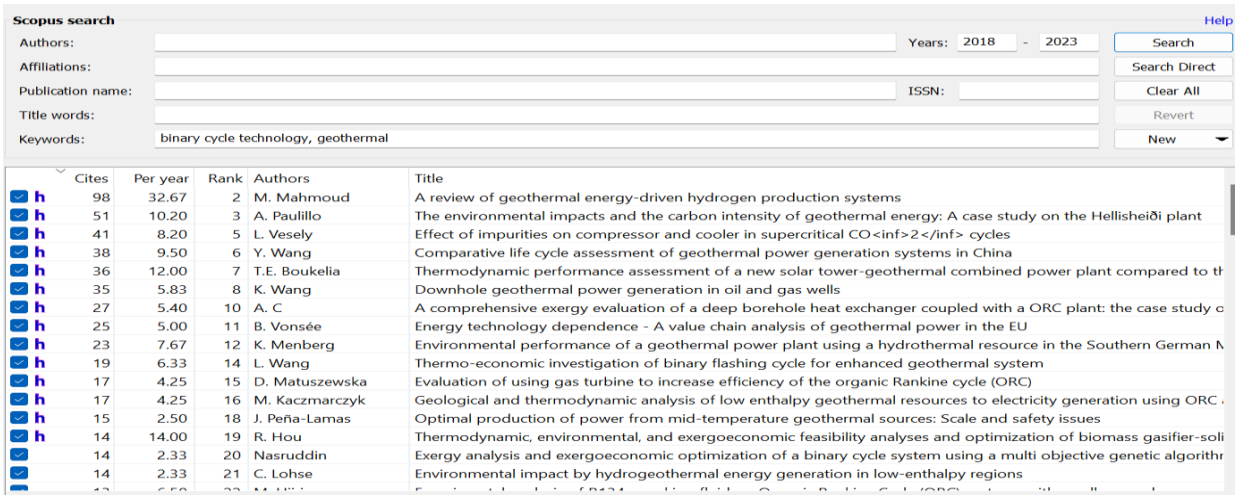


Figure 2. Flowchart for Selecting Journals to be Reviewed

Data Collection

At this stage, the data required for the research is collected for further analysis. Following are the data collection steps:

1. Open the Publish or Perish application
2. Select the Scopus search database
3. Enter the keywords "binary cycle technology and Geothermal"
4. In the Scopus search "Year" column, enter 2018 in the first box and 2023 in the second box. This shows that the selected range of article papers is from 2018-2023.
5. Click the 'Search' button and the 2018-2023 Scopus article database will appear.



Cites	Per year	Rank	Authors	Title
98	32.67	2	M. Mahmoud	A review of geothermal energy-driven hydrogen production systems
51	10.20	3	A. Paulillo	The environmental impacts and the carbon intensity of geothermal energy: A case study on the Hellisheiði plant
41	8.20	5	L. Vesely	Effect of impurities on compressor and cooler in supercritical CO<inf>2</inf> cycles
38	9.50	6	Y. Wang	Comparative life cycle assessment of geothermal power generation systems in China
36	12.00	7	T.E. Boukelia	Thermodynamic performance assessment of a new solar tower-geothermal combined power plant compared to th
35	5.83	8	K. Wang	Downhole geothermal power generation in oil and gas wells
27	5.40	10	A. C	A comprehensive exergy evaluation of a deep borehole heat exchanger coupled with a ORC plant: the case study c
25	5.00	11	B. Vonsée	Energy technology dependence - A value chain analysis of geothermal power in the EU
23	7.67	12	K. Menberg	Environmental performance of a geothermal power plant using a hydrothermal resource in the Southern German M
19	6.33	14	L. Wang	Thermo-economic investigation of binary flashing cycle for enhanced geothermal system
17	4.25	15	D. Matuszewska	Evaluation of using gas turbine to increase efficiency of the organic Rankine cycle (ORC)
17	4.25	16	M. Kaczmarczyk	Geological and thermodynamic analysis of low enthalpy geothermal resources to electricity generation using ORC
15	2.50	18	J. Peña-Lamas	Optimal production of power from mid-temperature geothermal sources: Scale and safety issues
14	14.00	19	R. Hou	Thermodynamic, environmental, and exergoeconomic feasibility analyses and optimization of biomass gasifier-soli
14	2.33	20	Nasruddin	Exergy analysis and exergoeconomic optimization of a binary cycle system using a multi objective genetic algorithr
14	2.33	21	C. Lohse	Environmental impact by hydrogeothermal energy generation in low-enthalpy regions

Figure 3. Search Results Using Publish or Perish with the Keywords Binary Cycle Technology and Geothermal

Data Analysis and Mapping

Based on the data that has been collected, an analysis process is then carried out using Microsoft Excel. Furthermore, to find out the progress of research and mapping, it is carried out using the Vosviewer application. This application can display visualizations of the data that has been obtained in the form of Network Visualization, Overlay Visualization, and

Density Visualization

Based on the visualization displayed, various information can be seen, such as research that has been carried out a lot, research that is still small, including what the latest research is. Apart from displaying visualization of mapping results, Vosviewer also provides cluster information and the items contained in it. Research from (Triwahyuningtyas et al., 2021) suggests that utilizing applications using Vosviewer is one of the applications that is widely used to search for the latest research..

Results and Discussion

Distribution by Year of Study

From the results of the search process using the Publish or Perish application, we obtained journals indexed by Scopus in the 2018-2023 period with the keyword "binary cycle technology and Geothermal". Table 1 displays these articles.

Table 1. Articles that Meet the Criteria

No	Citation	Writer	Title	Year
1	98	M. Mahmoud	A review of geothermal energy-driven hydrogen production systems	2021
2	51	A. Paulillo	The environmental impacts and the carbon intensity of geothermal energy: A case study on the Hellisheiði plant	2019
3	41	L. Vesely	Effect of impurities on compressor and cooler in supercritical CO<inf>2</inf> cycles	2019
4	38	Y. Wang	Comparative life cycle assessment of geothermal power generation systems in China	2020
5	36	T.E. Boukelia	Thermodynamic performance assessment of a new solar tower-geothermal combined power plant compared to the conventional solar tower power plant	2021
6	35	K. Wang	Downhole geothermal power generation in oil and gas wells	2018
7	27	A. C	A comprehensive exergy evaluation of a deep borehole heat exchanger coupled with a ORC plant: the case study of Campi Flegrei	2019
8	25	B. Vonsée	Energy technology dependence - A value chain analysis of geothermal power in the EU	2019
9	23	K. Menberg	Environmental performance of a geothermal power plant using a hydrothermal resource in the Southern German Molasse Basin	2021
10	19	L. Wang	Thermo-economic investigation of binary flashing cycle for enhanced geothermal system	2021
11	17	D. Matuszewska	Evaluation of using gas turbine to increase efficiency of the organic Rankine cycle (ORC)	2020
12	17	M. Kaczmarczyk	Geological and thermodynamic analysis of low enthalpy geothermal resources to electricity generation using ORC and Kalina cycle technology	2020
13	15	J. Peña-Lamas	Optimal production of power from mid-temperature geothermal sources: Scale and safety issues	2018
14	14	C. Lohse	Environmental impact by hydrogeothermal energy generation in low-enthalpy regions	2018
15	14	Nasruddin	Exergy analysis and exergoeconomic optimization of a binary cycle system using a multi objective genetic algorithm	2018
16	14	R. Hou	Thermodynamic, environmental, and exergoeconomic feasibility analyses and optimization of biomass gasifier-solid oxide fuel cell boosting a doable-flash binary geothermal cycle; a novel trigeneration plant	2023
17	13	M. Hijriawan	Experimental analysis of R134a working fluid on Organic Rankine Cycle (ORC) systems with scroll-expander	2022
18	11	M.D. Surindra	Comparison of the utilization of 110 °C and 120 °C heat sources in a geothermal energy system using Organic Rankine Cycle (ORC) with R245fa, R123, and mixed-ratio fluids as working fluids	2019
19	11	T.H. Cetin	Integration of cryogenic energy storage and cryogenic organic cycle to geothermal power plants	2020
20	10	L. Wang	Multi-objective optimization of Binary Flashing Cycle (BFC) driven by geothermal energy	2020
21	8	C.I. Birney	A spatially resolved thermodynamic assessment of geothermal powered multi-effect brackish water distillation in Texas	2019
22	7	L. Wang	Investigation on geothermal binary-flashing cycle employing zeotropic mixtures as working fluids	2019
23	7	D. Moya	Method for the technical, financial, economic and environmental pre-feasibility study of geothermal power plants by RETScreen – Ecuador's case study	2018
24	5	M.Z. Abidin	Tax incentive policy for geothermal development: A comparative analysis in ASEAN	2020
25	5	A.B. Alkhasov	Technologies of geothermal resources development in South of Russia	2020
26	3	Y. Başoğul	A parametric study on exergoeconomic analysis for a binary geothermal power plant with ORC	2021
27	3	Y. Zhao	Energy and Conventional and Advanced Exergy Analyses of Low-Temperature Geothermal Binary-Flashing Cycle Using Zeotropic Mixtures	2022
28	3	A. Alkhasov	Evaluating the Effect from Constructing Binary Geothermal Power Units Based on Spent Petroleum and Gas Boreholes in the South Regions of Russia	2018

29	3	Z. Liu	Research progress of technologies and numerical simulations in exploiting geothermal energy from abandoned wells: A review	2023
30	3	Y. Zhao	Thermo-Economic Comparison Between Organic Rankine Cycle and Binary-Flashing Cycle for Geothermal Energy	2021
31	1	M.M. Oreijah	A parametric analysis to evaluate the performance metrics of power generation system involving Trilateral Flash Cycle using three different working fluids for low grade waste heat	2019
32	1	Y. Tranamil-Maripe	Assessing the Hybridization of an Existing Geothermal Plant by Coupling a CSP System for Increasing Power Generation	2022
33	1	Q. Xiao	Simulation and study of the simultaneous use of geothermal energy and flue gas waste energy in an innovative combined framework for power, chilled water, and fresh water generation	2023
34	1	D. Chasapis	Thermodynamic analysis on the performance of a low-enthalpy geothermal field using a CO2 supercritical binary cycle	2019
35		K.A. Titus	Carbon negative geothermal: Theoretical efficiency and sequestration potential of geothermal-BECCS energy cycles	2021
36		S.A. Yankovsky	CYCLE DIAGRAM OF GEOTHERMAL ENERGY	2022
37		V.A. Butuzov	Experience of the Development of Geothermal Energy on the Example of Iceland	2021
38		C. Sahana	Optimum operation of an ejector-assisted combined flash-binary geothermal cycle using R245fa-isopentane mixture-based secondary working fluids	2021
39		G.V. Tomarov	Results from Optimization Studies of Multistage Binary Cycles for Utilization of Low-Temperature Geothermal Heat Carrier	2024
40		I.S. Serbin.	Turbogenerating Units for Cogeneration and Distributed Power Plants	2020

The results of the search process are displayed in Table 1. Grouped by journal type to make it easier to group the types of data or journal types obtained through the search process with the help of Publish or Perish

Table 2. Grouping by Journal

Source Journal	Year					
	2018	**2019**	**2020**	**2021**	**2022**	**2023**
Energy		4	2	1	2	1
Geothermal energy	1	1	1	1		
Renewable energy	1		1	1		
Green energy methodsX	1		1	1		
Advancement of science	1			1	1	
Environment Resources and Conservation	1	1	1			
Resource		2				1
Application of thermal energy	1		1	1	1	2
frontiers in earth science				1		
Geoenergy science						1
Chemical Engineering		1				
Greenhouse						1
geographic assets						1
Total	**6**	**9**	**7**	**7**	**4**	**7**

Journal articles in Table 2 are sorted based on the most citations in 2018-2023. Of the 40 articles that met the criteria, the highest number of publications was in 2019 with 9 articles, followed by 2020, 2021 and 2023 with 7 articles. Then, published articles experienced a drastic decline in 2022 with a total of 4 articles 4.. In 2018, there were 6 articles published.

Distribution Based on Research Theory

In research, you definitely need a theoretical basis that is used to strengthen the article. A total of 450 articles were used by researchers, there were quite a lot of theories used, but the most numerous were theories regarding geothermal with 8 articles, then theories regarding the application of geothermal with 6 articles and other articles related to geothermal. The following are the results of data visualization called Network Visualization using Vos Viewer. From the following visualization you can see the relationship between the variables in the article used by the researcher. The following image is divided into 4 clusters, namely (1) the red cluster which contains exergy, implication, and exergy analysis. , (2) green cluster containing development, reverse osmosis desalination, and review, (3) blue cluster containing geothermal energy and performance, (4) yellow cluster containing optimization and zetropic mixture. Can be seen in Figure 4.

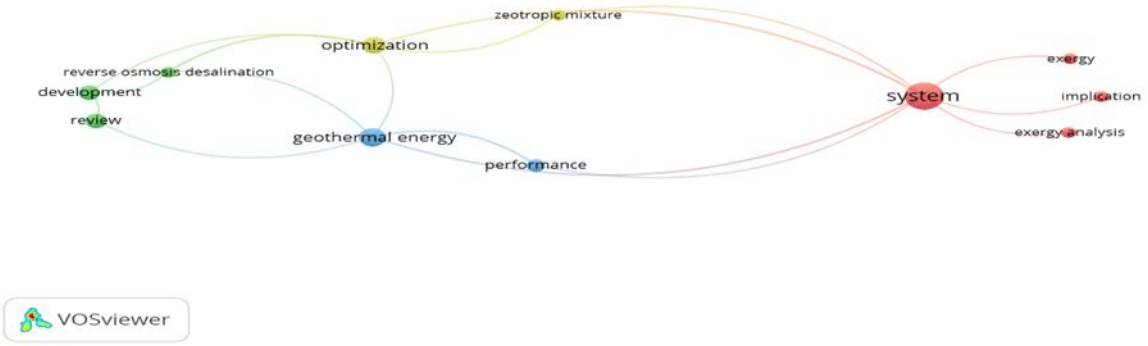


Figure 4. Network Visualization Display

It can be seen in Figure 4. That the system has the largest circular shape. This shows a strong relationship with other article research topics. It can be seen that the system is related to exergy, implication, and exergy analysis. Likewise with geothermal energy which has a close relationship with performance, optimization, reverse osmosis desalination, and review. Furthermore, the small circle shows a not so strong relationship spread across 4 clusters. This shows that there are not many research results and opportunities for renewable research to be carried out (Karim, 2022). Next is mapping with an overlay visualization display. At this stage, the color of each topic in the article is displayed based on the year of publication. The color range in the article is from blue to yellow. Topics in articles that have the lowest year, namely 2018, will be colored purplish blue, whereas topics in articles that have the highest year will be colored bright yellow. The following displays the visualization overlay in Figure 5.

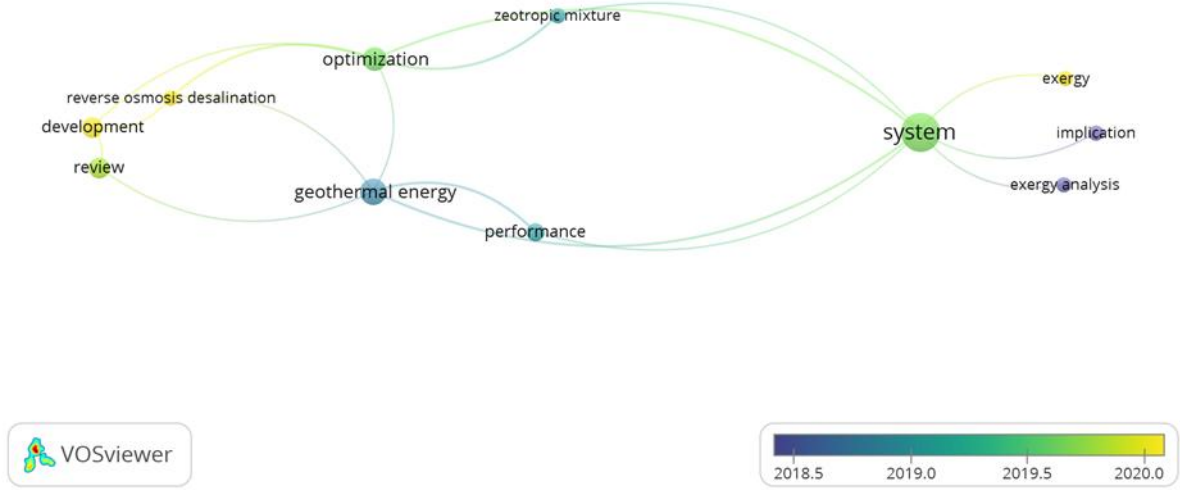


Figure 5. Overlay Visualization Display

Based on Figure 5, it can be explained that the 2018-2020 period has various colors. The blue-purple color indicates that the article was published in 2018 on the topic of exergy analysis and implications. Furthermore, in 2019 the color turquoise will be displayed on the topics of geothermal energy, performance and zeotropic mixture. Furthermore, in mid-2019 there was a green color which showed the topics of system, optimization and review. Finally, in 2020 it showed yellow on the topics of development, reverse osmosis desalination and exergy. Next is Density Visualization which is the final visualization of the VOSViewer system. It is illustrated that the brighter the color that appears on a variable, the more often that variable is examined as in Figure 3 below from the words that appear such as exergy, implication, exergy analysis, development, reverse osmosis desalination, review, geothermal energy, performance, optimization and zetropic mixture. Look at Figure 6.

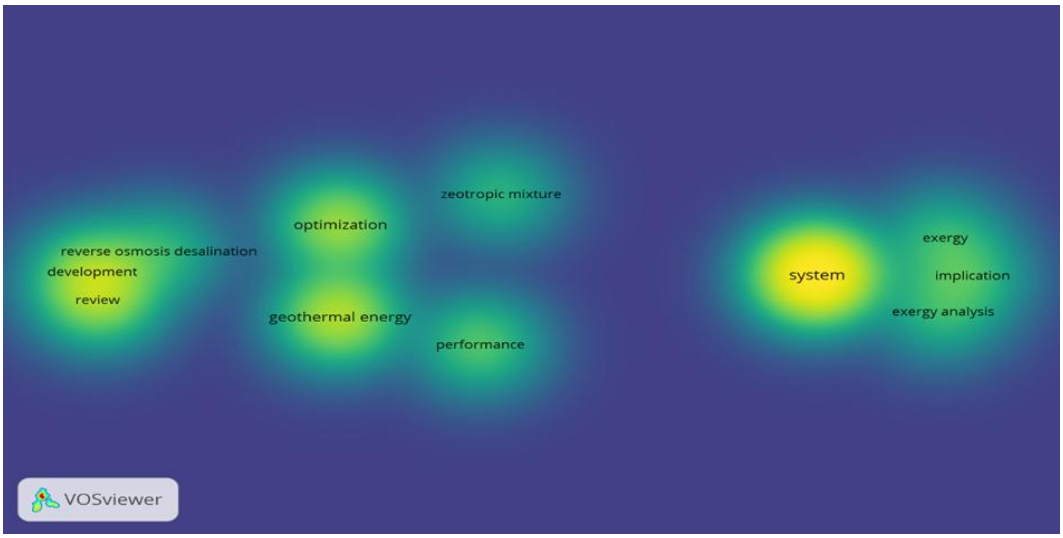


Figure 6. Density Visualization Display

In density visualization, bright colors indicate that the topic is the topic most researched by other researchers, while dark colors indicate that the topic is rarely researched by other researchers (Suhartini et al., 2023). In Figure 6, it can be seen that the brightest colors are system, development, and review, this shows that many people have researched these three topics. Furthermore, the colors are bright to dim on the topics of geothermal energy, reverse osmosis desalination, and impilcation, which shows that someone has already researched this topic. Next, the colors get darker on the topic of optimization and zeotropic mixture.

Conclusions

Based on the results of research that has been carried out, it can be concluded that the results of the Systematic Literature Review or SLR for 40 articles published in Scopus indexed journals from 2018-2023 regarding "Geothermal" have decreased from 2022. Many of these articles discuss the use of geothermal energy in the field of electricity. This is done to utilize electrical energy that can be used sustainably.

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