A bibliometric analysis of the application of solar energy to the organic Rankine cycle

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Abstract
Solar Thermal is one of many heat sources that support the organic Rankine cycle (ORC) system. The advantage of using solar thermal as a heat source when combined with the ORC system is that it can provide affordable energy supplies in remote areas and it is suitable in disaster territories. Growth in solar-ORC research is not only on a lab/workshop scale but also on an industrial scale. Most articles refer to methods and tools in the design process, combining heat and improvement of the cycle, working fluids selection, and case studies based on primary or secondary data. The paper reports the newest trends on the research of solar application on ORC using bibliometric analysis. The study of bibliometrics using VOSviewer was recognized as a captivating method in the literature that allows examining the scientific progress of a particular topic. Moreover, a qualitative approach can be performed by analyzing the keywords contained in different documents to identify a circumstance that features the research trend and to understand future viewpoints.

1. Introduction

Humankind had lived over many decades depending on fossil fuels, such as coal, oil, and natural gas, to fulfill their needs. These fossil fuels are more convenient and cheaper to use than alternative energy sources. But, using fossil fuel by combustion leads to the emission of CO\textsubscript{2}, NO\textsubscript{x}, SO\textsubscript{2} that bring harm to the environment, such as global warming and acid rains and these fossil fuels cannot be replenished (Aboelwafa et al., 2018; IEA, 2016).

Renewable Energy sources are the key to reducing fossil fuel usage to generate electricity. Renewable energy like solar thermal, geothermal, biomass, and waste heat sources from industries are capable of decreasing the rate of the consumption of fossil fuels and reducing the effect that brings harm to the environment. In addition, these residual moderate or low-medium temperature heat sources cannot be efficiently converted into electricity through the conventional Steam Rankine Cycle (SRC). So, it is necessary to study another type of process, such as the ORC that has been considered as the most feasible cycle to generating electricity while recovering various heat sources as proposed by many authors (Permana and Mahardika, 2019; Israel et al., 2021; Lecompte et al., 2015; Aleksandar et al., 2020; Ismail Permana and Sutikno, 2019; Macchi and Astolfi, 2016).

ORC utilizes steam heat such as the conventional Rankine cycle but uses a low-set temperature of organic fluids rather than water. The leverages of ORC system are lower temperature and pressure of turbine inlet, more significant condensing pressure, and no deaerator, robust and environmentally safe (Quoilin et al., 2013). The main disadvantages of the ORC system are separate precaution to prevent the leakage, contamination of organic fluid and having a lower efficiency compared to SRC (Wang et al., 2019). Despite, ORC is capable of producing electricity at a low-set temperature. However, it needs another heat resource from another system. There is a lot of heat resource in Hungary that can be combined with ORC such as geothermal excess steam (Permana et al., 2021), wastewater heat (Somogyi et al., 2018), solid biomass (Malico et al., 2019) and from solar thermal.

Solar is the primary source of renewable energy that sustains our earth. Around the 1.75 × 10\textsuperscript{18} TW, and that is the entire solar energy received by the earth continuously (Goswami, 2015) and it has been weakened twice by both atmosphere (16% absorption, 6% reflection) and clouds (3% absorption, 20% reflection) as shown in Figure 1. Solar Thermal is one of many heat sources that can support ORC system. The advantage of using solar thermal as a heat source when combine with ORC system, it can provide affordable energy supplies in remote areas and is suitable in disaster territory. The amount of annual global
horizontal irradiation for Hungary is between 1100 and 1350 kWh/m², which makes a relatively good site for installing solar thermal collectors (GHI, 2020).

Solar collectors and thermal storage are the two core subsystem components in solar thermal applications. A solar collector is the component that converts solar irradiation energy to thermal energy through working fluid in solar thermal applications. A good optical performance is required to absorb heat as much as possible. The heat carried by the working fluid can charge thermal energy storage or provide domestic hot water (Tian and Zhao, 2013; Hossain et al., 2011). Recent research recommends that small-scale Solar Thermal systems combined with ORC power may compete with Photovoltaic (PV) and diesel generators on levelized cost of electricity basis for off-grid duty (Orosz et al., 2008).

Nowadays, several types of research related to ORC using solar energy. Some authors (Kumar et al., 2016; Bellos et al., 2018) researched ORC based using solar parabolic through concentrator (PTC) type. Kumar et al. (2016) analyzed a solar thermal power plant using the PTC model, reflecting the solar radiation on the receiver. The result is a system having the highest output at 10 kW at the temperature of 259 °C. While it has been conducted a hybrid ORC driven with solar collector PTC type and waste heat of low-grade temperature (>150 °C), the prototype is resulting from the power around 479 kW–845 kW along with the system efficiency from 11.6% to 19.7%, respectively (Bellos and Tzivanidis, 2018). Another scenario was presented by Villarini et al. (2014) which has reviewed the solar ORC, which focuses on the different typology and technology perspectives.

Growth in solar-ORC research is on a laboratory/workshop scale and an industrial scale. Figure 2 shows the increased number of solar-ORC units that have been installed throughout the country in the last two decades, especially in the period from 2005 to late 2020. There was a significant increase with a total of 29 units installed (orc-world-map.org, 2021). Meanwhile, in Table 1, it can be seen the detail of the countries and the companies that have carried out ORC projects with sources of solar energy varying total capacity of the heat source. Based on data from the literature available, ORC companies that use solar as a heat source are mearily compared to other heat sources such as geothermal, biomass, WHR, sewage gas, and wastewater treatment (Anastasovski et al., 2020).

Turboden company has working on five solar-ORC construction projects for power plants in several countries, including Italy (1.7 MWe), Morocco (2MWe) and Denmark (3.8 MWe) (Turboden, 2021). In 2014 Exergy Company has constructed a power plant based on solar-ORC with the capacity of 1 MWe in Benguerir, Morocco (Exergy, 2021). Meanwhile, in 2019, Ormat Technologie Inc has announced the commercial operation of the geothermal and solar hybrid project of 7 MWe in Tungsten, Nevada (Ormat, 2021). Additionally mentioned, Luneng Group has been built the enormous tower Concentrated Solar Power (CSP) in China, precisely in the Delingha and Gonghe Provinces with a capacity of 50 MWe, respectively (SolarPaces, accessed 2021-03-04). Furthermore, GS energy has built the world’s biggest solar furnace located at Font-Romeu-Odeillo, France with a capacity of about 3200 kWe (GS energy, 2017). Lastly, Rank Company is one of the significant companies constructed in several countries (Spain, France, Italy and...
The growth of interest in solar-ORC technology research has increased over time in the past 10 years, and this can be seen from the number of published articles using keywords of Solar AND Organic Rankine Cycle. The number of published articles using keywords of “Solar AND Organic Rankine Cycle” increased over time in the past 10 years, and this can be seen from the number of documents in Scopus, Science Direct and Web of Science databases, using “Solar AND Organic Rankine Cycle” keywords. A comparison concerning the publications of these topics in different databases is shown in Figure 3. It shows an exponential increase in the number of articles published from 2010 until 2021 with a note that in 2021, the collection of published articles data is taken in September, which means that the articles on solar-ORC will increase ahead. Most articles refer to methods and tools in the design process, combining heat and improvement of the cycle, working fluids selection and case studies based on primary or secondary data. On the other hand, there are hundreds of research and literature review about solar-ORC power but to attain appropriate guidelines for the prospective improvement and study related to solar-ORC. It implies the necessity to inspect the solar-ORC’s studies over literature. One of the impressive methodologies to recognize the research roadmap that features the present research and development.

This paper reports the cutting-edge on the engineering analysis of solar application on the organic Rankine cycle using bibliometric analysis. It accommodates some guidance of the future analysis. The study of bibliometric using VOSviewer is recognized as a captivating method in the literature that allows examining the scientific progress of a specific topic. Moreover, a qualitative approach can be performed by analyzing the keywords contained in different documents to identify a circumstance that features the research trend and to understand future viewpoints. Imran et al. (2018) published a study on the bibliometric analysis in ORC technology. The most producing journal is Energy, the most active researcher is Ibrahim Dincer, and the most productive institute is Tianjin University from China, respectively. Meanwhile, Dong et al. (2012) use the bibliometric analysis to conduct research trends of solar power from 1991 to 2010. Therefore, this paper will serve a convenient way that researchers can use to understand the main networks and organizations working on the topic of solar-ORC.

2. Methodology

This chapter describes the methodology used to develop a literature study and bibliometric analysis. In this study, the Scopus database was used as a reference due to the greater number of documents available than other databases such as the Web of Science (Cabeza et al., 2020), and the databases such as ResearchGate and Google Scholar were eliminated in the source data collection, due to the low reliability of the bibliometric results.

2.1. Selection of the core categories

Table 2 includes the core of specific categories in the solar-ORC to find the number of documents or literature in Scopus by linking these categories with keywords that are often related. In this section, the bibliometric analysis considers the application of solar-ORC with five categories of the terms, including applications, working fluids, expander technology, cycle, design, dynamic and control. For example, the terms of applications in solar-ORC are associated with a commercial, demonstrative or small Table 2. Core category of solar-ORC that used for number of documents obtained.

| Category         | Query                                                                 | Number of documents |
|------------------|----------------------------------------------------------------------|---------------------|
| Applications     | TITLE-ABS-KEY ("solar ORC" AND "application" OR "utilization") AND ("commercial" OR "demonstration" OR "small scale") | 78                  |
| Working Fluids   | TITLE-ABS-KEY ("solar ORC" AND ("working fluid") AND ("selection" OR "optimization" OR "performance" OR "properties" OR "zeotropic")) | 298                 |
| Expander Technology | TITLE-ABS-KEY ("solar ORC" AND ("expander") AND ("piston" OR "screw" OR "turbine" OR "vane")) | 57                  |
| Cycle            | TITLE-ABS-KEY ("solar ORC" AND ("cycle configuration") AND ("recuperation" OR "regeneration" OR "trilateral" OR "flash" OR "comparison")) | 33                  |
| Design           | TITLE-ABS-KEY ("solar ORC" AND ("design" OR "architecture" OR "configuration")) | 391                 |
| Dynamics and control | TITLE-ABS-KEY ("solar ORC" AND ("control" OR "dynamic")) | 218                 |

Figure 3. The number of published articles using keywords of “Solar AND Organic Rankine Cycle” in different databases.
scale with the number result of 78 documents. Other examples are the term of cycle configuration often associated with keywords of recuperation, regeneration, trilateral, flash, or comparison with the number result of documents at 33.

2.2. Step of bibliometric analysis

To identify the solar-ORC circumstance and evaluate the research gap for each category related to the application of solar-ORC, the author keywords, bibliographical and citations were studied using the software VOSviewer. This tool is an open software that can generate, visualize and analyze bibliometrics based on a network among many documents from scientific publications (Boeri et al., 2020). In the process, the software uses several functions, including 1) importation of publication information in terms of bibliographic coupling, 2) creating a co-occurrence map by text data, 3) retrieving data for citation analysis by co-citation reporting and, 4) clustering and visualizing keywords by co-occurrence in-network and overlay form (Islam et al., 2018). This is one of the most automated and systematic approaches by which a large body of literature can conveniently be analyzed. The information of the publications can be selected to generate the layout of authors, institutions, countries and keywords. Table 3 shows the step of bibliometric analysis in this study.

3. Classification of solar-ORC

Solar-ORC is considered the most feasible and competitive power generation similar to the Rankine cycle but uses organic working fluid from the solar heat sources (Tsianidis et al., 2016). The primary system of solar-ORC has been touched on from the previous paragraph. They are as follows: 1) a solar thermal collector, 2) a thermal energy storage, 3) an ORC's components as given in Figure 4. The essential part of solar-ORC is the evaporator, which stands for evaporation of the organic fluids or refrigerants, the condenser is a component to condense a working fluid from vapour phase into fluid phase, the pump which is to pressurize a fluid and converts to electricity. The turbine is the component that expands the working fluid and converts to electricity. The solar-ORC-based may bear a low efficiency and energy output when the heating temperature of the heat source is low. Some authors have been solved these problems with their methods, for example, the replacement of components as carried out by Wang et al. (2019), Gao et al. (2015), Yamada et al. (2011), which replaces the electrical driven pump with thermal driven pump (TDP). The solar-ORC using TDP is consists of two heat exchangers, a turbine, a generator and other auxiliary components. The result shows an improvement in both power output and efficiency when the heating temperature of the heat source is high. Some authors have been solved these problems with their methods, for example, the replacement of components as carried out by Wang et al. (2019), Gao et al. (2015), Yamada et al. (2011), which replaces the electrical driven pump with thermal driven pump (TDP). The solar-ORC using TDP is consists of two heat exchangers, a turbine, a generator and other auxiliary components. The result shows an improvement in both power output and efficiency when the heating temperature of the heat source is high.

Table 3. Step of bibliometric analysis.

| Steps                        | Programs/ databases | Description                                                                 |
|------------------------------|---------------------|-----------------------------------------------------------------------------|
| Data collection              | Scopus database     | Timespan: 2010–2020 with keywords (‘solar AND organic Rankine cycle’). 1249 documents related to the solar applications on organic Rankine cycle, consist of 764 journal articles which will be further analysed. |
| Identification, analysis and mapping | VOSviewer, MS Excel | 764 documents are identified for bibliometric coupling analysis automatically. Qualitative analysis of bibliometric information involving: Co-occurrence keywords, Co-authorship of affiliations and country, Co-citation of cited references. |
| Research topic interpretation | Qualitative approach | The authors reviewed the titles, abstracts, keywords and analysis of each research topic. |

A method to increase the thermal efficiency of ORC can be performed through working fluid selection, as it is an influential factor as it depends on the heat characteristic. Tchanche et al. (2009) conducted a thermodynamic analysis of the performance and characteristics of different working fluids in a low-temperature solar-ORC. In comparison, Rayegan and Tao (2011 simualered of 117 organic fluid selections based on the T-s diagram, fluid effects and molecular components. The result is about improving thermal efficiency and choosing the suitable working fluids. In solar-ORC applications, there are two ways to utilize solar thermal energy. These are using an evaporator to heat working fluids directly, namely direct vapor generation (DVG) and indirectly by using heat transfer fluid (HTF). Figure 4 shows a solar-ORC scheme using DVG technology, while Figure 5 is a solar-ORC scheme using HTF technology.

One of the advantages of using DVG technology is the absence of heat exchanger components to evaporate the working fluid as presented in Figure 4. Some projects using the DVG system have been demonstrated by Alguacil et al. (2014) with a plant of 2.67 MWe and which has been built by Abengoa Solar. Another solar-ORC plant using DVG technology has been operated and generated 5 MWe with around 410 °C temperature and 78 bar pressure, respectively (Ochoa, 2014). Finally, the biggest solar-ORC plant has been built by Solar One Company with a capacity of 10 MWe and a temperature of around 425 °C in Barstow, USA (Feldhoff, 2012). Another advantages of DVG technology are (1) the high evaporation temperature that increases high efficiencies, (2) low thermal inertia, (3) a fast ignition system as compared with HTF technology. However, the DVG technology has also disadvantages including the immense environmental sensitiveness where the intensity of sun-ray, and cloudy periods can vary the temperature of evaporation that can lead to the vapor flow rate that enters the turbine and resulting in low power output and efficiencies (Marion et al., 2014). A comprehensive comparison between HTF and DVG methods is given in Table 4.

![Figure 4. Solar ORC base on using DVG technology.](image)

![Figure 5. Solar ORC using HTF.](image)
As a conclusion, it can be stated that most of the solar-ORCs, both the research scale and the industrial-scale are, generally use HTF technology (Delgado-Torres and Garcia-Rodrigues, 2007; Kosmadakis et al., 2009; Wang et al., 2014; Manolakos et al., 2009; Li et al., 2016). At the same time, the DVG is getting a well-known, promising method in consequence of some prior advantages concerning overpowering its disadvantages (Quoilin et al., 2011).

3.2. Classification based on temperature of solar collector

The solar collector is the component that converts solar irradiation energy to thermal energy through working fluid in solar thermal applications. Solar collectors can be classified based on the transport medium (heat transfer fluid or working fluid) heated to low, medium and high-temperature ranges. The low temperature of solar collector can heat the working fluid between 30–200 °C, the medium temperature of solar collector can heat the working fluid between 200–400 °C, while the high temperature of solar collectors usage is above 450 °C.

Figure 6 is an image made based on the solar collector classification table of solar collector by Tchanche et al. (2011). Figure 6 depicts the several types of solar collector technologies that are regularly used. The types of solar collectors that do not concentrate solar irradiance at one focal point include evacuated tube collector (ETC), compound parabolic collector (CPC), flat plate collector (FPC), and advance FPC, which can heat the working fluid at a low temperature of less than 200 °C. Nonetheless, solar collectors that concentrate solar irradiation at one focal point, such as parabolic through collector (PTC and LFR), can heat the working fluid in the medium temperature range from 100-400 °C. Meanwhile, at very high temperatures around >450 °C, the type of solar collector used are a dish concentrator and a heliostat + central receiver. The following sub-section will further explain the three categories of solar collectors based on temperature range.

3.2.1. Low temperature of solar collector

It can be seen in Figure 7 that the solar collector used in low temperature (<200 °C) solar-ORC applications includes the ETC, CPC, and the most common used both in a small and industry scale is FPC and advance FPC.

Figure 7a shows the ETC, consisting of single tubes connected to header pipes to the ambient air, and every single tube is evacuated. Besides different geometrical structures, it has to be considered that the collector must be mounted with a certain tilt angle to allow the fluid of the heat pipe to return to the heat absorber (Sarbu and Sebarchievici, 2017). The ETCs present the combined effects of a highly selective surface coating and vacuum insulation of the absorber element to generate more heat extraction efficiency. One benefit of such an arrangement is that collectors last to effort even if one or numerous pipes are broken. Spoiled pipes can be simply substituted (Dincer, 2018). Dami et al. (2021) have conducted a numerical analysis of the direct solar vapour generation of acetone on ETC that can activate a domestic scale ORC, and the result is the system, and can generate 218 kWh/year of electrical energy with the solar-ORC has a thermal efficiency of 3.25%.

A CPC (Figure 7b) is another through-type that concentrates solar irradiation onto the tube receiver. The reflector configuration is built by two symmetric parabolic arrangements with different central lengths. This geometrical configuration enables the compilation of any solar radiation entering the collector passage within an allowed angle (10°–80°) onto the tube receiver of multiple internal reflections. This feature allows CPs to work without continuously tracking and some portions of diffuse sunlight (Macchi and Astolfi, 2016). Meanwhile, Gang et al. (2011) were analyzed the feasibility of a low-temperature CPC combined with an ORC technology system. The result reveal that the system's electricity efficiency is about 7.8% on the condition of irradiation 750 W/m². Furthermore, the solar-ORC application depends not only on the type of solar collector. However, it is influenced by the working fluid that acts on

| Table 4. Comparison between HTF and DVG method (Behar et al., 2014; Feldhoff, 2012). |
|-----------------------------------------------|-----------------------------------------------|
| HTF Method | DVG Method |
| Technology Level | Marketable | Definite |
| Process Stability | Reliable | Volatile |
| Configuration | Mode | Robust |
| Control Effort | Easy | Hard |
| Scaling-up | Easier | Complicated |
| Performance | Finite | Pledge |
| Operating Temperatures | Finite | Pledge |
| Efficiency | Moderate, limited | Immense, promising |
| Thermal Storage | Low-cost | Costly |
| Fluid Toxicity | Positive | Negative |
| Environmental Risk | High | Low |
the ORC cycle, for example, such as research conducted by Delgado-Torres and Garcia-Rodrigues (2007) which they did a theoretical analysis of solar-ORC involving twelve working fluids and four different models of solar collector (FPC, CPC, ETC) with the parameters of temperature range at 70-150 °C.

The type of FPC is one of the solar collectors that most widely applied besides CPC and ETC. Most FPC consists of two horizontal pipes at the top and bottom with good thermal insulation covered by a black absorbing plate as shown in Figure 7c. An FPC supply heat is approximately below the temperature of 100 °C and has relatively low efficiencies but with the advantage of availability, low-cost investment, and low complexity. Moreover, there are so many applications of FPC on ORC, including theoretical, experimental and optimization. Based on Scopus databases with keywords “Organic Rankine Cycle AND Flate Plate Collector”, it was found of 86 documents from 2012 until 2021. Therefore, a research conducted by Wang et al. (2013) with the brief title of “Thermodynamic analysis and optimization of a solar-driven regenerative organic Rankine cycle (ORC) based on flat-plate solar collectors” is the highest cited paper with 175 citations. They conducted a parameter analysis to examine the effect of some thermodynamic parameters regarding ORC with FPC as heat sources using different working fluids. Marion et al. (2014) examined the effect of the wind speed on the FPC-ORC, and the result is the wind speed increase from 0–10 m/s decreases the collector’s thermal efficiency by 14%. Therefore, in an economic analysis related to FPC-ORC conducted by Hajabdollahi et al. (2015), isobutene is the best working fluid for a solar-ORC generation.

In summary, the use of CPC, FPC and ETC applications on ORC targets the energy generation of low temperatures in the range below 200 °C for simple systems with the resulting thermal efficiency range between 10%, 15%, and 20%, respectively. So that, CPC, FPC and ETC are suitable for small-scale research because it is very affordable and easy to install. Various optimizations can be carried out from geometry and phase change materials.

3.2.2. Medium temperature of solar collector

It can be seen in Figure 6 that the medium temperature of the solar collector is in the range of 200–400 °C, and the type includes PTC and linear Fresnel collector (LFC). Both PTC and LFC are solar collector that uses the mirror surface and receiver area to concentrate and collect solar radiation to convert it into heat, they are generally assigned to concentrating solar power (CSP). In these technologies, the solar concentrators focus solar radiation into a line.

PTC is a set of concave parabolic-shaped mirrors or reflecting material that concentrates solar rays onto a line toward a receiver tube that absorbs the concentrated solar energy to heat the fluid inside it, as shown in Figure 8, where an integrated solar combine cycle (ISCC) power plant located in Hassi R’mel Algeria, South Africa where the power plant uses PTC technology combined with a gas source. The operating temperature of PTC is in the range of 150–400 °C, and it depends on the working fluid inside the tube.

Achour et al. (2018) conducted a performance assessment of the ISCC. The analysis results showed that during sunny periods the solar to electricity efficiency could reach up to 14.4%, and the overall thermal efficiency is about 60%, which are feasible values. It has been stated in the previous paragraph that the working fluid also affects the performance of a PTC. Kizilkan et al. (2016) has conducted a comparative thermodynamic analysis of solar-ORC using eight working fluids (R170, R1270, R600, R600a, R717, R744, R218, and R161), and the result is R744 has the highest performance of energy and exergy analysis of 8% and 7.1%, respectively.

Linear Fresnel Reflector (LFR) is another solar collector that uses a mirror surface to concentrate the sunlight and convert it into heat. Unlike PTCs which consist of a continuous parabola-shaped reflector, LFRs are consist of many long strips of mirror that can be moved independently (single-axis tracking) to achieve a reflection of solar radiation onto absorber where concentration ratio of it is around 10–50 %, a typical image of LFR is presented in Figure 9.
In general, LFR used the water for the usual choice of working fluid for production of saturation or superheated steam (150–450 °C). The steam can be used directly for moving turbine of the conventional Rankine cycle and producing electricity or for industrial processes. On the other hands, some research uses molten salts as done by Grena and Taquiní (2011), who analyzed molten nitrates usage as heat transfer fluid in LFR and described the advantages and disadvantages of the system. While Bellos et al. (2018) researched on the comparison of three working fluids (thermal oil, molten salt, and liquid sodium) to LFR from optical and thermal analysis, liquid sodium was the best candidate. Both PTC and LFR are particularly encouraging, and solar concentrator technologies could revolutionize the use of solar collector power generation in forthcoming decades. In summary, Table 5 gives a comparison between PTC and LFR.

3.2.3. High temperature of solar application

According to Figure 6, the high temperature of solar collector is in the temperature range of 450–700 °C and the type includes parabolic dish concentrators (PDC) and heliostat field + central receiver. PDC consists of a set parabolic dish-shaped mirrors with two-axis solar tracking systems that concentrate the solar rays in the directions of cavity receiver based on the focal point of dish collector, as shown in Figure 10. The shape of cavity receiver is usually conical, cylindrical, or spherical, and the concentration ratio is more than 100 (Kumar and Reddy, 2008). Based on the Scopus database, the use of PDC in ORC applications is not widely found, both theoretically and experimentally, because the target of ORC is low-medium-temperature energy generation below 400 °C. In comparison, the PDC classification is a solar collector with high temperature over 450 °C. For example, using the keyword "ORC AND Parabolic Dish Collector" only eight documents were found in 2015, 2019, and 2021 with a distribution 1, 2, and 5 documents, respectively.

However, research on the application of PDC to ORC has been carried out by Loni et al. (2016), where the authors conducted a performance study of ORC using PDC. In his research, the authors varied the geometry of the PDC in the form of five aspect ratios and five cavity depths. The results show that the optimum characteristic of the cavity results in the highest overall thermal efficiency. Currently, Aghaziarati and Aghdam (2021) conducted a thermodynamic analysis of CCHP based on ORC and refrigeration cycle, they also compared three different types of solar collector (PDC, LFR and PTC). Meanwhile, Eterafi et al. (2021) conducted a thermodynamic design and performance assessment of a solar-driven ORC system using domestic hot water production as a heat source. The author uses a parabolic dish collector.

Heliostat field system is the double-axis tracking solar collector that consist of several mirror module panels or some of heliostat consist with a single large mirror as shown in Figure 11. The system of heliostat has a concentration ratio from 300 to 1500 and the temperature range between 200–2000 °C (Rabban et al., 2017). Consequently, there is a massive capacity for accomplishing high exergy efficiency, especially in combined system. According to an investigation by Han et al. (2015), it was found that the 500 suns will increase a system efficiency from 28.4% to 44% by using the hybrid system compared to the conventional CPV system.

Some several types of research related to heliostat application on ORC have been conducted by Balta et al. (2016), they performed an exergy analysis of combining system involving ORC, Brayton cycle, heliostat and electrolyzer for hydrogen and power generation. Khaliq (2017) has got a research of modified ejector for cooling and electricity of ORC. He used a heliostat to feed the system and increase the energy efficiency by about 30%. In other work, Loni et al. (2016) performed a study about SDC-ORC with rectangular cavity tubular receiver. They found an increase in overall thermal by decreasing the inner tube diameter and inlet temperature.

In summary, both of heliostat field and PDC applications on ORC are covered mainly by vast range cycles with high temperature working fluids. Many journals focused on assessing hybrid systems, e.g., heliostat system coupled with CPV system, Brayton cycles and hydrogen production. Lastly, future analysis of the heliostat field system is more focused on optimization and experimental works.

4. Results and discussions

4.1. Keywords analysis

This chapter reports the result of a bibliometric analysis conducted to study the cutting edge of the solar application on ORC using VOSviewer. After being analyse with the keyword search of “Solar AND organic Rankine cycle”, four clusters (red, green, blue and yellow) showed the relationship between one topic and another. Therefore, the size of circles and letters is indicated by the occurrences’ frequency. The more often a keyword appears, the bigger the letters and circles (Figure 12).

| Table 5. Linear CSP technologies and its application (Gharbi et al., 2011). |
|-------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                         | Capacity unit   | Concentration   | Peak solar efficiency | Annual solar efficiency | Capacity solar factor | Temperature output | Land use per MWh/y |
|                         | (MW)            | (%)             | (%)                  | (%)                  | (%)                  | (°C)             | (m²)             |
| Parabolic Through       | 10–200          | 70–80           | 21                   | 17–18                | 25–70                | 300–550           | 6–8              |
| Linear Fresnel          | 10–200          | 25–100          | 20                   | 9–11                 | 25–70                | 250–500           | 4–6              |

Figure 9. LFR: (a) construction (Rosell et al., 2005), (b) schematic (Romero and González-Aguilar, 2013).
In this study, the result is extracted from titles and keywords found 1249 documents consisting of 607 documents in the last five years and the rest of documents published before 2017. Data consisted of various types of publications: article (764), conference paper (408), review (28), book chapter (26), and conference review (18).

Figure 12 shows clusters in each of the topic areas studied. It can be seen that the keywords of “organic Rankine cycle” (yellow circle), “solar energy” (purple circle), “orc” (green circle), and “cogeneration” (red circle) are the keywords that have the most occurrence with the minimum ten times in Scopus database. On the other side, Table 6 shows the author keywords with the highest number of occurrences with the keyword “organic Rankine cycle” and “solar energy” with the number of occurrences at 193 and 103, respectively.

Figure 13 shows the keywords visualization of the trend from year to year related to this research. It can be seen that the keywords of “solar energy” have been used since 2015. Furthermore, the keywords of “parabolic through collector”, “cogeneration” and “optimization” were only used in the last three years, so that research conducts to these keywords, or this method is still lacking and is one of the research gaps that will be sought by further research in organic Rankine cycle scope. PTC is the most common medium to convert solar radiation into heat, the details are given in the previous sub-chapter. Cogeneration is the technology combines one or two more sources of heat or cycles to extract more energy at higher efficiency, namely combining cooling, heat, and power (CCHP) systems (Vieira et al., 2020). According to Scopus databases, as many as 121 obtained using the keywords of “solar AND ORC AND cogeneration” in the last ten years. In the application study, the paper with entitled of “Energy-exergy analysis and economic investigation of a cogeneration and trigeneration ORC-VCC hybrid system utilizing biomass fuel and solar power” by Karella and Braimakis (2016) is one of the highest citations (168).

4.2. Analysis of authorship, institutions and countries

Collaboration analysis between authors and co-authors on researches with keywords of “solar AND organic Rankine cycle” in the last five years is shown in Figure 14. In these networks, the size of circles and colors represent the most active collaboration between authors with a minimum of five publications in the Scopus database. According to observable keywords, Li J and Pei G (blue circle) has strongly connected with research collaboration around 2015–2017, meanwhile, Wang Y, Zhang Y, and Su Y (green circle) are the most active authorship in the last three years.

Table 7 presents the authors with the most contributions of work in the last decade with the keyword “solar AND organic Rankine cycle” in the Scopus database. Meanwhile, Dincer I has got the highest number of publications with 29 documents followed by Bellos E and Li J with 24 and 22 documents, respectively. Furthermore, Dincer I as a co-author (2011) published the article with the highest citations (165) on the solar-ORC applications with the title “Exergy modelling of a new solar driven trigeneration system”, which investigated the performance of the trigeneration system using PTSC-ORC from the point of view of exergetic. Followed by Bellos and Tzivanidis (2017) published a hot article with 90 citations in the scope of solar-ORC with the title of “Parametric analysis and optimization of a solar-driven trigeneration system based on ORC and absorption heat pump” wherein his investigation and optimization towards solar-driven trigeneration using PTC-ORC.

In the last ten years, in the course of the university rankings with the most documents, Greece universities were dominated including the National Technical University of Athens with 40 documents, followed by the University of Tehran, Ontario Technology University and University of Science and Technology of China with 38, 31 and 26 documents, respectively. Figure 15 represents the timeline of publications of these...
universities every year. Based on the graph, it can be seen that both Ontario Tech University and Tianjin University consistently publish a journal related activities to solar ORC every year. At the same time, the National Technical University of Athens and the University of Tehran are the most active institutions in the solar organic Rankine cycle research publications in the last five years with 26 and 32 documents, respectively.

In the previous paragraph, we discussed bibliometric analysis in the scope of keywords that often appear and the relationship between keywords, and it also discussed the relationship between authors and institutions that were the most active in the last decade with the use of keywords “solar AND organic Rankine cycle” based on Scopus database. Specifically, for the country of study, the bibliometric analysis is shown in Figure 16. In that figure, it can be seen that around 70 countries that study of “solar AND organic Rankine cycle” and only 30 countries that produce minimum of 5 documents in the last ten years dominated by China, Italy and United States with 180, 172 and 131 documents, respectively. Taking a note, Iran and Turkey have produced a significant number of publications in the last three years with 109 and 58 documents, respectively.

As shown by Table 8, Italy has the most citations, followed by China and Greece with 1910, 1429 and 1420 citations in the last decades, respectively. Apparently, in the category of one article that has the most citations written by Tchanche et al. (2011) from Greece with the title of “Low-grade heat conversion into power using organic Rankine cycles – A review of various applications” with 783 citations, which also discusses the ORC application with a solar collector. Meanwhile, Boyaghchi and Heidarnejad (2015) with the title of “Thermoeconomic assessment and multi-objective optimization of a solar micro CCHP based on Organic Rankine Cycle for domestic application” is the highest citation article in the last five years with 157 citations. It is an update of research in solar organic Rankine cycle for domestic application.

| Cluster Colour | Observable Keywords                                                                 | Number of occurrences |
|----------------|-------------------------------------------------------------------------------------|-----------------------|
| Red            | Solar orc, solar organic Rankine cycle, exergy analysis, solar desalination, solar thermal energy, parabolic through solar collect, cogeneration, reverse osmosis, exergoeconomic, desalination | 121                   |
| Blue           | Power generation, thermal energy storage, solar collector, exergy efficiency, absorption chiller, trigeneration, parabolic through solar collect, organic Rankine cycle (orc) | 108                   |
| Green          | Efficiency, parabolic through collector, orc, optimization, energy, biomass, solar, exergy, concentrating solar power | 228                   |
| Yellow         | Organic Rankine cycle, renewable energy, solar power, concentrated solar power, solar collectors | 244                   |
| Purple         | Solar energy                                                                         | 103                   |

Figure 12. Networks visualization of author keywords on “solar AND organic Rankine cycle”.

Table 6. Author keywords with the highest number of occurrences on “solar AND organic Rankine cycle”.
Figure 13. Networks visualization of author keyword on “solar AND organic Rankine cycle” using overlay visualization.

Table 7. Top 10 authors on documents of “solar and organic Rankine cycle”.

| Author name | No publications | Affiliation | Country          |
|-------------|-----------------|-------------|------------------|
| Dincer, I   | 29              | Ontario Tech University | Canada          |
| Bellos, E   | 25              | National Technical University of Athens | Greece         |
| Li, J       | 22              | University of Hull | England         |
| Papadakis, G| 20              | Geoponiko Panepistimion Athinon | Greece         |
| Tzivanidis, C| 19             | National Technical University of Athens | Greece         |
| Pei, G      | 18              | University of Science and Technology of China | China          |
| Manolakos D | 18              | Geoponiko Panepistimion Athinon | Greece         |
| Petrollese, M| 17              | Università degli Studi di Cagliari | Italy          |
| Markides, C.N| 16             | Imperial College London | UK             |
| Lemort, V   | 15              | Université de Liege | Belgium         |

Figure 14. Visualization of overlay authors and co-authorship relations.

Figure 15. Timeline of publications of the world’s universities on “Solar AND Organic Rankine Cycle”.

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4.3. Analysis based on main journals and subjects

Figure 17 shows the top 10 most published journals in solar and organic Rankine cycle in the last decade, based on the Scopus database. It can be seen that Energy Conversion and Management is the most published journal related to solar and organic Rankine cycle with 109 documents followed by Applied Thermal Engineering (68 papers), Energy Procedia (52 papers), Applied Energy (43 papers), Solar Energy (42 papers), Energies (36 papers), International Journal of Hydrogen Energy (31 papers) and Journal of Solar Energy Transactions of The ASME with 23 papers. Most of the papers published in journals are incorporated into the Elsevier Publisher. Only two journals are not included, namely Energies that belongs to MDPI and Solar Energy Transactions of The ASME belongs to the ASME group.

Classifications were identified in Figure 18. Most of the documents are the subjects of Energy and Engineering with 537 and 390 documents, respectively. Surprisingly, business, management and accounting are part of the solar and organic Rankine cycle research with 14 documents. It should be noted that some published documents may fall into interdisciplinary, which is shown by most of the papers is related to more than one subject area. Table 9 is containing the hot articles of each subject area of keywords “solar AND organic Rankine cycle” based on the Scopus index in the last ten years starting from 2011 until 2020.
Table 9. Top citation titles of the subject area.

| Subject Area                      | Hot Articles | Title                                                                 | Authors                          | Source                        |
|-----------------------------------|-------------|-----------------------------------------------------------------------|----------------------------------|-------------------------------|
| Energy                            | 785         | Low-grade heat conversion into power using organic Rankine cycles - A review of various applications | Tchance et al. (2011)             | Renewable and Sustainable Energy Reviews 15 (8), pp. 3963-3979 |
| Engineering                       | 236         | Expanders for micro-CHP systems with organic Rankine cycle             | Qiu et al. (2011)                | Applied Thermal Engineering 31 (16), pp. 3301-3307 |
| Environmental Science             | 198         | Systematic optimization of subcritical and transcritical organic Rankine cycles (ORCs) constrained by technical parameters in multiple applications | Maraver et al. (2014)           | Applied Energy 117, pp. 11-29 |
| Physics and Astronomy             | 43          | Experimental and thermoeconomic analysis of small-scale solar organic Rankine cycle (SORC) system | Baral et al. (2015)              | Entropy 17 (4), pp. 2039     |
| Materials Science                 | 285         | Performance and design optimization of a low-cost solar organic Rankine cycle for remote power generation | Qaslin et al. (2011)             | Solar Energy 85 (5), pp. 955-966 |
| Chemical Engineering              | 119         | Energy and thermoeconomic analyses of a combined solar organic cycle with multi effect distillation (MED) desalination process | Sharaf et al. (2011)             | Desalination 272 (1-3), pp. 135-147 |
| Mathematics                       | 56          | Systematic methods for working fluid selection and the design, integration and control of organic Rankine cycles - A review | Linke et al. (2015)              | Energies 8 (6), pp. 4755-4801 |
| Chemistry                         | 72          | Thermo-economic analysis of a combined solar organic Rankine cycle-reverse osmosis desalination process with different energy recovery configurations | Nafez et al. (2010)             | Desalination 261 (1-2), pp. 138-147 |
| Computer Science                  | 20          | Performance analysis of solar parabolic trough collectors driven combined supercritical CO2 and organic Rankine cycle | Singh and Mishra (2018)          | Engineering Science and Technology, an International Journal 21 (3), pp. 451-464 |
| Earth and Planetary Sciences      | 136         | Technical and economical analysis of a solar-geothermal hybrid plant based on an Organic Rankine Cycle | Astolfi et al. (2011)           | Geothermics 40 (1), pp. 58-68 |

4.4. Future research in solar organic Rankine cycle

The newest studies on solar applications in organic Rankine cycles focus on exergoeconomic analysis and multigeneration or polygeneration analysis. Figure 19 shows the overlay visualization of exergoeconomic and polygeneration appeared in late of 2019 according to VOSviewer analysis results. At the same time, based on a search on the Scopus using the keyword “solar AND ORC AND exergoeconomic”, obtained as many as 34 documents were collected ranging from 2015 to 2021. Boyagchi, F.A and Iran University of Science and Technology are the author and the institutions that publish in this field with four and six documents, respectively. Exergoeconomic is an analysis based on a combination of the concept of exergy and economics, which can help researchers or engineers to understand how much the cost flows in a system and optimize the system’s performance (Dincer, 2018). Furthermore, an article from Boyagchi and Heidarnajad (2015) with the title “Thermoeconomic assessment and multi-objective optimization of a solar micro CCHP based on Organic Rankine Cycle for domestic application has the most citations in the last five years.

However, for a search using the keywords of “solar AND ORC AND polygeneration” in the Scopus database, 17 documents were obtained from 2014 until 2021. The lack of articles published in the last five years makes this research fall into the category of further research and to find a novelty with a higher chance. Also there is no pattern in polygeneration system in ORC application. Calise, F and Università degli Studi di Napoli Federico II are the author and the institution that most active published in the last five years in this field with both are seven documents. Moreover, the article of Calise et al. (2016) got the highest number of citations (159) of entitled of “Exergetic and exergoeconomic analysis of a novel hybrid solar-geothermal polygeneration system producing energy and water” in the last five years.

Meanwhile, the newest application of solar organic Rankine cycle research focuses on using of phase change material as a suitable material for heat transfer, whether it is used in the solar collector layer or thermal energy storage application. It can be seen in Figure 20 that phase change material research material has been carried out since the end of 2019, where its use is closely related to thermal energy storage applications around 2016–2017, and as an excellent heat-converting material in evacuated tube collectors around 2018–2019. Moreover, according to the Scopus database using keywords of “solar AND ORC AND phase change material”, 35 articles were obtained from 2011 to 2021. Cioccolanti L and the University of Northumbria are the most significant author and institution that publish in this field with 6 and 5 articles, respectively. The article with the title of “A small-scale solar organic Rankine cycle combined heat and power system with integrated thermal energy storage” from Freeman et al. (2017) is the most cited article (108) in the last five years followed by Bhagat and Saha (2016) with 63 cited article with the title of “Numerical analysis of latent heat thermal energy storage using encapsulated phase change material for solar thermal power plant”.

5. Concluding remarks

From 2010 to 2020, 1249 documents were published in the solar organic Rankine cycle field based on Scopus indexed journals by 1217 authors from around 140 institutes, originating from 56 countries that China, the USA and Europe dominate. The National University of Athens is the institution that has the highest documents with 42 documents, and Dincer I is the most active author with 29 documents in the last ten years. Furthermore, Energy Conversion and Management is the most published journals with 109 documents, primarily included in subject area of Energy. According to the analysis of keywords using VOSviewer, 1005 keywords have been used with the minimum 10 occurrences. The “organic Rankine cycle” & “solar energy” are keywords that mostly appear with 193 and 103 occurrences, respectively. Furthermore, it can be stated that the use of VOSviewer in bibliometric analysis is beneficial for mapping further research in the field of solar applications on ORC. It was shown that exergoeconomic analysis and polygeneration are relatively new in ORC analysis. At the same time, the application of phase change materials, especially in thermal energy storage as a substitute for heat exchangers, which been a new thing applied to ORC applications in the last three years.
Figure 19. Overlay visualization of keywords "polygeneration".

Figure 20. Overlay visualization of keywords "phase change material".
Declarations

Author contribution statement

Diki Ismail Permana: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dani Rusirawan: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Istvan Farkas: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data will be made available on request.

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The authors declare no conflict of interest.

Additional information

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