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Global Trends and Opportunities in Hybrid Microgrid Systems Using Renewable Energies

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ABSTRACT

Access to energy is related to the essential aspects of modern survival, impacting production processes, access to knowledge and economic development. The global energy demand grows every year, and remote areas without connection to central grids need viable and sustainable alternatives for generating, distributing and storing energy at the local level. This paper presents an analysis through academic research, patent publications, reports and government information to map global trends and identify the opportunities for hybrid systems for power generation in microgrids from renewable sources and with several modes of generation. The data showed recent exponentially rising technologies with a tendency to continue for the next few years. China leads in isolation followed by USA and India. Countries like Brazil and Mexico, despite favourable conditions, do not present local technological development nor are they seen as a market of interest. Technological and research routes point to improving storage processes. Photovoltaic energy source was most used and to lesser extent wind, biomass, bioethanol, biogas, biodiesel and biohydrogen. Most of the inventions were focused on creating and improving machines, equipment, and systems to operate and control, utilizing the Homer software, for example.

Keywords: Microgrid, Renewable Energy, Energy Production, Global Trends, Patents
JEL Classifications: O3; Q2; Q4

1. INTRODUCTION

Access to energy is related to the essential aspects of modern survival, impacting production processes, access to knowledge and economic development. The supply of electricity in isolated communities - islands, remote villages, or rural areas of the mainland - has become increasingly important due to the growth in energy demand in recent years. According to the International Energy Agency (IEA), in 2019, the share of the world's population with access to energy increased 90% compared to 2010, with a greater advance, especially in rural areas, demonstrating an achievement for the social and economic development of the region's population (International Energy Agengy, 2019). Despite a slight drop in 2020 to the detriment of the substantial impacts caused by the Covid19 Pandemic, world demand for electricity grew by 6% in 2021 and continues in expand for the next decades according to recent reports (BP British Petroleum, 2021; International Energy Agengy, 2021c, 2022). Access to and reliability of electricity will be even more critical in many aspects of social and economic well-being (Barik et al., 2021; International Energy Agengy, 2021c).

The decentralized microgrid system is widely used when the community is far from the grid through a standardized approach to decision-making on extending electricity services to isolated areas (Rahman et al., 2013). For Islands it can be a viable option for application, where there is usually no network connection between the mainland or between islands due to the high value of subsea transmission cables, requiring the use of large amounts of fossil fuels such as the main source of supply (Kuang et al., 2016; Masrur et al., 2020). As the price of oil and its derivatives are 3-4 times more expensive than on the continent, the microgrid system together with renewable energies emerges as an alternative to deal with energy shortages and reduce dependence on fossil fuels and, consequently, also reduce the emission of greenhouse gases (Jensen, 1998).

Microgrid or backup systems can operate autonomously and integrate different energy generation resources, being able to be connected to a main electrical network, managing their distribution according to local needs. This system can usually be found in batteries, fuel cells or diesel generators, the latter two of which are not directly connected to the grid and cannot be autonomously controlled when electricity is no longer available. Anh demonstrated several systems using secondary sources and focusing on the microgrid method, in which he proposed the use of a backpropagation algorithm to generate the controller based on an adaptive neural model using photovoltaic solar energy with good performance (Anh, 2014).

The microgrid system has advantages mainly for providing the decentralization of energy generation that, based on the electricity demand, the topographical position and distribution of renewable resources in each location can be well used (Kuang et al., 2016; Williams et al., 2010). Due to advances in grid technology development, the use of renewable energy has been strongly encouraged in hybrid grid systems, particularly in remote islands and villages. Most of these places have ample resources for renewable energy, such as the wind being in a coastal region, the sun that is always available, especially in summer, and the local biomass (Kuang et al., 2016). For a hybrid system with renewable energy, it is necessary to consider the amount of energy produced over the total energy that the region demands to analyze its form of supply, whether from a reserve or primary source. With the use of software, it is possible to optimize the micro-network and set goals at a minimum cost to determine the form of supply (Neves et al., 2014).

Neves et al. (2014) demonstrated in their research that in the majority of the analyzed cases, the use of renewable energy in the islands represents a range of 20-80% of the total energy, also having two islands with the use of 100%, which produce more energy than the demand. Wind and photovoltaic energy are the most used in the hybrid microgrid system because they compete economically with traditional fossil fuel technologies. However, these energies are dependent on seasonality, and their combination must be analyzed concerning the cost of investment, operation and the variability of the climate in the place. The majority of remote villages, except villages in Africa, use diesel for power generation. Only one village has a direct connection to the grid. Renewable energy in these locations is applicable. In 30% of the cases, it has the potential to generate wind and photovoltaic energy and be the primary backup source for being of community access, unlike diesel. In comparison with the islands and remote villages, it was possible to conclude that the villages demonstrated to have greater potential for a renewable hybrid system (photovoltaic + batteries) because they have a much lower electricity demand than the islands and still have a great chance of being networks are connected because they are on the continent.

In the work by Masrur et al. (2020), a technical and economic feasibility study was carried out on installing a microgrid system based on renewable energy on the island of St Martin's. As a result, it was presented that using only diesel as an energy source in the region is not feasible because of the price and that a hybrid system using photovoltaic, wind energy, diesel and batteries is 1.412 times cheaper and has a 23% reduction in emissions of CO_2.

Vignesh and Udayakumar (2016) studied a hybrid microgrid system in autonomous, network connected, and islanding operation modes. Through the simulations, it was obtained as a result that the transition from the connected mode to the islanded mode is successfully achieved and that the hybrid systems (solar energy + fuel cell + batteries) provide stable operations.

Systems with microgrid technology also make it possible to take advantage of the heat that would be wasted, generating more energy in a distributed manner and increasing the efficiency of a cogeneration or heat and power combination (CHP) process. The by-product heat is captured and used for local domestic or industrial heating in these systems. By capturing this heat, plants that use this system can achieve an efficiency even greater than 80% compared to conventional plants and reduce 30% of gas emissions (Chowdhury et al., 2009).

The microgrid system can have an internal generation engine operating in both single-fuel and dual-fuel modes. The article by Kozlov et al. (2020) approaches problems in the control and optimization of a hybrid and isolated microgrid system using solar energy and biomass gasification together with a diesel power plant. In it, a more economical solution was found, compared to diesel generators, using the gas from the production of biomass gasification as a fuel in the mono-fuel mode and also in the dual-fuel mode, together with diesel oil. It was also pointed out that the mono-fuel mode was a little more economical due to the low cost of biomass, but the dual-fuel mode is more efficient because it can choose the type of fuel to use and it is the only one that operates with an internal combustion engine.

In addition to the search for system efficiency gains, social factors also justify the need to develop science, technology and innovation in microgrid systems using renewable energies. Access to energy is related to primary domestic conditions and production processes and access to information, directly impacting a region's quality of life and economic development. Dhiman et al., 2019 analyzed the population of India concerning access to electricity, which obtained the result that 240 million people in the country do not have this privilege. Because of this, they sought to study the feasibility of applying small-scale, type SPVHS, photovoltaic solar panels, and decentralized Direct Current (DC) microgrid distribution model to help community self-sufficiency in rural areas in the state of Assan, India. Through the study it was concluded that the applications served as a technological solution to reduce poverty, enabling the creation of jobs, with more hours of work and with better health conditions, as well as reducing the emission of greenhouse gases.

Besides that, the Paris Agreement entered into force in 2016 and was adopted by 196 countries to limit global warming through new clean energy systems, which indicates more significant investments in the area along with the goal set by the UN to advance access to electricity without leaving anyone behind, through cooperation between countries and between the private and public sectors. To achieve Nationally Determined Contributions it is necessary not only to increase new clean solutions but to improve existing ones and combine these technologies to arrive at a more reliable system production cost in renewable energy.

This paper aims to map global trends and identify the opportunities for hybrid systems for power generation in microgrids from renewable sources (solar, photovoltaic, organic waste, biomass, bioethanol, biogas, biodiesel and biohydrogen) and with several modes of generation. The research was carried out by analyzing academic research and patent publications, using scientific and technological information along with reports and marketing information.

2. METHODOLOGY

A bibliometric analysis was carried out to explore scientific articles and reviews (SAR) through the Web of Science database to analyze global trends and opportunities regarding the microgrid system using renewable energies. Also, a search in a FAMPAT database from the *Business Software Questel Orbit Intelligence* was used to find Patent Documents (PD) that deal with the technology analyzed. The FAMPAT database covers PD by more than 100 patent offices worldwide, and the use of the software can do competitive intelligence analysis from statistical data (Questel, 2021c, 2021a). Both searches used the same keywords and were divided into three categories connected by AND:

- System: ("microgrid" OR "micro-grid");
- Generation mode: ("hybrid" OR "cogeneration" OR "co-generation" OR "combined heat and power" OR "trigeneration" OR "tri-generation" OR "cchp" OR "dual-fuel" OR "dual fuel" OR "dual mode" OR "dual-mode" OR "internal combustion engin*" OR "blends");
- Sources: ("renewable" OR "sustainab*" OR "solar" OR "photovoltaic" OR "pv" OR "wind" OR "organic waste" OR "biomass" OR "bioethanol" OR "bio ethanol" OR "bio-ethanol" OR "biogas" OR "bio gas" OR "biodiesel" OR "bio diesel" OR "biohydrogen" OR "bio hydrogen" OR "bio-hydrogen" OR "hydrogen" OR "green hydrogen" OR "blue hydrogen").

After searching for SAR, OpenRefine software was used to reduce repeated words by merging their synonyms, plural with singular and abbreviations with their meanings, to be able to create a cleaner and easier-to-examine network map in the VOSviewer software. In this software, it was possible to create network maps to identify the focus of the study and the trends of technologies used in the microgrid system from renewable sources through the co-occurrence analysis of the author's keywords, as well as the countries and organizations that more use this system with the analysis of co-authorship of countries and organizations, being able to observe the interactions between the links and their approximation (van Eck and Waltman, 2014).

Inventions were statistically analyzed by combining and intersecting data contained in patent documents. Through the International Patent Classification (IPC) codes, it was possible to explore technological areas and fields, building clusters according to the affinity of the inventive activity. IPC features coding per sections, classes, subclasses, groups and subgroups. The sections are: human necessities (A); performing operations and transporting (B); chemistry and metallurgy (C); textiles and paper (D); fixed constructions (E); mechanical engineering, lighting, heating, weapons and blasting (F); physics (G); electricity (H) (WIPO, 2018). Through the IPC it was also possible to group 35 technological fields in 5 technology family fields: chemistry, mechanical engineering, electrical engineering, instruments and others.

The analysis of these technology domain able to identify the diversity or the specificity of an applicant's patent portfolio (Questel, 2021b) and enables users to, very quickly, identify the core business of the player being studied. For these analyses it was also used the *Business Software Questel Orbit Intelligence.* These methods process a large amount of data to make diagnostics and technological prospects important for decision-making in both public and private spheres. In addition to the scientific evidence obtained in the bibliometric analysis (Bortoluzzi et al., 2021; Liu et al., 2013; Mao et al., 2015; Rios et al., 2021; Spreafico et al., 2021), the search for PD can reveal scenarios and trends in certain technological areas (Dehghani Madvar et al., 2019; Karvonen and Kässi, 2013; Martins et al., 2019; Spreafico et al., 2021).

3. RESULTS AND DISCUSSIONS

3.1. Status and Year of Publication of SAR and PD

In this study, 1,319 articles and 75 reviews were found on the use of renewable energy in microgrid systems. Regarding patents, 802 PD were identified, being 79.6% alive (granted and pending) and 20.4% dead (expired, lapsed or revoked). Of these alive PD 329 are granted, guaranteeing protection in their technology for up to 20 years, while 308 are still pending, which demonstrates a great possibility for the amount of granted grows in the short, medium and long term. This data may indicate that there is a lot of recent investment in developing these technologies to control the way the microgrid is carried out with renewable energies.

In Figure 1, another element to reaffirm that the subject is a recent hot issue is possible from demonstrating documents over the years. The number of patents filed each year shows that the period between 2017 and 2019 represents approximately 48% of total documents searched and in general also indicates a growth trend. This scenario often occurs when the technologies analyzed have not yet reached a level of maturity sufficient to stabilize the need for so many new inventions. It should be noted that patent applications take a period of 18 months to be published due to the period of secrecy, which may make the number of patents applied much higher in 2020.

The first SAR published was in 2005 and the first PD application was in 2002. From 2005 onwards, exponential growth is observed, which can be explained by several factors, especially the solid public investments from many countries in renewable energies

(International Energy Agengy, 2021c; Junqueira et al., 2017; Londoño-Pulgarin et al., 2021). In addition to the growing environmental pressure for public policies aimed at sustainable development, critical geopolitical events took place in the period, pushing the governments of the leading world energy powers to seek the scientific and technological development of various renewable energies.

The beginning of the 2000s is marked by the attack of November 11 in US, the gulf war in 2003 and the intensification of conflicts in the Middle East. As a result, the price of oil suffered a tremendous increase and in 2008 it reached its maximum value of 140 dollars a barrel. These facts have driven several countries to allocate voluminous government incentives to develop cleaner technologies that can reduce the consumption of petroleum-derived sources (Albers et al., 2016; Jiankun et al., 2015; Londoño-Pulgarin et al., 2021). This growth in incentives for cleaner technologies since 2000 was also observed by Nordan (2011) in a research on public and private resources invested in startups in the sector. Between 2006 and 2008 alone, there was an increase of 50% per year in initial investments in clean technologies, leveraging energy, environmental, material and agricultural areas (Nordan, 2011).

From 2008 onwards, despite oil price fluctuations, scientific research and inventions related to microgrid systems using renewable energy continue to grow exponentially. First, the very need for energy security leads countries to prioritize resources for this purpose, in view of the economic and social losses caused by the discontinuity in energy availability. For example, the biggest blackout in India - the third-largest consumer of energy -, which affected 620 million people, with hydroelectric plants below capacity due to lack of rain, followed by the blackout in Pakistan in 2015 by cause of policy instability and various fuel shortages.

Second, the transition to renewable energy production continued to grow and several technologies have been consolidated as operational and economic viability. According to International Energy Agency (2020), Renewable Power, IEA, Paris, of all energy sources in the electricity sector, renewables had the highest generation growth rate in 2019, increasing 6.5% (almost 440 TWh) in which about a third of this growth is represented by solar PV and wind energy, hydro representing 23% and most of the rest represented by bioenergy. And in 2020, the annual addition of renewable capacity increased by 45% and the addition of global wind capacity increased by more than 90% in 2020 to reach 114 GW. Thus, the IEA expects the annual solar photovoltaic expansion to reach 145 GW in 2021 and 162 GW in 2022 (International Energy Agengy, 2021b).

3.2. Countries that Published SAR and Applied PD

The main origin of SAR on the use of renewable energy in microgrid systems was China (287), India (252), Iran (206), USA (152), Italy (74), Denmark (54) and South Korea (40), illustrated in Figure 2a. Regarding patents, the country of the patent office where the first filing was made (priority country) was considered as the origin of the technology. China emerges with 704 PD, the United States with a very small number, with only 36 patents, and India and South Korea with 22 patents each (Figure 2b).

Figure 1: Number of SAR published and PD applied

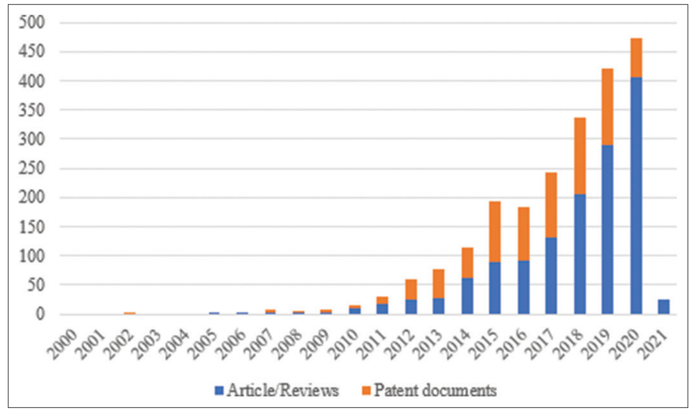
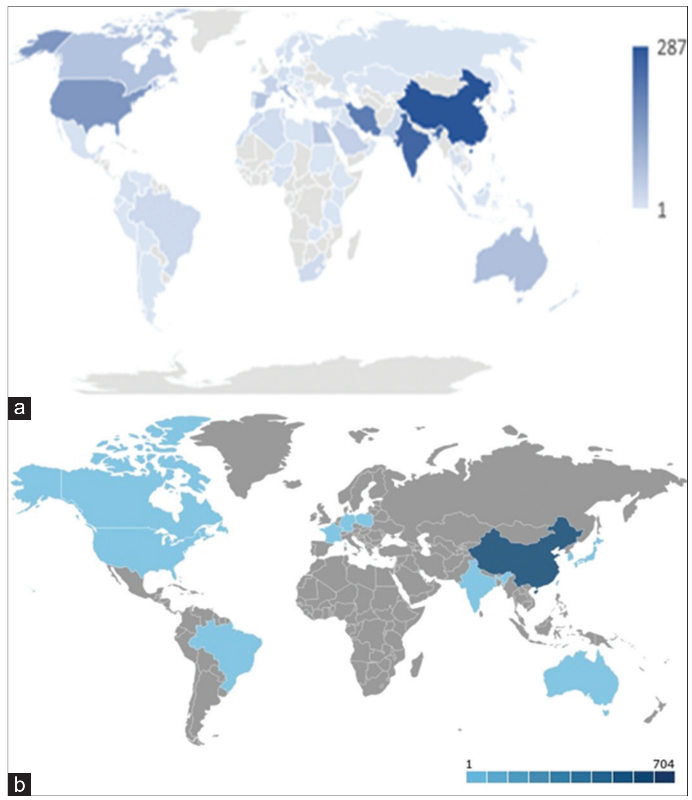


Figure 2: (a) Origin of SAR, (b) Origin of PD



Looking at the patent offices that received the most applications, the China National Intellectual Property Administration (CNIPA) is by far the office where the most patents have been applied, with 714 PD, followed by the World Intellectual Property Organization (48), the United States (43), India (27), and South Korea (26). This may indicate that the markets of interest in protecting the rights of inventions are strongly directed towards the domestic market of countries, which can also influence a low level of international technological transfer.

Several factors can explain China's prominence. The Chinese government has been investing heavily in R&D&I and encouraging companies and research groups to apply for patents (Chen and Zhang, 2019). The strategies were successful and from 2000 onwards China started to lead several indicators. In 2010, 19.6% of all patents applied globally were already Chinese. In 2020, this proportion increased to

45.7%, and the CNIPA alone received 1.5 million patent applications, 89.8% of which were residents. (WIPO, 2021).

Moreover, to encouraging the creation, development and protection of technologies in general, the Chinese government has been promoting public policies to promote and regulate specific renewable energies. (Hu and Phillips, 2011; International Energy Agengy, 2020; Jiankun et al., 2015). An example, China had a feed-in tariff (FIT) scheme to accelerate investments in renewable energy technology that should be connected to the electricity grid by the end of 2020, being also responsible for more than 80% of the increase in installation between the years 2019 and 2020 (International Energy Agengy, 2022).

As in China but to a lesser extent, the USA and India also have large populations, large territorial extensions, and have been investing heavily in renewable energy. The US is a major player in terms of renewable energy and has been growing a lot with this type of study and technology, especially with the Biden government, which showed great incentives for renewable energy and adherence to the Paris Agreement. Besides that, the Production Tax Credit (PTC) program that encouraged the development and production of renewable energy from a credit in the country, was extended for continuation until the year 2021. With the pandemic caused by COVID-19, India has faced significant difficulties with deploying renewable energy due to the financial crisis in the country. But to reverse this situation, there was recently a proposal to improve the operation and finances of distribution companies (Antar et al., 2021; International Energy Agengy, 2020; Konde et al., 2021; Taxpayers for common sense, 2021).

Iran also stood out in research and this can be explained by the country's geographic position, as 90% of the territory has enough sun to generate solar energy for 300 days a year and its windy regions have the potential to generate 20-30 GW of wind energy, representing half of the country's total energy consumption needs. However, the government has 50% of the state's revenue from oil exports, which could indicate an economic risk due to the growth of electric vehicles in Europe, China, and the US. Therefore, there is an interest and incentive to carry out new research and technologies to diversify the energy matrix with cleaner energy and reduce the percentage of oil exports in revenue (Global Solar Atlas, 2022).

Although not among the most prominent players, Brazil has a consistent number of communities without access to the National Interconnected System (SIN), where the microgrid system can be applicable, mainly with the use of solar and wind energy as the country has an average of 4.27 kWh/kWp of specific photovoltaic power per day, according to the Global Solar Atlas, and the average power density of 326 W/m^2. However, still, no new technologies are developed in relation to renewable energy for the microgrid due to financial challenges and delayed projects in 2020. The good thing is that these delayed projects will come on stream in Brazil, Mexico and Chile from 2022 (Global Solar Atlas, 2022).

Besides, through Figure 3 provided by the Global Solar Atlas (3A) and the Global Wind Atlas (3B), it is possible to observe that Brazil, Chile, Morocco, Egypt, and Australia have a large area of high irradiation intensity and average wind speed. This demonstrates that these countries have great potential to increase their participation in renewable energy and the growth of new articles/reviews and patent documents to benefit from the natural factors of the territories (Global Solar Atlas, 2022).

In Figure 4, it is possible to see that the network map performed by the VOSviewer software reaffirms that the most prominent players and the ones that most use and develop microgrid technology are China, India, Iran, and the USA with more than 50% of articles and reviews. It is possible to verify that Iran, India, and Egypt have stronger connections with other countries, presenting a well-built collaboration system, with its large area to explore, due to the high intensity of direct normal radiation and high average speed of wind located in parts of countries. In addition, these countries are seeking collaboration with Russia, Australia, and South Korea, for example, to help develop new technologies in these areas. Meanwhile, China - the world's largest publisher - does not have as many connections with other countries, seeking technology and its own areas to develop new patents and create new technological advances.

3.3. Organizations and Assignees of Articles/Reviews and Patent Documents

Regarding the articles and reviews, it is possible to analyze the organizations that published the most about renewable energies in microgrid systems in Figure 5. Most journals are on the subject area related to energy, sustainability, and electricity. Furthermore, it is notable that the Institute of Electrical and Electronics Engineers has strong participation in journals, and there are significant connections and interactions between the most cited ones, evidencing a solid network within the institute.

Just as the vast majority of PD are Chinese, most assignees, being companies, institutes, and universities, originate from China and are linked to the area of national energy supply and electricity education (Figure 6). The State Grid Corporation of China, along with its subsidiaries (State Grid Zhejiang Electric Power and State

Figure 3: (a) Global Solar Atlas, (b) Global Wind Atlas

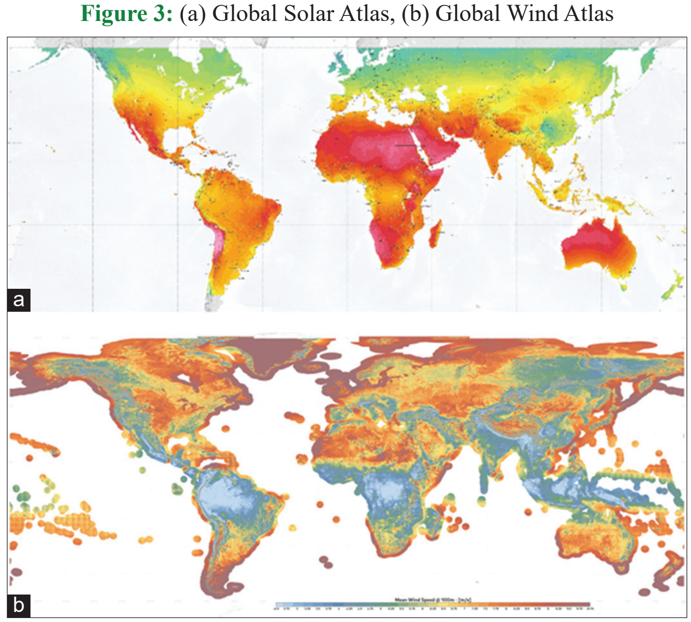


Figure 4: Co-authorship of countries

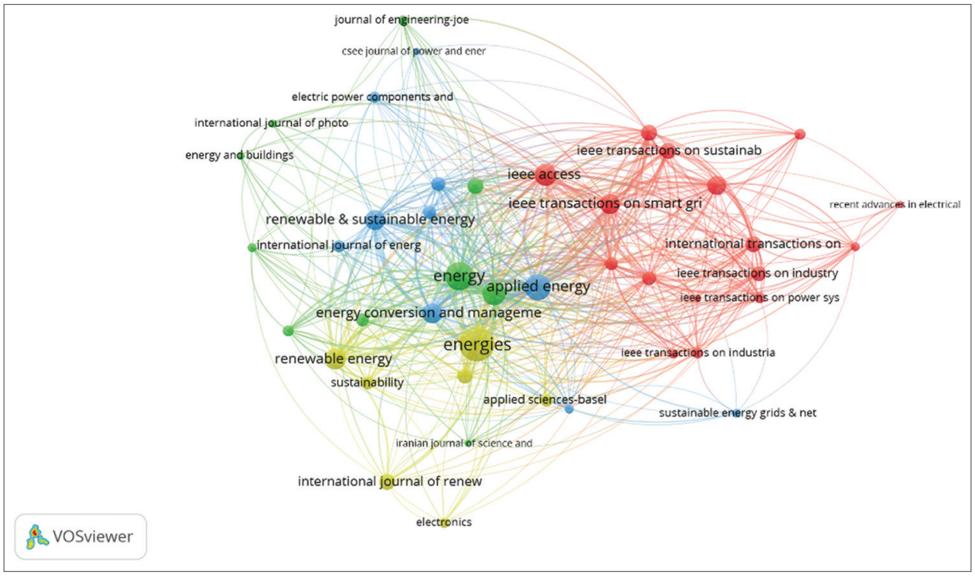
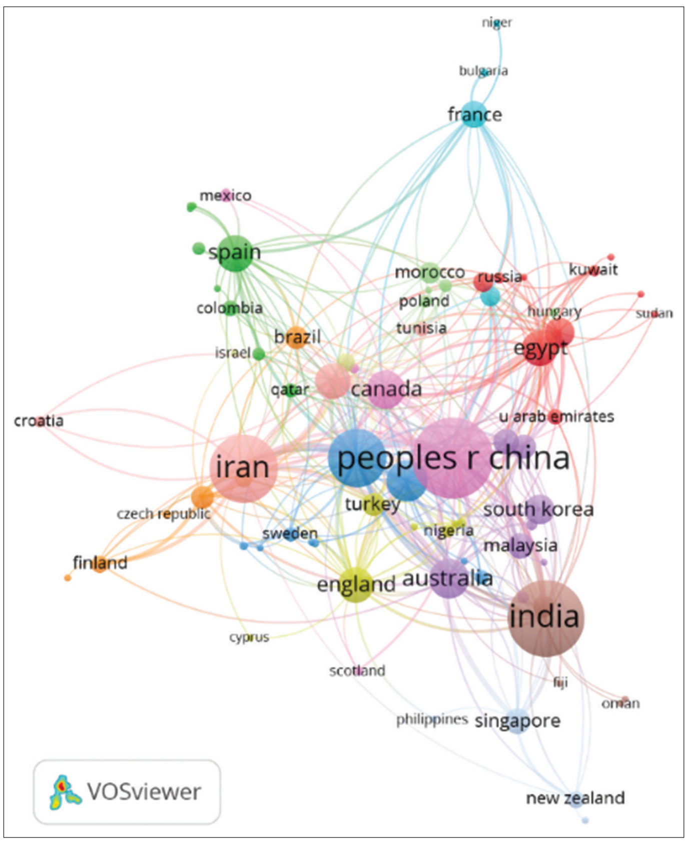


Figure 5: Organizations that published the most about the use of renewable energies in microgrid systems



Grid Shanghai Municipal Electrical Power Company), its institute (China Electric Power Research Institute), and a university that is part of the University Council of China (North China Electric Power University) holds a big peace of invention rights, presenting 219 patents. Note that all listed players, even in different measures, have protected technologies and requests under examination.

Furthermore, a survey was also carried out among the collaboration of assignees in which a minimum of 8 patents per assignee and a maximum of 2 co-assigned patents were determined. Figure 7 shows a strong link between document holders in China, both between offices and public institutions. It is possible to observe many collaborations concentrated among institutions in China, especially around the SGCC together with its subsidiaries, institute, and the participating university of the University Council of China. This indicates the development of new technologies in China due to new patents being developed in the country.

3.4. Research Areas and Technological Field

The microgrid system itself is a resource that integrates various types of energy, stores it, and then distributes it to an electrical network according to the local need, differentiating through the renewable energies used and its form of hybrid storage. The technological field of the inventions was mainly in the area of electrical engineering (Figure 8a), focusing on "electrical machinery, apparatus, energy" (Figure 8b). Making a connection between "IT methods for management," "Control" and "Computer technology" it can be inferred that many inventions are concentrated in management systems, networks and softwares, often embedded in the aforementioned electrical machines. It should be noted that usually the PD classifies more than one code related to each invention.

Figure 9 shows the International Patent Classification (IPC) which also demonstrates a direction for the area of electricity (H) with a focus on the generation, conversion, and/or distribution of electricity (H02) together with the part of arrangements or systems circuit for this energy storage and distribution (H02J). It also has a cluster related to physics (G), but relating to the computer area to program systems with data processing (G06Q) and analyze when there is a need for its energy distribution and how.

The concepts most used by the 20 main players were "Energy Store," "Direct Current," "Photovoltaic Power Generation" and to a lesser extent "Supercapacitor" and "Wind Power Generation." Similar points can be made by making a landscape in the technological clusters shown in Figure 10, where the set of

Figure 6: Assignee by legal status

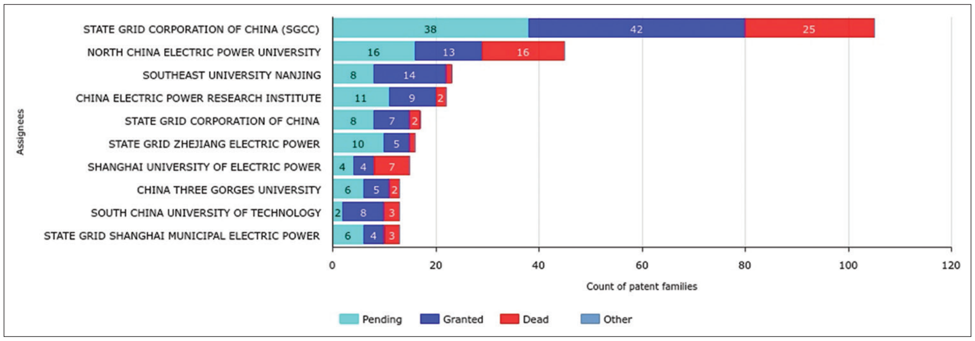
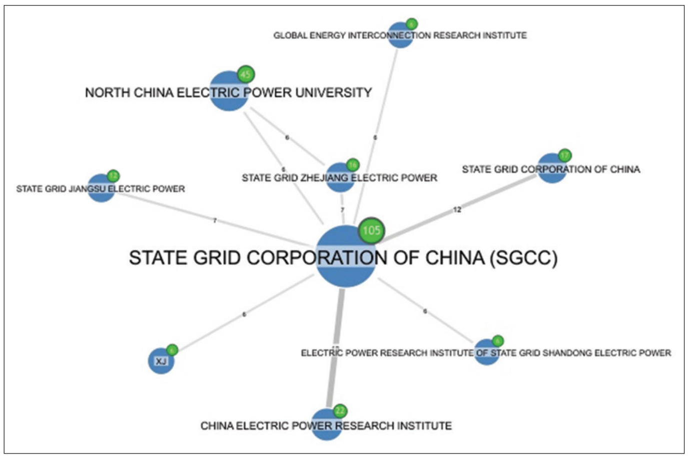


Figure 7: Assignee Collaborations



documents was clustered according to their semantic proximity. The data confirm that the main technology clusters protected in microgrid systems that use renewable energies are related to energy supply/storage and control/management systems.

Also, to analyze and determine the focus of the study and technologies concerning the publication of articles and reviews over the years, a network map (Figure 11) and an overlay map (Figure 12) of the co-occurrence of the keywords of the author in the VOSviewer software was performed with 10 occurrences per keyword. In Figure 11 it was possible to identify 6 clusters classified by the keyword that most appeared in the group and their interactions.

In the dark blue cluster, it is possible to see that the "uncertainty" keyword was one of the most recurrent words. Besides, the analyses using wind turbine and wind speed was carried out to optimize the microgrid system, among with keywords such as " combined heat and power", also presented in this cluster. That indicates the utilization of solar power to water heat and electrical energy generation among the wind turbine to diversify the microgrid power sources and reduce the uncertainty of the system, especially with CHP due to its liability. Lastly, in this cluster, it is possible to see that “plug-in hybrid electric vehicle” and “plug-in electric vehicle” indicate the use of renewable sources to power these vehicles.

One of the words that most appeared in the yellow cluster was “battery,” even though it was not part of the main search. This indicates the existence of studies on energy storage, mainly photovoltaic and wind, due to its inconsistency. Thus, according to the International Energy Agency (2020), Energy Storage, IEA, Paris, residential battery installation growth doubled per year and grid-scale storage dropped 20%, showing that off-grid systems - such as a microgrid - are growing and gaining a more relevant market share (International Energy Agengy, 2021a). On the other hand, batteries have a high cost and a great impact on the environment due to the need for mining to find the raw material. In the yellow cluster, it is also possible to see a relevant repetition about “power management” and its proximity to the system’s storage. Furthermore, it is possible to notice that “cogeneration” may indicate energy generation to immediate use and storage, or mechanical and electrical energy in which a turbine or a shaft generates mechanical energy to another process, e.g. combined heat and power.

In the light blue cluster, the relation between the microgrid system reliability and solar and wind power energy is perceptible, also related to the energy storage system, intending to guarantee energy supply even on days with low solar radiation and wind. This gap in reliability can also be filled by using biomass, bioethanol, biogas, biodiesel, or biohydrogen, supplying energy to the microgrid any hour of the day, regardless of the climate conditions. Furthermore, the graphic shows “combined heat and power” in this cluster, according to Lund, 2007, the system may take advantage of the heat that would naturally be wasted to generate more energy, which increases the efficiency of the process, that’s why this keyword is close to “optimization.” Another interesting point is that “reliability” and “uncertainty” are – theoretic – opposites, while the first one seeks more reliable systems, the other analyses situations through uncertain and unknown information.

It is possible to observe and analyze through the network map that, in the green cluster, “distributed generation” is connected to “droop control,” a method of tilt speed used on energy generators with different energy sources to regulate the rate of power produced according to the system frequency, integrated to the microgrid through inverters. Distributed generation is very important for enhances the sustainable integration of energy into a distribution network (Nithara and Anand, 2021). Another interesting point to analyze is that “renewable energy” is near to “microgrid,” such as “optimization” and “energy storage.” This indicates not only the utilization of sustainable and clean energy to supply energy needs in communities, due to the adaptability of the communities to solar, wind, and biogas. Also, new improvements are being made

Figure 8: (a) Technology domain areas, (b) Technology domain fields

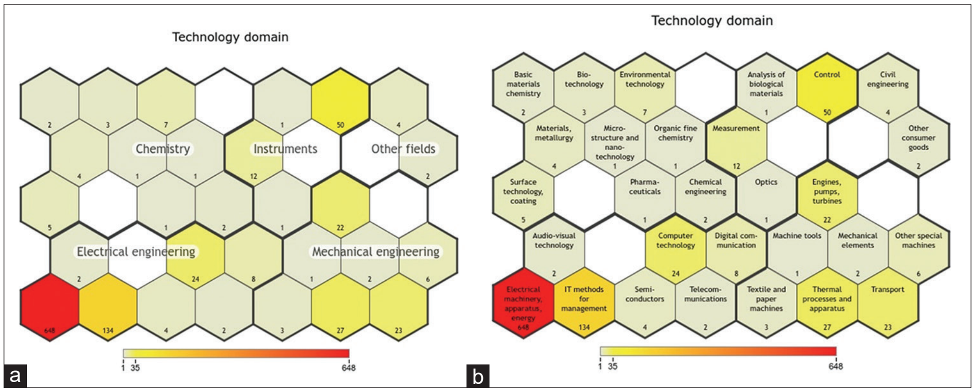
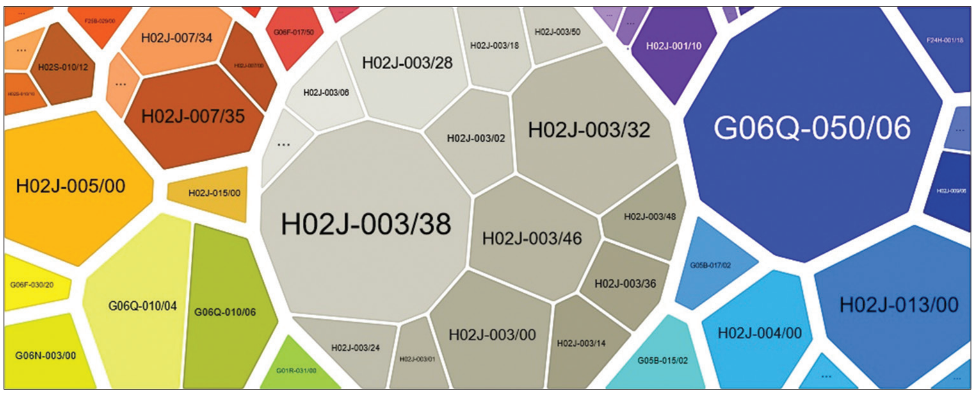


Figure 9: IPC clusters



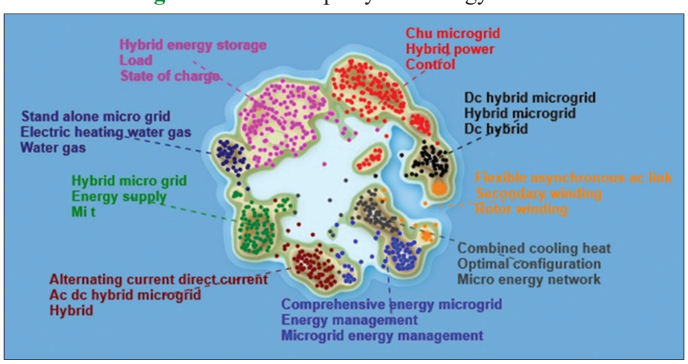


Figure 10: Landscape by technology custers

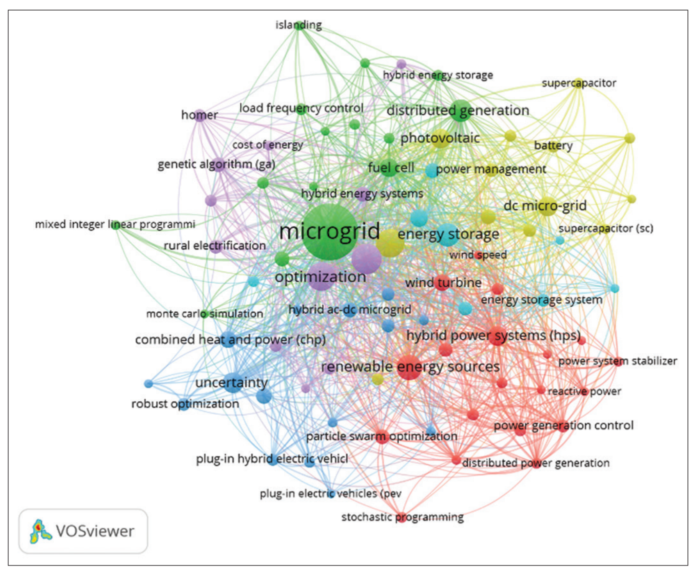
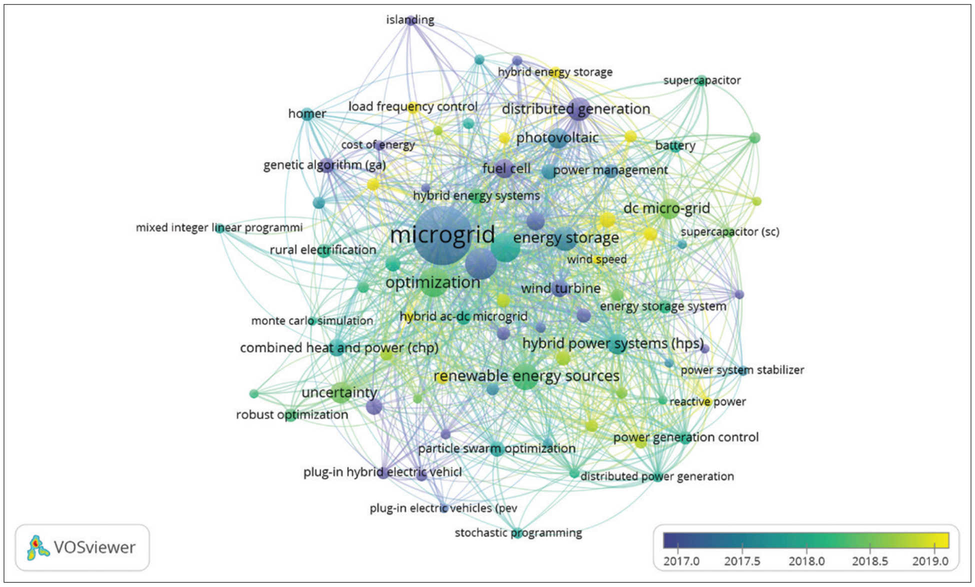


Figure 11: Co-occurrence of the author's keywords about microgrid using renewable energies

in the renewable sector seeking better ways to store clean energy to supply energy without interruption to the microgrid.

In the purple cluster, it is evident that "optimization" is the main keyword, and it is very close to "microgrid," linking "wind turbine" and "wind speed," demonstrating that wind energy is highly useful to optimize the microgrid system. Besides, "cost of energy," which indicates the practice of microgrids to reduce the cost of energy, one point to highlight is the link between the cost to the optimization of renewable energy, with the implementation of photovoltaic and wind energy has a high initial cost until the energetic return. It is also possible to see that "rural electrification" is relevant to the research, its apparition is because it is usually found in areas where the national grid does not reach, therefore it is a better cost-benefit to these areas. Moreover, hybrid microgrids using wind and solar energy seeking the optimization of the system. Furthermore, it is possible to see that the keyword "HOMER" in this cluster. HOMER is a software broadly used to simulate and optimize microgrid designs, including hybrid microgrid, showing through a searchable knowledge base how to optimize the microgrid for lowest net present cost for the microgrid options applying many optimization algorithms to electrical systems.

Figure 12: Co-occurrence of the author's keywords by years about microgrid using renewable energies



Lastly, the red cluster indicates "hybrid power systems (HPS)" close to "renewable energy sources" and "wind turbine." That indicates the substantial use of wind energy in the hybrid microgrid system. It is also possible to see the relevance of "power generation control," due to the necessity of managing the energy in the microgrid since some power sources do not produce energy every hour of the day such as wind energy which depends on the other keyword "wind speed" which is located close to the previous keyword.

In Figure 12 it is possible to identify the clusters being classified by the year in which the keywords most appeared along with their interactions.

As it is possible to see through Figure 12, the studies from 2017 are focused on distributed generation, which is the focus of the microgrid system. The analysis of the energy cost was also the focus of the first studies, together with the use of "genetic algorithm" and "islanding."

Then, in 2018, there were studies on HPS, combined heat and power, cogeneration, and the use of the HOMER software. This indicates the optimization of the microgrid system to generate more than one type of energy and use one or two types of energy to generate electricity. The energy output also led to optimizing the battery for better storage for a more extended period, which led to studies focusing on the energy storage system.

The uncertainty analysis started to gain more relevance late in 2018, also applying stochastic and robust optimization based on the DC microgrid system for small system extensions, with the possibility of using supercapacitors to store the generated energy and with frequency control.

Recently studies are being directed towards the use of wind energy in microgrids along with the optimization of batteries for greater storage. In general, the most recent studies seek to improve energy storage through batteries, supercapacitors, or hybrid systems, including two or more storage forms. Voltage control is also being studied to prevent the battery from having a surplus of energy and predict the results when used in a plant model, being able to solve optimization problems to find the best control action in the shortest time.

4. CONCLUSIONS

Scientific research and technological inventions found in the search reveal great interest in microgrid systems using renewable energies. The annual amount of SAR and PD grows exponentially and strong evidence suggests that this behavior will continue for years to come. Examples of these signs range from global trends such as the growth of energy demand, the use of renewable energies and the creation and renewal of public policies to promote the sector, as well as the specific data of this research that revealed a large proportion of granted and pending PD and growing movements in both SAR and PD. Added to the fact that these technologies still do not seem to have reached a level of maturity sufficient to stabilize or decline the upward curve. It should be taken into account that a renewable energy microgrid involves many different technologies in their particular technological developments and several possibilities of interactions, controls, and management.

China leads both in SAR and PD, and in terms of scientific research there is a greater balance between the powers, with India and Iran very close to China, followed by the USA, Italy, Denmark and South Korea. In the PDs, China is a point out of the curve, both because it is the origin of the absolute majority of inventions, and because its patent office (CNIPA) also houses the majority of applications. Technological information also revealed a behavior of little or no technology transfer between countries, especially in China, both because the patent office applications are primarily from residents and because the collaborations in the development of inventions were only between Chinese companies. The fact that China is still closed in relation to the international connection in scientific research with few interactions in other countries goes against the trend of cooperation advocated as a trending behavior for the players of the so-called third industrial revolution (Rifkin, 2011).

India and the USA stand out in both SAR and PD, as, like China, these countries have been investing heavily in public and private resources to produce more clean energy. Added to the fact that they also have favorable conditions for microgrids using renewable energies, such as large tracts of land, good sunlight and strong winds. Despite showing little or no PD development, countries such as Brazil, Chile, Morocco, Egypt, and Australia also show similar conditions, thus being good possibilities of interest from markets and governments. For countries like Brazil that, in addition to these favourable conditions and still have a large part of the population in isolated communities and without access to energy, microgrids using hybrid renewable sources can be a viable alternative, provided that, as in the countries that stood out, there is strong investment in the sector, especially public.

Technological routes vary according to the type of energy, ways of storing and distributing it in a network that balances obtaining and supplying energy according to availability and needs. In both SAR and PD, the development of technologies related to storage processes stands out, emphasizing research and development of more efficient and less polluting batteries and supercapacitors. As for generating sources, photovoltaic energy stands out, both in SAR and PD, then wind energy, and to lesser extent biomass, bioethanol, biogas, biodiesel and biohydrogen. Solar energy is being used both to generate energy directly and contribute to the production of other sources.

Several researches focus on optimization and efficiency processes to obtain more generating capacity and energy security in "combined heat and power" and "cogeneration," such as water heating that steam drives turbines and plug-in hybrid electric vehicle. The most used operating system for hybrid microgrids with renewable energies was Direct Current, at the expense of Alternating Current, probably due to the higher conversion efficiency, transmission, and reliability (Bhuyan et al., 2020; Veckta, 2021).

In general, inventions focused on creating and improving machines and equipment and systems to operate and control energy flow. Management, control and distribution systems seem to require many inventive solutions for better efficiency. Scientific research has also focused on methods of controlling and distributing energy in microgrids. Several software works to simulate and optimize hybrid microgrid designs, HOMER being the most used.

Thus, it is possible to observe that the increase in studies and requests for new patent documents on new technologies in the last 15 years is directly linked to the need for the physical deployment of renewable energies in isolated communities located to achieve equivalent electrification throughout the world. Future studies are needed to assess the feasibility of implementing hybrid microgrids using renewable energies in other locations and the development of more efficient and less polluting technologies for generation, storage, and distribution of energy.

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