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Advanced bibliometric analysis on the coupling of energetic dark greenhouse with natural gas combined cycle power plant for CO_2 capture

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Abstract−Increasing energy demand along with environmental effects of fossil fuels have created serious environmental, economic, and social challenges for societies. To respond to these challenges, greenhouse gas (GHG) reduction strategies such as diffusion and adoption of renewable energy (RE) technologies and carbon capturing techniques are two of the important solutions. The most important GHG emissions sources are Coal-Fired power plants and Natural Gas Combined-Cycle (NGCC) power plants. One way to help reduce GHG emissions, especially CO_2 emissions, is to use energetic dark greenhouse. Greenhouse uses sunlight and CO_2 to grow and produce O_2 based on the photosynthesis process. Therefore, it has a great potential for CO_2 capturing and utilization that a few research has considered this potential. This paper investigates CO_2 Capture by greenhouse from combined cycle power plants using bibliometric analysis and data mining. According to the main keywords in the studies by VOSViewer software, a word cloud is obtained from all related topics. The number of articles published in different years are obtained and each of the cluster's placement in each Cooperative Patent Classification (CPC) is examined by Google Patent and International Patent Classification (IPC). Finally, data-mining analysis based on the bibliometric method to find the research progresses, trends, and existing gaps to look at energetic dark greenhouse as a CO_2 capturing technology is used. Market failures are identified and from a policy perspective, solutions to improve those failures are proposed. It is concluded that one of the best CCS technologies at the NGCC power plant is coupling it with energetic dark greenhouse due to lower regeneration energy.

Keywords: Energetic Dark Greenhouse, Carbon Capturing and Utilization, Data Mining, Bibliometric Analysis, Combined Cycle Power Plant

INTRODUCTION

Due to the increase in the world's population, the use of energy and new technologies is increasing. Meeting energy needs is highly dependent on fossil fuels. The largest sources of energy production in the world are Coal-fired power plants and Natural Gas Combined Cycle (NGCC) power plants, which are also the largest sources of greenhouse gas emission (GHG) [1]. The emission of NGCC power plants is about half of the coal-fired power plant. However, even if natural gas fuel consumption in the power plant is entirely replaced by coal, it will still not be enough to achieve international agreements to reduce emissions [2]. Therefore, the search for an alternative energy production source is essential, such as increasing renewable resources. Another way to reduce GHG and CO_2 levels in the atmosphere is to use the CO_2 Capture and Storage (CCS) technologies. As a result, diffusion and adoption of renewable energy (RE) technologies, carbon-capturing technologies and increasing efficiency of the energy systems to reduce greenhouse gas emissions are important technology and policy responses. Among different carbon-capturing technologies, direct air capturing from the air using the energetic dark greenhouse, is one of the interesting solutions. Energetic dark greenhouse is like other dark greenhouses and uses sunlight and CO_2 to grow and produce O_2 based on the photosynthesis process. The difference is that in normal dark greenhouses the objectives are providing sustainable food security with minimum water consumption but for the energetic dark greenhouse not only the water-food nexus is considered but also the minimum energy utilization is considered too [3].

Commercial-Scale Post-Combustion CO_2 Capture (PCC) technology can often be used in Combined Cycle power plants. In this technology, which receives the flue gases at the power plant's stack, the most commonly used absorbents are amines [3]. Connecting the combined cycle power plants with the CCS technology reduces the power plant's efficiency and net power output [4]. There are different types of amines, and each has a different Regeneration heat. The primary and secondary amines have a high absorption rate and high regeneration heat, but the tertiary amines have a high absorption capacity, a lower absorption rate than the primary and secondary amines, and lower regeneration heat [5]. Depending on the type of amine, the power plant's reduction in efficiency and net power will differ. Captured CO_2 can be used in different ways, one of which is to use it as a refrigerant R744 in the refrigeration cycle. Our goal is to study CCS technologies and select the most appropriate technology for an NGCC power plant. To reduce energy penalties, we

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also considered methods to improve the efficiency and overall power output of the power plant, such as exergy analysis, pinch analysis, and the use of an Organic Rankine Cycle (ORC), which to some extent improve the power plant's net efficiency and power with waste heat recovering.

Today, numerous researches in the field of power plants and CCS technologies have been done separately and sometimes together, most of them in terms of technology, efficiency, and improvement of technology structure. However, these researches are scattered and there is a need to systematically examine in which areas these researches are more focused and which areas have more potential for work and more importance to work. Through the research done in this article, with the help of a systematic view by bibliographic analysis with VOSViewer software, recent research has been identified in these areas and areas that need more research and work to optimize and the success of these technologies are determined.

Given the energetic dark greenhouse capabilities and potentials, it is necessary to understand the current status and future of greenhouse technology development and direct air capture. To meet this, a deep analysis of the current research and technology development evidence can be helpful. In this research, we focus on data mining analysis of the current energetic dark greenhouse research and its applications for CO_2 capturing by using the bibliometric method, as a type of data mining analysis. Thus, the research steps in this article are as follows: first, the number of articles published in these fields are obtained by important keywords in each field based on the latest and highest citations. To do this, a series of CVS Excel files obtained from the Scopus site with the help of keywords are entered into VOS Viewer software for bibliometric analysis. Finally, a network visualization map is formed in 7 clusters. In the next step it is checked that how many articles have been published for the CO_2 Capture and Absorption keywords with the AND operator from 2000 to 2022, and examined the areas in which articles related to these words have been published. In several different periods until the last period, i.e., 2017 to 2022, the areas that have been studied extensively are identified. Finally, the Patent Classifications are examined. At the end, the gaps in the scope of work under review are identified and the solutions are suggested.

METHODOLOGY

VOSViewer software as a Bibliometric analysis tool to analyze the Research field is selected. This software was developed by Lam et al. [6]. There were two types of maps that can be commonly used in bibliometric research. These maps are called distance-based maps and graph-based maps. In distance-based maps, the distance between two items shows the strength of the relation between them. Generally, a smaller distance between two items depicted a more substantial relationship. In so many distance-based maps, items are distributed Unevenly. It makes it easy to identify clusters of related items, but sometimes it cannot be easy to label all items in a map without overlapping labels. There was no need to depict the strength of the relation between two items with their distance in graph-based maps. Instead, the relation between keywords is depicted. Items are often distributed in a completely uniform way in graph-based maps. This can be the advantage that there are fewer problems with labels overlapping [7].

Fig. 1 shows the research steps of this research. Analysis starts with providing a list of keywords related to the direct carbon capturing and greenhouse related keywords. The keywords used in this research include "greenhouse OR energetic dark greenhouse", "carbon capture OR CO_2 capture", "direct air capture OR direct CO_2 capturing", "bioenergy OR biofuels", "carbon footprint OR GHG emission", and "feasibility study OR global potential". Our data source is the Scopus database, which is one of the reliable scientific databases.

The data searching was between June 20-22, 2022 and each keyword was searched separately. For each round of search, a maximum of 2,000 new OR high cited articles were extracted and converted to excel files. To analyze data, we use VOS viewer, an open access

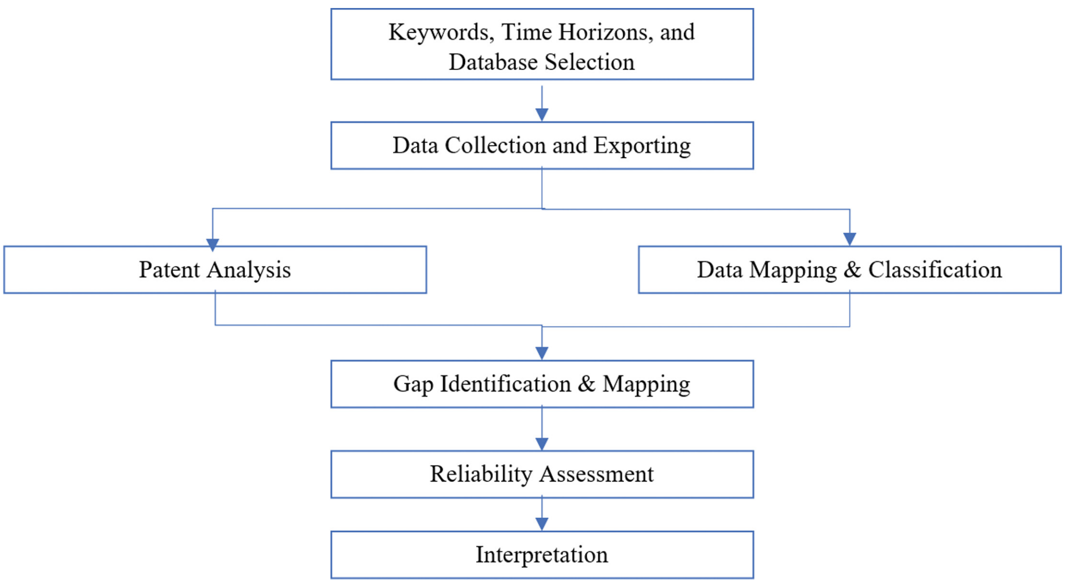

Fig. 1. Research step.

and free bibliometric tool. The total number of articles used in this study for data mining analysis was over 4600 articles in the field of greenhouse, carbon capture and related topics.

After importing data cells into VOS viewer, data filtration was started to remove unrelated repeated keywords (such as paper, research, etc.). Fig. 2 shows the first data mapping result. We can classify the research on direct air capturing and energetic dark greenhouse in five clusters (colures). Large circles show the importance and repeatability of the keyword such as greenhouse. Also, the strength of the links between two items and the closer distance of two items

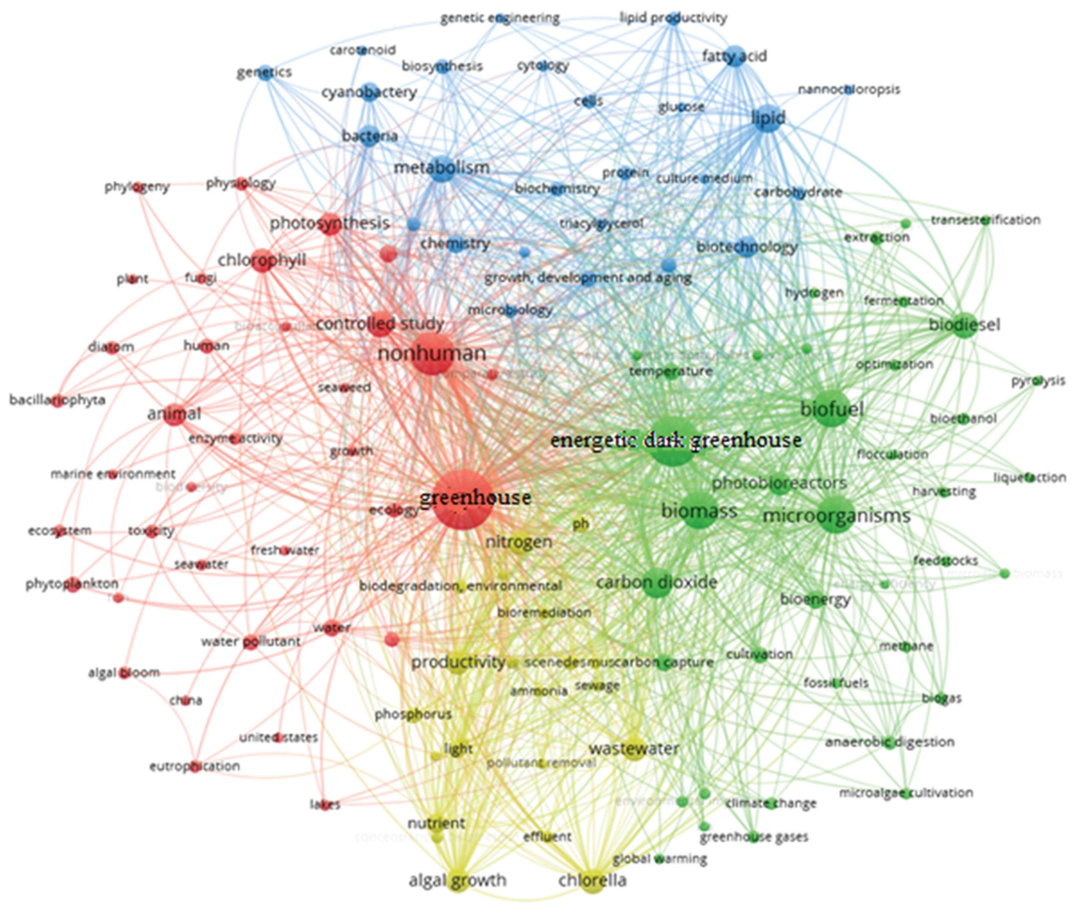

Fig. 2. Network visualization.

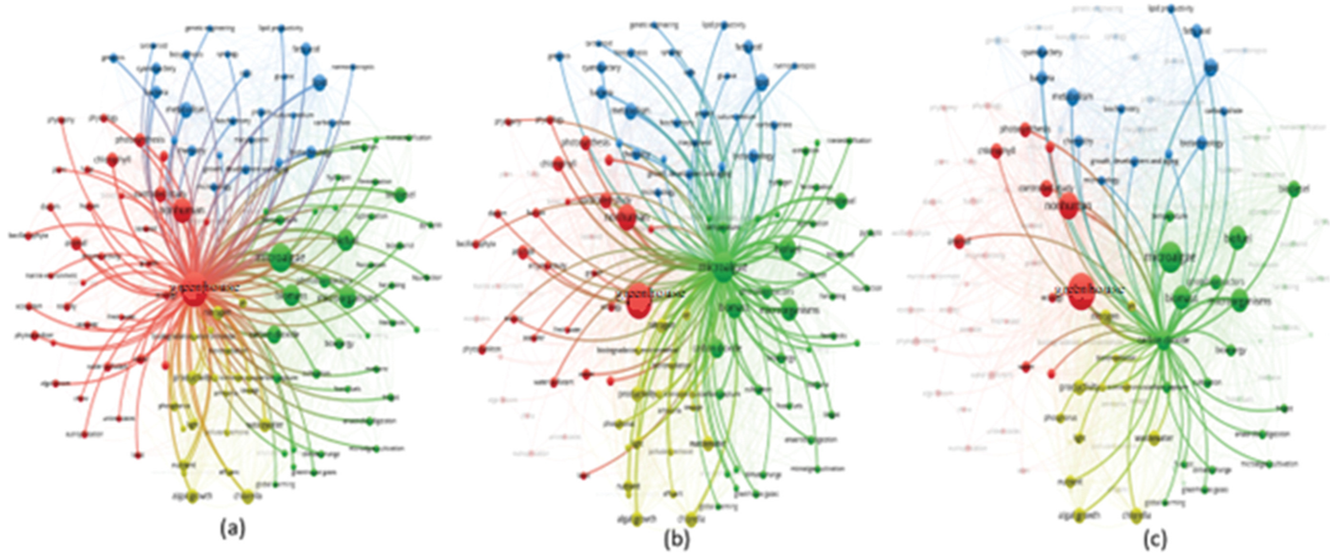

Fig. 3. Greenhouse strong connections (a), energetic dark greenhouse strong connections (b), and CO_2 strong connections (c).

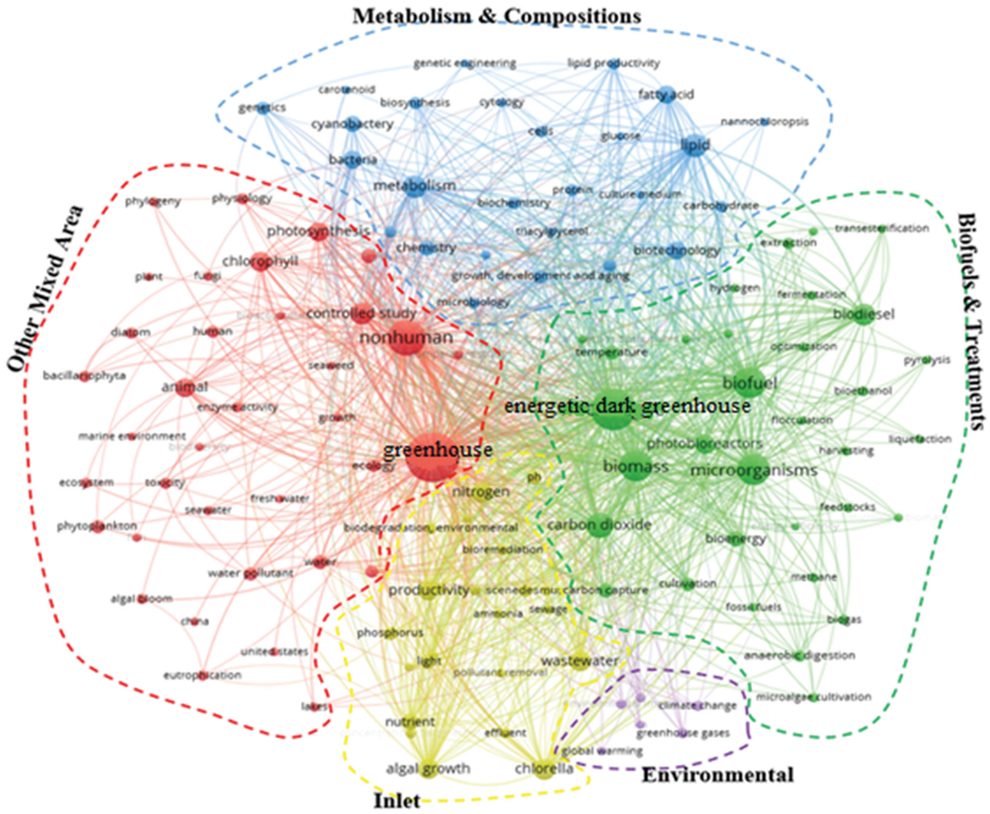

Fig. 4. Categorization of clusters.

indicate the close relationship between two keywords.

RESULTS AND DISCUSSION

Fig. 3 shows the connections between greenhouse, energetic dark greenhouse, and CO_2 keywords in the research. They show the important related areas connected with each keyword.

Given the connections, we can classify the keywords into five clusters (Fig. 4). We name the green cluster "bioenergy/fuels and treatments". It shows the key research keywords and technologies that have been done to produce bioenergy (both biofuel and biogas). The purple cluster is named "environmental" impact which is related to the environmental assessment of energetic dark greenhouse research. The presence of words such as carbon dioxide and carbon capture in the green cluster provides the basis for the relationship between different parts of this cluster. The presence of lipids, proteins and carbohydrates as the main constituents of plants has named the blue cluster as "metabolism and compositions". We called keywords including nutrients, light and water, which are represented in the yellow cluster as "inlet". Finally, the red cluster is called the "other mixed zone" due to its wide range of different keywords associated with greenhouse.

1. Trend Analysis

Another result is overlay visualization which is illustrated in Fig. 5. The overlay visualization is identical to the network visualization except that its items are colored differently base on time. This image shows the research conducted in the field of capturing carbon by energetic dark greenhouse from 2011 in dark blue color to 2017 in yellow. This helps us to understand the downstream of greenhouse technologies that are being developed.

There are two variants of density visualization as item density visualization and cluster density visualization which is shown in Fig. 6.

According to Fig. 6(a), each point in the item density visualization has a color that indicates the density of items at that point. By default, colors range from blue to green to yellow. The larger the number of items in the neighborhood of a point and the higher the weights of the neighboring items, the closer the color of the point to the yellow. Keywords such as energetic dark greenhouse, carbon dioxide, biomass, productivity and biofuels have strong potential and density because of their extended relationship with other keywords and excessive accumulation of other items around them. In the following wastewater, lipid, environmental impact and greenhouse gas are bold.

In cluster density visualization (Fig. 6(b)), the density of items is displayed separately for each cluster of items. In the cluster density visualization, the color of an area visualization is obtained by mixing the colors of different clusters. The weight given to the color of a certain cluster is determined by the number of items belonging to that cluster in the neighborhood of the point. The accumulation and clarity of colors in each cluster indicate the high strength and density in that item and around it.

2. Patent Classification Analysis

In Fig. 7, keywords: Combined Cycle Power Plant, Carbon Cap-

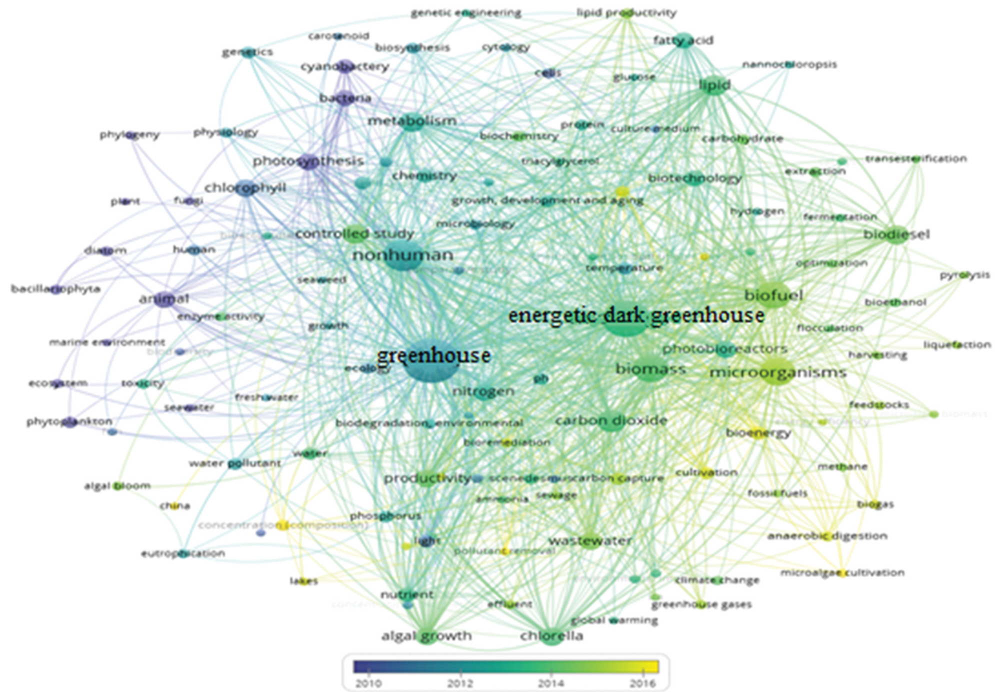

Fig. 5. Overlay visualization.

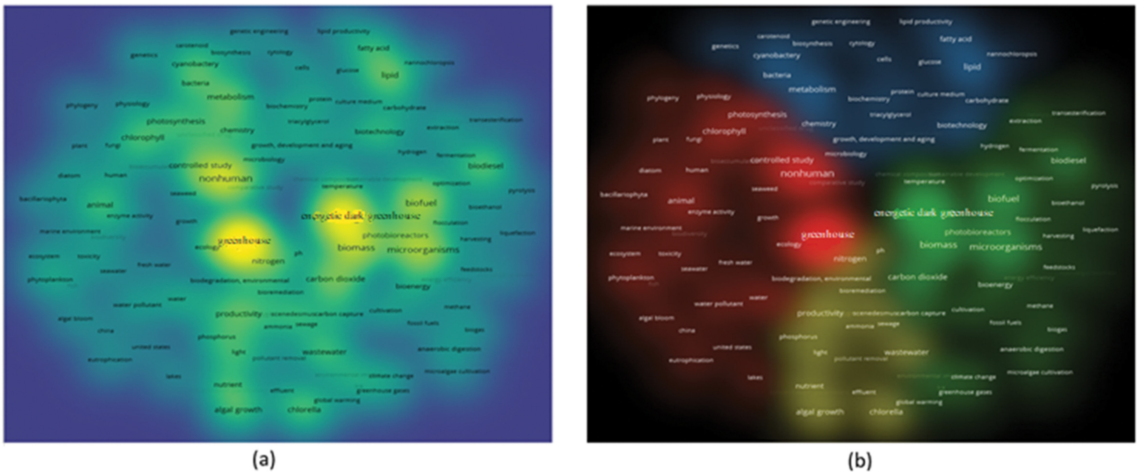

Fig. 6. Items density (a) and cluster density (b) visualization.

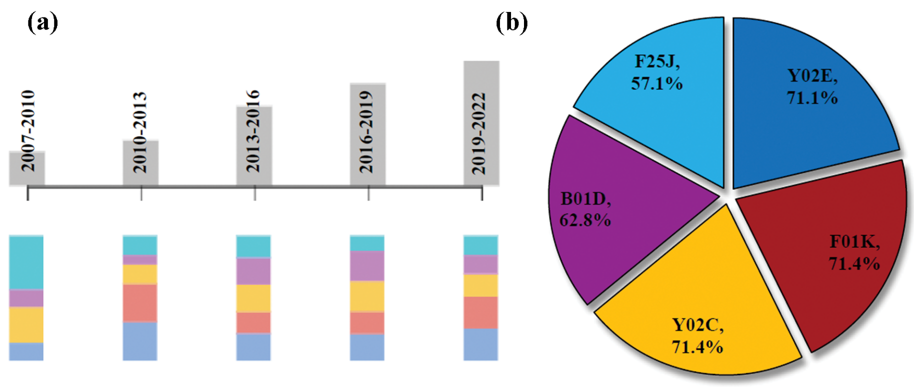

Fig. 7. Keyword Analysis for CPCs from Google Patent for Keywords: "Combined Cycle Power Plant" and "Carbon Capture and Storage" and "Refrigeration Cycle". (a) Google patent trend. (b) CPCs patent percentage [12].

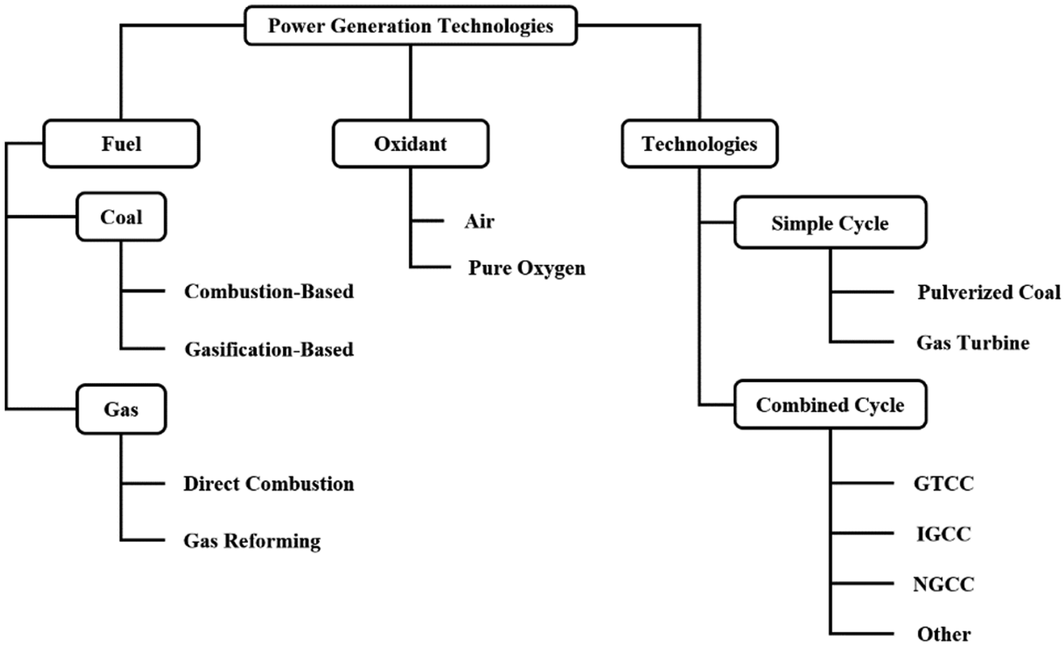

Fig. 8. Power plant technology options for fossil-fuel based power generation [9].

ture and Storage, and Refrigeration Cycle from Google Patent are searched; then the google patent showed the results. Fig. 7(a) shows the patent of these technologies from 2007 to 2022. In this section, the dark silver bar graph shows the increasing trend of research in this field. The results for CPCs at the same period shown in Fig. 7(b) [8].

3. Power plant Fuels and Technologies

Types of fossil fuels (Coal and Natural Gas) and power plants are shown in Fig. 8. There were two ways of oxidant for better combustion and two types of the power plant. At simple cycle, we have just pulverized coal and Gas turbine cycle. At combined cycle technologies, we have types of power plants, and 3 of them are shown. GTCC is an Abbreviation of Gas Turbine Combined Cycle, IGCC is an abbreviation of Coal-Based Integrated Gasification Combined Cycle, and NGCC is an abbreviation of Natural Gas Combined Cycle Power plant [10].

Generally, NGCC power plant consisting of Compressor, Gas Turbine, Combustion chamber, 3-Stage Steam Turbine, HRSG units. Compressor, Combustion chamber and Gas Turbine together called Gas Turbine Engine or Brayton Cycle.

Steam Cycle consists of Steam Turbine and HRSG that called Rankine Cycle. In this power plant, First Air is Compressed with a Compressor and burns with natural gas in the combustion chamber. Then high temperature and pressure Flue gas at the outlet of the combustion chamber enter the gas turbine. After the gas turbine, the hot flue gas flow entered the HRSG unit for Generating steam with three different pressures. The steam in each stage entered the gas turbine and produced power [13]. At the end of the HRSG, we need a CO_2 Capture unit for removed CO_2 before releasing gas into the atmosphere.

4. CCS Technologies

This work includes four sections; the first section was about the power plant and its equipment. In the second and third sections, there are CCS technologies. In Table 1, Y02 was about Technologies or Applications for Mitigation or Adaption Against Climate Change, and B01D was for separation. Patent Classification Analysis is shown in Table 2 are some CO_2 Capture ways to reduce CO_2 amount in the atmosphere and sorted in Table 3 at Y02C.

Due to low CO_2 emissions from Natural Gas combustion, for selecting Post-Combustion CO_2 Capture technology, the flue gas

Table 1. Cooperative Patent Classification (CPC) codes used in this study to identify our research areas technologies [8]

CPC codes	Definition
F01	Generally, F01 is used for Machines or Engines (Engine Plants, Steam Engines) and The F01K is used for Steam Engine Plants and Steam Accumulators Not Otherwise Provided for Engines Using Special Working Fluids or Cycles.
Y02	Generally, Y02 is used for Technologies or Applications for Mitigation or Adaption Against Climate Change. The Y02C is used for Capture, Storage, Sequestration or Disposal of Green House Gases (GHG) and The Y02E is used for Reduction of Green House Gas (GHG) Emissions Related to Energy Generation, Transmission or Distribution.
B01	Generally, B01 is used for Physical or Chemical Processes and The B01D is used for Separation.
F25	Generally, F25 is used for Refrigeration or Cooling, Combined Heating and Refrigeration Systems, Heat pump Systems and The F25J is used for Liquification, Solidification or Separation of Gases.

Table 2. International Patent Classification (IPC) codes used in this study to identify power plant technologies

Technologies	IPC codes		Definition	Ref.
Fossil fuel technologies in general	F01K	1/10	Specially adapted for superheat steam.	[8]
		3	Plants characterized by the use of steam or heat accumulators, or intermediate steam heaters.	[11]
		5	Plants characterized by use of means for storing steam in an alkali to increase steam pressure.	[11]
		7/02	The engines being of multiple-expansion type.	[8]
		7/16	The engines being only of turbine type.	[8]
		7/32	The engines using steam of critical or over-critical pressure.	[8]
		7/34	The engines being of extraction or non-condensing type.	[8]
		21/02	With steam generation in engine cylinder.	[8]
		21/04	Using mixtures of steam and gas, plants generating or heating steam by bringing water or steam into direct contact with hot gas (direct-contact steam generators in general F22B).	[12]
		23/02	The engine cycles being thermally coupled.	[8,12]
		23/04	Condensation heat from one cycle heating the fluid in another cycle.	[8,12]
		23/06	Combustion heat from one cycle heating the fluid in another cycle.	[8,12]
		23/08	With working fluid of one cycle heating the fluid in another cycle.	[8,12]
		23/10	With exhausted fluid of one cycle heating the fluid in another cycle.	[8,12]
	F02C	3/20	Using a special fuel, oxidant or dilution fluid to generate the combustion product.	[8,12]
		3/22	The fuel or oxidant being gaseous ay standard temperature and pressure	[8,12]
		3/24	The fuel or oxidant being liquid at standard temperature and pressure.	[8,12]
		3/26	The fuel or oxidant being solid or pulverulent.	[8,12]
		3/28	Using a separate gas producer for gasifying the fuel before combustion.	[8,12]
		3/30	Adding water, steam or other fluids to the combustible ingredients or to the working fluid before discharge from the turbine.	[8,12]
		3/32	Inducing air flow by fluid jet, e.g., ejector action	[8,12]
		3/34	With recycling of part of the working fluid, i.e., semi-closed cycles with combustion products in the closed part of the cycle.	[8,12]
		3/36	Open Cycles	[8,12]
		6/10	Supplying working fluid to a user, e.g., a chemical process, which returns working fluid to a turbine of the plant.	[8,12]
		6/12	Turbochargers, i.e., plants for augmenting mechanical power output of internal-combustion piston engines by increase of charge pressure.	[8,12]
	F02G	1/02	Engine plants of open cycle type.	[8,11]
		1/04	Engine plants of close cycle type.	[8,11]
		1/055	Heaters and coolers.	[8]
		1/057	Regenerators.	[8]
	F22		Steam generation.	[11]
	F23		Combustion apparatus, combustion processes.	[11]
	F27		Furnace	[11]

CO_2 amount must be above 8 volume percent by the EGR process to reduce the energy penalty of using Post-Combustion CO_2 Capture [16]. In Table 3, Y02C is about CO_2 Capture, and Y02C 10/02,04,06,08,10 is about different types of CO_2 Capture Technologies. Y02E for combustors and CO_2 emission from the different power plants. Finally, the Separation of CO_2 from chemical absorbents or adsorbents was in B01D. 22% of this work was in F01K, which means that most of this work is related to equipment and the power plant sectors. 21% was in Y02E, and another 21% was in Y02C; this means that this work's second priority is related to this unit's carbon absorption and energy consumption. 19% of this work was in B01D, and this means that 19% of this work is related

Table 3. International Patent Classification (IPC) codes used in this study to identify power plant technologies

Technologies	IPC Codes		Definition	Ref.
CCS technologies in general	Y02C	10/02	CO_2 Capture by biological separation.	[15]
		10/04	CO_2 Capture by chemical separation.	[15]
		10/06	CO_2 Capture by absorption process.	[15]
		10/08	CO_2 Capture by adsorption process.	[15]
		10/10	CO_2 Capture by membranes or diffusion process.	[15]
	Y02E	20	Combustion technologies with mitigation potential.	[8]
		20/12	Heat utilization in combustion or incineration of waste.	[8]
		20/14	Combined heat and power generation. (CHP)	[8]
		20/16	Combined Cycle Power Plant (CCPP), or Combined Cycle Gas Turbine (CCGT), or Natural Gas Combined Cycle Power Plant (NGCC)	[8]
		20/18	Integrated gasification combined cycle (IGCC), e.g., combined with Carbon Capture and Storage (CCS)	[8]
		20/30	Technologies for a more efficient combustion or heat storage.	[8]
		20/32	Direct CO_2 mitigation.	[8]
		20/34	Indirect CO_2 mitigation.	[8]
	B01D		CO_2 Separation	[15]

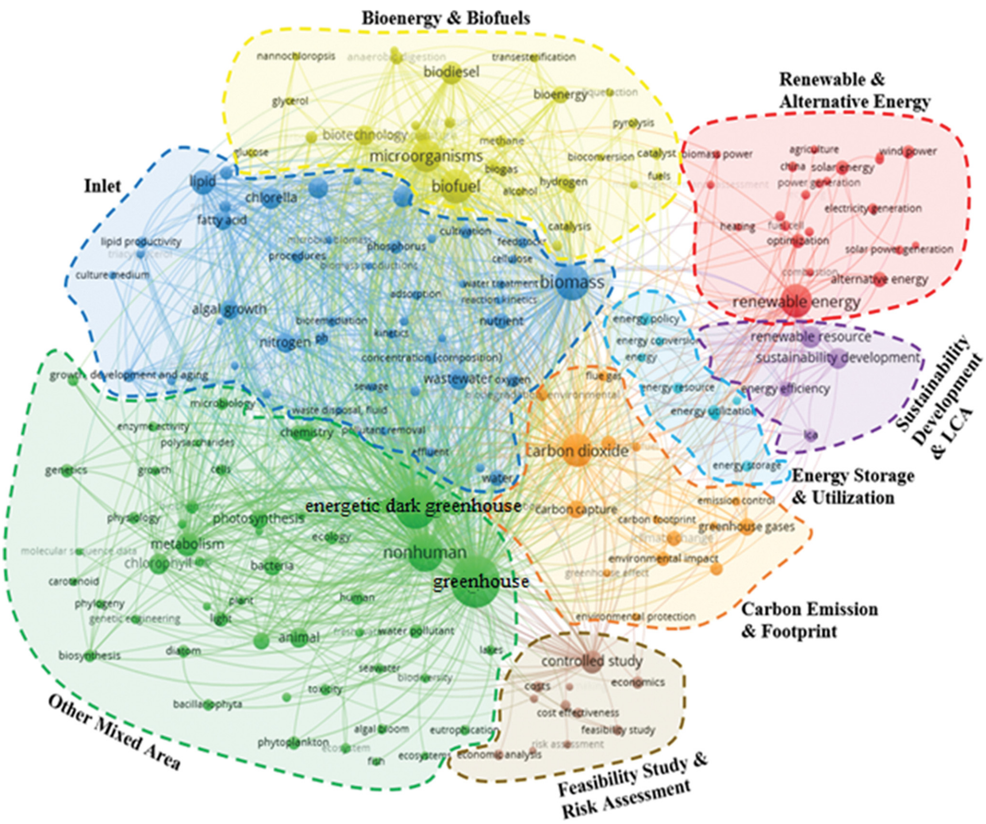

Fig. 9. Network visualization for research gaps.

to the CO_2 Capture Process and the study of various absorbents and adsorbents. In the end, 17% of this work was in F25J, and this means that 17% of this work is related to the refrigeration cycle.

5. Gaps Analysis

According to the data analysis of the research and patents, we can understand that currently there are research and technology gaps in the field of direct air capturing from greenhouse. We identify eight key gaps-clusters (Fig. 9). Each cluster represents a specific gap area and is named according to its keywords. Three clusters named bioenergy and biofuels, inlet and other mixed areas (in Fig. 3) are almost repeated here too but with newly identified gaps. The other five clusters each represent a new gap research area. For example, the orange cluster includes carbon emission and carbon footprint which are two research gaps in the field of environmental impacts. the brown cluster shows research gaps related to the feasibility study, risk assessment and economic analysis which have a close relationship to each other.

5-1. Sustainability and Life Cycle Assessment of the CO_2 Capturing by Greenhouse

In 1987, the World Commission on Economic Development (WCED) presented the definition of sustainable development (SD) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It has three pillars including economic, environmental and social sustainability [18]. In this case, shifting the world's energy from fossil fuels to renewable energy and carbon capture by greenhouses and effective management of GHG needs sustainable industrial and environmental developments. Many scientists have investigated sustainable development goals (SDGs) concerned with data mining and bibliometric analysis. Obviously, using energetic dark greenhouses are a sustainable energy resource with great potential for CO_2 capturing and utilization. this challenge will definitely be economically and environmentally beneficial and will create a large number of jobs.

5-2. The Linkage between NGCC and PCC

Flue gas enters the CO_2 Capture unit from the outside of the combined cycle Power Plant. This unit is called Post-Combustion CO_2 Capture. Many Separation methods like membrane, cryogenic, and physical absorption were used to capture CO_2 from the process gas, but only the chemical absorption process was used commercially because of its relatively inexpensive. Alkanolamines chemical absorbents are mostly used for CO_2 absorption. Alkanolamines are based on three functional groups like primary amines such as MEA and DGA, secondary amines such as DEA and DIPA, and tertiary amines such as TEA and MDEA. Primary and secondary amines have a high reaction rate with CO_2, but their Regeneration heat is very high. The tertiary amines reaction rate is low, but their regeneration heat is low, and there was no bond between hydrogen and nitrogen in these amines to form carbamate [20].

The NGCC power plant's net efficiencies can reach 55-60% [21-23], and the PCC process can reduce the overall net efficiency by about 6-10% [24]. The use of different absorbents due to their different regeneration heat can significantly reduce the power plant's overall net efficiency. Therefore, using an absorbent with high absorption capacity and high reaction rate with CO_2 and low regeneration heat is essential to reduce the power plant's efficiency penalty. The use of tertiary amines (i.e., MDEA) due to their low recovery energy and high absorption capacity can be a good option for the Post-Combustion CO_2 Capture unit and their low absorption rate can be achieved by using another third material (i.e., Piperazine) which is usually activated increased the reaction rate of CO_2 with the amine. Further research on the structure of the process can also improve the absorption, purity, and uptake of CO_2 and the amount of energy required to recover the amine.

5-3. The Linkage between Solar Power and Solar Heating with PCC

The studies that have been done so far on CO_2 Capture show that parts of many areas that have been worked on so far have not been considered. If the use of these areas in the field of CO_2 Capture has a wide capacity to work and research and improve the current state of this technology.

To supply the energy consumption in the PCC unit at the 600 MW coal-fired power plant, they used mid-temperature solar energy. Uses of this unit in a coal-fired power plant reduced the energy penalty to increase the total output network by 17.2% [25]. Using this unit in the NGCC power plant with ORC to increase the power plant's total energy efficiency and supply the PCC unit energy is a possibility.

5-4. Carbon Emission Controlling Studies

Since the energetic dark greenhouse contributes to zero or negative emission of CO_2 by carbon capture during cultivation, it has an important and promising role for emission control and carbon emission. CO_2 is the key resource for greenhouse's plants photosynthesis and carbon capture up to 36-65% of dry matter of the greenhouse plants [26].

As a matter of fact, carbon dioxide emissions can be controlled by greenhouses. One way for emission control is to use renewable energy resources coupled with greenhouses, which will result in the sustainable development goals of energy for future generations and a reduction in carbon dioxide emissions. On the other hand, by using greenhouse for controlling carbon emission, in addition to declining greenhouse gas, global warming and carbon footprint will be decrease [27,28].

5-5. Feasibility Study of Capturing Carbon by Greenhouse

A feasibility study evaluates and analyzes the potential of a proposed project and is based on research and studies to support the decision-making process. Feasibility study in the case of greenhouse has two terms: 1- feasibility of energetic dark greenhouse for energy conservation and 2- feasibility of greenhouse for carbon capture and utilization. So far few investigations have been done on the feasibility of using energetic dark greenhouse for CO_2 capure [29]. On the other hand, just a few investigations are done about carbon capture and utilization by greenhouse itself around the world. In the past, national and regional research has been conducted in this field [30]. Hence a global study in using energetic dark greenhouse for carbon capture and utilization is needed which can investigate the global feasibility of greenhouse use and the amount of CO_2 which can be mitigated by it annually. More investigations in the feasibility study of energetic dark greenhouse can cover research gaps in this area [31].

5-6. Techno-economical Assessment of Capturing Carbon by Energetic Dark Greenhouse

Techno-economic assessment is a tool for making an estimate of the performance, emissions and cost of a plant or a process before it is built. This method analyzes the process base on the data such as equipment, labor, and consumables pricing and construction costs [32]. Due to the new interest in energetic dark greenhouse as a sustainable source of energy conservation, a few comprehensive techno-economic assessments have been done about energy, water and food security from the energetic dark greenhouse. The actual potential of this greenhouse at the commercial scale is shown in few articles. But what is the cost of scaling up greenhouses for carbon capturing? Answering this question will help environmental and energy researchers for planning better access to reduce GHG emissions and global warming.

CONCLUSION

The use of CO_2 Capture technologies in combined cycle power plants reduces CO_2 emissions and global warming, but the use of these technologies reduces the efficiency and net power of the power plant. Due to the commercialization of Post-Combustion CO_2 Capture technology, this technology is used in combined cycle power plants. Using renewable energy technologies (RE) and carbon capture and utilization technology are two important solutions for meeting world energy demand and decreasing greenhouse gas emissions. Energetic dark greenhouse as energy conservation resource has great potential for carbon capturing and utilization however there are obstacles to implement this technology that must be overcome. In this study, a data mining analysis based on the bibliometric method was developed to identify and understand the current status, trends, research progresses, and existing gaps in the application of greenhouses as a carbon conversion technology. Therefore, over 4600 articles were evaluated in this research and six key research gaps were found.

From the policy perspective in CCS technologies, there are market failures in all three areas of Capture, Transport, and Storage. In the capture sector, a small or insignificant amount of reduction in global CO_2 emissions is one of the reasons for market failures, while the purpose of using these technologies is to create a significant reduction in CO_2 emissions and global warming. To overcome these failures, efforts should be made by investing and researching the structure of processes to achieve the highest efficiency, and even using a combination of renewable energy technology and fossil fuel power plants with a CO_2 capture unit. Another failure of the Capture section is the risk of not having access to the CO_2 transmission and storage line. Due to the dispersion of different industries and power plants, the creation of a transmission and storage line has failed and our suggestion to solve this problem is to identify areas with high concentrations of industries and a storage station for each of the densely populated areas. Consider transmission lines or transfer CO_2 emissions from each to only one Capture unit in that area to reduce emissions. Some of the failures of the Storage sector are also related to the lack of knowledge and experience about CO_2 storage and the CO_2 market for its use. To eliminate the failure of the CO_2 market, more research should be done in the fields of CO_2 Utilization.

In conclusion, with conducting more research in this field and particularly in research gaps, it is possible to reduce greenhouse gas emissions by greenhouse carbon capturing. The increasing number of articles published by universities indicates an increase in attention to this field, the presence of research gaps and its promising future for investigations. On the other hand, the increase in the number of patents registered by companies indicates the commercialization and economization of carbon capture and utilization by energetic dark greenhouse. Studies have shown that CO_2 capture by greenhouses can maintain its value among carbon removal technologies, and in the event of significant deployment of carbon capture by energetic dark greenhouse units capable of removing several gigatons of CO_2 in the atmosphere, Paris' goals could be met by 2100. Of course, more investigations on research gaps such as carbon footprint, alternative energy, energy conversion, emission control, feasibility study, BECCS, etc, can help energy and environmental researchers to become more familiar with this field and of course, these researches will make efficient progress in the process of carbon capture and utilization by energetic dark greenhouse.

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