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Artificial intelligence and clean production on the way to sustainability: a systematic literature review

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It is inevitable that new technologies are increasingly incorporated into the activities of institutions and people, this fact represents a challenge for sustainability, since an adequate use of advances will allow a more respectful development with the environment. Considering the above, the aim of this work is to investigate the research trends corresponding to artificial intelligence, clean production, and sustainable performance. For this, a bibliometric analysis of 110 papers was carried out in the scientific databases Scopus and Web of science. To carry out the process of unification, cleaning, and graphic visualization, the technological tools Vantage Point, Biblioshiny in R, and VoSviewer were used. The results present the topic addressed as a current trend in the scientific field in recent years. The analysis by countries exposes the Asian continent as a world leader. On the other hand, the study of keywords highlights the importance of the three fundamental pillars of the research with a possible non-empirical relationship. The results show the proximity between artificial intelligence, clean production, and sustainability.

Keywords -- Artificial intelligence, Clean production, Sustainability, Bibliometrics, Project Management.

I. INTRODUCTION

Industrialists have used the concepts of clean manufacturing during the last decades, there are environmental challenges with sustainability [1]. These previous challenges are being urgently addressed for current and future generations, becoming a necessity as a consequence of the regulations imposed by interest groups [2], [3]. Therefore, clean manufacturing practices are important as a way to achieve sustainable development [4].

For this purpose, information and communication technologies cataloged under industry 4.0 (IND4) emerge, contributing to cleaner production and sustainability [5], [6].

Artificial intelligence (AI) is part of this set of technologies, which can transform the way different interest groups understand and respond to climate and environmental change [7]. A concrete definition of AI is the manifestation of the intelligence of human beings by machines where they can think and act like people [8]. Technologies such as machine learning, robotics, artificial neural networks, artificial vision, and language processing are grouped under this set [9]. Clean production, is a manufacturing method to optimize the use of materials, reducing energy consumption and emissions, during the product manufacturing process [10]. Finally, the concept of sustainability can be approached from the Bruntland report as the coverage of the demands of present generations without risking the coverage of the demands of subsequent generations [11].

At present, there is research that relates AI, and machine learning with sustainable development goals to design simple instruments that relate the circular economy to the concept of sustainable development [2]. However, artificial intelligence can have positive and negative relationships (such as energy consumption) with sustainable development, focusing the discussion on the use of these technologies to achieve sustainability [2], [12], [13]. In addition, the lack of essential knowledge of how IND4, for example, AI, makes clean manufacturing possible is a problem for industries whose purpose is the incorporation of technologies and the sustainable paradigm, [14], [15]. For everything expressed in the previous paragraphs, the need arises to investigate the currents in research concerning AI and clean production with sustainability. Therefore, the following research question arises. 1. What is the trend in research on artificial intelligence, clean production, and sustainability? 2. What are the main countries research on the mentioned topics? 3. What are the main research and publishing journals? 4. How can keywords be related to current research trends?

This investigation will be developed as follows:

Previously, the introduction was made, contextualizing the importance and challenges for industrialists on clean production and sustainability. In addition, the contribution that AI can make to these two paradigms, also questions their effects. Section two presents the main bibliometric and Systematic Literature Review (SLR) studies. Section three presents the methodology used in scientific data mining. Next, the results

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obtained from the work are presented. Finally, they are concluded according to the results presented.

II. LITERATURE REVIEW

There are previous bibliometric studies and literature analyzes that have contributed to knowledge on the subject of artificial intelligence, clean production, and sustainability. First, the work by Cioffi et al. [21] investigated smart manufacturing with industrial technologies applied to sustainable industry, where they found that the circular economy can be generated when innovations are made with technology. In this vein, Cioffi et al. [22] specifically analyzed AI and machine learning in smart production, where the linking of this type of technology will promote clean production processes, creating a new stereotype of smart factories. One of these contributions was made by Zeba et al. [16]. It is related to the bibliometric analysis between artificial intelligence and manufacturing, finding current research trends such as cyber-physical systems, *smart manufacturing*, deep learning, big data, and online programming algorithms.

On this topic, Beltrami et al. [17] performed an SLR, analyzing the relationship between IND4 and sustainability. The greatest contribution was the design of a conceptual framework proposing hypotheses about the influence of IND4 on sustainable performance. However, the application of AI in clean production and sustainability was not studied in particular. Additionally, Khan et al. [18] have carried out a mapping of sustainable development about IND 4 addressing the triple bottom line model, identifying trends in future research such as increasing research around sustainable business models, the circular economy, and technologies. However, this research did not study the particular use of AI related to clean production and sustainability. Jamwal et al. [19] investigated the IND4 technologies to achieve the sustainability of companies through an SLR. The contribution of this work is the identification of AI situations for sustainability in companies, such as quality prediction problems. However, this study did not link AI to clean production. Rosário & Días [20] managed to identify technologies such as AI that allow generating solutions in sustainability in urban areas, sustainable production, control, and pollution. However, they did not specifically study AI with clean production and sustainability.

Finally, Kar et al. [2] carried out an SLR relating the IA impact with sustainability. This study identified important areas of research such as mapping the potential of digital technology as a driver across industries to stimulate sustainable activities across industries. However, this research did not address clean production related to AI and sustainability.

III. METHODOLOGY

Bibliometric studies as a fundamental part of the systematic review of the literature tend to make known the trends of scientific production and research. These investigations use quantitative computer programs to study the bibliographic information related to the works extracted from scientific databases such as Scopus and Web of Science (WoS ™). [23]. To carry out this study, the application of the method used by [24] was chosen to support the bibliometric study. This method consists of 5 fundamental phases which are integrated among them to give robustness to the study, according to the authors they are mentioned below:

The first phase, called recovery, used the scientific databases Scopus ® and WoS™. Where the first database contains millions of referenced citations since 1970 and 84 million records belonging to 17.6 million authors [25]. Regarding WoS™, it has 1.9 billion references and 171 million records [26]. Subsequently, the need for research was identified in the study by Jamwal et al. [19] where the authors propose the impact of AI on sustainability in manufacturing as a future line of research. Therefore, the above becomes an input for the search for information, helping to pose the problematic question. In addition, a search strategy was designed that links the thematic bases of the research, firstly clean production, then AI, and the concept of business sustainability.

Next, the ScienceDirect Thesaurus was used to search for similar terms and synonyms, keywords, and acronyms. Also, Boolean linking operators such as OR and AND, proximity operators such as quotation marks and asterisks were used to give breadth, but also accuracy in the research, limiting the search to the title, keywords, and abstract in papers from cataloged journals. in quartiles 1 and 2 (Q1 and Q2). The explorations in the research areas related to business engineering and administration were also parameterized, the aforementioned criteria guarantee the quality of the selected papers initial supply in the bibliometric processes. The search strategy was applied in the Scopus ® database, giving 86 documents and 59 for WoS ™ as an outcome. for a total of 145 papers. Table I presents the steps for the design of the search equation.

TABLE I
DESIGN OF THE SEARCH STRATEGY

Passed	search strategy _	Scopus	WoS
1	TITLE-ABS-KEY (“ sustainab * development " OR " Sustainabi *" OR "triple bottom line") AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "ENGI")) OR LIMIT -TO (SUBJAREA , "BUSI"))	537,968	235,714
2	TITLE-ABS-KEY (" Robotic*" OR "A rtificial Neural Network*" OR "Artificia l intelligence " OR "AI " OR "Machine Learning " OR "Neural Network*" OR " ANN") AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAR	334,878	169,665

	EA , "ENGI") OR LIMIT-TO (SUBJA REA , "BUSI"))		
3	TITLE-ABS-KEY (" Sustainab * manufacturing" OR "cleaner production" OR "Lean and Green" OR "circular economy") AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , " ENGI") OR LIMIT-TO (SUBJAREA , "BUSI"))	8,487	7,980
4	(TITLE-ABS-KEY(" sustainab * development " OR " Sustainabi *" OR "triple bottom line")) AND (TITLE-ABS-KEY ("Robotic*" OR "Artificial Neural Network*" OR "Artificial intelligence " OR "AI " OR "Machine Learning " OR "Neural Network*" OR "ANN")) AND (TITLE-ABS-KEY (" Sustainab * manufacturing" OR "cleaner production" OR "Lean and Green" OR "circular economy")) AND (LIMIT-TO (DOCTYPE , " ar "))) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI")).	100	71
5	Q1-Q2 Papers only	86	59

Note. The authors.

The next step after the recovery of the information is the migration phase. At this stage, the Scopus documents were downloaded in CSV format and in plain text for WoS to export them to Vantage Point Software. Regarding Biblioshiny in R, the results of both databases were exported in BibText format. This was done with the objective of unifying and cleaning the information, finding 35 duplicate documents for their subsequent elimination. The final result after applying the exclusion and quality criteria is the unification of 110 documents from the two databases. Table II summarizes the use of the different technologies used in the bibliometric study.

TABLE II
COMPUTER TOOLS

No	software	Application	Result
1	Vantage Point	Information cleaning, duplicate identification, information visualization	map, research cluster, relationship between countries with keywords, journals, keyword analysis
2	Biblioshiny in R		Trend chart, magazine publishing, keyword analysis
3	You Viewer	Information display _	Co-currency and keyword density graph

Note. The authors.

Next, the three final methodological stages of investigating, representing and interpreting are presented, whose objective is to use the final documents captured to answer the research questions posed [27]. First, the four research questions are presented, followed by the graphic display and its respective analysis.

IV. RESULTS

1. What are the trends in research on artificial intelligence, clean production and sustainability?

The accelerated progress in science and technology has generated a rapid increase in the number of scientific publications [28]. In this sense, research related to AI, clean production, and sustainability is a recent research topic in the last decade, originating from the work of [29] and [30] in 2012. As of 2019, There is a considerable increase in publications in that same year, reporting 4 research documents and 16 papers for the year 2020, representing an increase of 300%. Regarding the year 2021, the figure was 34 documents with an increase compared to the previous year of 47%. However, in 2022 the figure decreased by 6%, publishing only 32 papers. Currently, in the year 2023, 2 publications are presented. Fig. 1 illustrates the trend in research.

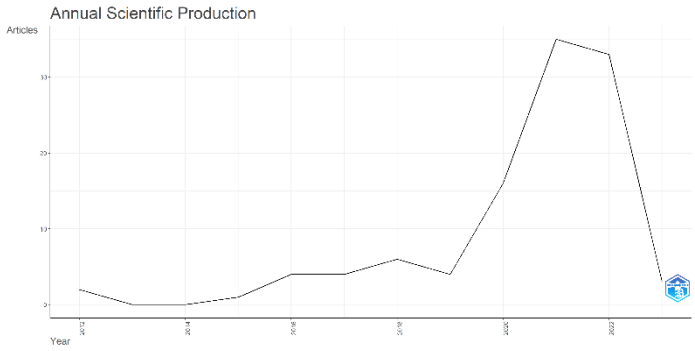

Fig. 1 Historical distribution of papers
Note. Own elaboration in Biblioshiny in R

2. What are the main countries that research on the mentioned topics?

Using the 5 main countries in research as a parameter, we can see that, currently, the research leader in the field studied in China with 30 published documents, followed by India and the United Kingdom with 19 papers respectively. In third place, France with 9 jobs. Fourth place Spain with 6 papers. Finally, Malaysia, Switzerland, and Taiwan with 5 papers respectively (Fig.2).

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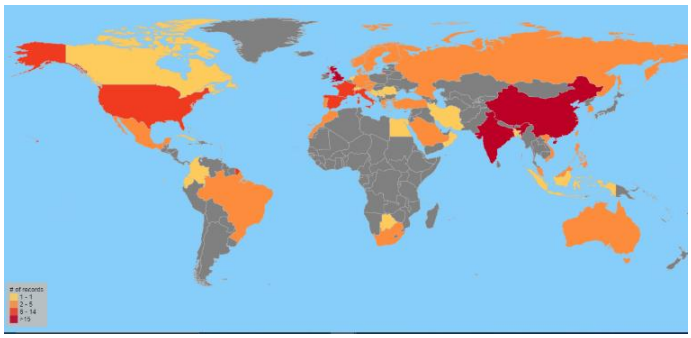

Fig. 2. Geographical distribution of papers
Note. Own elaboration in Vantage point.

The Gantt Chart relates time to countries, and presents China, France, and Italy as the pioneers in Research, entering in 2012. Then the United Kingdom in 2015. In 2017 India and the United States. Finally, in 2020 Spain, Malaysia, Switzerland, and Taiwan (Fig. 3).

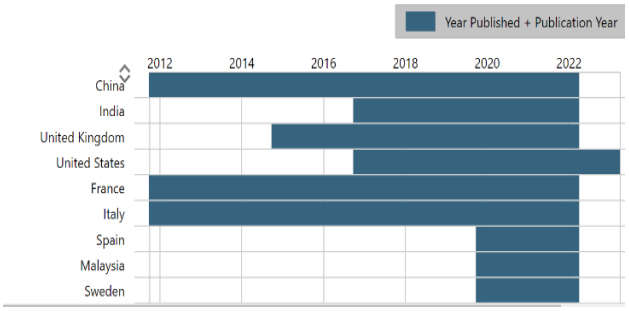

Fig. 3. Historical scientific production of the countries
Note. Own elaboration in Vantage point.

In this order of ideas, the co-authorship analysis inquiries about the relationships that may exist between researchers on a certain topic, these collaborations allow greater advances in science, the above being a relevant element in bibliometric studies [31]. Regarding the research network, the leading country is the United Kingdom according to the number of nodes in total 10 sharing jobs with the United States, India, France, Finland, Switzerland, Italy, Germany, Spain; China, Malaysia, and Taiwan. Fig. 4 presents the main research cluster associations.

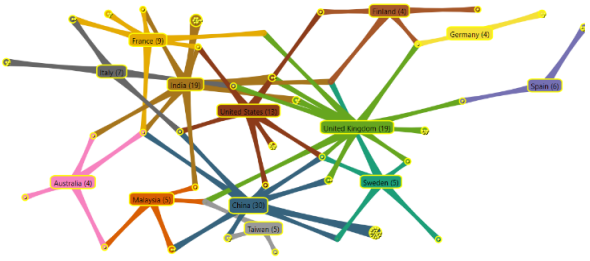

Fig. 4. Research cluster
Note. Own elaboration in Vantage point .

3. What are the main research and publishing journals?

The 110 papers are published in 48 journals categorized into quartiles 1 and 2. The journal that leads the publications is the Journal of cleaner production with 29 representing 26% of the total publications. Followed by sustainability with 11 papers with a participation of 10%. Third, Technological forecasting and social change with 6 registrations and a percentage of participation of 5%. Finally, Business strategy and the environment with 4 records with a 4% participation of the total (Fig. 5).

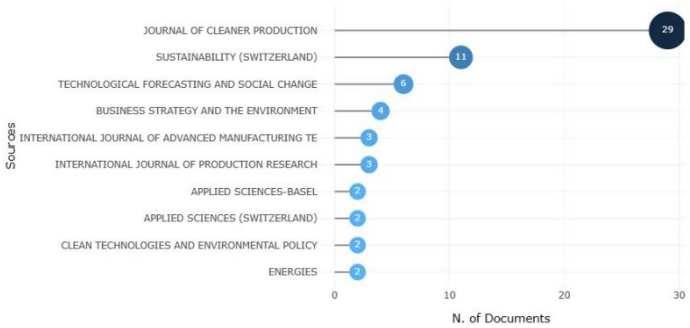

Fig. 5 Main publishing and research journals
Note. Own elaboration in Biblioshiny in R

Relating the countries with the journals, Fig. 6 presents China with the highest number of publications in the main research journal, the Journal of Cleaner Production, with 12. In the second place, the United Kingdom presents 7 records of publications. Finally India and Malaysia with 4.

Fig. 6. Relationship between countries and journals
Note. Own elaboration in Vantage point.

4. How can keywords be related to current research trends?

The importance of keyword mining is the direct relationship with the content of a document, therefore the keyword mining relationship allows visualizing relevant research topics [33]. In this order of ideas, the analysis of keywords reveals the inclination that researchers have towards a certain topic of study [23]. The size of the word in the cloud

graph means that the word is highly repeated in scientific documents, and is relevant in research [32]. Moreover, of the 110 documents presented 427 keywords of the authors and the additional ones, this last category is calculated by WoS™. Taking as selection criteria, those words with two or more records were chosen, to illustrate them in a point cloud graph. As can be seen in Fig. 7, the most representative word is Circular Economy according to the records presented: Circular Economy (39), Artificial Intelligence (29), Sustainability with (27), Sustainable Manufacturing (18), IND4 with (14).

Fig. 7. Cloud of keywords
Note. Own elaboration in Vantage point.

On the other hand, the Gantt Chart presented in Fig. 8 compares the keywords concerning the time we can see that the first concept spoken is that of sustainable manufacturing in the year 2012 up to the present time with 18 records. It is noteworthy that until 2016 the term is combined with AI and sustainability with 29 and 27 records respectively. Based on these data, it can be analyzed that the circular economy is linked to research in 2017 with 39 records.

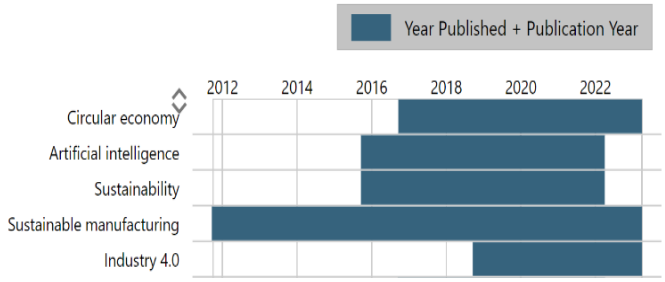

Fig. 8. Historical analysis of keywords
Note. Own elaboration in Vantage point.

In addition, regarding the trend in the use of keywords over time, Fig. 9 presents sustainable manufacturing as the most widely used word, followed by artificial intelligence. Finally, with 20 records, the words sustainability, sustainable development, and circular economy occupy third place.

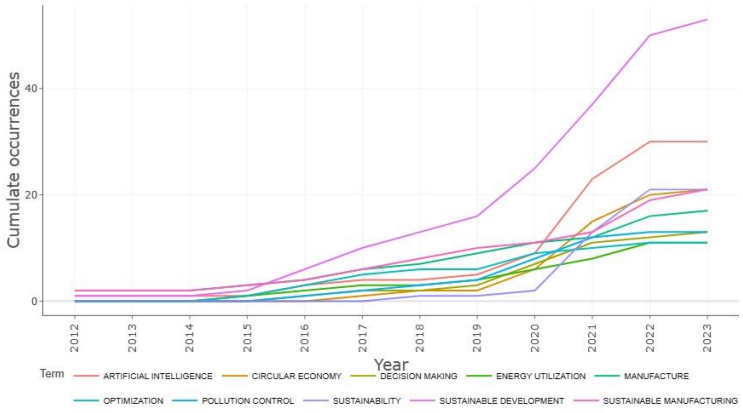

Fig. 9 Historical trend analysis of keywords
Note. Own elaboration in Biblioshiny in R

Furthermore, classifying the keywords used by the countries, Fig. 10 presents the circular economy and Industry 4.0 as the mosts used words in the United Kingdom. Then AI in India, sustainability in the US, and sustainable manufacturing in China.

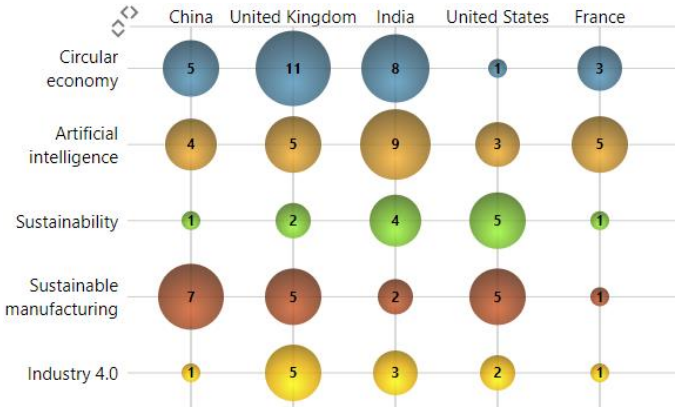

Fig. 10. Relationship between countries and keywords
Note. Own elaboration in Vantage point .

Regarding the concurrency analysis, the size of the circumference of the word means the records that are made in the papers, therefore the more the word is used, the greater the diameter of the circle, and the shorter the distance between the keyword connections the stronger the relationship [34]. As well as, in Fig. 11, the circular economy is the largest circumference in the graph, it presents figures of 85 relationships with other words followed by IA with 61, IND4 with 37, and sustainable manufacturing with 31. How can these words be evidenced? Apart from being the most closely related, their circumferences are the closest. Therefore, it can be affirmed that there may be a non-empirical relationship between them.

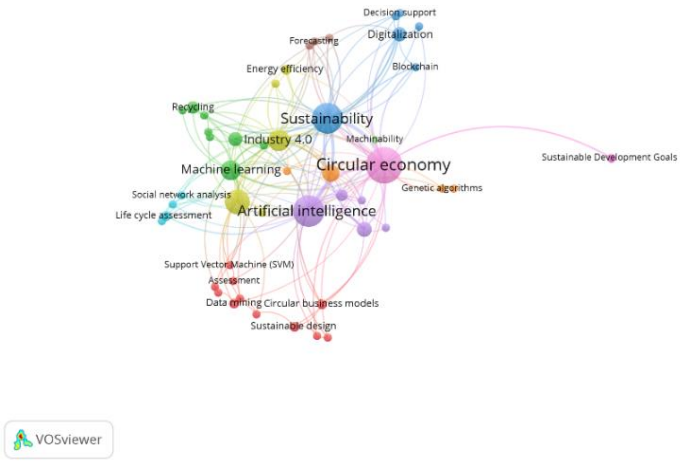

Fig. 11. Keyword co-currency analysis
Note. Own elaboration in Vos viewer.

Besides, the density visualization analysis allows the identification of areas formed by the proximity of the nodes, being the level of color saturation of the keyword, a topic of high research analysis [35]. In fact, Fig. 12 show the topics of AI, circular economy, IND4, and machine learning are trending in research.

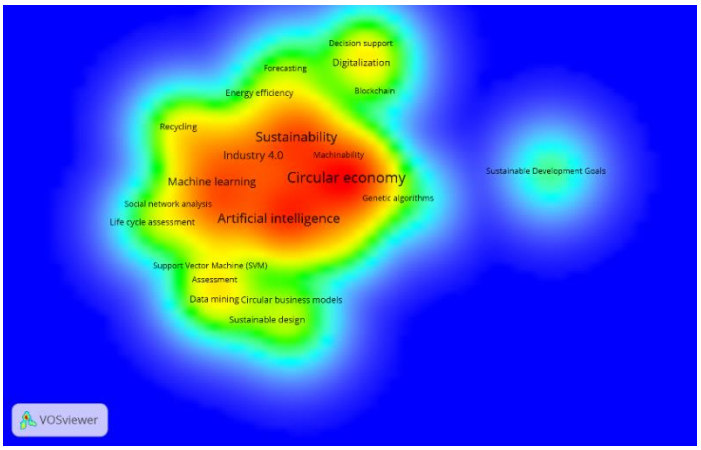

Fig. 12. Keyword density analysis
Note. Own elaboration in VoS viewer.

V. EXPLORATION OF THE FUTURE AGENDA IN RESEARCH

In order to relate the research to the current technological trend of artificial intelligence ChatGPT a search for the specific term was carried out in the applied database in the fields title, abstract and keywords, table III presents the results, finding only 7 articles related to the environmental component.

TABLE III
ChatGPT term exploration

Result	Scopus	WoS
Papers	323	167
Articles	106	64
Environmental area	5	1

Note. The authors.

The research has identified in the two data bases a series of general trends in research in the areas of social sciences 42 papers (Fig.13) and general internal medicine 17 papers (Fig.14). However, articles related to the environmental area presented very low participation percentages of 2.8% and 1.5%.

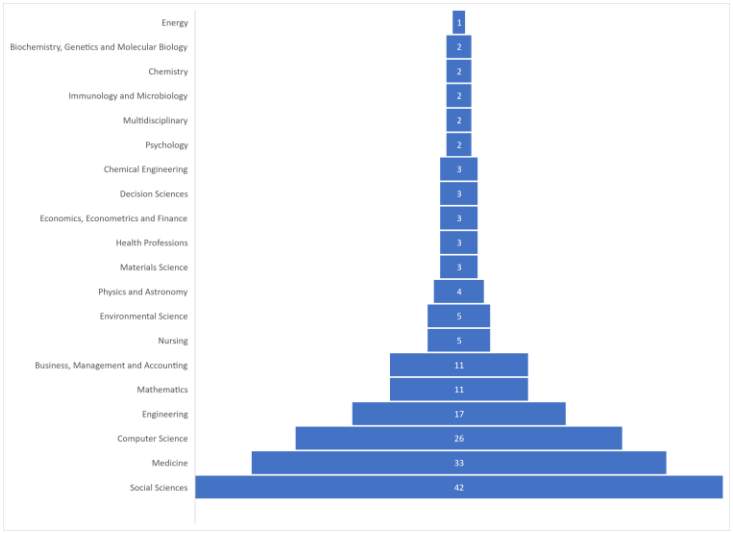

Fig. 13. ChatGPT Scopus research areas
Note. Own elaboration

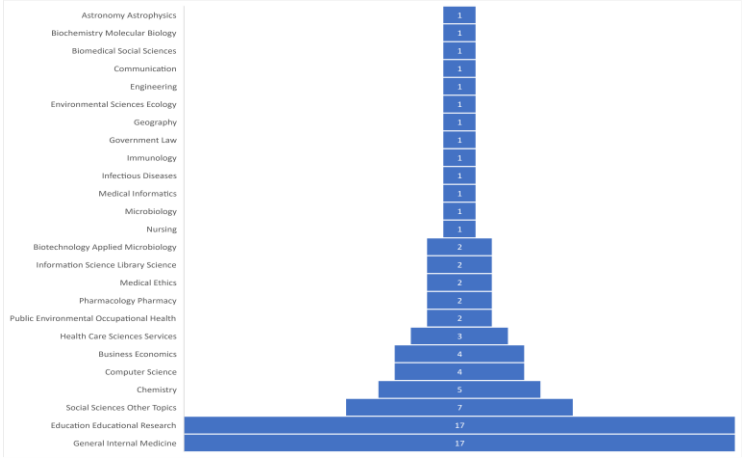

Fig. 14. ChatGPT WoS research areas

Note. Own elaboration

In addition, the table IV below explains the main applications of ChatGPT and its approach to sustainability.

TABLE IV
Productivity-related AI applications

Application	Function	Country	Approach	RSP
Wand AI 2022 https://wand.ai/	Self-service no code AI platform to generate AI with no friction.	Israel	Solve business problems and create value faster than ever before.	Automatically maximizes the impact of your solutions.
TL; DV Powered by GPT 2020 https://tldv.io/	Record meeting to help you share call moments with AI.	Aachen, NRW	Transcribe in 20+ languages	Productivity Tool, and Remote Work Enabler
Momentum 2020 https://www.momentum.io/	AI tool to help administer and automate sales calls.	San Francisco	Uses automation and AI to improve data and operations visibility for revenue teams.	Best industry standards available in terms of security, reliability, privacy, and encryption
SupernormalAI 2019 https://supernormal.com/	An AI-powered meeting recorder.	New York City	Automatically transcribes and writes the meeting notes, saving you hours each day.	Helps you get the most out of your work with amazing meeting notes in one place.
Roam around 2023 https://roamaround.app/	Plan your trips through an AI travel planner.	New York City	Roam Around will help you craft a hyper-customized travel plan.	Leverage ChatGPT's powers with this website and create a perfect travel plan for yourself.
HintsAI 2021 George, Alex y Gleb, https://hints.so/about	GPT-based assistant helps you to use productivity tools more efficiently.	New York City	Integrated with Notion, HubSpot, Trello, ClickUp, Google Calendar, Pipedrive, Jira and Obsidian.	Productivity without maintenance
RoomGPT https://www.roomgpt.io/	Helps you redesing your room with just a click of a button	Philadelphia,	RoomGPT uses an ML model called ControlNet to generate variations of rooms based on the user's uploaded photo	You can take a picture of your room and see how it looks in different themes.
Botify 2012 http://www.botify.com	Create digital humans for engaging conversations	New York City	Allows you to unleash the true growth potential of your website.	Offers a comprehensive SEO management solution
Nanonets 2017 https://nanonets.com/	Automates manual data entry using AI.	San Francisco, California	Nanonets OCR is an OCR (Optical Character Recognition) platform.	Create machine learning models with minimal training data or machine learning knowledge
MagicalAI 2020 https://www.getmagical.com/	Helps you automate repetitive tasks and saves hours per day.	New York City, New York	Magical is a productivity app that uses AI to speed up repetitive tasks as you work.	Accelerate repetitive tasks while you work, without integrations, APIs or magic wands.
D-ID 2017 https://www.d-id.com/	To create digital avatars giving you an immense human-like experience.	Tel Aviv, Israel	Reduce the cost and hassle of video production, at scale, in 100+ languages, with no technical knowledge.	Create and interact with talking avatars at the touch of a button

Note. The authors. RSP: Relationship to Sustainable Performance

Future and possible research questions that can be formulated from the results of this research include: How will this new technology ChatGPT support cleaner production practices; how will the combination of ChatGPT and cleaner production impact the economic, environmental and social pillars.

VI. CONCLUSIONS.

The main objective of this study was to know the trends in research regarding the selected topics regarding artificial intelligence, clean production and sustainable performance. The graphic analysis of the bibliometric study presents the theme as a trend in research. Regarding the geographical location of the investigations, China has led the work worldwide since 2012. However, the strongest network is led by the United Kingdom in association with 11 countries. The magazine with the largest publication is the Journal of Cleaner Production with 29 papers representing 26%. China participates in mentioned magazine with 12 publications leading the above. Regarding the keywords circular economy, AI, sustainability, sustainable manufacturing, and IND4. Regarding the location of the keywords over time, manufacturing was followed years later by artificial intelligence and sustainability, presenting a joint alignment of the research pillars in 2017. The most used keywords classified by country are in the United Kingdom circular economy together with IND4, India IA, United States sustainability, and sustainable manufacturing in China. Finally, the graphic analysis of co-occurrence presents the circular economy as the most important word followed by AI and sustainability. The proximity of these words possibly presents a non-empirical relationship that could become a future research paper. Likewise, density analysis presents this topic as a current and future research trend. Finally, technologies can help improve their production systems, making them more environmentally friendly, and generating well-being in the different interest groups.

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