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CAPÍTULO 8

Technological surveillance of energy efficiency in agricultural production systems: a systematic review

Vigilancia tecnológica de la eficiencia energética en los sistemas de producción agraria: una revisión sistemática

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ABSTRACT

This document highlights Energy Efficiency (EE) in agricultural production systems through the analysis of the life-cycle of publications in Scopus database, along with the help of SigmaPlot and SciMAT software. Among the results obtained; the growth rate on publications was determined until 2019, with trends in EE research in the agricultural sector. According to the search formulas "*energy efficiency*" (LIMIT-TO (DOCTYPE, "ar)) and "*energy efficiency* AND *agriculture*" (LIMIT-TO (DOCTYPE," ar), which made visible the scientific projection according to the inflection point, as well as the most important motor issues, where those related to soil, water, climatic variability, crops, nitrogen and phosphorus are emphasized, being The United States the country with the greatest scientific dissemination in this regard. In addition, publications and institutions relevant to the case of Colombia were established through TAK ("*energy efficiency*" AND *agriculture*) AND (LIMIT-TO (AFFILCOUNTRY, "Colombia").

Keywords: climate change, sustainability, S-curves, technological surveillance.

RESUMEN

Este documento resalta la eficiencia energética (EE) en los sistemas de producción agraria, a través del análisis del ciclo de vida de las publicaciones establecidas en la base de datos Scopus, con ayuda de los programas SigmaPlot y SciMAT. Dentro de los resultados obtenidos, se determinó la tasa de crecimiento sobre las publicaciones hasta el año 2019, con tendencias de investigaciones sobre EE en el sector agrario, según las fórmulas de búsqueda "*energy efficiency*" (LIMIT-TO (DOCTYPE, "ar) y "*energy efficiency* AND *agriculture*" (LIMIT-TO (DOCTYPE, "ar), que permitieron visibilizar la proyección científica de acuerdo al punto de inflexión, así como los temas motores de mayor relevancia, en donde se resaltan los relacionados con suelo, agua, variabilidad climática, cultivos, nitrógeno y fósforo; resaltando a Estados Unidos con la mayor divulgación científica. Además, se logró establecer las publicaciones e instituciones relevantes para el caso de Colombia, a través de TAK ("*energy efficiency*" AND *agriculture*) AND (LIMIT-TO (AFFILCOUNTRY,"Colombia").

Palabras clave: Cambio climático, Sostenibilidad, Curvas en S, Vigilancia tecnológica.

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC) (Marengo et al., 2014); one of the main adaptability strategies to adverse weather conditions is the use of practices in agricultural production that consume fewer fossil fuels, as a principle of closed production systems where inflows and outflows have no impact on natural resources, and on the contrary, interaction and translocation of internal factors are actively manifested.

This is how the statement by Antoine-Laurent Lavoisier "*Energy is neither created nor destroyed, it is only transformed*" has generated great interest in applicability in different fields of production, because according to Plazas-Leguizamón and Jurado-Álvarez (2018), the intrinsic principle of Energy Efficiency (EE) lies in the capacity of a process to strengthen the interaction of its aggregates, without demanding resources, without generating significant losses within the production system.

For this reason, in agriculture the systemic development of various practices has been carried out as a result of practicality and experience, which has allowed adaptability in the environment for many generations. However, processes such as climate change (ECLAC, 2018) occurred very rapidly, especially from the industrial era, where biological and natural changes were significantly affected by the constant demand for external raw materials from the systems. production and the exasperating output of energy flows from them, which has brought significant complications in the change of climatic conditions and therefore in the adaptability of animals and plants of environmental and agri-food interest (Harchaoui & Chatzimpiros, 2018).

One of the most relevant strategies that the agricultural sector has taken up again are agroecological practices, where the rescue of ancestral knowledge and the dialogue of knowledge, strengthens the empowerment of rural communities and the projection of scientific knowledge (Plazas-Leguizamón & Garcia-Parra, 2017; Suárez, Mosquera, & Castillo, 2018), in order to consolidate tools that allow solving local and regional problems in crops, livestock and forestry systems.

Thus, the need to disseminate knowledge has become one of the main strategies allied to the search for practices and tools that can be applied to mitigate the effects of climate change. For this reason, technological surveillance processes (VT) have been established to elucidate research work that can be applied to agricultural production systems, through techniques of organizing information present in books, databases, blogs, research centers. and academic institutions, in order to be projected according to their evolution over time and the needs linked to geographical areas, offers and demands, as well as pilot strategies in the construction of future research (Grajales-López et al., 2016; Schilling & Esmundo, 2009; Tobón et al., 2017).

One of the analyzes that are within technological surveillance and that allows the study of bibliographic information are the S curves, which according to Zartha et al. (2016), allows to explore selected information through statistical analysis, projected in time and in the number of publications. Likewise, another methodology that allows the qualitative analysis of the information is the automated exploration analysis through programs such as SciMAT, which carry out scientific mapping analyzes to explore issues that are projected into the future. (Cobo et al., 2012; Rodríguez-bolívar, Alcaide-muñoz, & Cobo, 2018).

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Therefore, this review aims to evaluate the relevance of energy efficiency in agricultural production systems through technological surveillance.

MATERIALS AND METHODS

Data for this study were extracted from Scopus database, in April 2019, through the search formulas presented in Table 1, which were downloaded in PDF and RIS formats. Linear regressions described as S curves were used as a bibliometric analysis method, using the methodologies proposed by Aguilar et al. (2012) and Kalasin et al. (2019), where the articles published for consecutive years were organized and categorized into: year of publication, articles published and sum of articles published. In addition, each search formula was organized by countries with the highest publication. For this phase, the statistical program SigmaPlot 11.0 (Systat Software Inc) was used, using the 13 models described by the program (sigmoid 3-4-5 parameters, logistic 3-4 parameters, Weibull 4-5 parameters, Gompertz 3-4 parameters, Hill 3-4 parameters and Chapman 4-5 parameters), in which those with the best fit to R^2 and the Durbin Watson (DW) parameter of independence were selected.

In addition, an automated exploration analysis was carried out, following the methodology proposed by Aria and Cuccurullo (2017) with the same search formulas of the previous analysis. The software used was SciMAT (SciMAT-v1.1.04). Subsequently, the file was loaded in RIS format, which allowed to organize the data by words, and then search for similar or plural words to unify them and limit them by the same meaning of plural or singular, while the words that were irrelevant for the context of the study were eliminated, taking into account the knowledge regarding the subject and its context.

Regarding the analysis of technological surveillance, the articles of each of the search formulas used were selected, which were developed for Colombia, taking into account their relationship with the area of agriculture. For both cases, the search periods corresponded to the first article published in the selected database.

Table 1. Search formulas

Search	Formula
Energy efficiency and agriculture	TAK ("*energy efficiency*" AND *agriculture*)
Energy efficiency	ATK ("*energy efficiency*") (LIMIT-TO (DOCTYPE, "ar"))
Energy efficiency and its relationship with soil	ATK ("*energy efficiency*" W/10 "*soil production*") (LIMIT-TO (DOCTYPE, "ar"))
Energy efficiency and its interaction with climate change	ATK ("*energy efficiency*" W/10 "*climate conditions*" AND "*climate change*") (LIMIT-TO (DOCTYPE, "ar"))
Energy efficiency and its interaction with agricultural production	ATK ("*energy efficiency*" W/10 "*vegetal production*" AND *crops*) (LIMIT-TO (DOCTYPE, "ar"))

Source: Authors

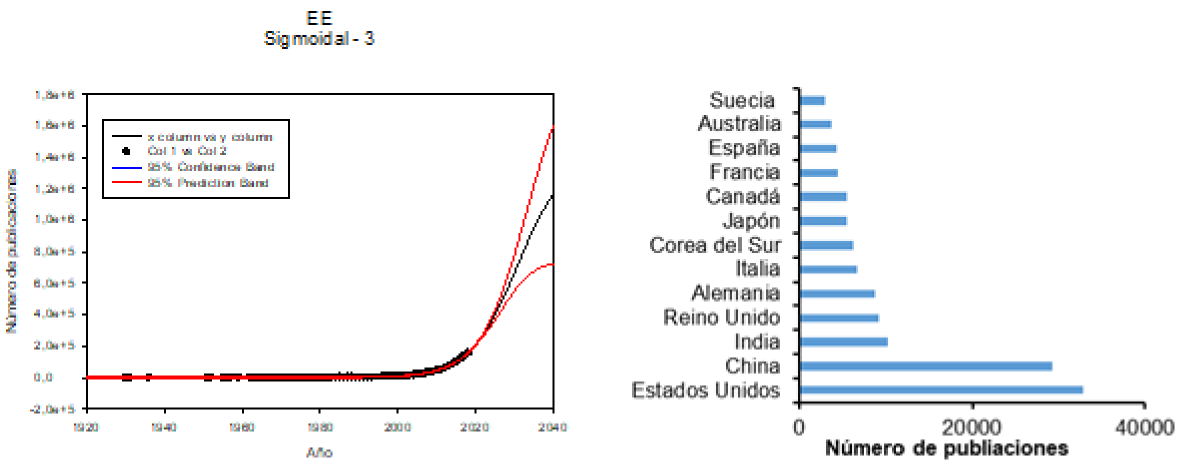
RESULTS AND DISCUSSION

Energy Efficiency

The efficient use of energy flows has become a key strategy for agricultural productions, because it allows the entry and return of energy, keeping it in balance so that the interaction within the production system is stronger, and thereby reducing the environmental impacts and increasing energy return (Smith, Williams, & Pearce, 2014). For this reason, the use of EE has become a key alternative for sustainability and a strategy to face climate change problems, giving priority to renewable sources and conservation of agroecosystems.

According to the data obtained, EE was discussed for the first time in 1930 according to Scopus, with a subsequent gradual increase in scientific research embodied in articles, books and conferences of worldwide impact. Therefore, the search formula expressed the best fit to the 3-Parameter Sigmoidal Model with an accumulated of 157,272 published documents, the contribution of countries such as the United States, China, India and the United Kingdom being significant, highlighting their scientific link in areas such as environmental sciences and agriculture (Figure 1).

Figure 1. S-curve and most widely published countries in the energy efficiency ratio search formula. inflection point: 2030.

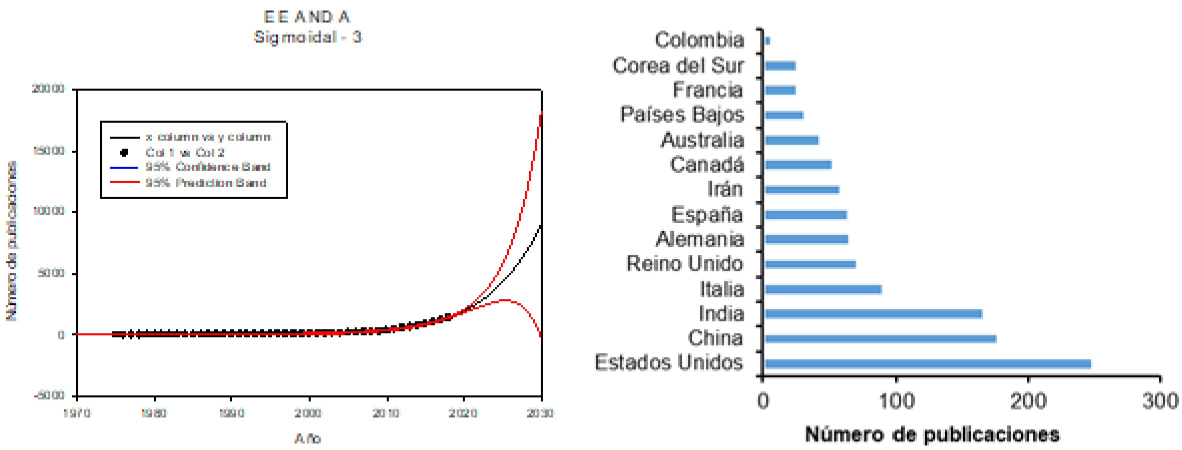


Source: Authors

Energy efficiency and agriculture

The progress of work in agriculture has presented changes during the last decades as a consequence of the population increase and its relationship with climatic factors. Thus, the generation of new strategies applied to work in the agricultural sector are a priority for different national and international entities. In this regard, integrated agricultural production systems as a basis for food security require a foundation on EE for the optimization and management of natural resources, as well as on their environmental impact focused on sustainable development (Álvarez-Jaramillo, Zartha-Sossa-JW, & Orozco-Mendoza, 2018; Rasul, 2016). According to the data obtained in relation to EE, it was evidenced that the first published document was in 1975, with a gradual increase in publications, presenting the best fit to the three-parameter sigmoidal regression model and a turning point for 2020 (Figure 2). According to the documents analyzed, 1,400 were found, with the United States, China, India and Italy being the countries with the greatest contribution to this area of knowledge, with the China University of Agriculture standing out in particular.

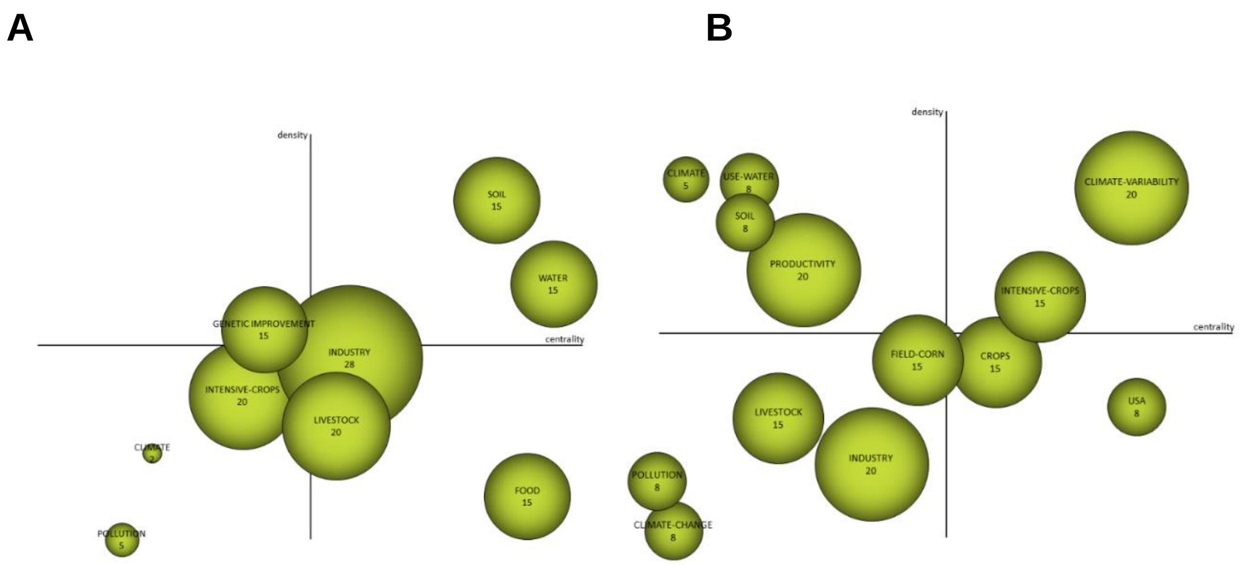
Figure 2. S-curve and countries with the highest publication in the search formula for energy efficiency and agriculture. Inflection point: 2020



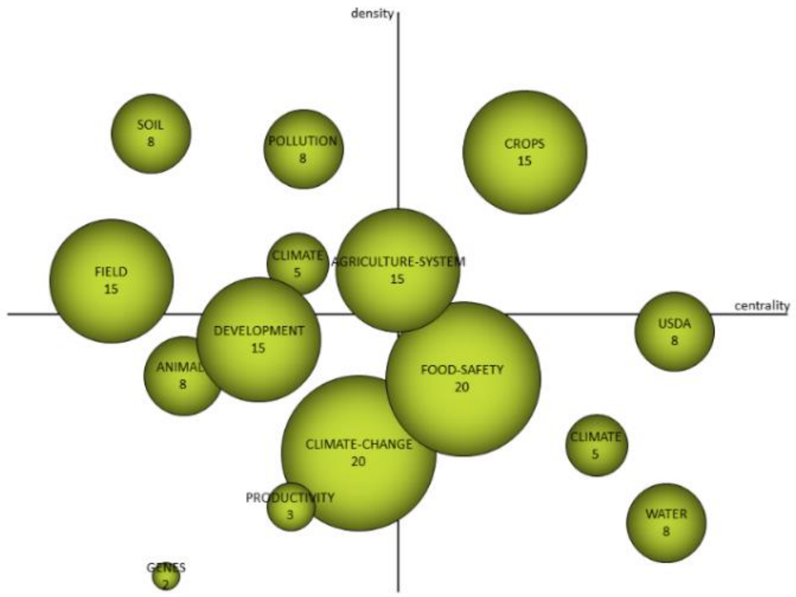
Source: Authors

Likewise, according to the analysis of the strategic maps for the periods between A (1998-2004), B (2005-2011) and C (2012 -2019) (Figure 3), the themes were not very diverse. However, there are themes that emerge, and variation in those that are in motor groups according to their centrality and their density. For period A, only two topics are relevant: Water and Soil. In period B, it is observed that themes such as climatic variability and intensive crops converge, while in period C, crops and agricultural systems are the most outstanding.

Figure 3. Strategic diagrams of publication topics on energy efficiency and agriculture according to Scopus. **A** (1998-2004), **B** (2005-2011) and **C** (2012 -2019).



C



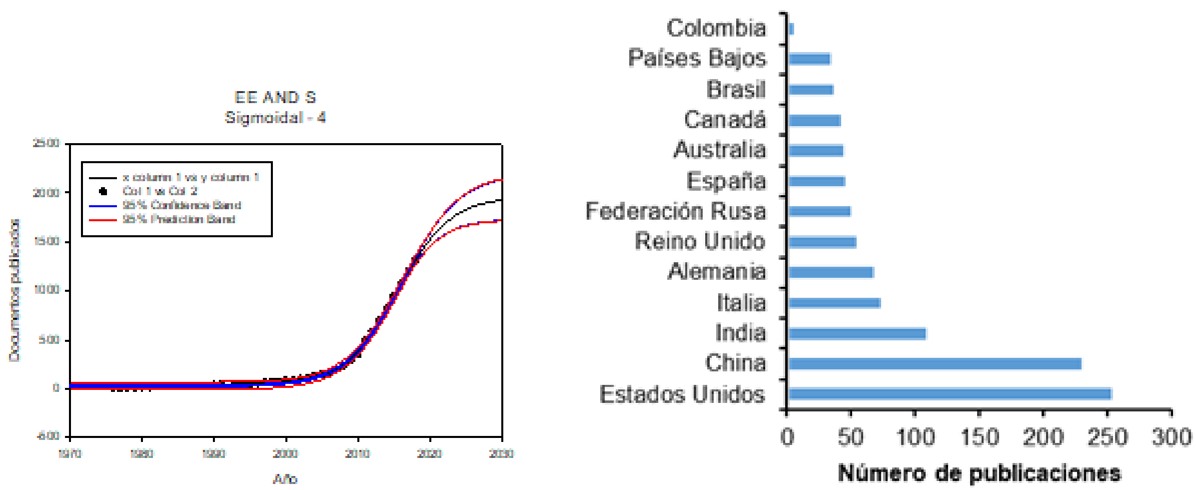
Source: Authors

According to the analysis of the data obtained, the different approaches that scientific research has had in relation to EE and agriculture are the results of the transfer of technologies to production systems, but also to the effects of climate change, (Woods et al., 2010), studied mainly by the USDA United States Department of Agriculture and agreeing with the countries of greatest contribution to the area. Thus, intensive activities such as bovine production, intensive crops and the industrialization of agriculture, seek new alternatives that generate less impact on the environment and adaptability to extreme agro-climatic conditions (Harvey et al., 2018; Kabir, Alauddin, & Crimp, 2017).

Energy efficiency and its relationship with land use

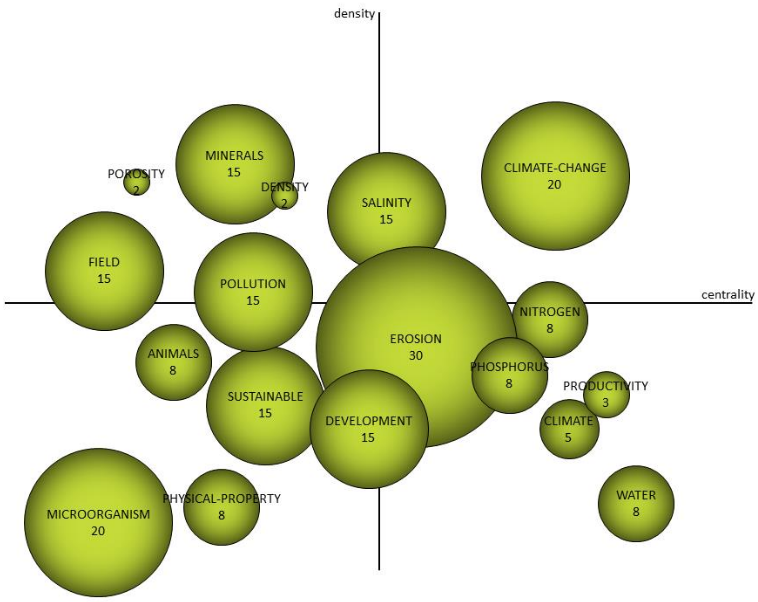
Soil is one of the main resources in agricultural production systems, which expresses different characteristics according to its parent material and climatic conditions (García, 2006; Hamidov et al., 2018). However, the development of anthropic work has generated changes in evolutionary times and the behavior of physical, chemical and biological characteristics. This is why the data obtained show remarkable importance in the search for efficient alternatives in soil management, however, developing countries such as Colombia are in the last positions in relation to their research interest compared to the advances made by American, European and Asian countries (Figure 4).

Figure 4. S-curve and most widely published countries in the search formula for the relationship between energy efficiency and land use. Inflection point: 2015.



Source: Authors

Figure 5. Strategic diagram of publication topics on energy efficiency and land use according to Scopus, in period C (2012 -2019)



Source: Authors

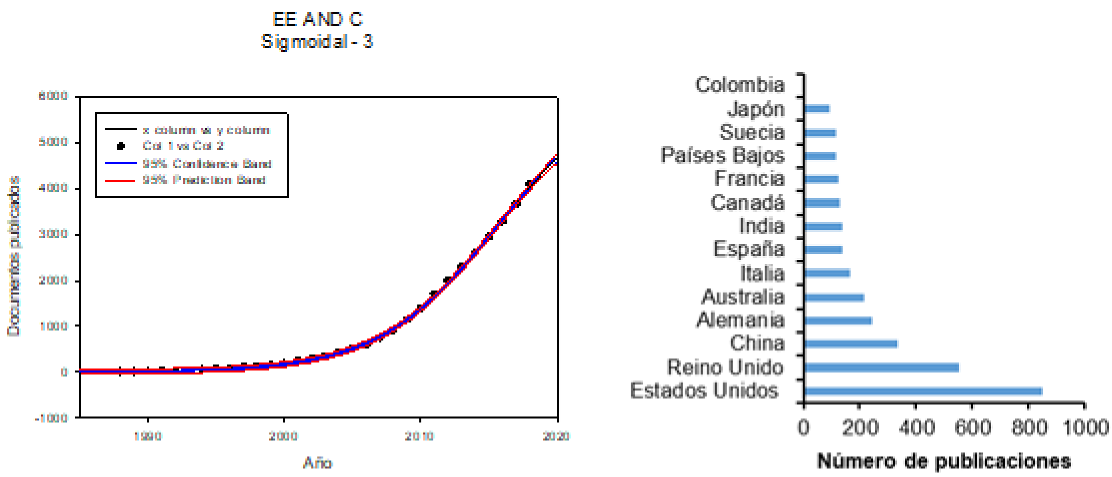
According to Figure 5, for period C, it discriminates 18 themes with the highest density of areas mainly related to climate change, salinity and erosion. While in periods A and B the themes did not change significantly, so the driving themes for these were: food, climatic variability, animals and crops.

According to Casierra-Posada, Carreño-Patiño and Cutler (2017), problems such as salinity are the result of the indiscriminate use of fertilizer materials, which has also generated eutrophication problems in water sources and in many cases, modifications in the soil structure. In addition, the effects of climate change, the situation worsens, particularly with longer periods of drought and rain, which affects first-hand production systems and therefore the economy of producers (ECLAC, 2018).

Energy efficiency and climate change

Climatic factors are a subject of constant research given its dynamics of change and the susceptibility that it presents due to external effects, however, there is little interest of businessmen and governments to address this issue from scientific research (Hoffman, 2005), which according to the bibliometric analysis is reflected in the inflection point (2015) (Figure 6). However, countries such as the United States, United Kingdom, China and Germany have been the pioneers in research related to mitigation and adaptability to climate change, mainly in the construction and implementation of strategies that allow the reduction in the emission of carbon dioxide. (CO_2), nitrous oxide (N_2O) and methane (CH_4), as a result of agricultural work.

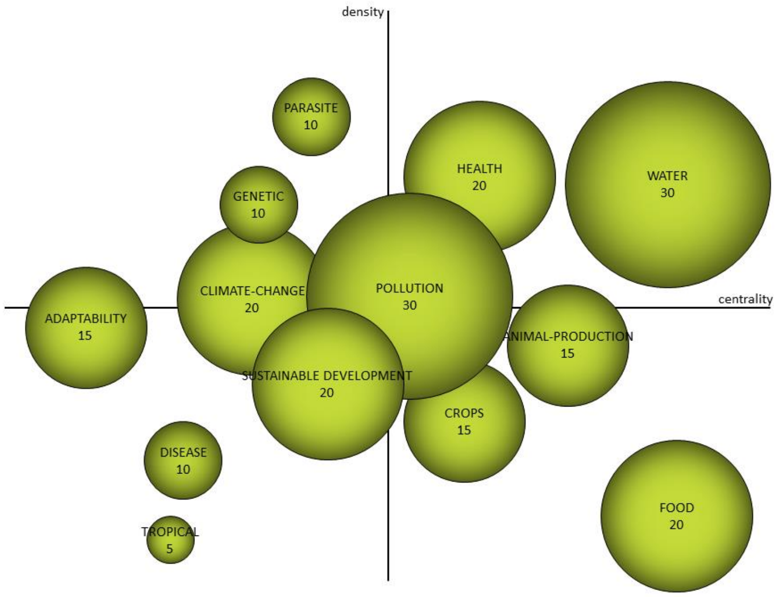
Figure 6. S-curve and most widely published countries with a search formula for the relationship between energy efficiency and climate change. Inflection point: 2015.



Source: Authors

Among the most relevant strategies to face climate change according to the Scopus database, agroecology is the main alternative. The above, due to the fact that numerous studies have determined that the application of ancestral knowledge and its interaction with scientific knowledge has generated positive responses in the return of energy flows, due to the fact that their entry and exit is reduced, and therefore, the interaction within the systems is strengthened, resulting in sustainability and resilience of non-renewable resources (Altieri et al., 2015; Gómez-Echeverri, Ríos-Osorio, & Eschenhagen, 2017; Kmoch et al., 2018), according to figure 7, where the issue of water is the driving force in the period between 2012 and 2019, in addition to areas with greater centrality and density such as health, pollution and animal production. While for periods A and B, the driving themes were focused on the climatic factors that influenced the industrial production of crops and animals.

Figure 7. Strategic diagram of publication topics on energy efficiency and climate change according to Scopus, in period C (2012 -2019).



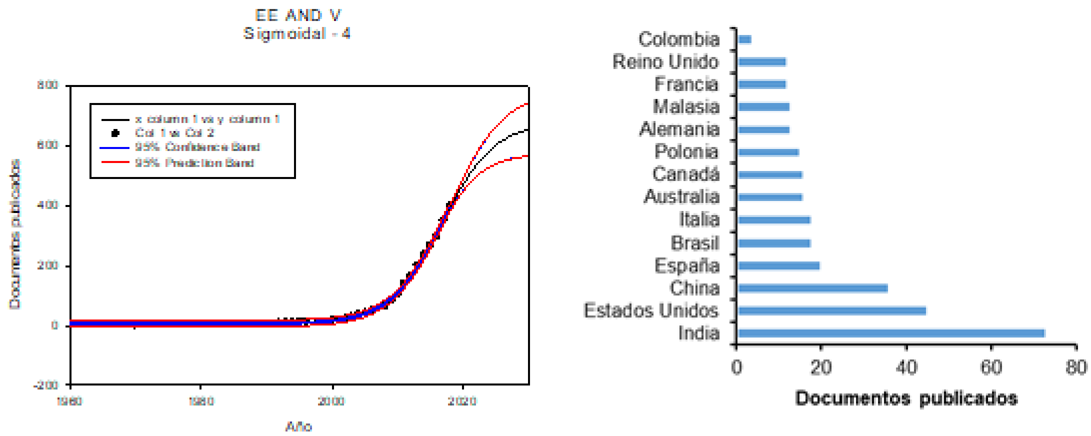
Source: Authors.

The data in Figure 7 agree with the different campaigns carried out by the Economic Commission for Latin America and the Caribbean ECLAC in the 2030 sustainable development goals, where the care of natural resources, the vulnerability of human health, the strategies of production in agriculture and the implementation of plans for adaptability to climate change are the priority (ECLAC, 2016; ECLAC, 2018).

Energy efficiency and crops

The crop production of food and industrial interest are one of the main lines that has generated the greatest environmental impact, mainly as a consequence of the uncontrollable use of fertilizers, pesticides, water, constant tillage of the soil and genetic erosion, which has resulted in, contamination of natural resources and alteration of biogeochemical and biological cycles (Kukal & Irmak, 2018; Moore et al., 2017). According to results of the search formula used, 399 published articles were found, where the participation of countries such as India, the United States and China is highlighted (Figure 8).

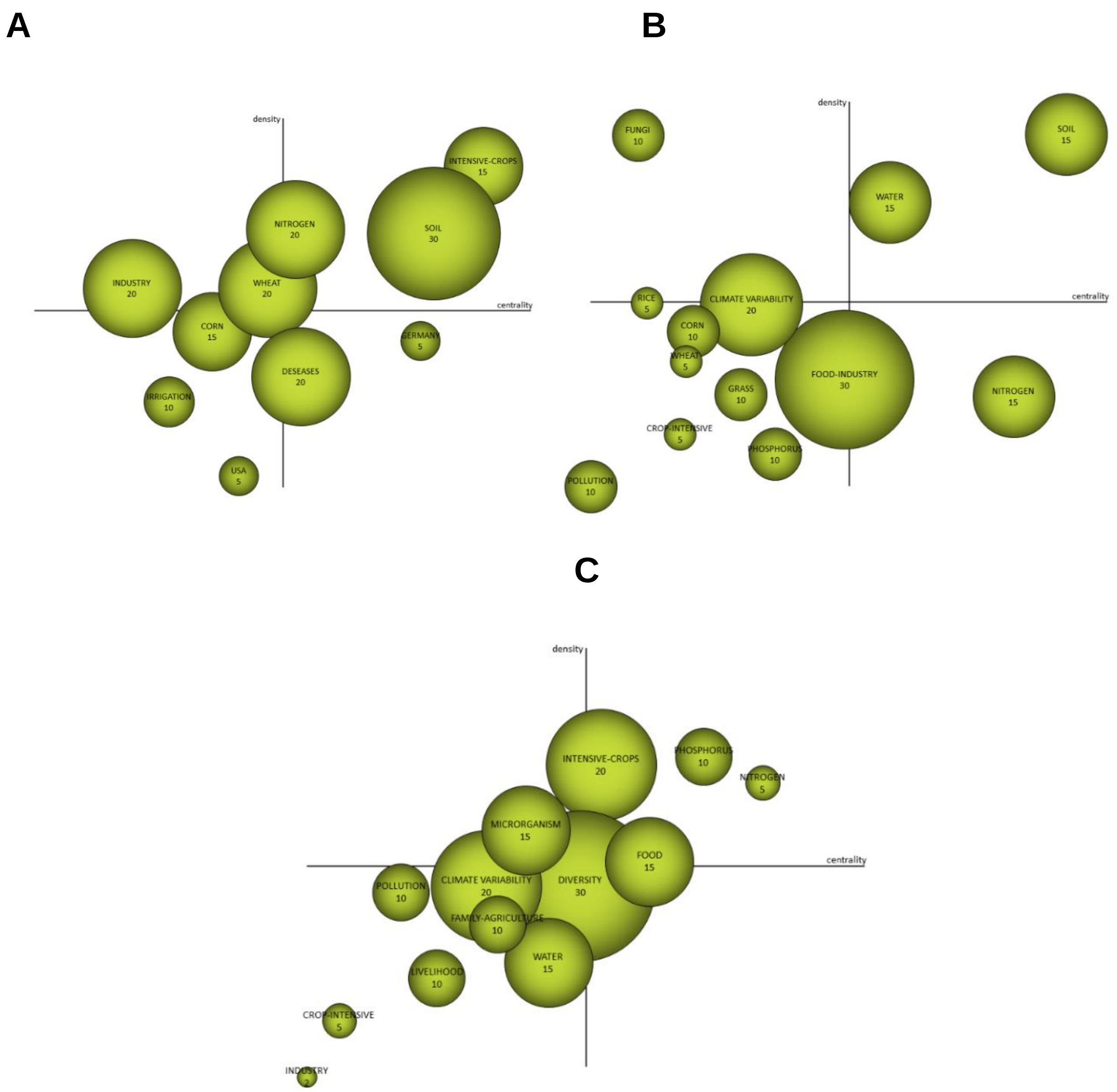
Figure 8. S-curve and most widely published countries with a search formula for the relationship between energy efficiency and crops. Inflection point: 2016.



Source: Authors

Consequently, crop production has been affected by the effects of climate change, which has caused research centers, universities and public sector institutions to focus their efforts on the search for crops that have the capacity to tolerate conditions. adverse agroclimatic conditions, the rescue of native crops becoming relevant, particularly in Latin America, where tubers and some cereals are the main strategy, due to their broad adaptive capacity as a result of their great genetic diversity, which allows them a marked reduction in external energy use (García-Parra & Plazas-Leguizamón, 2019; Korres et al., 2016; Reguera et al., 2018).

Figure 9. Strategic diagrams of publication topics on energy efficiency and crops according to Scopus. A (1998-2004), B (2005-2011) and C (2012 -2019).



Source: Authors

Giving to the previous Figure, the periods between 1998 and 2011 show in particular driving themes such as soil, water and intensive crops, in contrast to the green revolution, characterized by the extraction of nutrients from the soil to sustain monocultures, and as a consequence, the low availability of nitrogen N and phosphorus P has been present in recent years; An aspect that has generated in agronomic processes a constant requirement of external energy, which is normally supplied through chemical synthesis fertilizers. However, the use of organic fertilizers made with raw materials from the same productive agricultural units has been preserved, as an agroecological alternative with energy efficiency (Krebs, 2018; Plazas-leguizamon & García-Molano, 2014; Wezel et al., 2014).

According to the analysis of the information, Colombia has focused on managing the efficient use of fossil fuels and lighting energy. Higher education institutions such as the Universidad del Cauca University, Universidad Santo Tomás

University-Bogotá Campus, Universidad Industrial de Santander University, The National University of Colombia-Manizales Campus, Universidad del Valle University, Universidad del Bosque University, and Universidad Jorge Tadeo Lozano University, stand out as pioneers in EE in Colombia, according to Scopus database.

Table 2. Articles from higher education institutions and research centers in Colombia that stand out on issues related to Energy Efficiency and agriculture

Search formula		TAK ("*energy efficiency*" AND *agriculture*) AND (LIMIT-TO (AFFILCOUNTRY, "Colombia"))		
N°	**Title**	**University**	**Journal**	**Source**
1	A multi-criteria approach for comparison of environmental assessment methods in the analysis of the energy efficiency in agricultural production systems	Universidad el Cauca - Popayán	Journal of Cleaner Production	Felipe, Rodas, Cristian, Carlos y Mu, (2019)
2	Estimation of energy efficiency in solar photovoltaic panels considering environmental variables	Universidad Santo Tomás de Aquino -Bogotá	IOP Conference Series: Materials Science and Engineering	Martinez y Forero (2018)
3	Methodology for the Life Cycle Assessment (LCA) in combustion processes where the fuel is pelleted agricultural biomass	Universidad Industrial de Santander	Chemical Engineering Transactions	(Villabona & Kafarov, 2018)
4	Energetic and environmental assessment of thermochemical and biochemical ways for producing energy from agricultural solid residues: Coffee Cut-Stems case	Universidad Nacional de Colombia -Manizales	Journal of Environmental Management, Volume 216, 15 June 2018, Pages 160-168	García, Peña, Betancourt y Cardona, (2017)
5	A comparison of energy use, water use and carbon footprint of cassava starch production in Thailand, Vietnam and Colombia	Universidad Del Valle y Centro Internacional de Agricultura Tropical CIAT - Palmira	Resources, Conservation and Recycling	Tran et al. (2015)
6	Energy efficiency procedures for agricultural machinery used in onion cultivation (*Allium fistulosum*) as an alternative to reduce carbon emissions under the clean development mechanism at Aquitania (Colombia)	Universidad El Bosque	IOP Conference Series: Materials Science and Engineering	Ochoa, Carrillo y Gutierrez (2014)
7	Extending the input–output energy balance methodology in agriculture through cluster analysis	Universidad Jorge Tadeo Lozano	Energy	Bojacá, Casilimas, Gil, & Schrevens, (2012)
8	Sustainable ethanol production from lignocellulosic biomass - Application of energy analysis	Universidad Industrial de Santander	Energy	Ojeda, Sánchez y Kafarov, (2011)
9	Energy assessment of peri-urban horticulture and its uncertainty: Case study for Bogota, Colombia	Universidad Jorge Tadeo Lozano	Energy	Bojacá y Schrevens, (2010)

Source: Authors

According to table 2, Colombia has generated initiatives regarding energy efficiency in different areas of agriculture, and particularly in crops. This highlights its importance, when talking about agricultural production systems, as in the case of articles; number one, seven and nine, which manages to determine the energy input and output flows through the evaluation of the Energy Efficiency of the productive agricultural units, through the ecological footprint, the analysis of the flow of materials, the analysis of networks, the analysis of the life cycle, of exergy and emergy. With this, the established by García-Molano (2016) is retaken, who recognizes that the sustainability of agrarian systems is based on the interaction between the soil, plant, climate and man, which seeks to obtain food, substances and materials to satisfy the needs, with relevance in the resilience of resources in each one of the processes of the agricultural work.

On the other hand, the importance of the change in climatic conditions has generated that technological equipment that uses renewable energies for its operation, manages to be designed according to the context (Chel & Kaushik, 2011), where variables such as wind speed , temperature, relative humidity, radiation and precipitation, are determinants of the equipment's development power, being its applicability of great interest for fuel reduction in tasks such as irrigation, fertilization, harvest and postharvest for crop production, while in livestock productions, the use of light, thermoregulators, electrical instruments in animal benefit plants are the equipment and facilities with the highest demand for external energy (Gingrich & Krausmann, 2018; Santika et al., 2019).

CONCLUSIONS

The analysis of technological surveillance shows the importance of energy efficiency in the different links of agricultural production systems, having relevance the aspects related to crops to obtain food for man and animals. Likewise, it recognizes the influence of climate change as a factor resulting from the constant demand for external energy and proposing the exchange of scientific knowledge for adaptability to extreme agroclimatic conditions. In addition, it recognizes that countries such as the United States and India have been the pioneers in scientific activities of Energy Efficiency in agriculture, and highlights agroecology as the area called to colonize the countryside throughout the world.

The development of this research presented some theoretical limitations, correlated with the search for scientific information mainly from the conception of agrarian processes and their relationship with environmental sustainability, given its involvement in natural processes, seeing the need to match energy consumption from the conception of the economic development of communities, allowing to understand energy efficiency and the relationship of the need for dissemination, according to the local contexts, so that it contributes to the exchange of knowledge between producers, academics and researchers, in order to favor and establish social appropriation on the subject, in the long term.

The authors suggest future research based on the results and the generated discussion presented from the contribution of the basic sciences, managing to correspond the development of soil recovery, contributing to urban and rural localities and their incorporation of new technologies, for their analysis, replication and diversification concerning energy recycling techniques, such as composting in bioremediation processes applied to reduce costs, contributing to social welfare, productive capacity and the potential development of an economy, from the revitalization of food security at the global level, for the benefit of territories and communities.

AUTHOR'S CONTRIBUTION

First author: methodology, research, data analysis, conceptualization, writing, original draft. Second author: research, conceptualization, writing, revision and editing. Third author: research, logistics, review and editing. Fourth author: data analysis, review and editing. Fifth author: supervision, conceptualization, writing, revision and editing.

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