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Review

On-Farm Renewable Energy Systems: A Systematic Review

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Abstract: Over the years, energy is becoming an essential factor with an impact on social, economic, and environmental aspects. More than 2.5 billion people are connected to agriculture worldwide, so the importance of agricultural energy production has become increasingly important. This study provides a comprehensive review of renewable energy, environment, and farm publication trends. Two hundred articles from 1988 to 2022 were analyzed, with special attention devoted to the last three extreme years, using the Scopus database and the Bibliometrix tool for analysis and visualization. Research on this topic experienced significant developments after 2008, with many fluctuations being revealed. Historically, China and the USA were the most productive countries in agricultural energy production advancements. However, in the last three years, the research center's respective contributions have undergone major changes. China maintained its dominance, but the importance of the USA fell sharply, and new centers (India, Poland) appeared. Biogas is the most popular method which is used and searched in this area between 1988–2022 since it includes both sustainability and locality. However, between 2020–2022, the importance of the circular economy has been highlighted in the literature. Complex energy systems, dual use of land, and energy storage might be the most important challenges for future research.

Keywords: Bibliometrix tool; agriculture; environment; locality; sustainability; circular economy; COVID; Russian-Ukrainian war

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1. Introduction

The sustainability of energy utilization is one of the most important driving forces for the development of renewable energy [1] due to the fluctuating prices and availability of conventional fossil energy sources. Sustainable agriculture has an enormous potential in renewable resources, while the low-carbon energy supply and the diversification of energy structure have become the direction of energy transformation through the promotion of renewable resources.

The intensive economic development of the last years and decades has been accompanied by considerable energy use worldwide. For most countries, especially developing and emerging countries, greenhouse gas emissions have increased significantly in recent decades. This has exacerbated the problems of global climate change, environmental pollution, and energy security. This has led to important milestones, such as ratifying the Kyoto Protocol and the Paris Agreement and developing and prioritizing further programs and initiatives to promote climate action. These commit participating states to reduce greenhouse gas emissions [2].

As fossil fuels, among their many drawbacks, are a significant contributor to global warming, the international focus is increasingly turning to a sustainable development agenda that requires cleaner and renewable energy sources [3]. Renewable energy sources play a vital role in economically efficient and technically feasible strategies to reduce greenhouse gases. Numerous studies and policy reports emphasize the indispensable and fundamental role of non-fossil energy sources in diversifying energy supply sources and mitigating environmental and energy problems [4,5]. These energy sources, particularly solar, wind, hydro, biomass, and geothermal energy contribute to various economic, social, and environmental goals [6]. Their use can, among other benefits, contribute to energy security, reduce energy costs and dependence on fossil fuels, foster local economic development, and job creation, improve air quality and, thus, human health, and reduce negative environmental and climate impacts [7,8]. These benefits are increasingly driving countries to turn to renewable energy sources [9]. By the second half of the 2020s, renewables are expected to overtake coal in electricity generation, and by 2050, renewables will account for 50% of global electricity generation [8].

Although the amount of organic matter potentially available is almost infinite, its diversification limits energy use. Solar energy allows plants to sequestrate 125 gigatons of carbon from the atmosphere per year, equivalent to using 300 million tons of oil per day [9]. However, a Hungarian study found that among sustainability attributes, biomass was less important for GHG emissions than land demand and increasing local incomes [10]. This fact highlights the necessity of studying energy self-sufficiency at the farm level.

1.1. The Impact and Potential of Renewable Energy Production

The share of renewables in global energy consumption (in 2021:595 EJ/year [11], is estimated at only 14% according to WBA (2021) [12], with the largest share (70%) coming from biomass, which will play a major role also in future energy systems [13]. Conventional utilization methods account for 85% of the biomass used for energy purposes, liquid biofuels for 8%, and biogas for 7% [12]. However, energy use of biomass accounted for only 27% of global biomass production (1260 EJ/year, [9]), food and feed for 55%, biomaterials for 8%, while other uses and losses account for about 10%. In the EU, the structure differs slightly, with less energy (21%), higher food and feed (59%), and biomaterials (about 20%). At the same time, the demand for biomass is growing; EASAC (2017) [14] estimates that food demand will increase by 60% by 2050. However, limited land and sustainability criteria may limit future biomass use for energy [15], which according to Popp et al. (2013) will be in the range of 100–300 EJ/year by 2050, contributing 25–33% to the future global energy mix, according to [16]. IEA (2019) [17] estimated that the fastest growth would be expectable in solar energy, followed by wind and hydropower.

Globally, the promotion of the use of biomass in household applications and energy generation is conducted by all agricultural countries, and most governments have introduced schemes, incentives, and methods to increase investments in the generation of energy from renewable energy sources [18]. In addition, for dominant EU countries (France, Germany, and Italy), biomass is considered the main source of renewable energy, accounting for nearly 60% [19]. Countries such as The Netherlands, Germany, and Belgium produce the most energy from agriculture in the European Union. Germany can serve as an example of the successful use of renewable energy sources since a significant part of agricultural waste is already used there to produce energy (especially biogas), and, for example, the gross (theoretical) potential of the biogas industry in Germany is estimated to be 100 billion kWh of energy by 2030, which will equate to approximately 10% of the energy consumed by the country [20]. In connection with the annual increase in the consumption of thermal and electric energy in the agricultural sector and rural areas, it becomes necessary to improve power supply systems, heat supply, as well as compliance with the rational use of energy resources and the search for alternative methods and technologies for generating energy through the use of non-traditional renewable energy sources [21].

As an EU country, Hungary is an export-oriented economy with profitable opportunities in agriculture. Agricultural residues are rich in resources and are also an important source of raw materials for the biomass briquette fuel industry in the future. [22] reviewed the sustainability of the Hungarian agricultural woody biomass pellet fuel market and summarized the biomass energy industry chain of agricultural and forestry residues.

A study in Croatia showed that biomass is a great energy source, and its apropos management practices would create value for energy production [23]. In Croatia, maize stalks have the highest energy potential for generation, followed by soybean and wheat straw and the residues of grapevine pruning. Considering the residues of conventional crops and waste of agro-industrials, the country could provide important quantities of biomass in agricultural land, which would participate in total energy production, reducing energy imports, increasing the share of renewable energy, and reducing the environmental pollution.

Based on India's current energy structure and development, [24] pointed out that renewable energy plays a significant role in solving India's energy poverty and optimizing the energy structure. The sustainability of India's energy sector is closely related to the development and utilization of renewable energy. By selecting the data of 31 OECD countries and 49 non-OECD countries from 1990 to 2010 to analyze the panel data and establish the panel vector error correction model, the conclusion is that in developed countries, economic growth has a one-way causal relationship with renewable energy consumption. In less developed countries, economic growth and renewable energy have a two-way causal relationship [25]. To address these challenges, sustainable agriculture is constantly being enriched. Its leading role is to increase the use of renewable energy sources as a proven alternative to resource conservation. Integrating renewable energy into sustainable agriculture and livestock is critical to access modern energy technology on any farm, regardless of location or power transmission infrastructure. This is a great opportunity not only to reduce energy and carbon costs but also to improve the standard of living in rural communities, as well as increase food security.

Replacing fossil fuels with renewables is a serious challenge, as ensuring the most parsimonious balance between environmental friendliness and energy efficiency in practice is significantly different from laboratory experiments [26]. Previous mainstream economic growth models have historically been far too parochial in their view of renewable energy's contribution to economic growth [27]. Nowadays, this is no longer the case, but—as Geng et al. (2016) [28] concluded in an economic analysis of six developed country economies from 1980–2010—the impact of technological innovations on renewable energy production is a long-term process.

Regarding the demand for renewable energy, Li et al. (2020) [29] discovered that eco-innovation, income, and human capital were the main drivers. In addition, Su et al. (2021) [30] emphasized the role of fiscal decentralization and political risk.

Ji et al. (2020) [31] analyzed global supply chains for biomass use and the transfer of environmental benefits from primary extractors to final consumers; final trade-in biomass use and imported service products accounted for 49% of final U.S. imports. For Australia, imports of services and products accounted for 42% of its final imports. Agricultural, food, manufacturing, and service products accounted for 21%, 38%, 20%, and 20% of their imports. The share of agriculture, food, and manufacturing in Cyprus, Brazil, and China in total final exports was 78%, 80%, and 75%, respectively. This partly reflects the region's reliance on agriculture and manufacturing. Analyzing the volume of existing research, the authors found that publications on each of the four main biomass sources (agriculture, forestry, waste, and others) account for about a quarter of the 4911 extracted bioenergy records [32]. The most important renewable energy source is biomass, and current global energy supplies are about 45 $\pm$ 10 EJ. Energy potential in biomass up to 2050 residues from agriculture will reach about 15–70 EJ [33], and approximately 40% of this total would originate from agricultural residues and waste (37–66 EJ) [33,34]. On average, biomass accounts for less than 10% of the total energy supply in industrialized countries but as high as 20–30% in developing countries. In some countries, biomass provides 50–90% of total energy needs. Ethanol produced from sugar cane and additional from corn and cereals account for 1.5 EJ of global transportation fuel use. Especially in Europe, Brazil, and Asia (most notably Japan, China, and India), there is a growing interest in transporting biofuels. Increased biomass production for biofuel in agriculture could lead to higher land and food prices, implying competition with food and feed production. However, biomass potential depends on yield, product ratios, and total agricultural land area [33].

All the literature mentioned above highlights that renewable energy production is an important factor worldwide because the energy produced has less impact on global warming, provides jobs for the local community, and can promote energy self-sufficiency and local economic development.

1.2. Environmental Considerations

Although on an upward trend, renewable energy production and consumption are still limited due to technological barriers and relatively high costs in many countries [2]. The economics of renewable energy devices also depend largely on the current market situation, supply and demand conditions, potential feedstock supply problems, and the regulatory environment in a country or region. Examples include different crises, such as the military conflict in Ukraine in 2022 and the accompanying energy crisis. The supply risks of fossil fuels have also led to increased competitiveness of renewables. Still, they have also caused supply problems (e.g., inventory shortages, capacity problems) and other difficulties (limited flexibility of energy systems and infrastructure) in the renewable sector. Sayed et al. (2022) [35] highlighted in their research that although renewables have become more prominent over the last few decades, they can also negatively impact the environment, which can be considered a disadvantage. Assessing this requires more consideration and appropriate precautions. Emphasis will be placed on examining the entire life cycle of renewable energy equipment, from planning and design, through construction and installation, to end-of-life (recycling or disposal).

Amponsah et al. (2014) [36] reviewed and synthesized the knowledge and estimates of lifecycle greenhouse gas emissions from renewable electricity and heat technologies. A total of 79 studies reviewed covered life cycle assessment (LCA) of renewable electricity and heat generation based on wind, hydropower, marine technologies (wave and tidal), geothermal, solar, biomass, waste, and heat pumps. Based on the study, GHG emissions are higher for conventional (fossil) sources (pprox.. 500–1100 gCO_2eq/kWh, from natural gas to lignite) than for renewable sources. Although the most commonly used technologies of nuclear-based electricity generation have relatively low emissions, the disposal of radioactive materials causes a higher environmental burden on the environment [37]. Among renewables, waste treatment and biomass technologies are notable for their potentially high GHG emissions, primarily due to the feedstock and inputs required for their production. For example, the estimated carbon dioxide emissions of electricity generated from the combustion of chips from short rotation coppice energy plantations are between 60 and 270 gCO_2eq/kWh, while for straw, the range is between 200 and 550 gCO_2eq/kWh [38]. In terms of environmental factors and emission characteristics, it is necessary to point out that, in addition to CO_2, several other pollutants can be mentioned (e.g., NH_3, NO_x, and SO_2, which contribute to acidification and eutrophication) [39].

Moreover, renewable technologies, particularly biomass production and solar energy, have a significant land demand when the whole supply chain is considered [40]. The available literature suggests that the land use of energy industry chains for fossil energy sources during their life cycle may be similar to or higher than the land use of renewable energy sources [41,42]. There are also (site-specific) impacts on ecosystems and biodiversity that are closely linked to land use. Sathaye et al. (2011) [40] implied that biodiversity impact assessment is not currently classified as part of LCA methodologies, and although efforts are being made to identify and integrate appropriate indicators [43], there is currently no comprehensive methodology available for this purpose. Campos-Guzmán et al. (2019) [44] also emphasize that LCA alone does not lead to a comprehensive sustainability assessment and suggest combining it with other methodologies as a sufficiently sound framework for assessing energy systems.

The energy crisis and the increase in fossil fuel prices have hit energy consumers worldwide. This current situation significantly impacts the socio-economic dimensions as energy is essential for all sectors. The study of Chomać-Pierzecka et al. [45] elaborates on the role of hydropower in energy security and its importance in the future of energy transition. As nearly 71% of the globe's surface is covered by water, it represents great potential in energy production. It is considered to be a great source of energy generation.

Renewable energy sources can help to improve the environment by reducing exposure to indoor pollutants, less GHG emissions, less agricultural waste, and fewer energy costs.

1.3. Importance of RES in Agriculture

While agriculture has significant potential and untapped opportunities to contribute to Sustainable Development Goals, there are also some environmental risks and negative trends. In order to mitigate and avoid adverse environmental impacts, a sustainable production, consumption, and distribution chain need to be established to increase agricultural productivity, ensure food security and provide better nutrition [46], in line with the goals set in the areas of energy production and use and climate protection. Achieving the 2030 goals will require a global transformation of the food and agriculture system that considers climate change [47].

Agriculture is an essential sector due to its many economic, social, and environmental functions, particularly its role as a producer of raw materials, energy, food, and jobs [48]. However, in most cases, agriculture leads to an increase in water, land, and carbon footprints. Agriculture accounts for 70% of global water withdrawal, e.g., livestock and crop irrigation [49]. In addition, greenhouse gas emissions and carbon footprint increase during the primary production phase, when livestock are being bred, the soil is being cultivated, and agricultural inputs are being used. The land footprint of food production also increases over time [50]. Farms using old technologies and fossil fuel-based inputs can cause environmental damage and hinder the achievement of Sustainable Development Goals (SDGs). Agricultural production is responsible for about 20% of global CO_2 emissions [51] and as this negative trend exacerbates global environmental problems, reducing agricultural emissions is a critical issue for sustainable development [52,53]. According to the OECD/FAO (2022) [54], agriculture is one of the three largest contributing sectors to climate change: with a share of about one-third of the energy sector, it has approximately the same contribution to anthropogenic GHG emissions as an industry, with a share of 22%. As fossil fuels increase pollution and damage agricultural soils, renewable energy sources benefit farmers as they compensate for economic and environmental losses [55]. Renewable energy sources can be used for various purposes to support agricultural activities, such as irrigation, heating, cooling, product drying, and soil improvement [56]. In addition, green investments can also be made in agriculture to mitigate environmental problems. More investments are needed in the agricultural sector to address groundwater pollution, forest degradation, and resource depletion [57].

The partial or complete substitution of the fossil energy demand of different farms and agricultural enterprises and the positive environmental impacts that can be achieved depends largely on the type of renewable energy source or combination of renewable energy sources.

According to the UN (2021) [58], the agri-food sector uses large amounts of energy. In 2019, the sector was responsible for 16.5 billion tons of GHG emissions, from which farm gate contributed 7.2 billion tons, land use change with 3.5 billion tons, whereas 5.8 billion tons from supply-chain processes. An Indian case study researched using biomass residues for electricity production and the role that this source can play in creating self-sufficiency in terms of electricity production in rural areas. According to WBA (2021) [12], it is known that biomass is a great source of energy production, and its share in the primary energy supply on the world scale is 11.8% (55.6 EJ), considered to be the largest source of renewable energy worldwide. Whereas for India, this source of energy is highly available due to the agricultural sector, which has a 17% share of GDP. Researchers studied the estimation of the potential of crop biomass of the whole country, which is concluded to be around 450–686 million tons, whereas the annual surplus of biomass is 150–213 million tons which can be used as a huge generator in terms of energy self-sufficiency [59]. The study of the Bhawan Bahadur Nagar block showed that the potential from surplus biomass per-capita electricity was 655.1 kWh/capita, which was considered to be higher than the current consumption per capita (350 kWh/capita) and indicates that the block can achieve energy self-sufficiency in terms of electricity from this surplus of biomass. Moreover, the energy GHG emissions could be lower than coal energy production, from 51,956.4 t CO_2eq. to 16,761.6 t CO_2eq. It should be taken into consideration that there also exist barriers to developing biomass energy production technology.

The use of renewable energy sources is driven by increasing energy demand and self-sufficiency [60], and the agricultural sector is particularly important in this aspect [61]. Currently, forest biomass accounts for the largest share of biomass used for energy purposes [12] which can be considered an opportunity for future energy production. However, the spread of agricultural innovations and increasing crop yields could significantly reduce the trade-off between food and energy production [62]. Ref. [12] estimated that with the right agricultural policies, around 240 million ha of arable land (5% of the current arable land) could be saved for energy crops by 2035.

The previous studies prove that there is significant potential for agricultural involvement in producing and consuming renewable energy that helps them save money, tackle climate change, increase local development, farm self-sufficiency, and decrease energy costs.

1.4. Significance and Possibilities of Energy Self-Sufficiency in Farms

Solar energy has many applications and is one of the least developed renewable technologies being applied to agricultural use [63,64]. According to Pascaris et al. [64], solar energy can be an integrated part of the agriculture sector through agrivoltaic projects that are considered an innovative opportunity to maintain the agricultural function of land while increasing solar generating capacity. Furthermore, the study of Elahi et al. [63] analyzed the attitude of farmers in terms of green energy. According to their results, there is a negative relationship between the costs of green energy technology and their willingness to install a PV water pump and pay extra for energy generated from green sources. Concretely, educated young farmers that are wealthier in financial aspect were expected to pay more for green electricity. Solar technology helps to develop economic activity and increase the productivity of agriculture, but also to improve the quality of life of the rural population [65–68]. The role of the farmers, access to land, and education in the generations of renewable energy from farms have an impact on energy sustainability. According to Kovách et al. (2022), the pursuit of innovative and sustainable precision farming does not depend on farmers' age. It is widely believed that the successful practice of sustainable precision and organic farming requires more experience and a wide network of contacts [69].

Biofuel utilization, primarily livestock effluent and municipal solid waste, have great potential. Combining waste management and alternative energy in one direction seems logical for agriculture since the intensive development of animal husbandry and poultry farming prescribes the development of environmental waste disposal methods [15,70]. RES are successfully used in animal husbandry, fodder production, peasant (farm) households, and the rural residential sector. They are used for drying agricultural products, heating livestock buildings and heating process water, autonomous power supply to farms, and water lifting. The energy obtained from RES can be used for various purposes [71]. For example, with the help of electricity from a wind power plant (WPP), it is possible to ensure the operation of a pumping station that supplies water for irrigating land, water supplying settlements, and watering livestock. In addition to wind turbines, electricity can be obtained from photovoltaics by converting solar energy (thermodynamic method) or using biogas to operate gas-generating stations. Producing energy from biogas using agricultural waste will contribute to managing waste from livestock and poultry farming, helping farmers reduce the needed area for storage of wastes and maintaining environmental safety, reducing GHG emissions charges for farmers, and stimulating the development of local economies [72]. In European Union, there is strong support for energy generation from biogas. Germany has the highest energy production from biogas, followed by Italy and Austria. This information creates opportunities for the future development of other countries in this regard.

Other great sources of renewable energy are agrivoltaics (APV) and solar panels for agriculture, including growing various crops under ground-based photovoltaic panels. Although this concept has been proposed for a long time, little attention has been paid to APV until recently. Today, many scientists have confirmed the benefits of implementing it, such as generating more electricity, achieving higher yields, and using less water [73]. In order to prevent the construction of solar systems from reducing agricultural land and damaging the ecosystem, there are some requirements. For example, ground-mounted photovoltaic systems may only be installed in so-called "disadvantaged areas." These include areas in which the abandonment of land management threatens due to unfavorable location or production conditions [65]. One way to combine the expansion of renewable energies with nature and species conservation is the agri-photovoltaic system. This process is intended to enable the production of feed and food as well as the production of electricity in the same place. For this purpose, solar systems are built over agricultural land [74]. Solar energy is an important source in European Union and has grown very strong in the last years, especially photovoltaics, which is considered an important factor of green energy in the EU market, led by Germany with a 50 GW total capacity [75]. Moreover, the photovoltaic market is developing rapidly in Poland and the Baltic States. Regarding agriculture, solar energy can dry hay, heat water, and create more efficient greenhouses to provide energy for buildings and equipment remote from power lines of residential buildings, etc. Due to the mandatory use of energy supply measures in all areas, the role of RES will increase.

Based on the degrowth theory, the current principle is not how to meet the present demands of energy with new technologies but how to achieve an energy demand that could be provided by using renewable energy [76]. Moreover, according to Sertolli et al. (2022) [77], the importance of renewable energy is connected to the increasing energy demand and today's need for self-sufficiency.

The main challenges of the local agricultural energy systems might be the following:

(a) Agricultural by-products have low economic value but great quantity. These factors made the marketization problematic (transportation costs may exceed the real value). Therefore, their local utilization is reasonable, and energy methods have high added (or substitutional) value.

(b) Photovoltaic panels become increasingly important on farms, typically on rooftops and occasionally on the ground. These types of equipment might occupy land (a possible solution may be agrophotovoltaic systems), and fluctuations in electricity production and consumption can cause storage problems, not only in farms but also in national electric networks.

(c) Local renewable energy production could work much more efficiently in complex systems, where sub-systems can use each other's by-products and produce only marketable outputs. The production of specialized energy crops could also be considered in these systems, which are more expensive than by-products but can produce more energy from a smaller area.

It can be stated that on-farm energy production has great potential for farms' profit capacity and reducing the GHG emission of agriculture.

Case Studies in Self-Sufficiency

A study in Latin America shows the importance of energy self-sufficiency and the reduction of GHG emissions in dairy farms where cows' manure would be used as a source of biogas production, which indeed has an impact. According to Villarroel-Schneider et al. (2022) [78], the potential of Latin American dairy farms' biogas production is sufficient to meet their own energy demands (50% of the energy service demand would be covered by the capacity of 81 TWh/year biogas production). Dairy farms are of great importance in Latin countries, especially in Brazil, Colombia, Mexico, and Argentina. Regarding milk production, Brazil is the top producer of milk, with 45% annually, while 85% of the milk supply production is reached together with Argentina, Colombia, and Mexico. Based on the [78] study, it was found that biogas and electricity production in terms of techno-economic evaluation is feasible in all types of dairy farms, which allows the self-sufficiency of energy based on organic waste. Even that is considered not so attractive for farms under 15 cows because biogas can only be used for cooking and heating the water. Conversely, this technology is a solution for reducing the emissions of CH_4 and N_2O from the manure of dairy farms. It was concluded that 19.6 Mton/year is the reduction of CO_2 eq., for all of Latin America. In terms of implementing the solution of biogas for dairy waste management, this would enable a 60% reduction of GHG emissions currently generated by manure management, energy, and soil application (fertilizers) in the countries mentioned above. Overall, the promoted solutions seem attractive for Latin America to achieve energy self-sufficiency in agriculture, giving an advantage for the farm level.

Moreover, another study is conducted on biogas production from dairy manure in Canarian Archipelago. The total manure production in these islands is 495,622 t annually, mostly from Gran Canaria and Tenerife, with the contribution from goats, cows, poultry, and swine [79]. The potential of biogas from manure on a dairy farm basis counted 44.7 Mm^3 $year^{-1}$, respectively 27.1 Mm^3 $year^{-1}$ after considering the limitations (manure availability and farm size) with 6.8 Mwe equivalent installed power capacity. This is considered to be 0.22% equivalent in terms of electricity share. Furthermore, this idea of biogas production is widely spread in seven islands with around 546 farms with the potential to install their own biogas plant for electricity production or heat production with electrical power capacity ranging from 3 to 185 kWe. Furthermore, the study predicts a reduction in GHG emissions because biogas stands better in this regard than other renewable sources, and it is favorable and advantageous against climate change.

Studies [78,79] show the possible ways to farm self-sufficiency and its importance at the farm level. Agriculture has opportunities in the generation of energy from the farm since, in the power plant, the biomass generated by the farm is used as efficient fuel for energy production, which is fed into the regional power supply system.

In this context, it can also be stated that for evaluating and planning agricultural or even farm-level energy production and self-supply, the choice of the optimal method or tool or their combination depends on several factors.

The specific objective of this study is to present the trend line analysis as a bibliometric review in the field of renewable energy with a special use in agriculture based on the most appropriate literature data sources, such as the Scopus database, through bibliometric analysis and visualization. This study makes a relevant contribution to the existing literature and serves as a brief guide of trend publications in this specific field from 1988 to 2022.

This article brings new insights regarding renewable energy applications in agriculture, emphasizes the importance attached tp this field from scholars and their publications for years, and evaluates the most used keywords through the years. Moreover, it is probably the first article about the trend of research made both in the short term and in the long term considering the three areas mentioned above (agriculture, energy, and environment).

2. Materials and Methods

2.1. Data Collection and Management

Our ambition for writing this paper was to find out the systematic aspect of the publications in the meeting point of renewable energy, farm, and environment at a global level. For this reason, we used three keywords, "renewable energy," "farm," and "environment," in order to execute further analysis, whereas search fields included title, keywords, and abstract. Even though many articles have expressed the importance of renewable energy usage in agriculture worldwide, this article aims to give information about the publication of articles globally in this field. On the other side, tables and figures categorizing different periods give added value to the article and the field in order to see the trends of publications and the importance attached to this sector throughout the decades. Moreover, statistical data, citations, keywords, and collaborative work between countries enrich the outcome of this article. The main objective is to find out the productiveness of scholars in the number of publications in the field of energy generation from agricultural sources and the usage of renewable energy from farmers. Another objective is to understand the impact of the financial crisis on the generation of energy and the readiness to produce energy from alternative sources, especially the engagement of agricultural sources in this regard.

Therefore, the Scopus database was used to query the metadata of documents related to the topic. Through Scopus, it was possible to obtain a sufficient number of articles to gain interpretations and conclusions from the analysis.

Bibliometric analysis is a popular and rigorous method for exploring and analyzing large volumes of scientific data. It enables us to unpack the evolutionary nuances of a specific field while shedding light on the emerging areas in that field [80]. The main reason for the use of bibliometric analysis is to uncover emerging trends in article and journal performance, collaboration patterns, and research constituents and to explore the intellectual structure of a specific domain in the extant literature [81]. The bibliometric methodology encapsulates the application of quantitative techniques on bibliometric data [82]. The advent of scholarly databases such as Scopus has made it relatively easy to obtain large quantities of bibliometric data, and bibliometric software such as Bibliometrix enables the analysis of such data. The Scopus database contains the most influential academic journals and can provide the most crucial insights into energy, agricultural and environmental science. Indeed, the bibliometric methodology has been applied in a variety of fields of scientific research [83–85], wherein the application of bibliometrics ranges from studying publications to collaboration patterns and exploring the intellectual structure of the research field.

In our paper, the primary query string was as follows: TITLE-ABS-KEY (“renewable energy” AND “farm” AND “environment”) to locate papers published from 1988 to 2022 (see Appendix A). The reason for starting searching in 1988 is that the first published paper including these three keywords turned out to be this year. This query returned 925 results. After we excluded the conference review, notes, editorial, and letters, it turned out to be 894 articles to be reviewed. After categorizing it into the categories, the number of articles with applications in agriculture is something above 200 (excluding wind energy with applications in other fields) (Table 1).

Table 1. Main information regarding the collection.

Description	Results
Period	1988–2022
Documents	200
References	8982
Author’s Keywords	715
Authors	788
Document Types	
article	142
book	1
book chapter	7
conference paper	33
review	17

Source: created by the authors.

2.2. Data Analysis

Bibliometrix is a unique tool developed in the statistical computing and graphic R language, according to a logical bibliometric workflow. Bibliometrics is a popular tool that helps to identify key research trends being utilized through different calculations (number of keywords, citations, authors, countries, affiliations, etc.) [86]. Moreover, this tool includes the collection of metadata from scientific literature, descriptive analysis, and network analysis, with the main help of measuring the productivity of authors in a scientific way, the citation analysis, the rate of publications annually, and other information [87]. In this review, the bibliometric analysis has been performed using the Bibliometrix—R package tool, designed and developed by [88]. Furthermore, R is highly extensible because it is an object-oriented and functional programming language, and therefore is pretty easy to automate analyses and create new functions. As it has an open-software nature, it is also easy to get help from the users' community, mainly composed of prominent statisticians [88].

According to Bibliometrix (2022) [89], it is a widely used tool in more than 80 countries, with over 1000 publications that use Bibliometrix with the main aim of fostering international collaboration. In 2021 alone, nearly 500 articles cited Bibliometrix as a proven academic tool. Bibliometric quantitative research has become an important tool for different research areas.

The analysis was performed by conducting the three main stages, as shown in Figure 1. The first stage contains Data Collection, a general search of the articles based on the selected keywords. In this stage, 894 articles were obtained after excluding the conference review, notes, editorials, and letters. Since the articles were categorized into different fields of use, the 894 articles were analyzed in an MS Office file by abstracts, keywords, and titles, evaluating the relationship with the scope of this review. Two hundred articles were selected related to the applications of renewable energy in farms and environmental aspects in order to narrow down the field of farm and renewable energy, excluding the non-relevant shots, e.g., "wind farm" (operated out of farms). The second stage contains data analysis through descriptive bibliometric analysis to have a clear idea about the papers, authors, years, countries, keywords, and so on; creation of the network for bibliographic coupling, collaboration, co-citation, and co-occurrence analyses and normalization. The third stage involves Data Visualization through the performance of descriptive analysis using Bibliometrix Science Mapping and R Studio for Conceptual structure and network mapping to analyze the collaborations between countries in terms of publication documents and co-occurrences of keywords, analyzed through different clusters.

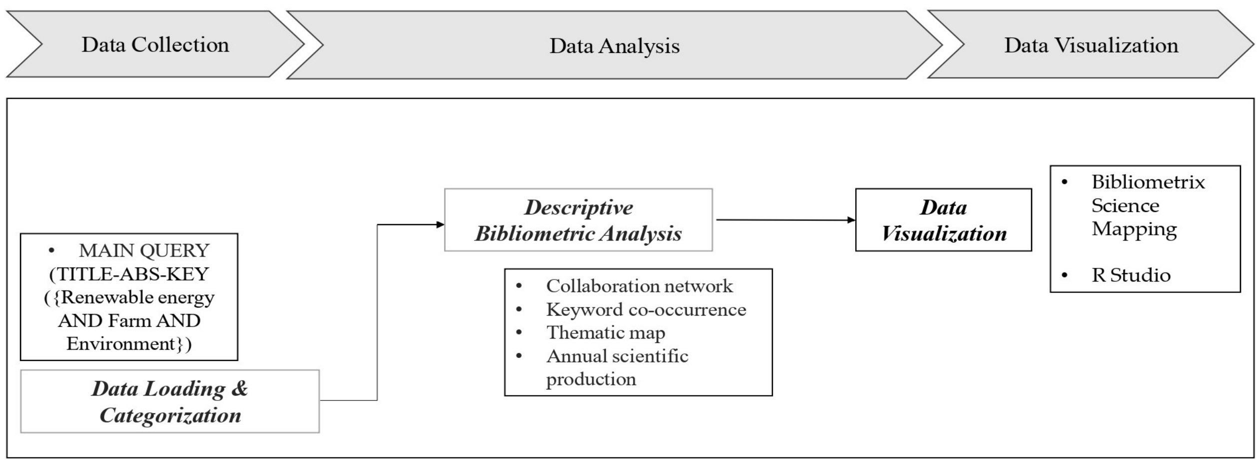

Figure 1. Workflow of the methodology process. Source: Authors' construction.

2.3. Interpretation

We performed a comprehensive search of journal articles to cover the entire research domain of renewable energy applications in agricultural farms, pursuing the following four steps:

1. Global data collection through Scopus is one of the most trustworthy databases.
2. Analyzation of title, abstract, literature review, and keywords of articles. Each search result was downloaded in a.csv file containing the following Citation information: Authors, Author IDs, Title, Year, Source title, Volume, Issue, Art. No, Pages, Citation count, DOI, Link, Abstract, Author Keywords, Document type, Open access, and EID.
3. Each above-mentioned aspect of the data was analyzed and studied.
4. Finally, the connections between countries, authors, annual scientific production, journals, and collaboration networks were analyzed and presented through data visualization.

The clustering analysis method is used to process data into groups and categories, such as grouping keywords into different categories. The keyword analysis aims to highlight the direction and key trends of the research topic. In a keyword co-occurrence network, each keyword is represented as a node, and each co-occurrence of a pair of words is represented as a link. The number of times a pair of words co-occurs in multiple articles constitutes the weight of the link connecting the pair. The network constructed in this way represents the accumulated knowledge of an area. It helps to reveal significant knowledge components and insights based on the patterns and strengths of relationships between keywords appearing in the literature [90]. Moreover, the keywords that authors select for the article are of a crucial impact on how the paper is represented, distributed, and communicated within the scientific communities.

Additionally, the conceptual structure of publications related to renewable energy is provided and helps to understand the topics and define the most important and recent ones. Identifying the conceptual structure could also be helpful in studying the research topic's evolution over time [91]. The basic idea is that terms (keywords, terms extracted from titles or abstracts) that appear together in a document can be represented as a term co-occurrence network. This analysis allows finding subgroups of strongly linked terms, where each subgroup corresponds to a center of interest or a given research topic of the analyzed collection. Once the analysis is conducted, it is possible to plot the results in a so-called strategic or thematic diagram [92]. The graphical representation allows defining of four typologies of themes [93], depending on the quadrant in which they are plotted. Motor themes: in the upper-right quadrant are characterized by high centrality and high density, meaning they are developed and essential for the research field. Basic Themes in the lower-right quadrant are characterized by high centrality and low density, meaning that these themes are important for a domain and concern general topics transversal to the different research areas of the field. Emerging themes in the lower-left quadrant are characterized by low centrality and low density, which are weakly developed and marginal. Niche themes in the upper-left quadrant are well-developed internal links (high density) but unimportant external links (low centrality), meaning they are of little importance to the field. Specific details of the focus areas are shown in Figure 6.

3. Results and Discussion

A helpful indicator in bibliometrics is the total number of publications produced by a country within a period of time. In this section, we perform a bibliometric analysis to explore the trends of publications regarding renewable energy applications in agriculture and their impact on the environment, including annual scientific production, most productive countries, most cited articles, collaboration network, and keyword co-occurrence network. Furthermore, it is interesting and important to elucidate a path that delineates the scientific progress of specific topics that have changed over the years based on the trends and identify the benefits and significance that are expected to occur in the future.

3.1. Trend of Publications

We analyzed the developments in publication output in the current literature on renewable energy use in farms. The annual scientific production of scholarly research is shown in Figure 2, where we enumerate the number of publications in the 34 most recent years of research in this field. Only a few documents on the above-mentioned topic were written each year from 1988 to 2008; even though the trend was improving and increasing from 2008, total publications never exceeded 22 publications per year, and there were fluctuations during the last years. It is observed that the number of publications started to increase significantly from the year 2009 (with 11 publications) as a result of the financial crisis in 2008 and the significant impact on the crude oil market. Whereas, due to the COVID-19 pandemic, the number of publications has fallen due to significantly reduced renewable energy production globally. A tendency to increase the publications in this field has to do with the importance of renewable energy in agriculture, cheaper technologies as a result of economies of scale, and supply chains operation in competitive aspects. Extreme situations (COVID-19, Russian–Ukrainian war) have resulted in high instability in energy supply and volatile prices on the European and World markets, which has meant extra demand for renewable energy sources as a potential for energy generation. In spite of the fact that the upward tendency changed into a fluctuation in the last three years due to daily financial problems for farmers, our opinion is that energy self-sufficiency will gain increasing importance in the long term in farm management.

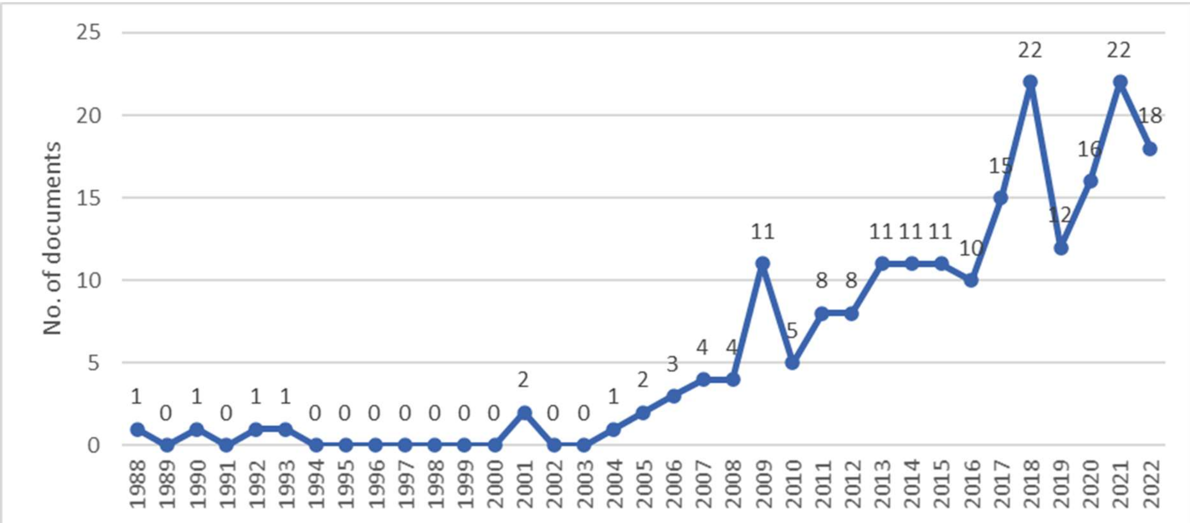

Figure 2. Annual scientific production. Source: created by the authors.

The ten main journals connected to the search field performed with the Scopus database are shown in Table 2. All journals belong to the "Renewable Energy, Sustainability and the Environment" subject area. Most articles can be found in Q1 and Q2 categories in Elsevier and MDPI journals. These two publishers attach importance to renewable energy with its application to agricultural farms. Despite smaller SJR and H-index, Energies and Sustainability can be regarded as attractive target journals in this special field.

Table 2. List of the most relevant journals.

Journal	Publisher	Country	H Index	SJR	TP
Journal of Cleaner Production	Elsevier	United Kingdom	232	1.92 (Q1)	8
Sustainability	MDPI	Switzerland	109	0.66 (Q2)	8
Renewable and Sustainable Energy Reviews	Elsevier	United Kingdom	337	3.68 (Q1)	7
Energies	MDPI	Switzerland	111	0.65 (Q1)	5
Science of the Total Environment	Elsevier	The Netherlands	275	1.81 (Q1)	5
Renewable Energy	Elsevier	United Kingdom	210	1.88 (Q1)	4
Atmosphere	MDPI	Switzerland	46	0.69 (Q2)	3
Biomass and Bioenergy	Elsevier	United Kingdom	189	1.01 (Q2)	3
Fourrages	AFPF	France	13	0.14 (Q4)	3
Environmental Science and Pollution Research	Spinger	Germany	132	0.83 (Q2)	3

Legend: TP—the number of total publications; AFPF—Association Francaise pour la Production Fourragere; MDPI—Multidisciplinary Digital Publishing Institute. Source: Created by the Authors.

3.2. Worldwide Distribution of Publications

Table 3 presents the most productive countries or territories as an investigation of the number of documents published from the countries worldwide. This type of analysis is a great help to better understand the geographic distribution of scholars who contribute to the applications of renewable energy and environmental aspects in agriculture. Considering the results in Table 3, most of the countries that publish articles in this area are those that attach huge importance to the development of renewable on-farm energy production. The two dominant countries at the top of Table 3, China and USA, have installed high capacities in the generation of energy and electricity from renewables. They were the most productive countries in RES, in the article of [94].

Table 3. Top 20—Most productive countries in the research area (1988–2022).

Country	No. of Documents	Country	No. of Documents
China	49	Turkey	13
USA	49	Germany	12
Italy	32	Romania	11
France	29	South Korea	11
India	29	Japan	9
UK	28	Spain	9
Poland	19	Thailand	9
Iran	17	Algeria	8
Brazil	15	Malaysia	8
Canada	14	Netherlands	8

Source: Created by the Authors.

According to Yang et al. (2016) [95], China was a leader that installed more renewable energy capacity than all Europe countries and the rest of the Asia Pacific region in 2013. Moreover, many countries have set impressive goals for the development to increase the share of renewable energy in global energy generation. In this regard, China aims to generate 86% of its electricity and 62% of its energy from renewables by 2050, whereas the USA and Germany aim to achieve an 80% renewable energy share. As a result of global warming, China is following targets to reach peak carbon by 2030 and consequently achieve carbon neutrality by 2060 [96]. In 2018, the World's final energy consumption was reported to be 9938 Mtoe, led by oil consumption of 4051 Mtoe (40.8%) [97]. In 2020, the share of renewable energy in gross final energy consumption among the European Countries was the highest in Iceland at 83.7%, followed by Norway (77.3%) and Sweden (60.1%), respectively [98]. The share of renewable sources in gross final energy consumption in the European Union (EU) reached from 8.5% in 2004 to 18.0% in 2018, with targets to raise this share to 32% by 2030 [99]. In this regard, the objective of France ranked in the fourth position in Table 3, is to attain a 32% share of renewable energy by 2030, while 30% by Italy [100,101].

Considering the last three years, the research centers have undergone major changes (Table 4). China maintained its dominance, but the importance of the USA fell sharply, and new centers (India, Poland) appeared, where the share of small-size farms is decisive in agriculture. They have better opportunities in local by-product utilization, from plant production, animal husbandry, and energy production. According to the general rule, by-product utilization is given priority under extreme economic conditions, and these three years have been like that.

Table 4. Top 20—Most productive countries in the research area (2020–2022).

Country	No. of Doc.	Country	No. of Doc.
China	20	USA	6
India	20	Spain	5
Poland	16	Canada	4
South Korea	10	Pakistan	4
Iran	9	Romania	4
Brazil	8	Ecuador	3
France	7	Japan	3
Italy	7	Uzbekistan	3
UK	7	Hungary	2
Ireland	6	Cyprus	2

Source: Created by the Authors.

Figure 3 shows a visual cluster of cooperation between countries, in which the size and color of nodes represent the number of publications in each country separately.

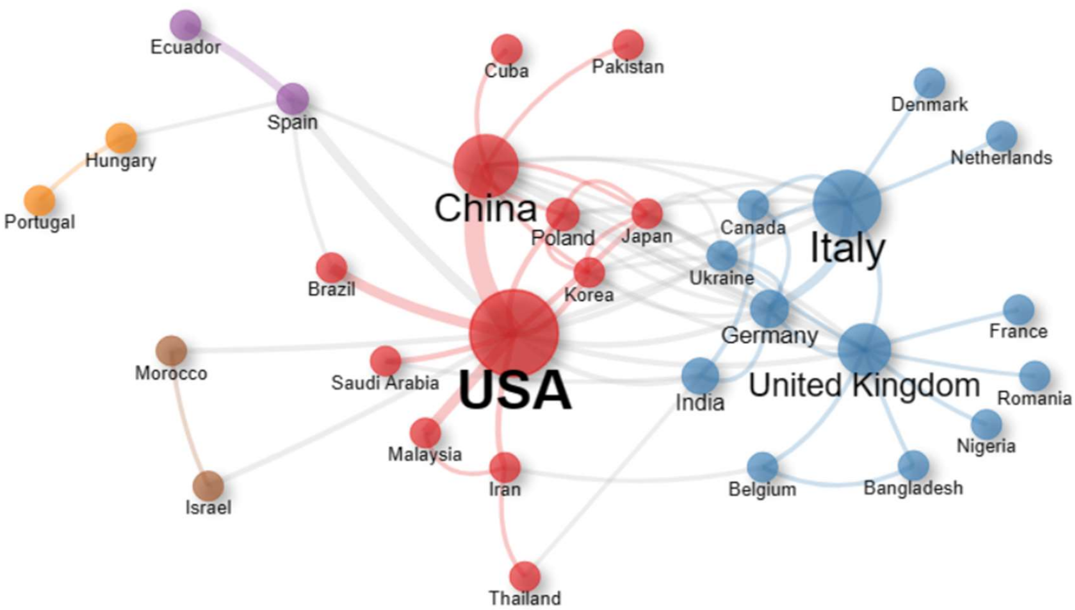

Figure 3. Collaboration network (1988–2022). Source: created by the authors.

The 31 items are countries that publish articles in the analyzed area, categorized within five clusters, in a relationship with each other. The width of the connection indicates the degree of cooperation between countries (the higher the degree of cooperation, the thicker the connection). Nodes with the same color have stronger cooperation than nodes with differing colors. With the depletion of conventional energy sources, renewable energy has gained the attention of countries worldwide and its collaboration network. The USA, which has the highest publication number, has a strong collaboration with China. Another bibliometric study regarding renewable energy from the ocean has the same strong collaboration between China and USA [94]. This can happen due to the future power of these two countries regarding renewable energy as the two largest markets worldwide. On the other hand, Italy, the United Kingdom, and Spain are sub-centers of international collaborations, especially with European ones, while India cooperates mainly with overseas countries.

3.3. Most Globally Cited Documents

Citations reflect the importance of the papers' contributions to the literature on a specific topic and field. Additionally, the impact of an article can be observed from the citations it obtains, and the research community recognizes that a highly cited work is important. We conducted a citation analysis to determine the most cited and influential studies on renewable energy applications in agricultural farms.

Table 5 represents the list of ten top-cited articles from 1988 to 2022 in terms of the total number of citations (TC) or the total number of citations per year. The power of total citations determines the ranking of scientific journals based on their impact factor. The most cited publications, as shown in Table 5, include publications dealing with each energy production option, economic and environmental characteristics, and studies that examine several alternative sources simultaneously. Based on Table 1. The number of authors of the papers in this review is 788 for 200 articles, understanding that the collaboration is high between the authors. Interestingly, the journals of the most cited articles were published outside the lists of the most relevant journals detailed in Figure 1, highlighting the research area's specialty. The publication from [102] leads the list and describes the importance and potential contribution of on-farm biogas production in order to reduce greenhouse gas (GHG) emissions and other environmental impacts related to livestock operations, including the interest in technologies that minimize environmental impacts. It also presents the results of studies evaluating the environmental, social, and agricultural benefits of AD technologies. As per the study of Choudhary et al. (1996) [103], the usage of AD has more benefits for the soil in comparison to the usage of mineral fertilizers, riches the soil with more organic matter, and enhances the structure and its capacity for water holding. According to Singh et al. (2022) [104], AD is a great technique for managing biodegradable waste, converting them into energy and nutrients. This is an eco-friendly method for the management of food waste that contains organic matter generated from households, harvest, vegetable and fruit markets, food processors, malls, restaurants, or in general, from the food supply chain. Furthermore, based on the study of Mühl and Oliveira (2022) [101], the interest in AD is increasing in Brazil, with an exponential trend from 2003 to 2020, while most AD plants focus on livestock and agriculture.

Table 5. List of the most cited articles on the topic.

Document	DOI	TC	TC per Year
MASSÉ DI, 2011, ANIM FEED SCI TECHNOL	10.1016/j.anifeedsci.2011.04.075	122	10.17
CLIFTON-BROWN J, 2017, GCB BIOENERGY	10.1111/gcbb.12357	121	20.17
PANDEY J, 2009, ENVIRON MONIT ASSESS	10.1007/s10661-007-0139-8	115	8.21
WALMSLEY JD, 2009, FOR ECOL MANAGE	10.1016/j.foreco.2008.11.015	110	7.86
BENLI H, 2009, ENERGY BUILD	10.1016/j.enbuild.2008.09.004	110	7.86
CHEL A, 2011, AGRON SUSTAINABLE DEV	10.1051/agro/2010029	107	8.92
SONI P, 2013, AGRIC SYST	10.1016/j.agsy.2012.12.006	99	9.90
ADEH EH, 2018, PLOS ONE	10.1371/journal.pone.0203256	85	17.00
BATTINI F, 2014, SCI TOTAL ENVIRON	10.1016/j.scitotenv.2014.02.038	85	9.44
VANOTTI MB, 2009, BIORESOUR TECHNOL	10.1016/j.biortech.2009.02.019	78	5.57

TC: Total Citations. Source: Created by the Authors.

3.4. Keyword Co-Occurrence Network

Figure 4 reveals the most commonly used keywords categorized into four clusters; the former contains 30 out of 715 keywords, with the main ones such as: "renewable energy," "biogas," "sustainability," "biomass," and "environment", to emphasize the main themes with the highest occurrence. The red cluster is the main one which contains more keywords from the database, with the most important one that is "renewable energy." Similar to our results, the keyword "renewable energy" was frequently used in the systematic review of Ragazou et al. (2022) [105], which elaborates on the welfare of farmers and its links to energy efficiency and farm sustainability have attracted worldwide scientific interest in recent decades. Their study, which included a bibliometric analysis, investigated how Agriculture 5.0 contributes to farmers; well-being in the post-pandemic era and the gradual transition to an energy-smart economy. According to Rahman et al. (2022) [106], the highest share of on-farm energy is required for irrigation by groundwater pumping. As a result, the use of locally available renewable energy sources (solar, wind, biomass, and geothermal), together with energy-efficient technologies, has become increasingly attractive in the agricultural field for minimizing the impacts of rising energy costs and contributing to climate change protection.

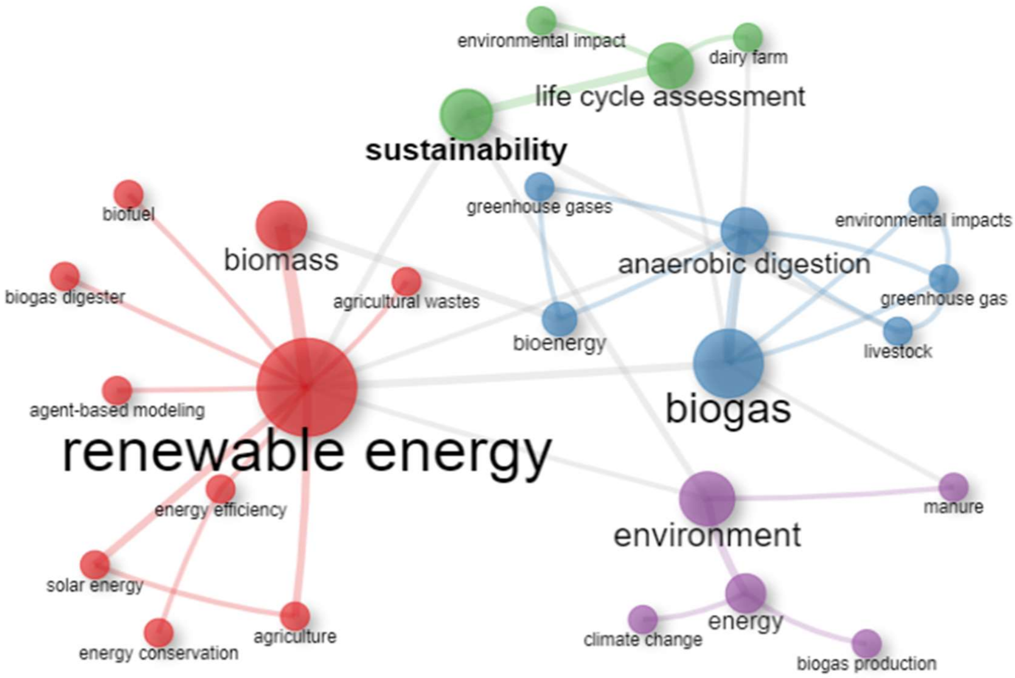

Figure 4. Keyword co-occurrence network (1988–2022). Source: created by the authors.

The blue cluster with the "biogas" keyword is the main one in this category, the purple cluster with the category of the environment (including manure, energy, climate change), and the remaining green cluster with just four keywords out of 30 (sustainability, life cycle assessment, environmental impact, and dairy farm) and overlapping with the blue cluster, it proves that biogas is that on-farm renewable energy source, which has been mostly searched among the RES and its environmental effects has been highlighted in the research. It is referred to as clean or "green" energy, produced from sources that do not run out or can be replenished, with a special aspect: environmental consciousness and waste management. It also shows that "anaerobic digestion" is a more frequently used keyword than "bioenergy." As per Massé et al. (2011) [102], anaerobic digestion is one of the most popular processes of organic matter from livestock manure; producing biogas and bio-manure are very important elements of sustainable farming.

Figure 5 reveals the co-occurrence keyword visualization network, analyzing which areas have become more significant or have developed the most since 2019. From 20 keywords, the most used ones are: "renewable energy resources," "greenhouse gases," "sustainable development," "energy efficiency," and "fertilizers." These keywords are always the focus of attention for scholars. Since the energy crises, carbon emissions, energy consumption, and climate change, the attention to renewable energy sources and green energy has increased. According to Kim and Park. (2023) [107], fossil fuels are being replaced with renewable energy sources, particularly in countries with high climate risks. Additionally, since 2000 more than 120 countries have been producing renewable energy, as it has been considered a crucial tool for climate change mitigation worldwide. As shown in Figure 5, the red cluster has the majority of the keywords, nearly the same as in Figure 4; the connection between the clusters is increased. The blue cluster has considerably increased in importance during this last decade as an advancement in the research on keywords for agricultural renewable energy, such as biomass, biogas, and fertilizers. According to Sertolli et al. (2022) [77], the biomass potential is huge, with a total of 1260 EJ/year annual primary biomass production on the surface of the Earth. The significance of biomass energy use is dominant among renewables, mainly in heat production. The green cluster shows the co-occurrence of keywords related to the environment and climate change. Several studies emphasized the importance of bioeconomy, biomass, sustainability development, and energy utilization. In addition, they highlighted the importance of the circular economy as a research area due to the number of publications indexed in the most important bibliometric databases [77,108,109].

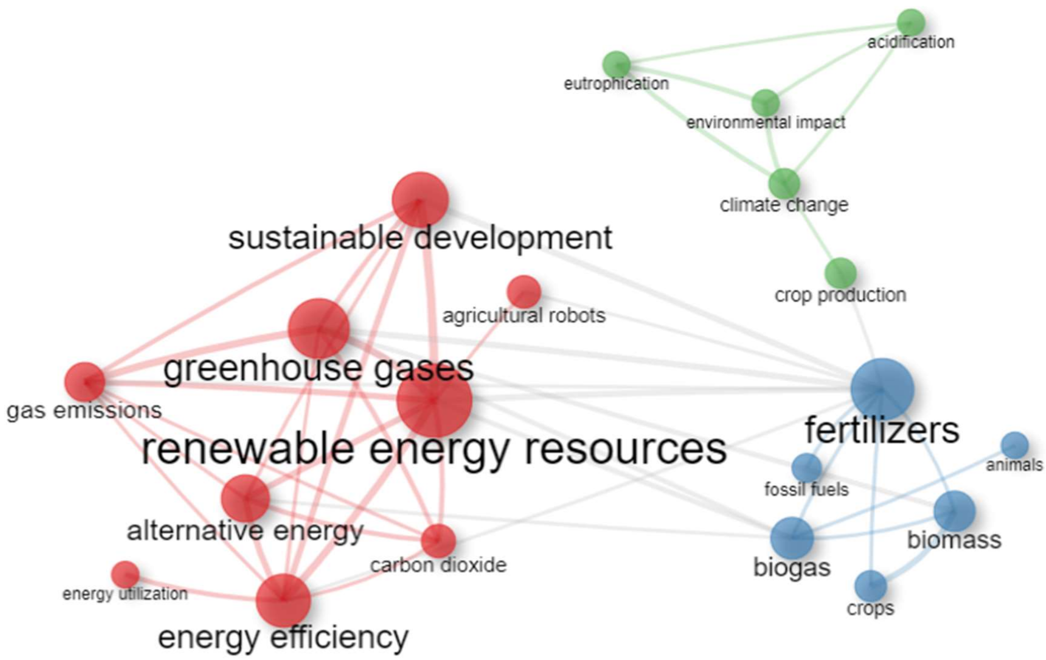

Figure 5. Keyword co-occurrence network (2019–2022). Source: created by the authors.

This section shows the conceptual structure of publications related to renewable energy. Figure 6 shows four main topics that emerged. According to the strategic diagram of keyword mapping, there are four related circles such as (i) biogas, (ii) bioenergy, (iii) environment, (iv) renewable energy. 'Biogas' is the motor theme of the topic, whereas 'renewable energy' appeared as a general theme and also included the topic's different applicative domains. According to Massé et al. (2011) [102], biogas is an outstanding alternative to fossil fuel energies such as coal, oil, and natural gas for electricity generation and heating. Biogas from farm production contributes to more sustainable livestock operations by considerably reducing other environmental impacts related to managing manure. Furthermore, renewable energy sources, in this case also biogas, are crucial in the transition to low-carbon economies and environmental sustainability.

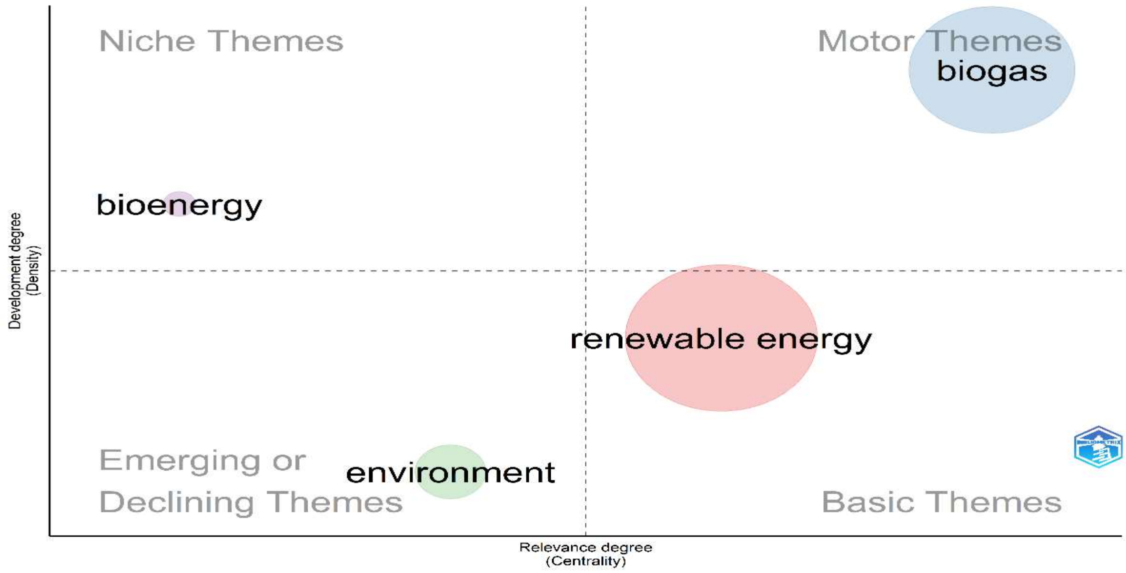

Figure 6. Thematic map (1988–2022). Source: created by the authors.

Whereas, according to the strategic diagram of keywords for the period 2019–2022, there are four related circles such as (i) renewable energy resources and alternative energy, (ii) crop production and environmental impact, (iii) greenhouse gas and cultivation, (iv) renewable energies and fertilizer (Figure 7). Renewable energy is important in agriculture due to energy access in off-grid locations, alternative profit options for farmers, and no health costs due to burning less fossil fuel [106]. In developed countries, renewable energy application in agriculture is well adopted. In contrast, developing countries are still struggling to apply renewable energy sources in agriculture for challenges such as technical and economic ones, and RES application in agriculture could be the key to sustainable agriculture sector development.

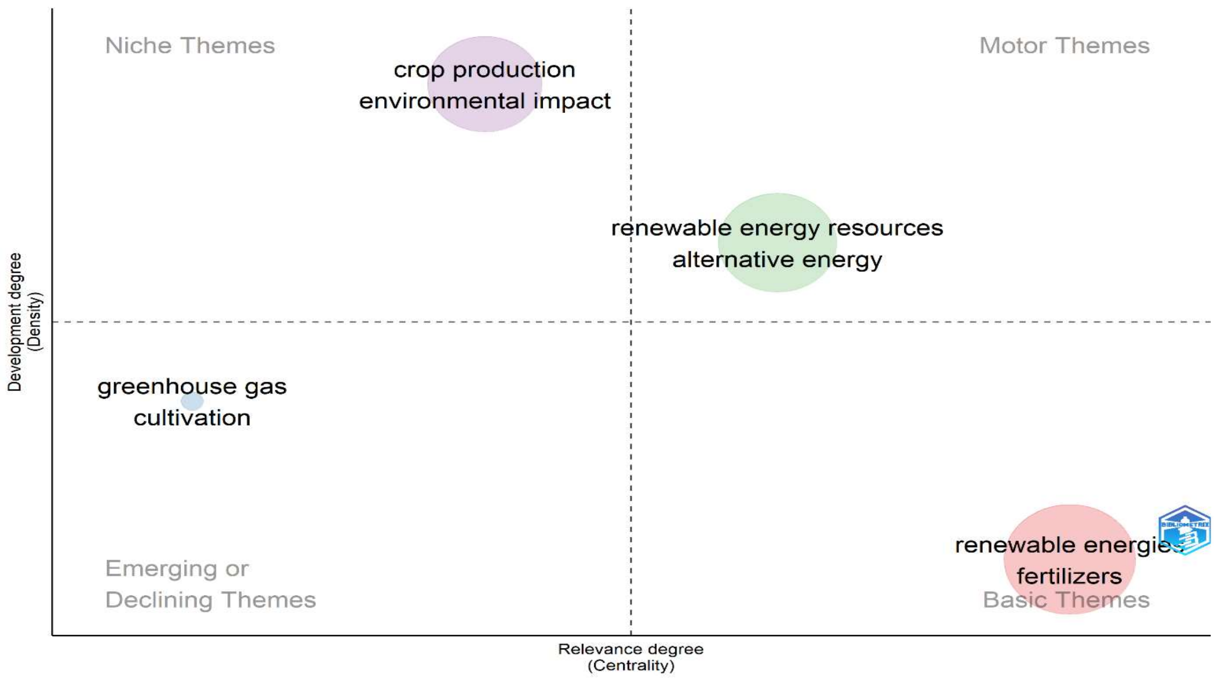

Figure 7. Thematic map (2019–2022). Source: created by the authors.

4. Conclusions

Globally, the agri-food chain today consumes about one-third of global energy production. Agricultural energy resources and their utilization are linked to sustainable development. Modern agriculture requires much greater energy input than traditional agriculture. Additionally, climate change and its impact can be eased by promoting renewable energy applications in the agricultural sector. In light of sustainable and resilient renewable energy usage in agriculture, this article highlighted the importance and contribution of publications over the years.

From the perspective of the variation trend of the number of published papers, the number of published papers for the relevant literature in the field of renewable energy with application in agriculture shows a growth trend year by year with the exception of the years of extreme crisis (COVID-19). Especially since the recession of 2008, there has been a growth in the number of published papers. Scientific outputs of China and the USA show a high trend and have the most achievements in this research field, while in terms of scientific journals, the highest number of publications are available, especially in Elsevier journals (with more articles published in Q1 and Q2), and the MDPI journals of Energies and Sustainability have published several articles. However, the top ten highly cited papers are published by scholars from the United Kingdom, the United States, India, Turkey, Thailand, Italy, and The Netherlands. It indicated that developed and developing countries of Europe and Asia had begun the interest in this research field early, whereas China, as a developed country, indicated it would pay more attention as a result of the goal of carbon peak and neutrality set by the Chinese government. In addition, an analysis of the keywords for the period 2019–2022 shows that there is an increase in the importance of research for the themes such as "renewable energy resources," "greenhouse gases," and "sustainable development." The extreme crisis (Ukraine War, COVID-19) increased the concentration of generating green energy from natural sources that can be replenished and increased the opportunities for new energy policies and climate goals on applying renewable energy sources instead of fossil fuels.

From the perspective of the co-occurrence of the keywords and cluster mapping, highly used keywords in the literature are mainly focused on renewable energy, environment, energy, anaerobic digestion, biogas, sustainability, and biomass; at the medium level. The focus is attached to the environment and energy sustainability, such as agricultural wastes, climate changes, livestock, greenhouse gas, environmental impact, and biofuels. It is seen that the focus on the application of RES in agriculture is increasing day by day.

Regarding future directions, it can be stated that publication and research activity are dominated by different biogas production and utilization methods in the analyzed time period. Solar energy probably has great potential in research and farms' energy production. Energy communities, including farms located close to each other, exist both in biogas and bioethanol production, with low importance; however, their spreading could help keep the added value of energy on farms. Another new area is agro-photovoltaic systems, which allow the dual use of agricultural land (for energy and food production) at the same time. Publications are available in a limited number in this area due to many ongoing research projects without final results.

This study has limitations related to its themes variety. The methodology always emphasizes the statistically most relevant themes, but we do not represent all the themes of the research field. We used one database and considered articles, books, book chapters, reviews, and conference papers. Thus, the results could be a little different with the inclusion of all documents in the research field. Another limitation is the non-existence of another article that elaborated on the same keywords in order to make the comparison between the results.

The results can be helpful for researchers and scholars to understand the upward trends of the application of renewable energy in agriculture as a result of environmental sustainability, productivity, and thematic share of relevant publications from countries during the chosen period, co-occurrence of keywords in this regard.

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Data Availability Statement: All the data is available within this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

AD	Anaerobic digestion
APV	Agrivoltaics
CH_4	Methane
CO_2	Dioxide carbon
DOI	Digital Object Identifier
EJ	Exajoule
eq	Equivalent
EU	European Union
EU3	France, Germany and Italy
GHG emissions	Greenhouse gas emissions
ha	hectare
KWe	Kilowatt-electric
kWh	kilowatt-hour
LCA	life cycle assessment
Mm^3	Metric cubic meter
Mton	metric ton
MWe	Megawatt electric
N_2O	Nitrous oxide
NH_3	Ammonia
NOx	Nitrogen oxides
OECD	Organization for Economic Co-operation and Development
PJ	petajoule
RES	Renewable energy sources
SDGs	Sustainable Development Goals
SJR	Scientific Journal Rankings
SO_2	Sulfur dioxide
T	ton
TC	Total citations
TWh	terawatt hour
USA	United States of America
WPP	Wind power plant

Appendix A

Academic Literature Search

The academic literature review was determined through research in the Scopus database using the keywords listed in Table A1. The results were generated using categories of the application of renewable energy in agriculture and environment considerations.

Table A1. Selection Parameters used for peer-reviewed literature.

Number of Key Words	Key Words Selected
KW1	((TITLE-ABS-KEY ("renewable energy") AND TITLE-ABS-KEY ("farm") AND TITLE-ABS-KEY ("environment")) AND (EXCLUDE (DOCTYPE, "cr") OR EXCLUDE (DOCTYPE, "no") OR EXCLUDE (DOCTYPE, "ed") OR EXCLUDE (DOCTYPE, "le"))
Filters	Language: English Sectors: renewable energy, farm, environment, agriculture Country: All countries in the World Type: articles, book, book chapter, reviews and conference papers

References

1. Nyga-Łukaszewska, H. Energy security and sustainable development. In *Encyclopedia of the UN Sustainable Development Goals*; Springer International Publishing: Berlin/Heidelberg, Germany, 2021; pp. 289–300.
2. Nguyen, K.H.; Kakinaka, M. Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. *Renew. Energy* **2018**, *132*, 1049–1057. [CrossRef]
3. Elum, Z.A.; Momodu, A.S. Climate change mitigation and renewable energy for sustainable development in Nigeria: A discourse approach. *Renew. Sustain. Energy Rev.* **2017**, *76*, 72–80. [CrossRef]
4. Chen, W.M.; Kim, H.; Yamaguchi, H. Renewable energy in eastern Asia: Renewable energy policy review and comparative SWOT analysis for promoting renewable energy in Japan, South Korea, and Taiwan. *Energy Policy* **2014**, *74*, 319–329. [CrossRef]
5. Doğan, B.; Driha, O.M.; Balsalobre Lorente, D.; Shahzad, U. The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries. *Sustain. Dev.* **2021**, *1*, 1–12. [CrossRef]
6. Edenhofer, O.; Pichs-Madruga, R.; Sokona, Y.; Seyboth, K.; Kadner, S.; Zwickel, T.; Eickemeier, P.; Hansen, G.; Schlömer, S.; von Stechow, C. *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2011.
7. Al-mulali, U.; Solarin, S.A.; Sheau-Ting, L.; Ozturk, I. Does moving towards renewable energy cause water and land inefficiency? An empirical investigation. *Energy Policy* **2016**, *93*, 303–314. [CrossRef]
8. EIA. *International Energy Outlook 2019 with Projections to 2050*; EIA: Washington, DC, USA, 2019.
9. Kopetz, H. Build a biomass energy market. *Nature* **2013**, *494*, 29–31. Available online: https://www.nature.com/articles/494029a (accessed on 25 November 2022). [CrossRef] [PubMed]
10. Dombi, M.; Kuti, I.; Balogh, P. Aspects of the Sustainable Utilization of Renewable Energy Sources. *APSTRACT Appl. Stud. Agribus. Commer.* **2013**, *6*, 91–94. [CrossRef]
11. Primary Energy. 2022. Available online: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/primary-energy.html (accessed on 20 October 2022).
12. WBA. *Global Bioenergy Statistics*; WBA: Stockholm, Sweden, 2021.
13. WBA. *Global Biomass Potential Towards 2035*; WBA: Stockholm, Sweden, 2016.
14. EASAC. *Opportunities and Challenges for Research on Food and Nutrition Security and Agriculture in Europe*; EASAC: Halle, Germany, 2017.
15. Popp, J.; Kovács, S.; Oláh, J.; Divéki, Z.; Balázs, E. Bioeconomy: Biomass and biomass-based energy supply and demand. *N. Biotechnol.* **2021**, *60*, 76–84. [CrossRef]
16. Popp, J.; Harangi-Rákos, M.; Pető, K.; Nagy, A. Bioenergy: Risks to food-, energy- and environmental security. *Appl. Stud. Agribus. Commer.* **2013**, *7*, 4–5. [CrossRef]
17. IEA. *Market Analysis and Forecast from 2019 to 2024*; IEV: Paris, France, 2019.
18. Vaish, S.; Kaur, G.; Sharma, N.K.; Gakkhar, N. Estimation for Potential of Agricultural Biomass Sources as Projections of Bio-Briquettes in Indian Context. *Sustainability* **2022**, *14*, 5077. [CrossRef]
19. Nicolae, S.; Jean-Francois, D.; Nigel, T.; Manjola, B. *Brief on Biomass for Energy in the European Union*; Publications Office of the European Union: Luxembourg City, Luxembourg, 2019.
20. Ma, X.; Ahmad, N.; Oei, P.Y. Environmental Kuznets curve in France and Germany: Role of renewable and nonrenewable energy. *Renew Energy* **2021**, *172*, 88–99. [CrossRef]

21. Testa, R. An Opportunity for the Agricultural Sector: The Renewable Energy Sources. *American Journal of Agricultural and Biological Science* **2016**, *11*, 100–102. [CrossRef]
22. Szakály, Z.; Balogh, P.; Kontor, E.; Gabnai, Z.; Bai, A. Attitude toward and Awareness of Renewable Energy Sources: Hungarian Experience and Special Features. *Energies* **2021**, *14*, 22. [CrossRef]
23. Bilandzija, N.; Voca, N.; Jelcic, B.; Jurisic, V.; Matin, A.; Grubor, M.; Kricka, T. Evaluation of Croatian agricultural solid biomass energy potential. *Renew. Sustain. Energy Rev.* **2018**, *93*, 225–230. [CrossRef]
24. Rani, P.; Mishra, A.R.; Pardasani, K.R.; Mardani, A.; Liao, H.; Streimikiene, D. A novel VIKOR approach based on entropy and divergence measures of Pythagorean fuzzy sets to evaluate renewable energy technologies in India. *J. Clean. Prod.* **2019**, *238*, 117936. [CrossRef]
25. Bilgili, F.; Ozturk, I. Biomass energy and economic growth nexus in G7 countries: Evidence from dynamic panel data. *Renew. Sustain. Energy Rev.* **2015**, *49*, 132–138. [CrossRef]
26. Jaiswal, K.K.; Chowdhury, C.R.; Yadav, D.; Verma, R.; Dutta, S.; Jaiswal, K.S.; Sangmesh, B.; Karuppasamy, K.S.K. Renewable and sustainable clean energy development and impact on social, economic, and environmental health. *Energy Nexus* **2022**, *7*, 100118. [CrossRef]
27. Ayres, R.U.; van den Bergh, J.C.J.M.; Lindenberger, D.; Warr, B. The underestimated contribution of energy to economic growth. *Struct. Change Econ. Dyn.* **2013**, *27*, 79–88. [CrossRef]
28. Geng, J.-B.; Ji, Q. Technological innovation and renewable energy development: Evidence based on patent counts. *Artic. Int. J. Glob. Environ. Issues* **2016**, *15*, 217–234. [CrossRef]
29. Li, J.; Zhang, X.; Ali, S.; Khan, Z. Eco-innovation and energy productivity: New determinants of renewable energy consumption. *J. Environ. Manag.* **2020**, *271*, 111028. [CrossRef]
30. Su, C.W.; Umar, M.; Khan, Z. Does fiscal decentralization and eco-innovation promote renewable energy consumption? Analyzing the role of political risk. *Science of The Total Environment* **2021**, *751*, 142220. [CrossRef] [PubMed]
31. Ji, X.; Liu, Y.; Meng, J.; Wu, X. Global supply chain of biomass use and the shift of environmental welfare from primary exploiters to final consumers. *Appl. Energy* **2020**, *276*, 115484. [CrossRef]
32. Ladanai, S.; Vinterbäck, J. Global Potential of SustainableBiomass for Energy. 2009. Available online: http://pub.epsilon.slu.se/4523/1/ladanai_et_al_100211.pdf (accessed on 16 September 2022).
33. IEA. *Potential Contribution of Bioenergy to the World's Future Energy Demand*; IEV: Paris, France, 2007.
34. IRENA. *Global Bioenergy Supply and Demand Projections*; IRENA: Abu Dhabi, United Arab Emirates, 2014.
35. Sayed, E.T.; Wilberforce, T.; Elsaid, K.; Rabaia, M.K.H.; Abdelkareem, M.A.; Chae, K.J.; Olabi, A.G. *A Critical Review on Environmental Impacts of Renewable Energy Systems and Mitigation Strategies: Wind, hydro, Biomass and Geothermal*; Elsevier: Amsterdam, The Netherlands, 2022. Available online: https://www.sciencedirect.com/science/article/pii/S0048969720380360 (accessed on 26 November 2022).
36. Amponsah, N.Y.; Troldborg, M.; Kington, B.; Aalders, I.; Hough, R.L. Greenhouse gas emissions from renewable energy sources: A review of lifecycle considerations. *Renew. Sustain. Energy Rev.* **2014**, *39*, 461–475. [CrossRef]
37. Prakash, R.; Bhat, I.K. Energy, economics and environmental impacts of renewable energy systems. *Renew. Sustain. Energy Rev.* **2009**, *13*, 2716–2721. [CrossRef]
38. Bates, J.; Edberg, O.; Nuttall, C. Minimising Greenhouse Gas Emissions from Biomass Energy Generation. Environment Agency: Bristol, UK, 2009.
39. Turconi, R.; Boldrin, A.; Astrup, T. Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. *Renew. Sustain. Energy Rev.* **2013**, *28*, 555–565. [CrossRef]
40. Sathaye, J.; Lucon, O.; Rahman, A.; Christensen, J.; Denton, F.; Fujino, J.; Heath, G.; Mirza, M.; Rudnick, H.; Schlaepfer, A.; et al. Renewable Energy in the Context of Sustainable Development. *Renew. Energy Sources Clim. Change Mitig.* **2011**, 707–790. [CrossRef]
41. Hirschberg, S.; Dones, R.; Heck, T.; Burgherr, P.; Schenler, W.; Bauer, C. Strengths and weaknesses of current energy chains in a sustainable development perspective. *ATW-Internationale Zeitschrift fur Kernenergie* **2006**, *51*, 447–457.
42. Fthenakis, V.; Kim, H.C. Land use and electricity generation: A life-cycle analysis. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1465–1474. [CrossRef]
43. Schmidt, J.H. Development of LCIA characterisation factors for land use impacts on biodiversity. *J. Clean. Prod.* **2008**, *16*, 1929–1942. [CrossRef]
44. Campos-Guzmán, V.; García-Cáscales, M.S.; Espinosa, N.; Urbina, A. Life Cycle Analysis with Multi-Criteria Decision Making: A review of approaches for the sustainability evaluation of renewable energy technologies. *Renew. Sustain. Energy Rev.* **2019**, *104*, 343–366. [CrossRef]
45. Chomać-Pierzecka, E.; Kokiel, A.; Rogozińska-Mitrut, J.; Sobczak, A.; Soboń, D.; Stasiak, J. Hydropower in the Energy Market in Poland and the Baltic States in the Light of the Challenges of Sustainable Development-An Overview of the Current State and Development Potential. *Energies* **2022**, *15*, 7427. [CrossRef]
46. Yu, Z.; Razzaq, A.; Rehman, A.; Shah, A.; Jameel, K.; Mor, R.S. Disruption in global supply chain and socio-economic shocks: A lesson from COVID-19 for sustainable production and consumption. *Oper. Manag. Res.* **2022**, *15*, 223–248. [CrossRef]
47. FAO. *The State of Food and Agriculture Climate Change, Agriculture and Food Security*; FAO: Rome, Italy, 2016.

48. Gokmenoglu, K.K.; Taspinar, N.; Kaakeh, M. Agriculture-induced environmental Kuznets curve: The case of China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 37137–37151. [CrossRef]
49. Pellegrini, G.; Ingrao, C.; Camposeo, S.; Tricase, C.; Conto, F.; Huisingh, D. *Application of Water Footprint to Olive Growing Systems in the Apulia Region: A Comparative Assessment*; Elsevier: Amsterdam, The Netherlands, 2016. Available online: https://www.sciencedirect.com/science/article/pii/S0959652615015590 (accessed on 26 November 2022).
50. FAO. *State of Food and Agriculture 2019. Moving forward on Food Loss and Waste Reduction*; FAO: Rome, Italy, 2019.
51. FAO. *The Contribution of Agriculture to Greenhouse Gas Emissions*; FAO: Rome, Italy, 2020.
52. Gokmenoglu, K.K.; Taspinar, N. Testing the agriculture-induced EKC hypothesis: The case of Pakistan. *Environ. Sci. Pollut. Res.* **2018**, *25*, 22829–22841. [CrossRef]
53. Ridzuan, N.H.A.M.; Marwan, N.F.; Khalid, N.; Ali, M.H.; Tseng, M.L. Effects of agriculture, renewable energy, and economic growth on carbon dioxide emissions: Evidence of the environmental Kuznets curve. *Resour Conserv Recycl* **2020**, *160*, 104879. [CrossRef]
54. OECD/FAO. *OECD-FAO Agricultural Outlook 2022-2031*; FAO: Rome, Italy, 2022.
55. Jebli, M.; Youssef, S. Renewable energy consumption and agriculture: Evidence for cointegration and Granger causality for Tunisian economy. *J. Sustain. Dev. World Ecol.* **2016**, *24*, 149–158. [CrossRef]
56. Jebli, M.B.; Youssef, S.B. *The Role of Renewable Energy and Agriculture In reducing CO_2 Emissions: Evidence for North Africa Countries*; Elsevier: Amsterdam, The Netherlands, 2022. Available online: https://www.sciencedirect.com/science/article/pii/S1470160X16306690 (accessed on 26 November 2022).
57. Aydoğan, B.; Vardar, G. Evaluating the role of renewable energy, economic growth and agriculture on CO2 emission in E7 countries. *Int. J. Sustain. Energy* **2020**, *39*, 335–348. [CrossRef]
58. United Nations. *New FAO Analysis Reveals Carbon Footprint of Agri-Food Supply Chain*; United Nations: Midtown Manhattan, NY, USA, 2021.
59. Vijay, V.; Subbarao, P.M.V.; Chandra, R. An evaluation on energy self–sufficiency model of a rural cluster through utilization of biomass residue resources: A case study in India. *Energy Clim. Change* **2021**, *2*, 100036. [CrossRef]
60. Pintér, G.; Zsiborács, H.; Baranyai, N.H. Aspects of Determining the Energy Storage System Size Linked to Household-Sized Power Plants in Hungary in Accordance with the Regulatory Needs of the Electric Energy System. *Sustainability* **2022**, *14*, 2622. [CrossRef]
61. Liu, T.; McConkey, B.; Huffman, T.; Smith, S.; MacGregor, B.; Yemshanov, D.; Kulshreshtha, S. Potential and impacts of renewable energy production from agricultural biomass in Canada. *Appl. Energy* **2014**, *130*, 222–229. [CrossRef]
62. Szőllősi, L.; Béres, E.; Szűcs, I. Effects of modern technology on broiler chicken performance and economic indicators—A Hungarian case study. *Ital. J. Anim. Sci.* **2021**, *20*, 188–194. [CrossRef]
63. Elahi, E.; Khalid, Z.; Zhang, Z. Understanding farmers' intention and willingness to install renewable energy technology: A solution to reduce the environmental emissions of agriculture. *Appl. Energy* **2022**, *309*, 118459. [CrossRef]
64. Pascaris, A.S.; Schelly, C.; Burnham, L.; Pearce, J.M. *Integrating Solar Energy with Agriculture: Industry Perspectives on the Market, Community, and Socio-Political Dimensions of Agrivoltaics*; Elsevier: Amsterdam, The Netherlands, 2022. Available online: https://www.sciencedirect.com/science/article/pii/S221462962100116X (accessed on 12 December 2022).
65. Feuerbacher, A.; Laub, M.; Högy, P.; Lippert, C.; Pataczek, L.; Schindele, S.; Wieck, C.; Zikeli, S. An analytical framework to estimate the economics and adoption potential of dual land-use systems: The case of agrivoltaics. *Agric. Syst.* **2021**, *192*, 103193. [CrossRef]
66. Parker, B.F. *Solar Energy in Agriculture*; Elsevier: Amsterdam, The Netherlands, 1990.
67. Santra, P.; Singh, K.R.; Poonia, S.; Jain, D. *Solar Energy in Agriculture 1st Edition*; CRC Press: Boca Raton, FL, USA, 2021.
68. Schepens, G.; Mahy, D.; Buis, H.; Palz, W. *Solar Energy in Agriculture and Industry: Potential of Solar Heat in European Agriculture, an Assessment (Solar Energy R&D in the Ec Series H: 1)*; Springer: Berlin/Heidelberg, Germany, 1986.
69. Kovách, I.; Megyesi, B.G.; Bai, A.; Balogh, P. Sustainability and Agricultural Regeneration in Hungarian Agriculture. *Sustainability* **2022**, *14*, 969. [CrossRef]
70. Nagy, L.; Dávid, L.; Vasa, L.; Gál, T.; Vasa, L.; Balogh, P. Technology Planning System as a Decision Support Tool for Dairy Farms in Hungary. 2022. Available online: https://www.researchgate.net/publication/287294761 (accessed on 26 November 2022).
71. Popp, J.; Harangi-Rákos, M.; Gabnai, Z.; Balogh, P.; Antal, G.; Bai, A. Biofuels and Their Co-Products as Livestock Feed: Global Economic and Environmental Implications. *Molecules* **2016**, *21*, 285. [CrossRef] [PubMed]
72. Sobczak, A.; Chomać-Pierzecka, E.; Kokiel, A.; Różycka, M.; Stasiak, J.; Soboń, D. Economic Conditions of Using Biodegradable Waste for Biogas Production, Using the Example of Poland and Germany. *Energies* **2022**, *15*, 5239. [CrossRef]
73. ISE. *Agrivoltaics: Opportunities for Agriculture and the Energy Transition*; ISE: Breisgau, Germany, 2022.
74. Trommsdorff, M.; Kang, J.; Reise, C.; Schindele, S.; Bopp, G.; Ehmann, A.; Weselek, A.; Högy, P.; Obergfell, T. Combining food and energy production: Design of an agrivoltaic system applied in arable and vegetable farming in Germany. *Renew. Sustain. Energy Rev.* **2021**, *140*, 110694. [CrossRef]
75. Chomać-Pierzecka, E.; Kokiel, A.; Rogozińska-Mitrut, J.; Sobczak, A.; Soboń, D.; Stasiak, J. Analysis and Evaluation of the Photovoltaic Market in Poland and the Baltic States. *Energies* **2022**, *15*, 669. [CrossRef]
76. Tsagkari, M.; Roca, J.; Kallis, G. From local island energy to degrowth? Exploring democracy, self-sufficiency, and renewable energy production in Greece and Spain. *Energy Res. Soc. Sci.* **2021**, *81*, 102288. [CrossRef]

77. Sertolli, A.; Gabnai, Z.; Lengyel, P.; Bai, A. Biomass Potential and Utilization in Worldwide Research Trends—A Bibliometric Analysis. *Sustainability* **2022**, *14*, 5515. [CrossRef]
78. Villarroel-Schneider, J.; Höglund-Isaksson, L.; Mainali, B.; Martí-Herrero, J.; Cardozo, E.; Malmquist, A.; Martin, A. Energy self-sufficiency and greenhouse gas emission reductions in Latin American dairy farms through massive implementation of biogas-based solutions. *Energy Convers. Manag.* **2022**, *261*, 115670. [CrossRef]
79. Ramos-Suárez, J.L.; Ritter, A.; González, J.M.; Pérez, A.C. Biogas from animal manure: A sustainable energy opportunity in the Canary Islands. *Renew. Sustain. Energy Rev.* **2019**, *104*, 137–150. [CrossRef]
80. Donthu, N.; Kumar, S.; Mukherjee, D.; Pandey, N.; Lim, W.M. How to conduct a bibliometric analysis: An overview and guidelines. *J. Bus. Res.* **2021**, *133*, 285–296. [CrossRef]
81. Verma, S.; Gustafsson, A. Investigating the emerging COVID-19 research trends in the field of business and management: A bibliometric analysis approach. *J. Bus. Res.* **2020**, *118*, 253–261. [CrossRef]
82. Broadus, R.N. Toward a definition of 'bibliometrics'. *Scientometrics* **1987**, *12*, 373–379. [CrossRef]
83. Kumar, S.; Lim, W.M.; Pandey, N.; Westland, J.C. 20 years of Electronic Commerce Research. *Electron. Commer. Res.* **2021**, *21*, 1–40. [CrossRef]
84. Xu, X.; Chen, X.; Jia, F.; Brown, S.; Gong, Y.; Xu, Y. Supply chain finance: A systematic literature review and bibliometric analysis. *Int. J. Prod. Econ.* **2018**, *204*, 160–173. [CrossRef]
85. Ellegaard, O.; Wallin, J.A. The bibliometric analysis of scholarly production: How great is the impact? *Scientometrics* **2015**, *105*, 1809–1831. [CrossRef]
86. Mas-Tur, A.; Roig-Tierno, N.; Sarin, S.; Haon, C.; Sego, T.; Belkhouja, M.; Porter, A.; Merigó, J.M. Co-citation, bibliographic coupling and leading authors, institutions and countries in the 50 years of Technological Forecasting and Social Change. *Technol. Forecast. Soc. Chang.* **2021**, *165*, 120487. [CrossRef]
87. Ramanan, S.S.; George, A.K.; Chavan, S.B.; Kumar, S.; Jayasubha, S. Progress and future research trends on Santalum album: A bibliometric and science mapping approach. *Ind. Crops Prod.* **2020**, *158*, 112972. [CrossRef]
88. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
89. Bibliometrix. Bibliometrix Around the World. 2022. Available online: https://www.bibliometrix.org/home/index.php/about-us-2/bibliometrix-around-the-world (accessed on 27 July 2022).
90. Radhakrishnan, S.; Erbis, S.; Isaacs, J.A.; Kamarthi, S. Correction: Novel keyword co-occurrence network-based methods to foster systematic reviews of scientific literature. *PLoS ONE* **2017**, *12*, e0172778. [CrossRef]
91. Oliveira, T.D. From Modelmania to Datanomics: The Top Journals and the Quest for Formalization. STOREP 2018—Whatever Has Happened to Political Economy? 2018. Available online: http://conference.storep.org/index.php?conference=storep-annual-conference&schedConf=2018&page=paper&op=view&path%5B%5D=333 (accessed on 25 November 2022).
92. Cobo, M.J.; López-Herrera, A.G.; Herrera-Viedma, E.; Herrera, F. An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *J. Informetr.* **2011**, *5*, 146–166. [CrossRef]
93. Cahlik, T. Search for Fundamental Articles in Economics. *Scientometrics* **2004**, *49*, 389–402. [CrossRef]
94. Hu, H.; Xue, W.; Jiang, P.; Li, Y. Bibliometric analysis for ocean renewable energy: An comprehensive review for hotspots, frontiers, and emerging trends. *Renew. Sustain. Energy Rev.* **2022**, *167*, 112739. [CrossRef]
95. Yang, X.J.; Hu, H.; Tan, T.; Li, J. China's renewable energy goals by 2050. *Environ. Dev.* **2016**, *20*, 83–90. [CrossRef]
96. Cheng, Y.; Gu, B.; Tan, X.; Yan, H.; Sheng, Y. Allocation of provincial carbon emission allowances under China's 2030 carbon peak target: A dynamic multi-criteria decision analysis method. *Sci. Total. Environ.* **2022**, *837*, 155798. [CrossRef] [PubMed]
97. IEA. Key World Energy Statistics 2020. 2020. Available online: https://www.iea.org/reports/key-world-energy-statistics-2020/final-consumption (accessed on 27 October 2022).
98. Eurostat. Share of Renewable Energy in Gross Final Energy Consumption. 2022. Available online: https://ec.europa.eu/eurostat/databrowser/view/t2020_rd330/default/bar?lang=en (accessed on 19 April 2022).
99. Eurostat. *Renewable Energy in the EU in 2018*; Eurostat: Luxembourg City, Luxembourg, 2020.
100. Perrin, J.A.; Bouisset, C. Emerging local public action in renewable energy production. Discussion of the territorial dimension of the energy transition based on the cases of four intermunicipal cooperation entities in France. *Energy Policy* **2022**, *168*, 113143. [CrossRef]
101. TRADE. Official Website of the International Trade Administration. 2020. Available online: https://www.trade.gov/country-commercial-guides/italy-renewable-energy#:~:text=The%20Plan%20aims%20to%20bring,power%20generation%20from%20renewable%20sources (accessed on 22 October 2022).
102. Massé, D.I.; Talbot, G.; Gilbert, Y. On farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations. *Anim. Feed Sci. Technol.* **2011**, *166–167*, 436–445. [CrossRef]
103. Choudhary, M.; Bailey, L.D.; Grant, C.A. Review of the Use of Swine Manure in Crop Production: Effects on Yield and Composition and on Soil and Water Quality. *Waste Manag. Res.* **1996**, *14*, 581–595. [CrossRef]
104. Singh, R.; Paritosh, K.; Pareek, N.; Vivekanand, V. Integrated system of anaerobic digestion and pyrolysis for valorization of agricultural and food waste towards circular bioeconomy: Review. *Bioresour. Technol.* **2022**, *360*, 127596. [CrossRef] [PubMed]
105. Ragazou, K.; Passas, I.; Garefalakis, A.; Dimou, I. Investigating the Research Trends on Strategic Ambidexterity, Agility, and Open Innovation in SMEs: Perceptions from Bibliometric Analysis. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 118. [CrossRef]

106. Rahman, M.; Khan, I.; Field, D.L.; Techato, K.; Alameh, K. Powering agriculture: Present status, future potential, and challenges of renewable energy applications. *Renew. Energy* **2022**, *188*, 731–749. [CrossRef]
107. Kim, S.K.; Park, S. Impacts of renewable energy on climate vulnerability: A global perspective for energy transition in a climate adaptation framework. *Sci. Total. Environ.* **2023**, *859*, 160175. [CrossRef] [PubMed]
108. Ranjbari, M.; Esfandabadi, Z.S.; Quatraro, F.; Vatanparast, H.; Lam, S.S.; Aghbashlo, M.; Tabatabaei, M. Biomass and organic waste potentials towards implementing circular bioeconomy platforms: A systematic bibliometric analysis. *Fuel* **2022**, *318*, 123585. [CrossRef]
109. Luis, E.C.; Celma, D. Circular Economy. A Review and Bibliometric Analysis. *Sustainability* **2020**, *12*, 6381. [CrossRef]