USE OF GEOTHERMAL ENERGY IN THE FOOD INDUSTRY: A REVIEW*

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ABSTRACT

This paper aims to make a bibliographic literature review about the current and potential uses of geothermal energy within the food industry, which uses a third of the world's energy during production in all the processes involved. Fossil fuels are the most common sources for generating electrical energy for the food industry. However, it is known that they cause adverse environmental effects such as atmospheric pollution, ecosystem disturbances and natural resource depletion. Due to the lack of published studies about this subject, this review was carried out using different databases. Of the 77 documents published between 2010 and 2020, more than 70 % of them were written in English by researchers from 67 institutions from around the world. These documents allow us to analyze a sample of countries where the implementation of geothermal energy has a greater advance in processes implementing geothermal energy in the food industry; such as heating and cooling systems for the drying

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of fruits and vegetables, and producing various foods, achieving energy coverage close to 10 % in this industry.

Keywords: renewable energy; geothermal energy; food industry; bibliographic review.

Uso de la energía geotérmica en la industria alimenticia: una reseña

Resumen

Este artículo tuvo como objetivo realizar una revisión bibliográfica sobre el estado actual de la energía geotérmica en la industria alimenticia, la cual usa una tercera parte de la energía mundial para la producción en todos sus procesos involucrados. Los combustibles fósiles son una de las fuentes comunes para la generación de energía eléctrica para la industria alimenticia. Sin embargo, es bien sabido que éstas causan efectos adversos ambientalmente tales como polución atmosférica, perturbación de ecosistemas y agotamiento de recursos naturales. Debido a la falta de estudios publicados sobre este tema, esta reseña fue llevada a cabo usando distintas bases de datos. De los 77 documentos publicados entre 2010 y 2020, más del 70 % de ellos fueron escritos en inglés por investigadores de 67 instituciones alrededor del mundo. Estos documentos permiten analizar una muestra de países en los que la implementación de la energía geotérmica tiene un gran avance en procesos que implementan la energía geotérmica en la industria alimenticia, tales como calentar y mantener sistemas de refrigeración para el secado de frutas y vegetales y la producción de varios alimentos, alcanzando una cobertura energética cercana al 10 % de esta industria.

Palabras clave: energía renovable; energía geotérmica; industria alimenticia; reseña bibliográfica.

INTRODUCTION

During the last 50 years, the concentrations of pollutants in the environment have increased exponentially due to anthropogenic activities, such as fossil fuels consumption, deforestation, and exponential population growth. Those have led to air, water, and soil degradation, compromising biological diversity and the human race's existence [1].

For this reason, renewable energies have gained significant importance in recent years since they are characterized by being clean and from abundant natural resources, presenting little or no impact on the environment [2]. Geothermal can be defined as heat from the subsurface that can serve as an energy resource for human use, making it an affordable and sustainable alternative capable of generating energy in a continuous and reliable way. It can be used globally, and its implementation reduces greenhouse gas emissions, contributing to climate change mitigation [3].

Literature about renewable energies is numerous and diverse. One of the most truthful tools to synthesize information is bibliometric analysis, which integrates the data used to answer a research question [4]. This study was carried out to give an overview of the applications of geothermal energy in the food industry, considering the publications between 2010 and 2020, through the databases Researchgate, SpringerLink, SemanticScholar, ScienceDirect, MDPI, Google Academic, Scopus, ScienceDirect, Journals, Ebsco, and Elsevier. Making the analysis of these publications, no previous review studies were found in which the use of geothermal energy in the food industry was analyzed in depth. None of the studies were found with a scope related with geographical location for diverse geothermal energy applications in the food industry, as we make in this revision.

To our knowledge, there is not a comprehensive study published on the subject. There has been an exponential growth of alternative energies defeating fossil fuels. And, in particular, geothermal energy application in the food industry is an emerging technology that heavily promotes the circular economy. Therefore, this study provides a perspective of its application in this industry, while also providing a basis for research, analysis, and broadcast for all the stakeholders.

APPLICATION OF GEOTHERMAL ENERGY IN THE FOOD INDUSTRY

Today, humanity is continuously searching for new alternatives to replace fossil fuels. Thus, the global challenge is to avoid future energy shortages to meet agricultural and food demand due to the progressive increase in population [9, 10]. In the same way, industries' growth must move towards non-conventional energy sources [11] and to overcome the growth in demand for water and energy required by these industries to carry out

their growing productivity demands [12]. Therefore, the study of the use of alternatives such as the use of energy generated by the heat coming from the earth's core becomes an interesting alternative [6] since it produces low levels of greenhouse gas (GHG) emissions and replaces this depletable traditional energy sources [13].

The use of conventional energy within the food industry can be classified into two categories. The first is direct use, which refers to the energy needed for the industry's inputs and supply chain [14]. The second is indirect use, which refers to the energy used in the industry's processes and delivery of inputs [5]. The Agro-food industry is one of the most energy intensive industries, consuming one-third of the world's energy production [15]. Of that third of the energy, more than 80 % is conventional (electricity consumption and LPG "Liquefied Petroleum Gas") generating a significant impact on the environment [16, 17]; causing at the same time a discontinuous and unstable offer [18].

The use of renewable energy guarantees energy security since it is a continuous energy with low or no environmental impact [19]. In Europe, it has been demonstrated that geothermal energy has high efficiency, which can be used mainly by agriculture, reducing costs, and pollution [21]. According to the above, the need to implement geothermal energy is exposed, both at the scale of large industries and small industries [22], because with this, new forms of cleaner production arise in systems in a controlled environment, which allow developing production of food without causing numerous environmental impacts [23, 24].

A great example of the above is the widespread and massive use of geothermal energy for cooling or heating in food production processes [25], solving one of the most common conflicts related to food conservation. In this way, the food industry develops a simple process of high efficiency and offers products in good condition [26]. The consumer takes advantage of this in variable weather conditions, guaranteeing, in the same way, ambitious productions at low cost and low environmental impact [27].

Geothermal energy used for agri-food processes is divided into four groups: hydro geothermal energy from surface hot water sources, hydro geothermal energy from water vapor sources, hydro geothermal from hot water energy at great depths, and petroleum thermoelectric energy [29]. They have proven to be profitable in the sectors of processing foodindustries [30], through industrial processes and heating and cooling districts [31], reaching a global application of 5.5 % in greenhouses and open-air heating, 2.8 % in heating industrial processes, 2.7 % in heating ponds and aquaculture channels, and 0.4 % for agricultural drying for 2010 [7, 32].

1. MATERIALS AND METHODS

The review was carried out using information from the aforementioned databases. The searching terms on a general scale were: "geothermal energy," "geothermal energy and food," "geothermal energy and food and industry," and "geothermal energy and agriculture" for the period 2010 - 2020. The collected information was classified into the following headings: university's name that carried out the study; countries in which the publications were made; document's primary language; type of publication; research focus; number of citations; and journal's impact factor. Additionally, the state of geothermal energy application in the food industry worldwide was reviewed through the literature.

The data obtained were tabulated and graphed. This facilitated the analysis of the trends and importance of each of the documents on geothermal energy use in the food industry in the last ten years.

2. RESULTS

2.1. Bibliometric analysis

Carrying out a bibliometric analysis within this review is of great importance for the research since it generates an analysis about quality and impact indices on the knowledge framework about this subject. In this way, we covered several topics such as research institutions, productivity, country distribution, citation indexes, among others.

2.1.1 Document type and language

Publications were classified as scientific articles, conference proceedings and books (or book chapter), Languages used are: English, Korean, and Mandarin. A total of 77 documents were found. Most of them, 77.9 % (60 publications), were research scientific articles. The most common document's primary language was English, 97.40 %; followed by Korean: 1.29 % and mandarin: 1.29 %. The main publication type was scientific articles, followed by the conference proceedings. See results in the Figure 1:

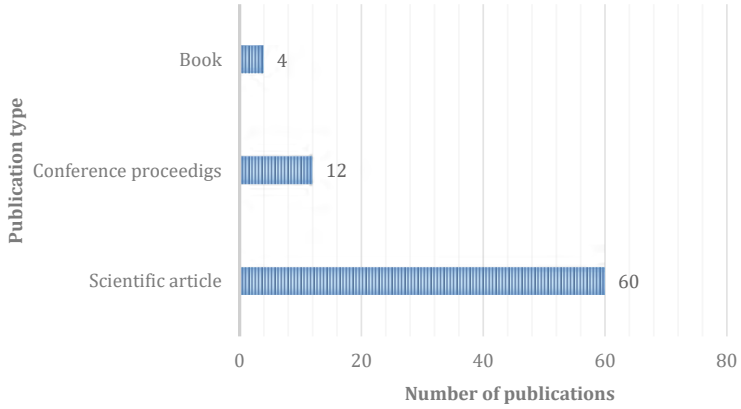

Figure 1. Type of publication. Documents about geothermal energy in the food industry (2010-2020).

Source: own elaboration.

2.1.2 Annual research production

Over the period from 2010 to 2020, publication trends of research articles by year were analyzed. From 2010 to 2014, the trend was approximately constant, with an average of 5 - 6 publications per year. However, between 2015 and 2017 the number was doubled to 10 -11 publications per year, and it decreased afterwards to 7- 8 publications in 2018-2019. For 2020 we reported only four publications. The research production showed an increasing interest from the researchers regarding the study of geothermal energy in the food industries in the last six years, as shown in Figure 2. The production could influence the technological advances that have developed throughout these years. In 2015, the largest number of publications was recorded, corresponding to 11 documents.

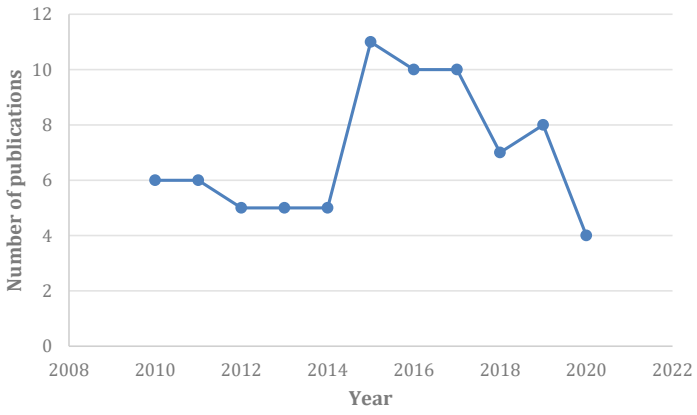

Figure 2. Publications per year. Documents about geothermal energy in the food industry (2010-2020).

Source: own elaboration.

2.1.3 Research distribution by country

40 countries around the world are involved in publications and research found by this study. The fourteen most productive countries are listed in Figure 3. The number of publications produced by each country and the percentage concerning the total number of articles is presented. The country with more publications was Turkey with 9 publications (22.5 %), followed by the USA, Romania, and Canada with four documents each one (10 %); Kenya, Mexico, Korea, and Australia had three publications (7.5 %); Indonesia, Germany, China, and Greece had two publications (5 %). Turkey stands out over several countries for the publication of documents on geothermal energy, contrary to the case of India and Japan, which have just one or Iran, Kenya, Egypt, Poland, Iceland and other countries, which had a very low number of publications.

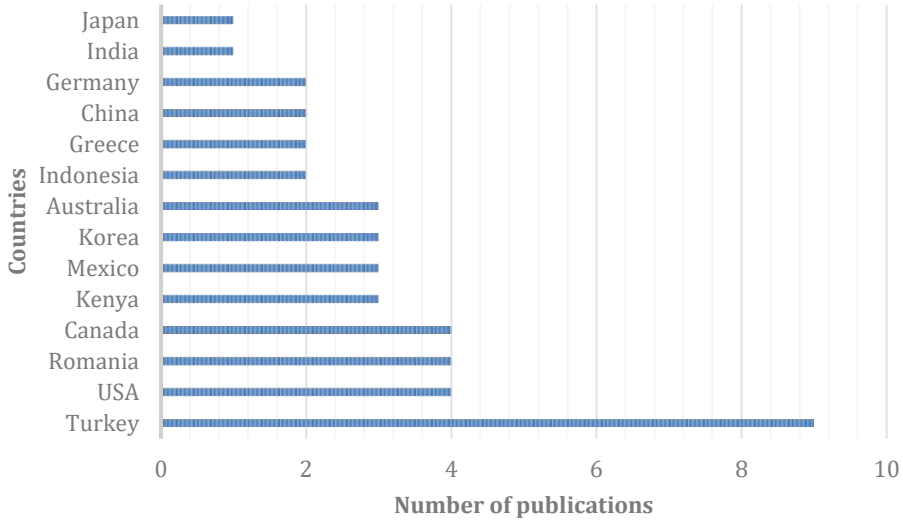

Figure 3. Publications by country. Documents about geothermal energy in the food industry (2010-2020).

Source: own elaboration.

2.1.4 Research distribution by institutions

Sixty-seven institutions participated in the analyzed publications related to geothermal energy in the food industry during 2010-2020. Table 1 shows that the institution with the highest production is Yasar University with three publications, followed by nine institutions which had two publications and 57 institutions with one publication each. Based on the above, it is evident that geothermal energy applied to the food industry is addressed globally by several institutions in Asia, North America, Europe, and Oceania.

Table 1. Publications by institution. Documents about geothermal energy in the food industry (2010-2020)

Position	Country	Institutions	Number of publications
1	Turkey	Yasar University	3
2	Turkey	Ege University Solar Energy Institute	2
	Iceland	ÍSOR-Iceland GeoSurvey	
	Saudi Arabia	King Saud University	
	India	Pandit Deendayal Petroleum University	
	Japan	United Nations University	
	Australia	Universidad Southern of Queensland	
	Mexico	Universidad Nacional Autónoma of Mexico	
	Romania	University of Oradea	
	Canada	University of Waterloo	
3	Turkey	Ahi Evran University	1
	Iraq	Baghdad University	

Source: own elaboration.

2.1.5 Journals

A classification of the journals was made based on the number of articles published and their number of citations, which shows a positioning of the journals. The magazine with the highest number of publications was "Applied Thermal Engineering" which stood out both in its number of publications and citations ("TLCS" Total Local Citation Score), where the total number of citations is the total number of publications made in each journal, as shown in Table 2:

Table 2. Publications by journal and citations. Documents about geothermal energy in the food industry (2010-2020)

Position	Journal	Number of publications	TLCS	Year of publication
1	Renewable and Sustainable Energy Reviews	7	251	2012,2014,2015,2017
2	Applied Thermal Engineering	3	308	2011,2012,2013
3	Solar Energy	2	63	2016,2020
4	International Journal of Hydrogen Energy	2	55	2011,2017
5	Energy	2	24	2016,2019
6	Annual Reviews	1	252	2011
7	Energies	1	120	2010

Source: own elaboration.

2.1.6 Research focus

This study analyzed the frequency of terms related to geothermal energy in the food industry. Some topics specify the application of this type of energy within the

investigation, selected from the title and keywords of the papers, as can be seen below in Table 3:

Table 3. Publications by subject. Documents about geothermal energy in the food industry (2010-2020)

Subject	Number of publications	Percentage (%)
Geothermal food production resources	31	40
Food safety	10	12,9
Food drying	9	9
Food processing	7	9
Heating and cooling	4	5,1
Food production	3	3,8
Greenhouse application	3	3,8
Food preservation	3	3,8
Milk pasteurization	3	3,8
Aquaculture	2	2,5
Crops	2	2,5
Total	**77**	**100**

Source: own elaboration.

According to Table 3, it can be observed that the topics with the most significant number of publications are those that deal with the application of geothermal energy within the food industry in a general context. They focused on high-impact social engagement, such as food security or mass food production. On the contrary, more complex topics such as aquaculture or crops, have fewer publications.

2.1.7 IMPACT OF WRITERS

Table 4 shows the articles with the greatest impact by the number of citations of their contributors. Therefore, it was found that the authors of the article "Energy Intensity of Agriculture and Food Systems" have been referenced 252 times in several publications. The authors of the article "Energy Consumption and Conservation in Food Retailing" had 197 citations. The author of the article "Direct Utilization of Geothermal Energy" had 120 citations, and the authors of the article "Utilization of renewable energies in Turkey's agriculture " had 71 citations.

Table 4. Highest impact publications by author´s citations. Documents about geothermal energy in the food industry (2010-2020)

N°	Authors	Title	Journal	(TLCS)	Year of publication
1	-Nathan Pelletier -Eric Audsley -Sonja Brodt -Tara Garnett -Patrik Henriksson -Alissa Kendall -Klaas Jan Kramer -David Murphy -Thomas Nemecek -Max Troell	Energy Intensity of Agriculture and Food Systems [5]	Annual Reviews	263	2011
2	-S. A Tassou -Y. Ge -A. Hadaway -D. Marriott	Energy Consumption and Conservation In Food Retailing [6]	AppliedThermal Engineering	210	2011
3	-Jhon W.Lund	Direct Utilization of Geothermal Energy [7]	Energies	127	2010
4	-AsiyeGül Bayrakcı -Günnur Koçar	Utilization of renewable energies in Turkey's agriculture [8]	Renewable and Sustainable Energy Reviews	71	2012

Source: own elaboration.

3. ANALYSIS OF RESULTS

3.1 Application of geothermal energy in the agroindustry

From the first indications of geothermal energy application worldwide, widespread use was established to cool or heat production processes [33]. In India's case, a global lead food producer, implementing space cooling and heating systems using geothermal energy has reduced food losses and waste [34]. The most important example of these systems is greenhouses, which become more effective than some outdoor crops, exposed to various physical, chemical, and biological factors that cause low crop probability. These greenhouses operate by heating and cooling different spaces so that sufficient protection is given to crops, generating optimal plant growth [2, 35, 36]. Similarly, geothermal energy applied in greenhouses provides an energy source to sustain lighting and the continuous enrichment of CO_2 within the facility, highlighting the crop's quality throughout the year, regardless of external environmental conditions [37]. For this reason, the use of geothermal energy in the food supply chain gives communities the advantage of having a controlled environment to produce [18]. Due to the benefits in food security and the feasibility of producing plants in a greenhouse environment [38],

this has given place to the widespread use of modular agriculture in vertical farms from geothermal heating systems, as is the case of Canada [39].

Likewise, due to the increase in the use of renewable energies [40], geothermal energy has been implemented in the production of milk and ice, being indispensable for its conservation in the creation of new derived foods [41, 42]. Also, geothermal energy is applied to the production of tomatoes, cucumbers and peppers, and it is important in the development of sauces and seasonings [43]; or as provider of the heat necessary for the operation of food dryers such as those aforementioned [44, 45]. Thus, worldwide agro-businesses already supply markets with vegetables, fruits, flowers, and seedlings produced from geothermal energy facilities from Hungary, Russia, New Zealand, Japan, Iceland, China, Tunisia, US, Kenya and Pakistan [7, 46, 47].

Another example of geothermal energy application in the food industry is implementing an efficient aquaculture heating system [48]. This application has been made in countries with high potential in this kind of technologies, such as Italy, which stands out for its large production of said energy used in thermal waters, fish farming, and spa areas [49]. Other implementing countries are Kenya, Iceland, China, Germany and Poland [50, 53] among several countries having relatively high population acceptances, willing to transform their behaviors and attitudes to apply new alternatives [54]. This type of energy is used quite a lot for fish farms or fish farming. That´s the case of the city of Meshkin-Shahr in northwest Iran where the energy extracted accounts for 34 % of this activity, as well as the United States, Iceland, New Zealand, Japan and China [7, 55]. The success of this application lies in the control of temperatures in the pond, optimizing the growth of species such as catfish, shrimp, tilapia, eels, tropical fish [7], and salmon.

Similarly, another application is the drying of fruits and vegetables, which emerged to meet the growing demand for food around the world. In the case of Egypt, in the agricultural sector has established energy and food security [57] through diverse processes using geothermal energy in agricultural drying [35]. This technique's selection depends on the type of food and its characteristics [58]. Generally, the process has a geothermal cycle consisting of a heat pump, cooling system, turbines, and hot water and drying systems [59]. In the geothermal drying system, fresh air is required to pass through a converted air-water duct and is heated by geothermal steam to a temperature between 40 and 100 ºC [60], which is responsible for eliminating the humidity present in the food and subsequently reducing its volume [61]. This is a model that can be used to optimize drying [62], and can also be part of cooking processes in industrial food processing [63].

Its application occurs on various foods such as algae (Iceland), onion (USA), wheat and other cereals (Serbia), fruits (El Salvador, Guatemala, and Mexico), alfalfa (New Zeeland), coconut flesh (Philippines) [7], tomato, avocado, green chili (Mexico and Turkey) [64] and beer malt [65]. Besides, this is used for food de-hydration, in Turkey and Pakistan [47], [66]. All these processes have in common that geothermal energy has a 24-hour availability, a benefit that, in general, is not achieved with other renewable energies [47].

Another geothermal energy application in food industries, is the production of bottled water and soft drinks [67]. It does not significantly influence the food, but one of the main components to store the product and make it available to the market; this application has been carried out in Bulgaria, Serbia, Turkey, and the United States [68, 69].

The dairy industry is also characterized by its high energy consumption [70]. Geothermal energy is used to carry out milk pasteurization processes in Romania, New Zealand, Kenya and Turkey [46, 55]. Especially in Turkey, geothermal energy is applied in the use of heat pumps [71] and the production of milk powder. The last one is carried out using a processor consisting of eight units such as the evaporator, the feed pump, the dryer spray, cooler, economizer, fan, heater, and compressor [72].

For the process, the milk enters the evaporator to reduce the water and leaves the same temperature. After that, it passes to the next feeding and drying pump in which the powdered milk is obtained [73, 74]. Finally, it is cooled by the contact of air and is headed to packaging.

All of the above is given to show a circular food production system with the direct use of geothermal energy to contribute to the efficiency not only of heat, water, and nutrients but also for the energy sector and food industry [75, 76]. Thus, geothermal energy is efficient in food processing since it is self-sufficient with positive impacts on the environment. Likewise, it promotes sustainability, increases food security, benefits consumers [8], and allows food to be stored and preserved, reducing shortage risks [77]. It is also a profitable alternative since it reduces costs in various processes of a large part of the world's food industries [45].

4. CONCLUSIONS

The potential of geothermal energy use is very high in the food industry. This is mainly because it allows companies the decrease their conventional energy costs, making it a viable alternative to implement. A bibliometric analysis of applications of geothermal energy in the food industry was carried out worldwide. Based on 77 articles analyzed, 76.6 % belong to research articles, most of which use English as the primary language.

The analysis was conducted from 2010 to 2020. Also, this study found that the magazine Renewable and Sustainable Energy Reviews had the highest number of publications with seven articles.

On the other hand, Turkey is characterized by being the country with the largest number of publications regarding the use of geothermal energy in food industry.

Trends of great importance were observed, such as that a 96.62 % of scientific articles identified display a comprehensive and compiled information on the subject. This was because they generated great data and contributions related to uses, processes and applications of geothermal energy, while the remaining 3.4 % did not address the issue with sufficient criteria and / or contributions on geothermal energy in the food industry. Likewise, 97.4 % of the total records were published in the English language. In the same way, the number of publications has increased since 2015 thanks to the incursion of renewable energies in different industries, even more in countries with great technological progress such as Turkey, USA, Romania, Canada, and others, through the participation of approximately 67 institutions. Regarding to interest and research contribution, the journal "Comments on renewable and sustainable energy" was the one where more records were found related to food safety issues, food processing, and geothermal resources for food production. Finally, high-impact articles with the highest number of citations were also evaluated. In this sense, the article "Energy intensity of agricultural and food systems" of the Annual Magazine Comments was the most important within the community interested in the subject investigated.

It is then defined that the need to replace the use of fossil fuels gave way to applying geothermal energy in different industries around the world. However, the food industry has excelled through this type of renewable energy. It has managed to satisfy the energy demand of certain agricultural and food production, providing these for a big part of the population. On the other hand, it is stated that geothermal energy is highly efficient in this industry since it results in quality products at low cost without producing pollution rates as high as those that use fossil fuels and allowing food preservation processes (Iran, Kenya, Egypt, Poland, Iceland). In this way, at a global level, geothermal energy is implemented in the food industry in a representative percentage through different activities.

In refrigeration or heating systems in controlled environments or greenhouses, countries such as India, Hungary, Russia, New Zealand, Japan, Iceland, China, Tunisia and USA stand out. The USA, Kenya, and Pakistan manage to reduce waste and food loss by providing crops with better conditions for developing fruits, vegetables, and seedlings necessary to generate food security in their territories. Similarly, geothermal energy in the aquaculture sector allows countries such as Iran, the United States, Iceland,

New Zealand, Japan, China, Kenya, Italy, Iceland, Germany, and Poland to optimize the growth of different species of fish through temperature control in the breeding ponds, allowing a position in world trade and the adaptation of sustainable alternatives in their production processes.

Additionally, the drying process of fruits, vegetables, and cereals through the application of this type of energy has been used by many countries: Egypt, Mexico, Serbia, the Philippines and Turkey. There are other activities such as beverage bottling, milk pasteurization, and milk powder production, which have demonstrated the commitment of many territories to contribute sustainably to the energy, food processing, and production sector, benefiting not only the industry and the environment but also the world population. In this sense, geothermal energy provides food security at a low cost in high-quality indices.

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