PROFILE OF ENERGY GENERATION USING PIEZOELECTRIC MATERIAL IN THE PERIOD 2010-2017.

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ABSTRACT

The main purpose of this article is to create a profile of the generation of electrical energy through the use of piezoelectric material in the period 2010-2017, in order to be a reference for innovation opportunities, entrepreneurship and scientific research, helping in a disruptive manner to the environmental reality that is experienced today, because of the generation of electric power from traditional methods, since this has forced the human being to search for clean and sustainable sources of energy in order to reduce the use of fossil fuels and other pollutants, and thus mitigate the different environmental phenomena caused by these practices.

The piezoelectric material is composed of crystals that when subjected to mechanical stresses acquire an electric polarization in their mass, which produces a potential difference and the appearance of electric charges on the surface thereof, from this, the piezoelectricity is visualized as one of the promising renewable alternatives for the generation of electric power.

This research incorporates a study of patents, through the analysis of indicators that relate the inventive and patenting activity in the 2010-2017 period. This process was divided into the following phases: Selection of the database, review and processing, formulation and analysis of the database, compilation of ideas and preparation of the scientific article. All of this had as a result the determination of the state of technology, identification of trends, type of applicants for this technology, potential markets and as an important contribution an inventory of ideas for the innovation opportunities, entrepreneurship and scientific research.

Keywords: Patents; Innovation; Piezoelectric Material; Electric power; sustainable; Inventive Activity

INTRODUCTION

The current environmental reality has forced the human being to clean and sustainable sources of energy, all this, to improve environmental indicators that show the decrease in the use of fossil fuels and other pollutants in order to break down the different environmental phenomena caused by pollution.

The study of these technologies is increasingly exhaustive for its greater use, as a result, some alternatives as wind energy has been discovered and developed, one of the oldest resources exploited by the human being, which consists in taking advantage of the kinetic energy generated by the currents of air to later transform it into electric fluid. Another widely used source is solar energy, which consists of the capture of UV rays through panels that transform electrical energy. Everything is based on the fact that the transport and energy sectors are the main anthropogenic sources, responsible for more than 20% and 60% of greenhouse gas emissions, respectively (European Environment Agency, 2004).

According to Dayou, Man-sang, Dailimin, & Wang, (2009) recent fluctuations in the price of oil have affected the world economy, which has caused an increase in the price of other items. Some people even link what happened with the collapse of a few financial institutions in countries like the United States and the United Kingdom. This proves that we are too dependent on oil as a source of energy; in addition, this has contributed to serious environmental pollution. Therefore, an alternative method to produce energy has to be considered. Nuclear energy and hydroelectric power can be explored among other solutions. However, these options require enormous financial capacity for their execution and maintenance, also, not many countries are "authorized" to use nuclear power generators due to the global political scenario. Clean energies such as photovoltaic cells and wind turbines have been the most popular options; these renewable energies, however, are very expensive and remarkable in many countries. Therefore, other possible energy sources were explored and one of the promising options is through the use of piezoelectric material or "PZT".

Piezoelectric materials can generate an electrical signal when subjected to a mechanical effort, all this is due to the ability of some crystals to generate energy when bending under a voltage, these piezoelectric crystals to be subjected to the mechanical stresses acquire an electric polarization in its mass, which produces a potential difference and the appearance of electric charges on the surface thereof, consequently, the piezoelectric material adopts its name that comes from the Greek "piezein" that translates squeeze.

The presentations of this materials are diverse in the field of small and large-scale energy generation, that is, it presents a great technological variability. As an example, there are studies carried out to generate electrical power for biomedical devices (Ramsay & Clark, 2001), tests that demonstrate the viability

of using piezoelectric ceramic (PZT) to generate electrical energy in orthopedic implants (Platt, Farrior, Garvin, & Haider , 2005) and the search for Energy Harvesting food solutions focused on piezoelectric sources (Vasquez-Rodriguez, Jimenez-Martinez, & de Frutos, 2011), all this demonstrates the importance of research in the field of electric power generation through this material.

For this reason, the present study is carried out, in which an evaluation of the technologies developed in the period 2010-2017 that describes the current situation of the subject in question is explored. In the elaboration of the investigation the inventive and patenting activity of the generation of energy through the piezoelectric materials is examined, which will be extracted from the Derwent Innovations Index Database, and it will form the registries in which all the relevant information will be grouped making the search for innovation opportunities or scientific research more structured.

METHODOLOGY

The analysis of patents was carried out in the framework of new technologies related to the generation of electrical energy through the use of piezoelectric material, a process that was divided into the following phases: selection of the database, review and processing, formulation and analysis of the database, inventory of ideas and preparation of the scientific article.

i. Selection of the database: In this first phase, different official databases were investigated, considering the need of inclusion of the inventive and patenting activity, on the other hand, the revision of the registers was carried out according to the generation of energy through the use of piezoelectric material during the period of 2010-2017, during this phase the Derwent Innovations Index database stood out regarding the above criteria and which in turn allowed the search and download of the information.

ii. Review and processing: This phase includes the construction of the search equation according to the nomenclature and operators provided by the Derwent Innovations Index database for the download, review and registration of the information, after this, the inventive and patenting activity were collected and related to the generation of energy through the use of piezoelectric material in the period 2010-2017.

iii. Formulation and analysis of the database: The third phase includes the formulation of indicators that relate inventive activity, patenting activity, leading countries, leading applicants, inventors, life cycle analysis, potential markets, types of applicants and technological trends.

iv. Inventory of ideas: From the construction of the database, the formulation and the description of indicators, an inventory of ideas was built for the opportunity of innovation, entrepreneurship and scientific research.

v. Elaboration of the scientific article: This phase includes the scientific production from the creation of an article that harmonizes and internalizes all the phases attended within this investigation, setting conclusions useful

for new inventors, entrepreneurs or companies in terms of the innovation opportunities and topics for new studies.

FINDINGS

Database selection and construction of the query string

Database selection

Web of Science is an online scientific information service provided by Clarivate Analytics, which provides the Derwent Innovations Index database that covers more than 14.3 million basic inventions from 40 global authorities that issue patents. This database was selected because its records presented inventive and patenting activity, and reliability, however, it allows you to search and download the complete registry, including dates, applicants, IPC codes, among other information for the construction of a robust database.

Construction of the query string

Query string: TS= (PIEZOELECTRIC AND ELECTRICITY) AND TI= (PIEZOELECTRIC OR ELECTRICITY OR GENERATION).

The description of this search equation can be seen in Table 1. It states that the advanced search was the most promising tool for the rigorous identification of the desired records, including the operators and keywords that would allow the identification of patents accordingly to this technology and the same equation was also structured at the level of the title and theme of each of the registers. On the other hand, it is considered that the study period is introduced directly in the platform and for this reason it is not visualized in the equation.

Type of search	Advanced search
Search operators	AND - OR
Keywords	PIEZOELECTRIC, ELECTRICITY, GENERATION
Search level	Title (TI), Subject (TS)
Time horizon	2010-2017

Table 1. Structure of the search equation

Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Profile of the inventive activity

Life cycle for the technology

In order to have a vision of the development of technology in the field of electric power generation using piezoelectric material in the period 2010-2017, *Figure 1* shows an analysis of the life cycle of the technology where its inventive activity is quantified and the accumulation of inventions over the years is presented. From this way, we have identified that until the period 2007-2008 the technology ends its emerging stage with 49 inventions and an accumulation of its inventive activity of 56 inventions, and from this date approaches its growth stage showing its largest cumulative inventive activity with 876 and with 147 inventions in 2015, however, we can see after this date a decline in the number of inventions, where it is said that this occurs because the requests made in recent years might not have been published yet, since the inventions were mostly published after a year or more after their first request.

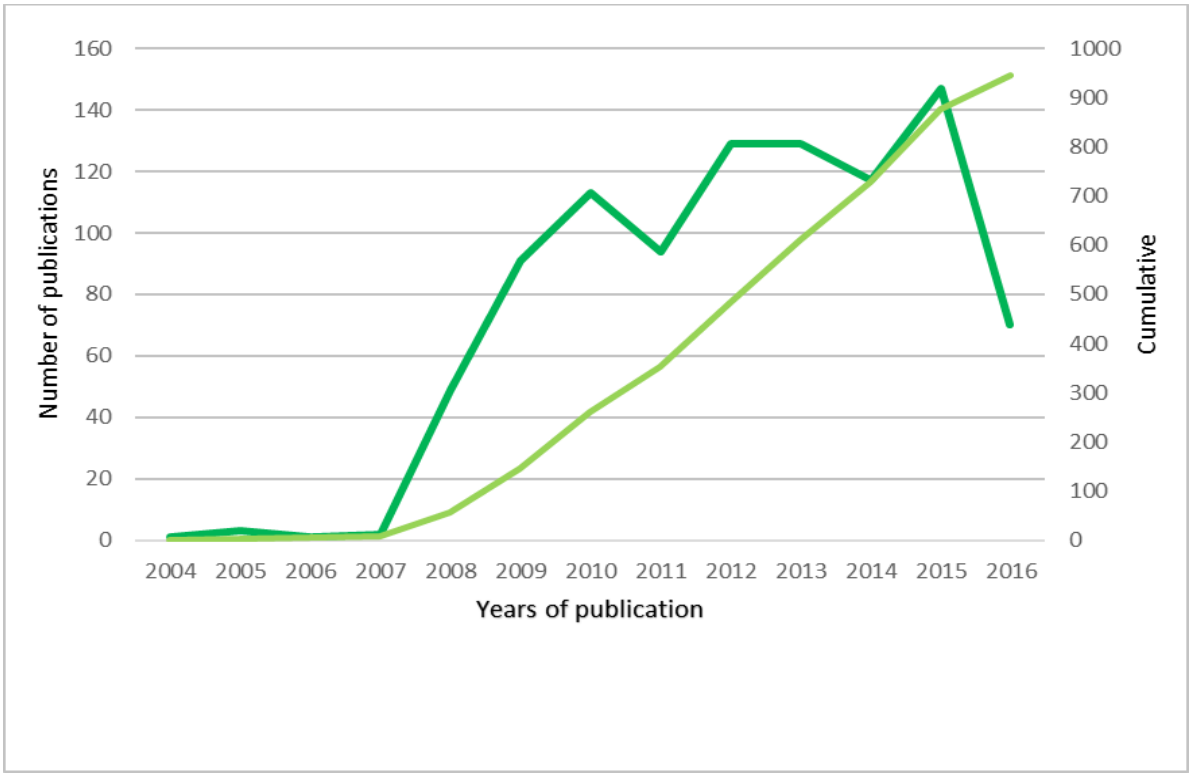
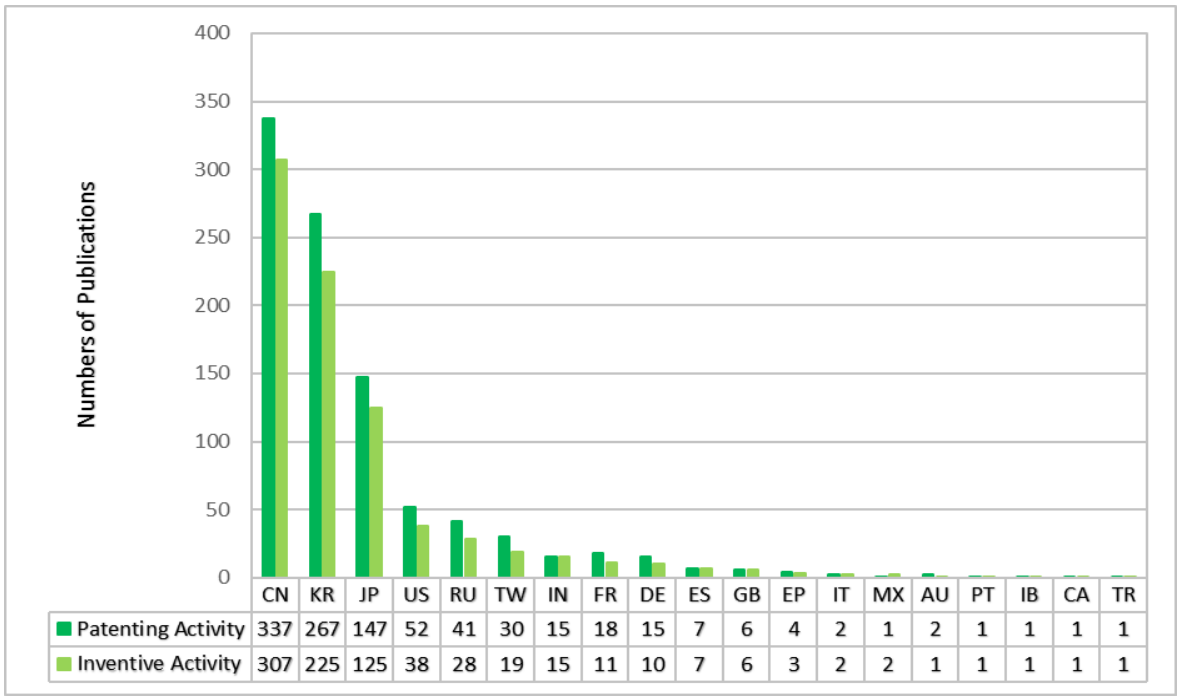


Figure 1. Analysis of the life cycle for the technology
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017



	CN	KR	JP	US	RU	TW	IN	FR	DE	ES	GB	EP	IT	MX	AU	PT	IB	CA	TR
Patenting Activity	337	267	147	52	41	30	15	18	15	7	6	4	2	1	2	1	1	1	1
Inventive Activity	307	225	125	38	28	19	15	11	10	7	6	3	2	2	1	1	1	1	1

CN	China	GB	United Kingdom
KR	Korea	EP	Eurepoean patents
JP	Japan	IT	Italy

US	United States	MX	Mexico
RU	Russia	AU	Australia
TW	Taiwan	PT	Portugal
IN	India	IB	International Bureau
FR	France	CA	Canada
DE	Germany	TR	Turkey
ES	Spain		

Figure 2. Leading countries based on their scientific and patenting activity.
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Leading countries

Figure 2 shows the place of origin of the patents registered, where China stands out as a leader in technology with 307 inventions in 337 applications, followed by South Korea that presents 225 inventions in 267 applications, as well as other Asian and North-American countries such as Japan and the United States, present 125 inventions in 147 applications and 38 inventions in 52 applications respectively, on the other hand, it was highlighted the presence of a Latin-American country, which is Mexico.

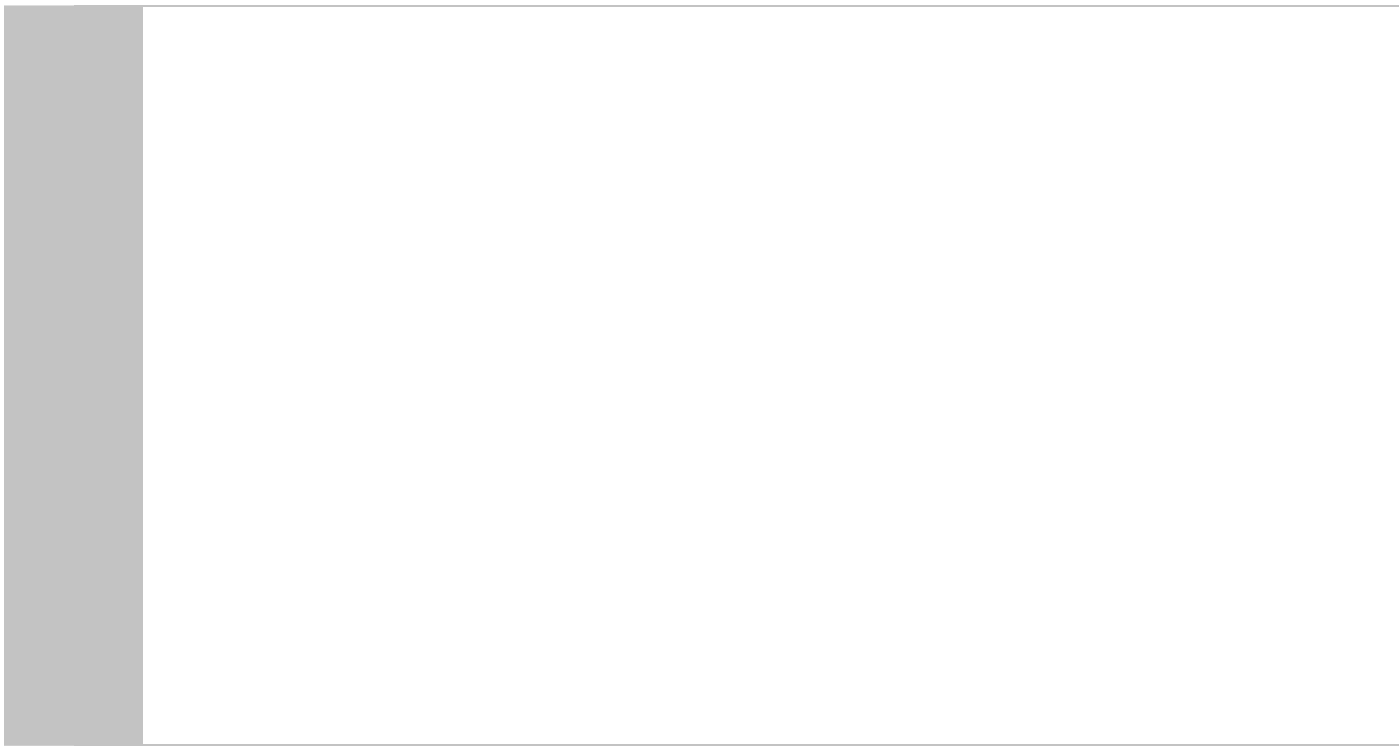


Figure 3. Main offices and potential markets for the inventions
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

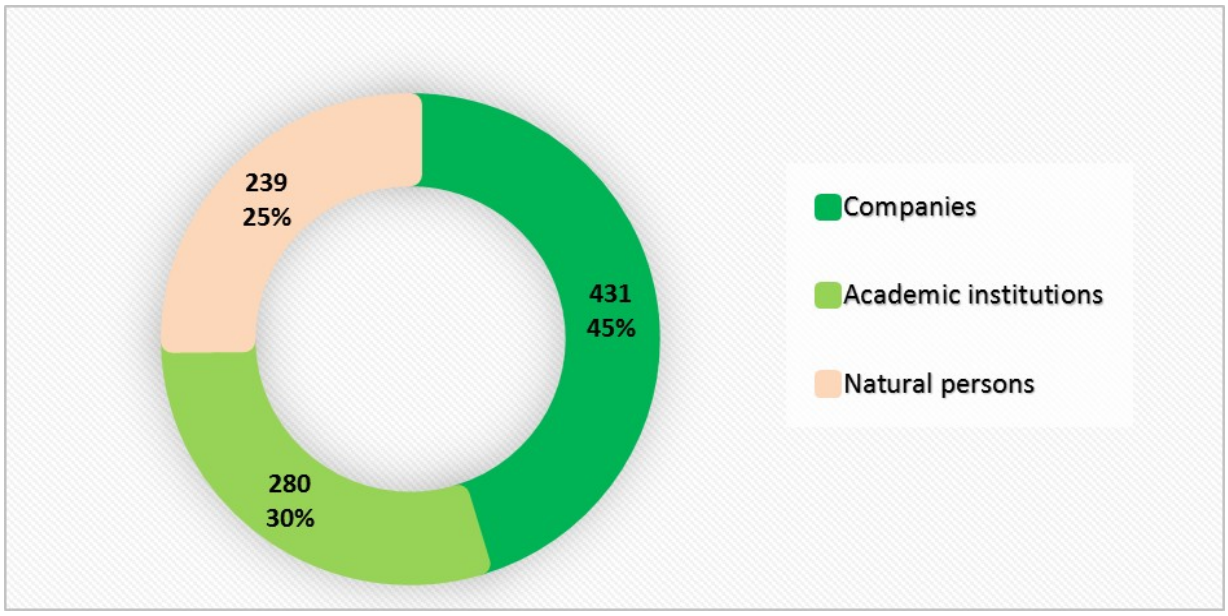
Leading offices and potential markets

The patent publishing process includes presenting the document in an office for later evaluation and publication; therefore, it is important to know where are the patents being published to determine where are the main markets for technology and innovation in the field of power generation through the use of piezoelectric material. In *Figure 3*, it is observed that all the inventions in this technology are concentrated in 5 offices which are, China, Korea, Japan, the United States and Russia, all these countries protect their inventions in United States' office and in the world office except Russia which is assumed that it does not publish in other offices due to political-economic conditions. On the other hand, potential markets that have few publications in their offices, but may be future leaders are Germany and China.

Type of applicants for the technology

Figure 4 identifies the types of applicants classified by companies, academic institutions and individuals, which have a participation percentage of 45%, 30% and 25% respectively, however, it must be considered that these were grouped by sections, according to each of the patents, that is, a record corresponds to a section comprising several applicants, from which the following attributes were taken to classify them according to the aforementioned criteria:

If a section is made up of individuals and companies, it is established that this section belongs to companies, since it is taken as a criterion that people made agreements with these organizations, also, if the section is composed of natural persons and academic institutions, it will prevail academic institutions, taking as criteria that they have made agreements with these institutions. In this sense, the university profits of a higher level of priority against companies.



Type of applicants		
Applicant	**Number of registrations**	**Percentage**
Companies	431	45%
Academic institutions	280	30%
Natural persons	239	25%

Figure 4. Type of applicants for the technology
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

On the other hand, it is highlighted that the Derwent Innovations Index database has the following classification for the names of transferee, ABCD-C, ABCD-N, ABCD-R and ABCD-I, which refers to the companies, not standardized, Soviet institute and individual person respectively, which did not contribute to the study, in this sense, this code was reclassified for research purposes.

Industrial impact for the leading applicants

Figure 5 relates the inventive activity and industrial impact for the applicants, classified into 3 levels, the first level was called "leaders", and it is made up of Panasonic Corp, Japanese company that has high results in inventions and appointments received. It was also distinguished the following level named "promises" conformed by the Univ Zhejiang Normal and Murata MFG Co Ltd, which receive this classification for having a high number of inventions, but a mid-range industrial impact. Finally, in the third level named "emergent", we found the Univ Shanghai Jiaotong, and Univ Wuhan Technology, which have low results in the aforementioned criteria, but are above the other applicants with minimal inventive activity. On the other hand, it also confirms the fact that the leading applicants are made up of companies and academic institutions.

Number	Applicant	Inventive activity	Industrial impact
1	Panasonic Corp.	19	117
2	Univ Wuhan Technology	5	34
3	Univ Zhejiang Normal	17	33
4	Univ Shanghai Jiaotong	2	30
5	Murata Mfg Co Ltd	16	29

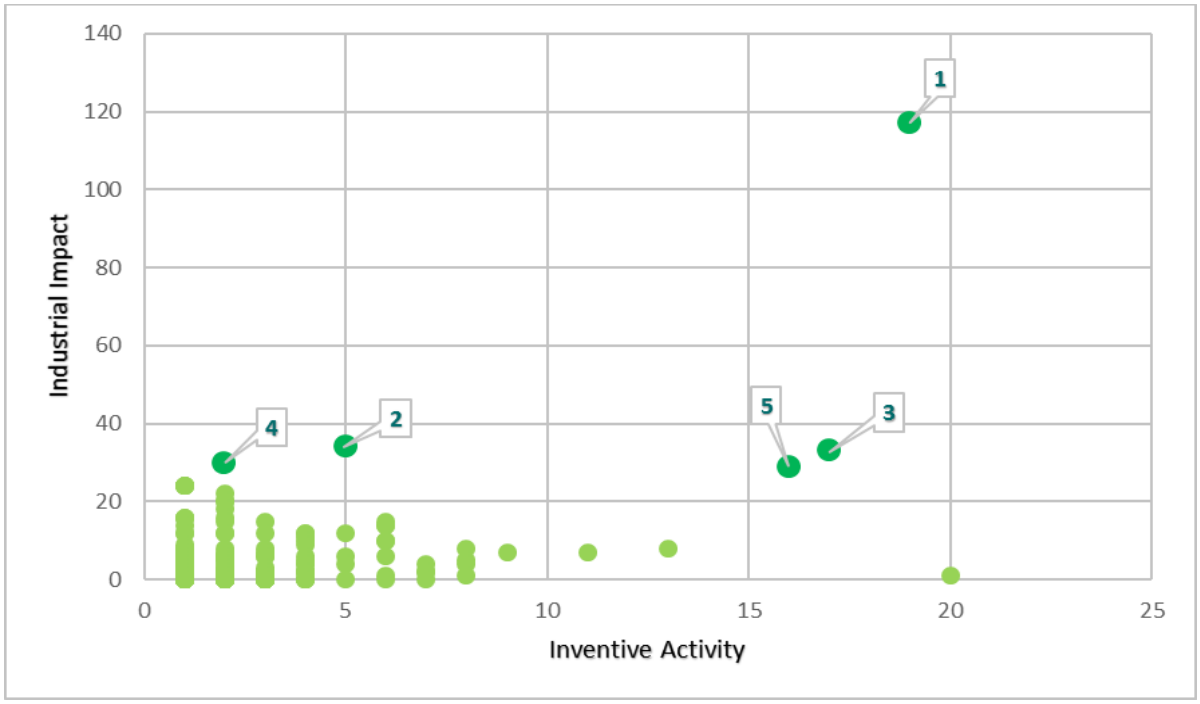


Figure 5. Industrial impact for the applicants
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Technological variation for the leading applicants.

The data concerned to inventive activity and technological variability are related in *Figure 6*, where two leaders, Samsung and Panasonic corp. stand out, being these ones the companies with greater inventions and great technological development in different fields, where the leadership of Samsung corporate group is reaffirmed since this company is dedicated to the manufacture of electronic equipment and appliances, followed by Kim J, Wang, Zhan and Fuji Film

Number	Applicant	Inventive activity	Technological variability
1	Samsung	20	20
2	Panasonic Corp.	19	16
3	Kim J	8	12
4	Wang	8	11
5	Zhan	9	11
6	Fuji film Corp.	4	11

Corp., although they are not leaders and have a low level of inventions, highlighted anyway because of their high diversity of technological sectors where their inventions can be useful.

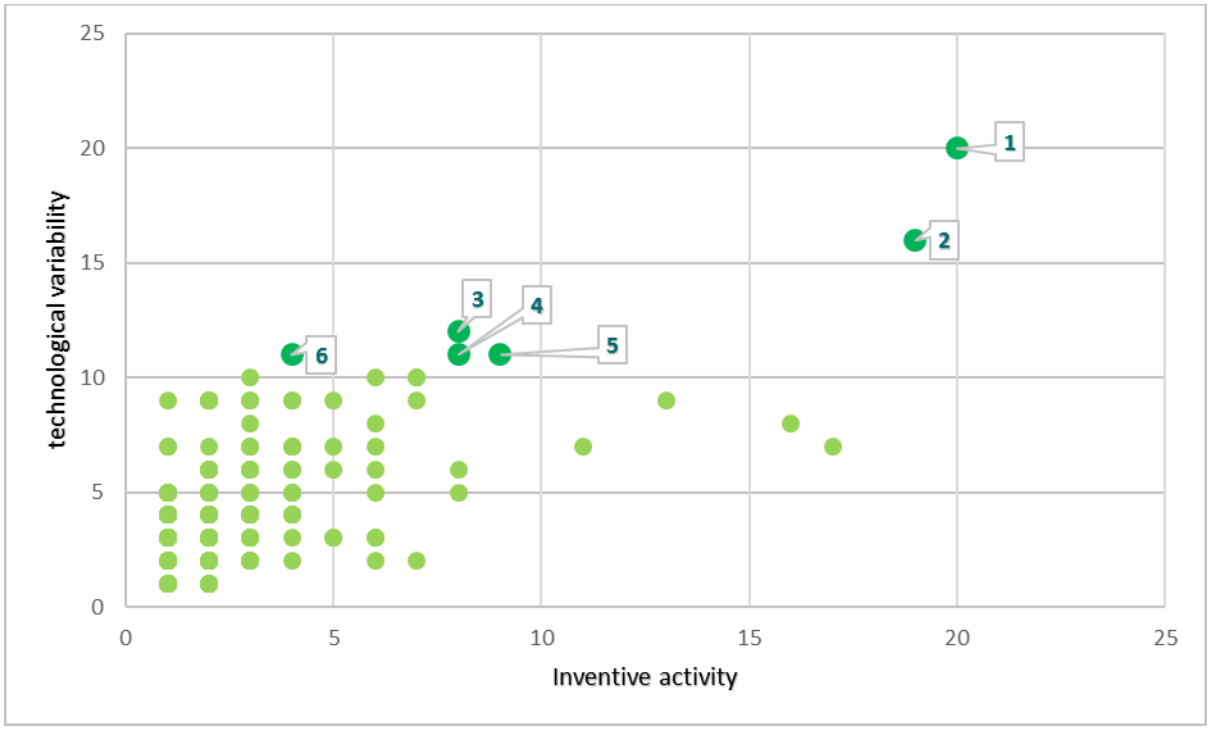


Figure 3. Technological variability for the leading applicants
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Technological trends

Preliminary selection of the trends

For the preliminary selection of trends, we build a Pareto diagram, under the criterion that six tendencies corresponding approximately to 3% represent more than 50% of the records studied, these tendencies have a nomenclature established by the WIPO (World Intellectual Property Organization) and for this case, it can be seen below:

Table 2. Preliminary trends

Subclass	Inventive activity	Description
H02N	436	Electric Machines Not Otherwise Provided For
H01L	234	Semiconductor Devices; Electric Solid State Devices Not Otherwise Provided For
H02J	92	Circuit Arrangements Or Systems For Supplying Or Distributing Electric Power; Systems For Storing Electric Energy
F03G	50	Spring, Weight, Inertia, Or Like Motors; Mechanical-

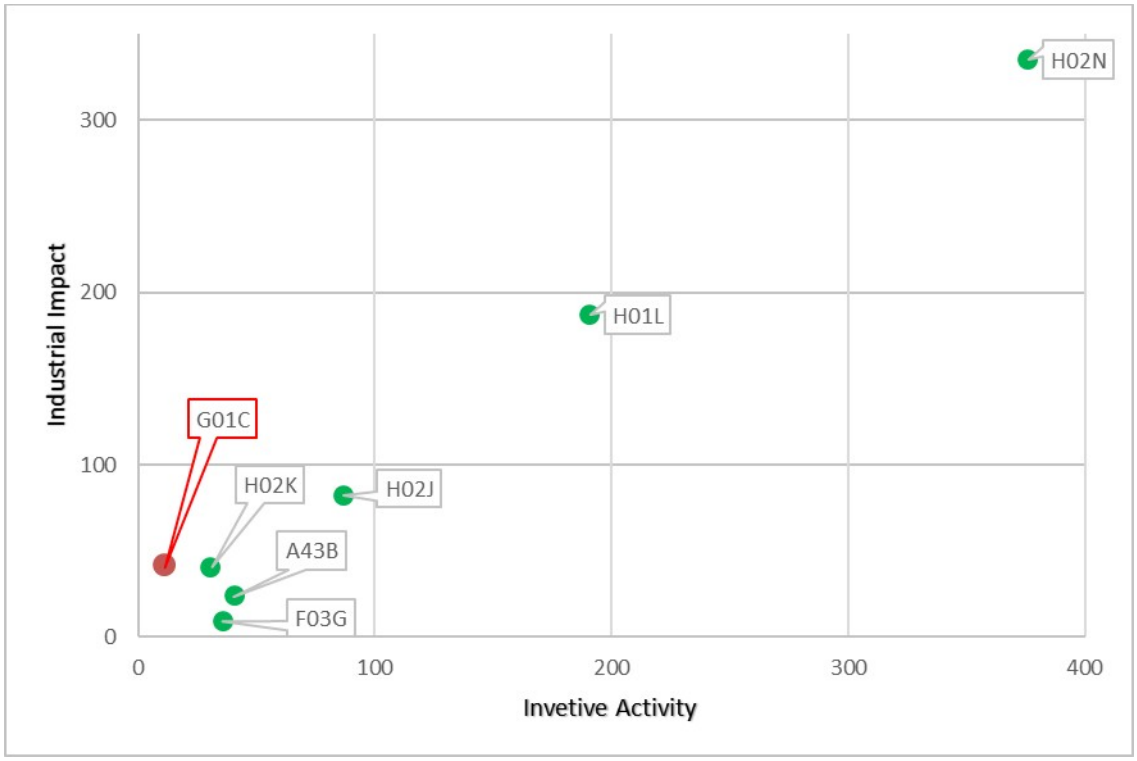
		Power-Producing Devices Or Mechanisms, Not Otherwise Provided For Or Using Energy Sources Not Otherwise Provided For
A43B	41	Characteristic Features Of Footwear; Parts Of Footwear
H02K	37	Dynamo-Electric Machines

Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Trends selection

Figure 7 shows the relationship between the inventive activity and the industrial impact, and from this it is noted that subclass G01C had greater industrial impact than some trends already identified, so it was decided to discriminate those that were below the mentioned subclass.

Once the trends in *Figure 7* have been defined, it is shown that subclasses H02N (electric machines not otherwise provided for) and H01L (semiconductor devices; electric solid-state devices not otherwise provided for) have a strong and medium industrial impact respectively. Below these trends is subclass H02J (circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy) that has a lower industrial impact, however, it is observed that the industrial impact is measured by the number of citations received by a patent register, likewise, it should be noted that the name that constitutes these classifications was granted by the WIPO (World Intellectual Property Organization).



Graph 7. Technological variability for the leading applicants
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Inventive activity for the selected trends

Figure 8 corresponds to the technologies organized according to their inventive activity, here, we found a total of 813 inventions in 950 requests related to the generation of electrical energy through the use of piezoelectric material, in which 3 trends stood out framing the majority of technological developments , these trends include: electric machines not otherwise provided for, which contains 376 inventions in 436 applications, likewise, we found semiconductor devices; electric solid state devices not otherwise provided for, that contains 191 inventions in 234 requests, finally, the trend of circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy with 87 inventions in 92 applications.

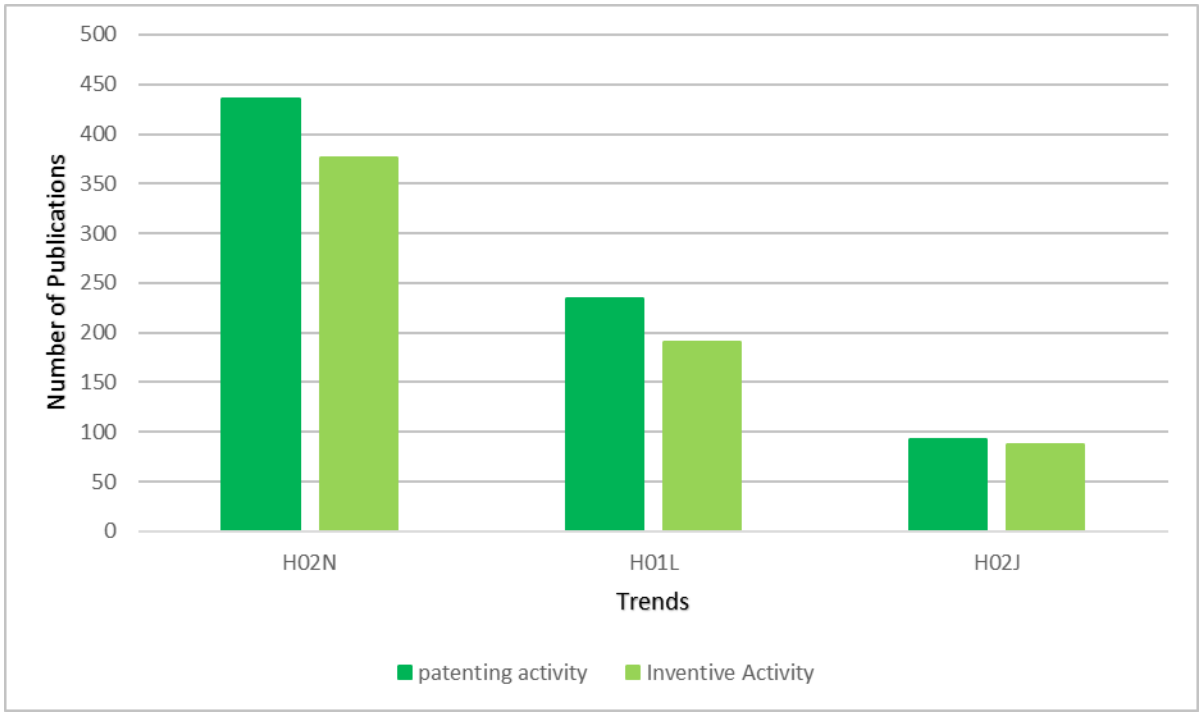


Figure 4. Technological trends based on their inventive activity.
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Technological dynamics of the selected trends

Figure 9 analyzes the chronological evolution of trends from 2010 to 2017, identifying that subclasses H02N and H01L have their greatest inventive activity in more than a single year, the trend H02N in the years 2012 and 2016 shows 67 inventions and the trend H01L in the years 2011, 2015 and 2016 presents its

greatest inventive activity with 35 inventions. On the other hand, the H02J classification presents its greatest inventive activity in 2015 with 22 inventions.

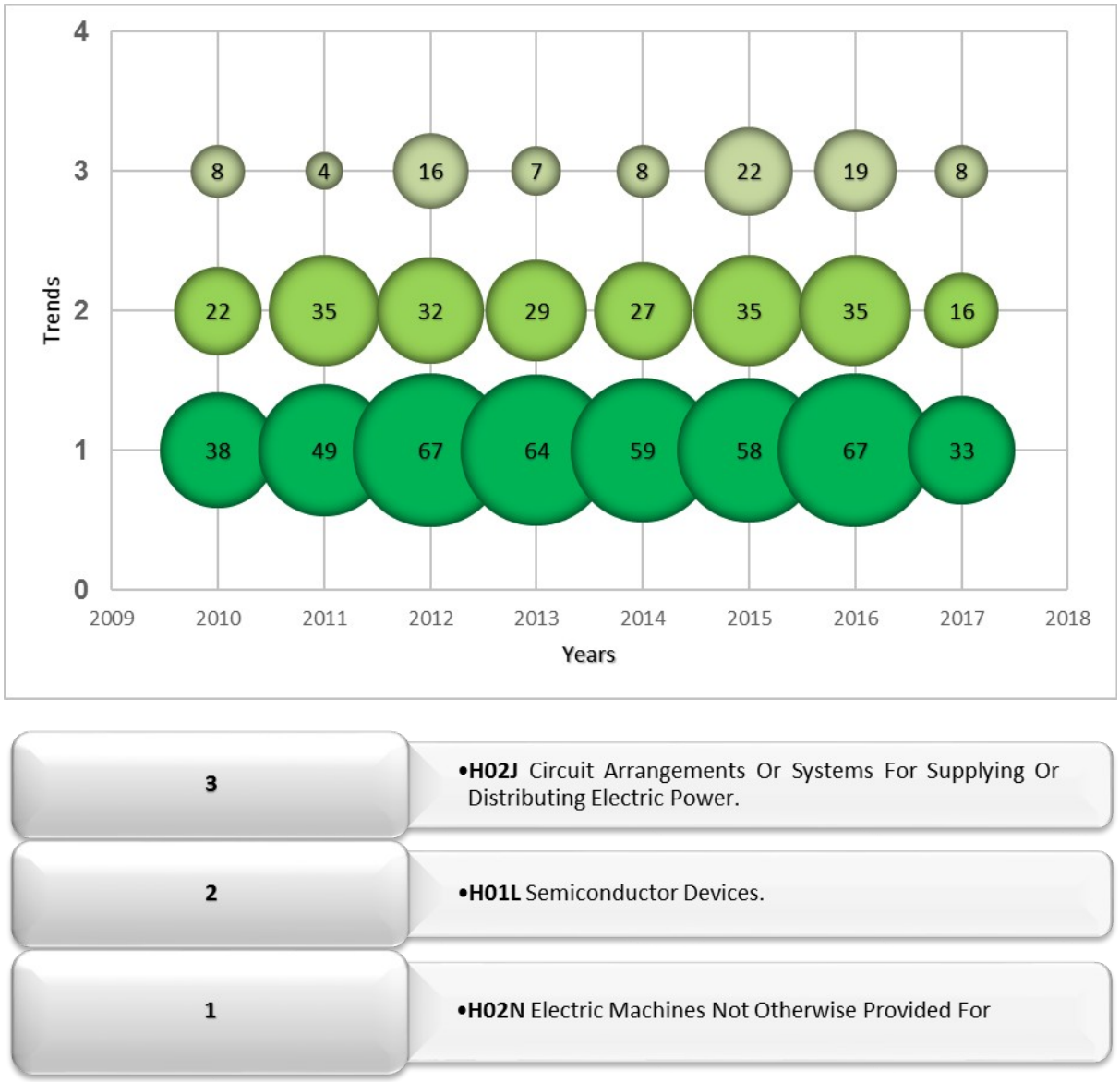


Figure 9. Technological dynamics for the selected trends.
Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Electric machines not otherwise provided for (H02N)

The international classification containing subclass H02N (*Electric machines not otherwise provided for*) is broken down from section H which refers to electricity, in this sense; class H02 describes the production, conversion or distribution of electric power. According to WIPO (2017) subclass H02N covers:

i. Generators, motors, clutches or electrostatic maintenance devices.

ii. The devices for starting, regulating, braking or any other control of such machines, unless they work together with a second machine.

In addition, in this trend stands out as the main applicant Panasonic Corp., organization that is classified as MATU-C in the database Derwent Innovations Index, this company presents 18 inventions regarding electrical machines not available otherwise. On the other hand, we found that 2012 is the year with the greatest inventive activity with 6 inventions, as it can be seen in Table 3.

Trend	Main applicants		Years with the greatest inventive activity	
	Applicants	Number of inventions	Year	Number of inventions
H02N	Panasonic Corp	18	2012	6
	Univ Zhejiang Normal	14	2012	7
	Murata Mfg Co Ltd	12	2011	5
	Samsung Electro-Mechanics Co	9	2014	3
	Triforce Management Corp	6	2015	3

Table 3. Main applicants for H02N.

Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Semiconductor devices; electric solid-state devices not otherwise provided for (H01L)

In the international classification subclass H01L (Semiconductor devices; electric solid-state devices not otherwise provided for) is broken down from section H which in the classification refers to electricity, in this sense class H01 covers basic electrical elements. According to WIPO (2017) subclass H01L includes:

i. Solid state electric devices not covered by another subclass, as well as their details. Includes: semiconductor devices adapted for rectification, amplification, oscillation generation or switching; semiconductor devices sensitive to radiation; solid state electrical devices that use thermoelectric, superconducting, piezoelectric, electrostrictive, magnetostrictive, electroplating, or negative-resistance effects and integrated circuit devices.

In this trend, Panasonic Corp. stands out as the main applicant, which is classified in the database Derwent Innovations Index as MATU-C, because of its

previous name "Matsushita Electric Industrial Co., Ltd". This applicant presents 14 inventions, in the subject of semiconductor devices; and solid state electrical devices not otherwise available. 2010 is the year with the greatest inventive activity with 5 inventions, as evidenced in Table 4.

Table 4. Main applicants for H01L.

Trend	Main applicants		Years with the greatest inventive activity	
	Applicants	Number of inventions	Year	Number of inventions
H01L	Panasonic Corp	14	2010	5
	Murata Mfg Co Ltd	12	2015	4
	Seiko Epson Corp	9	2010	3
	Leey-Individual	7	2015	6
	Zhao-Individual	3	2012	1
	Fuji Film Corp	6	2015	2
	Univ Kunming Sci&Technology	2	2010	2
H02J	Samsung Electro-Mechanics Co	2	2014	1
	State Grid Corp China	2	2015	1
	Daegu Gyeongbuk Inst Sci & Technology	2	2013	1

Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Table 5. Main applicants for H02J

Source: Own elaboration using Derwent innovations index
Consultation date: 10/07/2017

Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy (H02J)

In the international classification subclass H02J (devices or circuit systems for the supply or distribution of electrical energy, electrical energy storage systems) is broken down in section H, which in the classification refers to electricity. In this

sense, class H02 includes production, conversion or distribution of electric power. According to WIPO (2017) subclass H02J covers:

i. The main networks or distribution of direct current or alternating current.
ii. Circuits for the feeding by battery, including the load or the control of these or the coordinated feeding coming from two or more sources of any type.
iii. Circuits or systems for wireless supply or distribution of electric power.

In this trend, ZHAO stands out as the main applicant. These applicants are classified in the database.

Derwent Innovations Index as ZHAO-Individual, and presents 3 inventions for devices or circuit systems to supply or distribute electrical power; and electrical energy storage systems. 2012 is the year with the greatest inventive activity with 1 invention, as evidenced in Table 5.

INVENTORY OF IDEAS

Investigation and development ideas

Conduct bibliometric investigation

This idea includes a study of databases that provide scientific records and identify trends based on study areas of this technology, in the same manner; it reviews the scientific production that is already provided by natural or legal persons, making the bases for this type of technologies more structured and solid. Consequently, it is proposed to carry out a mixed methodology that contains the different analysis for the indicators of patents, as well as the ones for scientific articles. This will allow the knowledge of the different non-technological fields of power generation through the use of piezoelectric material.

Trends' deepening

Perform a more detailed analysis of the trends involved in the generation of energy through the use of piezoelectric material, based on the structural analysis of the patents highlighted in each trend, to understand the inventions and in turn review the impact on each of these since this is measured by the number of citations that a patent document receives.

On the other hand, it is proposed to review those trends that were discriminated, evaluating the feasibility of including them in subsequent studies and provide the possibility of a theoretically solid study.

Analysis of sections

The analysis of other technologies for the generation of renewable and non-renewable electric power, looking for the possibility of making hybrids in two or more types of technologies and knowing other opportunities for innovation. All this, from the study of the electricity section or another one that has similarity with the technology studied.

Innovation and entrepreneurship ideas

Take advantage of the state of the technology

The technology is in its growth stage, which is a latent opportunity to discover which aspects can be innovated or improved in terms of energy generation through the use of piezoelectric material, since it's in this stage where the inventions increase and the market is open for new businesses and innovations.

Take advantage of the technological variability

Due to the technological variability presented by the generation of energy through the use of piezoelectric material, the application of this material can be seen in public spaces, roads, treated areas, among other possible varieties of uses. On the other hand, it is important to see the advantages of the material in its application in macro and micro scale, and by this way exploit the efficiency of the material and be pioneers in the using of this technology as a renewable energy source.

Generate a competitive advantage from the technology in a disruptive way

In this sense, generating a competitive advantage is related to the fact of being owners of a remarkable attribute such as technology and innovation, and, at the international level, the requirement of renewable energy sources is seen as a competitive advantage in an uncertain future, that is, the industries must understand the impact of clean technologies and develop strategic plans to adapt to changes in the market's requirements. This is where this technology enters in a disruptive way to generate competitive advantages in companies in the market.

CONCLUSION

Within this scientific article, it was identified that the trends are mostly framed by electrical machines not provided elsewhere, semiconductor devices and circuit devices or systems to supply or distribute electrical energy. In this sense, 2008 is also highlighted as the focal date where the number of inventions and research of this type increased, leaving its emerging stage and maintaining a sustained growth through the years. On the other hand, the leading actors for the initiatives in this technology as a renewable alternative are countries of the Asian continent. First, we found China, in second place Korea and the third one is Japan, including a slight immersion by Latin American countries such as Mexico and Brazil, which exposes a situation of opportunity to venture into the American market with this type of technology, as a solution to the environmental impact that is currently present due to the use of fossil fuels and other means of generating non-renewable energy.

To carry out these premises it is recommended to strengthen agreements between the academy and organizations since with the evaluation it was verified that these are the most interested in the development and research on the

generation of energy through the use of piezoelectric material. The industrial impact and technological variability presented in this research shows the empowerment that this type of technology can have towards the use of clean and sustainable energy.

Electric power generated by piezoelectric material is definitely a latent opportunity for innovation, but it needs to strengthen weak links in terms of research and development. Also, ensuring the effective economic-technological performance of this type of technologies so it can meet the needs at the global, national and regional environment in the rational use of electricity, sharing a paradigm of environmental sustainability supported scientifically in search of a better future.

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