REVISTA BRASILEIRA DE ENERGIAS RENOVÁVEIS

SOLAR ENERGY AND ITS GLOBAL INVESTMENTS[1]

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Abstract

This study aimed to analyze the research about solar energy on a global scale over the past five years, in order to identify the way to apply this source of energy and which countries are participating in the solar area investigation. In this context the scientific journals publications on solar energy of the last five years (2010-2015) were analyzed, focusing on renewable energies and as selection criteria, the Impact Factor (IF) was adopted. The articles were analyzed in a summarized manner for a sample population of over 350 publications, from which the IF index ranged from 3 to 15. The results show that in the whole world the countries with the highest number of publications in the solar energy field are India, China, Spain, Malaysia and the United States, totaling more than half of the worldwide research. Solar thermal energy had an increasing participation in the polls and the year 2014 got the highest number of publications linked to solar energy in the world.

Key-words: solar energy, global solar research, ways of applying.

ENERGIA SOLAR E SUAS APLICAÇÕES GLOBAIS

Resumo

Este trabalho teve por objetivo analisar as pesquisas de energia solar em escala global nos últimos cinco anos a fim de identificar as formas de aplicação dessa fonte de energia e quais países estão participando das pesquisas na área solar. Neste contexto Foram analisadas as publicações sobre energia solar dos últimos cinco anos (2010 – 2015) de revistas científicas voltadas a temática de energias renováveis, sendo adotado o Fator de Impacto (FI) como critério de seleção. Os artigos foram analisados a nível de resumo para um universo amostral de mais de 350 publicações, das quais o índice do FI variou de 3 a 15. Os resultados mostram que os países com maior número de publicações na área de energia solar no mundo foram Índia, China, Espanha, Malásia e Estados Unidos, totalizando mais da metade das pesquisas mundiais. A energia solar térmica teve maior participação nas pesquisas e o ano de 2014 o maior número de publicações em relação a energia solar no mundo.

1. INTRODUCTION

Since the last decade, the development of renewable energies exceeded all expectations. The 70s' energy crisis and the worry concerning the environmental issues as well as a possible energy collapse caused in many countries an awakening to the development of clean technologies and policies for the implementation of economies focused on renewable energy. This set of attitudes was so efficient that the growth levels of renewable energy expected for 2020 had already been exceeded in 2010.

However, fossil energy sources are still responsible for providing about 80% of the energy consumed worldwide. In power generation, coal provides 42% of the demand, and the growth prospects of electricity consumption are localized in developing countries with rates of 3.3% per year (SAHU, 2015; LUNA-RUBIO et al., 2012).

However, many of the scenarios of transition to a renewable energy model rely mainly

on solar energy in combination with the wind energy, creating a perspective of solar energy as the largest source of electricity worldwide up to 2050, according to the International Energy Agency (ESI) (JACOBSON and DELUCCHI, 2011; STEIN, 2013).

This study aims to draw a panorama of the current global solar energy scenario in a different perspective, looking up the data of the last 5 years of research on every continent, in order to know the solar energy status and the ways of applying it.

2. SOLAR ENERGY (REVIEW)

2.1 Solar energy and its ways of applying

The solar energy applications can be basically divided in photovoltaic energy (PV), concentrated solar thermal power (CSP) and solar thermal energy without concentration (fluid heating). Photovoltaic energy is the technology that grew the most among all the renewable ones, increasing 53 times its global capacity in the period between 2004 and the end of 2013. The advance of industrial production technology and the improving of the PV modules in efficiency caused a significant decrease in energy prices, falling 60% only between 2011 and 2012, and has today an average cost of US$ 0.38 for 0,57.kWh^{-1}. China is the country with the greatest emphasis within the photovoltaic industry, which left levels approaching zero about a decade ago becoming the largest photovoltaic global market in 2013 (REN, 2014; GAN and LI, 2015). Table 1 shows the generation costs, initial investments and CO_2 emissions of some renewable and fossil sources.

The CSP is considered one of the most promising sources of electricity generation on a large scale. From 2004 to 2013, the CSP had a globally tenfold growth, with investments prevalent in the United States and Spain expanding to markets in South Africa, Asia and Latin America. Also has cost projections for 2020 from US$ 0.06 and 0,12.kWh^{-1}, where will be decisive a cost reduction in solar thermal plants, and the heliostat field is the key element to achieve this goal (REN, 2014; HINKLEY et al., 2013; EMES et al., 2015) .

Solar thermal energy without concentration (fluid heating) is also under constant increase in capacity and was added on the global stage in 2013, 57.1 GW_{th}, leading to a total of 330 GW_{th} already installed worldwide. In this context, the world leader is China, which alone was responsible for adding 46.2 GW_{th}, using collectors with coverage as main system, so that some other world markets such as Australia and Brazil, were notable for the use of collectors with no coverage for heating water (REN, 2014).

Table 1 - Cost of installation and power generation from different sources

Source of electricity generation		Initial Investment (US$.kW^{-1})	LCOE[3] (US$.kWh^{-1})	CO_2 emission (gCO_2.kWh^{-1})
Nuclear	---	4,375	0.10	20
Renewable energy	SHP[2]	10,000 – 12,500	0.057-0.698	11
	solar Photovoltaic	4,375 – 6,875	0.058-0.143	38
	Wind (terrestrial)	2,500 – 4,375	0.043-0.075	25
	Geothermic	8,750 – 11,250	0.043-0.053	13
Thermal	Oil	2,375	0.045-0.14	738
	GNL[1]	1,500	0.045-0.14	474
	Coal	2,875	0.12[4]	943

Note:1- GNL: Liquefied Natural Gas; 2- Small Hydro Power; 3 – Levelized Costs without taxes; 4 – Considering coal plants able to remove 30% of the carbon emissions.
Source: Adapted from LAN and LINE [6]; EIA (2017)

In Table 1, it is clear the advance of the renewable energies in comparison to fossil sources in terms of cost of energy. The photovoltaic solar energy has been reducing its production costs due to technological advances in panels making, a reduction of silicon waste in manufacturing, thinner wafers, among others, while wind energy made efforts in cheaper turbine manufacturing and optimization of power generation at lower wind speeds . However, to meet the challenges required to implement energy policies geared toward solar energy, it is necessary to analyze the current global situation, considering the research conducted and which the purposes of energy use in the world are.

2.2 Overall Picture

Arguably, renewable energy has assumed an increasingly important role in the global energy scenario. Public policies aimed at encouraging the deployment of renewable sources are on an increasing scale, mainly pressured by environmental issues. Solar energy has been following this rate, both in its photovoltaic and thermal form, as shown in Table 2.

Table 2 - Evolution of the installed capacity of solar Technologies at a global level (2004 to 2013)

Source	Unit	C.I[1] (2004)	C.I (2013)
Solar photovoltaic	GW	2.6	139
CSP	GW	0.4	3.4
Solar for Heating[2]	GW_{th}[3]	98	330

Note: [1]Capacity installed; [2]Considering water and air collectors; [3]Gigawatt thermal.
Source: adapted from REN 21[5].

According to REN 21, the global investment in renewable energy grew by over 500% between 2004 and 2013, jumping from US$ 39.5 to US$ 214.4 billion. Photovoltaic solar energy went from 3.7 GW to 139 GW in the same period last year, while solar energy for heating was 98 GW to 326 GW.

The energy via solar thermal concentrators (CSP), which includes the parabolic trough, parabolic disk, central tower and Fresnel type, went from 0.4 to 3.4 GW, considering the same period (SKOURI et al., 2013; WU et al., 2010; ZHANG et al., 2013; HAN et al., 2014; HEFNI, 2014; SAIT et al., 2015).

The development of solar energy applications can be seen in Figures 1, 2 and 3.

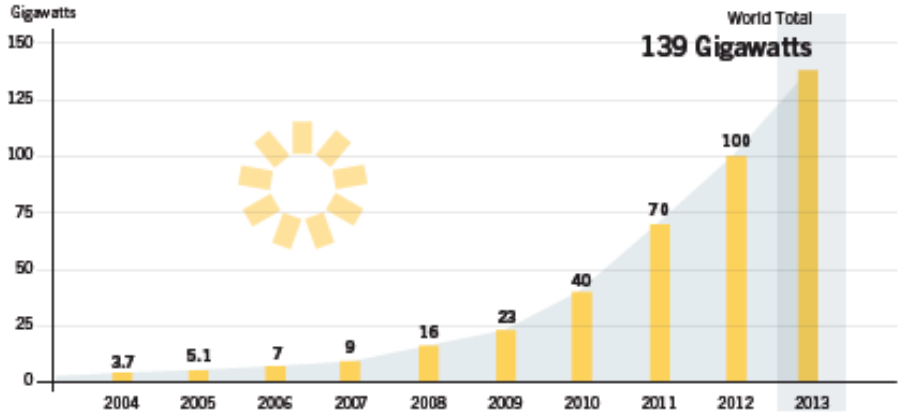

Figure 1. Behavior of photovoltaic solar energy between 2004 and 2013.
Source: (REN, 2014).

Figure 1 shows the rapid annual growth of the photovoltaic source in the world. According to the International Energy Agency (2014), it is expected that photovoltaics represent 20% of all renewable electricity up to 2050, with about 4,600 GW installed

worldwide and 65% of reduction in power generation costs, reaching an amount of US$ 40/160.KWh^{-1} case keep up this pace of growth.

In the case linked to evolution of the solar installations for heating, in Figure 2 is shown that in 2013 about 330 GW_{th} were installed, covering an area equivalent to 471 million square meters and preventing the burn of 30.1 million tons of oil and the emission of 97.4 million tons of CO_2 per year. Approximately 80% of all solar thermal energy produced is intended for residential water heating, mainly using flat or tubular plate collectors' technology. For 2050, only the European Union, expects to reach about 1200 GW of solar capacity in operation (WANG et al., 2015; MAUTHNER and WEISS, 2014).

The CSP market, in turn, displayed in Figure 3, grew dramatically between 2008 and 2013, reaching 50% per year rate. Since 2004, the installed capacity rose about ten times and the participation of countries other than Spain and the United States begins to be evident like the United Arabian Emirates, India, Morocco, among others. The main type of technology used in the CSP facilities such as in the construction of new plants is the parabolic trough, followed by central towers, which has expanded its market since the beginning of 2014. Other technologies (Fresnel and parabolic dish) are still in early stages of development (REN, 2014).

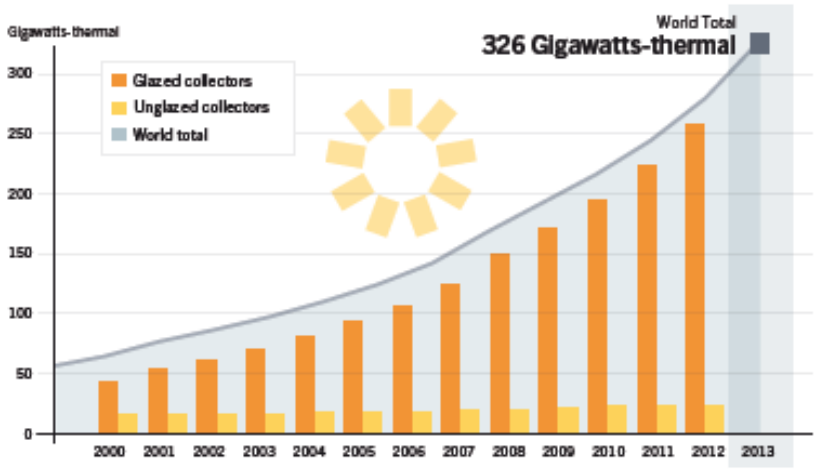

Figure 2 - Evolution of solar thermal energy (excluding the air collectors).
Source: (REN, 2014).

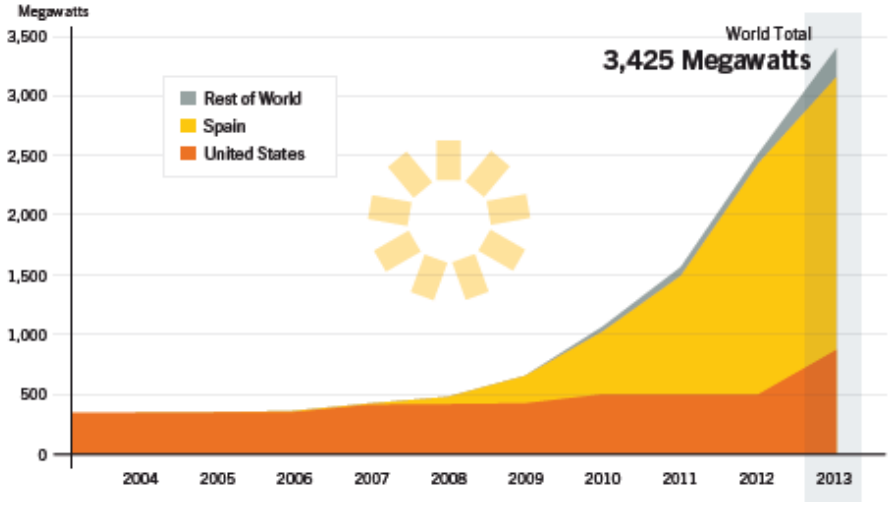

Figure 3 - Evolution of the CSP between 2004 and 2013.
Source: (REN, 2014).

Considering as a continental division by energy markets, the countries of Central and South America are world leaders in auctions for the sale of renewable energy as a whole. In 2013, Brazil negotiated about 5.68 GW of this energy, 122 MW of which was solar energy and a larger part of wind energy (GREENPEACE, 2013). Chile, in the same year, held an auction for the purchase of solar energy type CSP, while in 2016 Peru has set aside US$ 3.6 billion for investments in renewable area. El Salvador, Ecuador and Uruguay are other countries with guaranteed investment for the purchase of solar energy in its various forms, and other natural sources of energy (REN, 2014). The United States already have a consolidated market in this area, with 12.1 GW currently installed photovoltaic power and 918 MW of CSP. However, this market is booming, since in the last 18 months have been deployed more solar systems than in the past 30 years (ACORE, 2014).

In Europe, Germany and Italy lead the photovoltaic business. Germany, a world leader in consuming and installation of this system, 5.3% of the electricity consumed was generated to 36 GW installed by the end of 2013 (BURGER, 2014; SUEYOSHI and GOTO, 2014). Already Italy, which between 2008 and 2013 increased by 3591% the presence of photovoltaics and by 1315% the number of photovoltaic power plants. In 2013, they had installed 17 GW producing enough to sustain 7% of the Italian electric power consumption. Other European countries that had more than 3% of its electricity demand sustained by solar energy were Czech Republic, Spain, Greece, Belgium and Bulgaria [IEA, 2014; RED, 2013; PAIANO, 2015).

In Asia and other Pacific islands, from 7.1 to 15.8% of the electricity market will be

supplied with non-fossil energy type, percentage this that varies as it will depend on the introduction of systems that improve power distribution in some countries. Only China and Japan were responsible for more than half of the global demand for solar energy in 2014 and along with India, USA and UK will represent over three quarters of the global solar market in 2015, with about 27 GW installed in the whole planet. South Korea is another important country in the photovoltaic solar energy scene, with a contribution of 0.4 GW in 2013, as well as the possession of small CSP plants (REN, 2014; AICHBERGER and SHARMA, 2015).

In the African continent, the majority of people (almost 60%) sparsely live in rural areas, which makes the access to energy dependent almost always from the reachable local energy source (UN-WB, 2011). So, biomass is one of the most important resources of the continent, primarily supplying the residential sector. However, this raw material is often not exploited in a sustainable manner and often is not burned at appropriate furnaces, which eventually causes a worsening in the quality of air inside the residence. Among the six of Africa's leading countries in energy generation from renewable sources (Mozambique, Zambia, Namibia, Kenya, Ghana and Cameroon), with the exception of Kenya, which considerably explores geothermal ones, hydroelectricity represents almost the totality of exploited renewable resources.

3. GLOBAL SOLAR ENERGY

Scientific journals publications on solar energy of the last five years (2010 – 2015) were analyzed, focusing on renewable energies, and the Impact Factor (IF) was adopted as a selection criteria. The articles were analyzed in a summarized manner for a sample population of over 350 publications, from which the FI index ranged from 3 to 15. The variables sampled for the publications analysis were: the participating countries (considering the corresponding country of the first author research institution), year of publication and the research characteristic. For the year 2015, only the articles pre-selected for publication were recorded, showing only an early portion of the expected ones.

The selected articles were classified according to the approach of solar energy upon the research, as shown in Table 3.

Table 3 - Rating adopted to analyze the research study.

Types of approach	Description
1 – T	Solar thermal Energy application
2 – PV	Solar Photovoltaic Energy application
3 - PPPE-T	Prospects, potentiality and energy policies (solar thermal)
4 - PPPE-PV	Prospects, potentiality and energy policies (Solar photovoltaic)

The reason of the classification shown in Table 3 is due to the different realities that each country faces in relation to availability and demand of energy. To facilitate data analysis, the results were broken out separately by continents.

Figure 4 shows the solar energy research segregated by continent on a global scale.

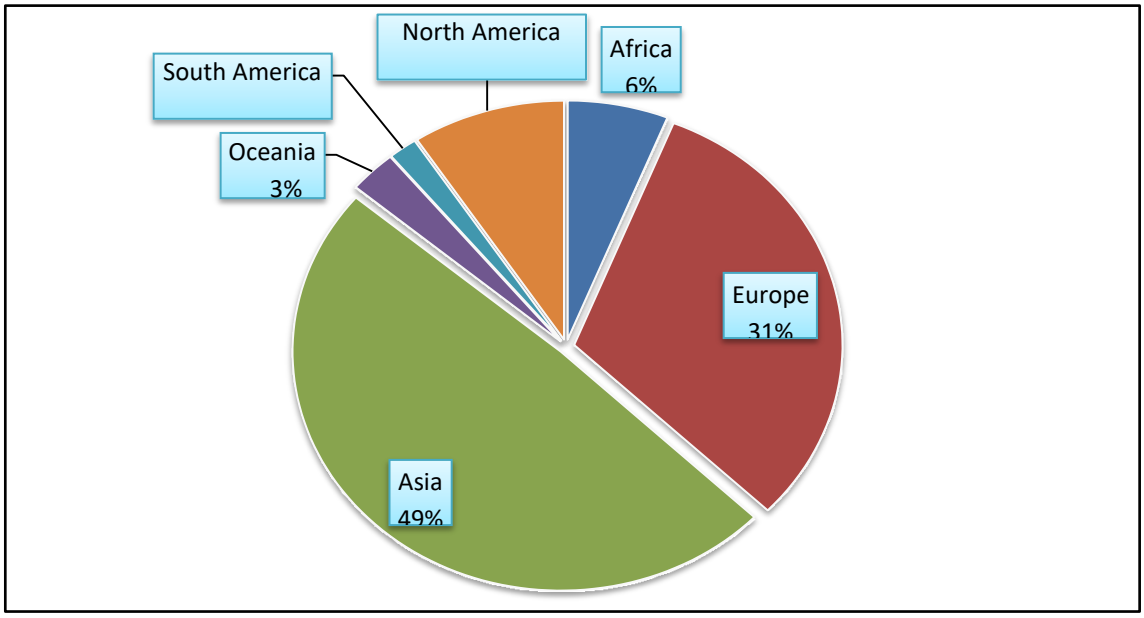

Figure 4 - Solar energy research on a global scale.

Note in Figure 4 that the Asian continent is the prevalent continent in terms of global research on solar energy, followed by Europe, North America, Africa, Oceania and South America. The hegemony of Asia is due to participation of the scientific community of countries like India, China and Malaysia, which account for a reasonable portion of the research done on the continent. Central America was missing due to lack of investigations on solar energy in the period established in this work.

On a global scale, the countries that account for a considerable part of the research (in decreasing order) are: India (13,54%), China (12,10%), Spain (10.37%), Malaysia (10.09%)

and the USA (6.92%), totaling about 53% of all samples.

Regarding the way of applying solar energy, the solar thermal energy was the one that got most attention, followed by solar PV, as shown in Figure 5.

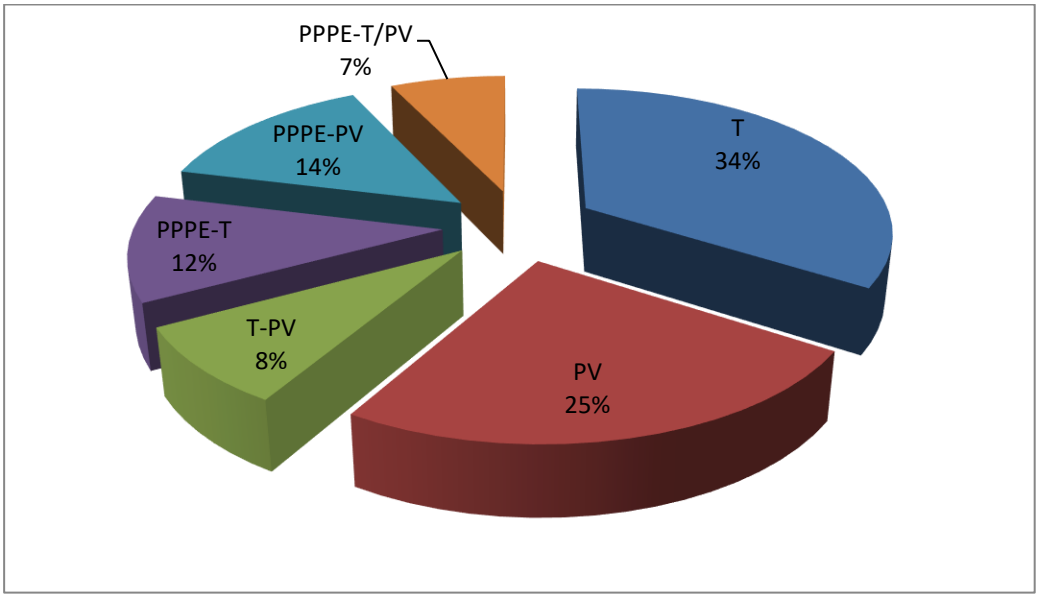

Figure 5 - World solar energy types.

In Figure 5, solar thermal energy highlights, with 46% (T + PPPE-T) of the global research, 34% focused on improvements and technological innovations and 12% on prospects, potential and energy policies studies (PPPE). In this context, photovoltaic solar energy proved to be a lesser value in comparison to the thermal source, although getting a higher index for PPPE- PV (14%) compared to PPPE-T (12%). The remainder 15% refers to solar energy that looks toward a joint research (PV / T) with individual applications and hybrid systems.

Considering the spread of solar energy in the world, during the recent years there has been a significant increase in research on this renewable source. This fact may be related to the attempt to remedy the difficulties faced with the purpose of meeting the demand of energy, as much as promoting progress in the development of forward-looking technologies in order to generate clean and renewable energy. In Figure 6 we see represented the percentage of global studies conducted over the past five years and the researches already anticipated for 2015.

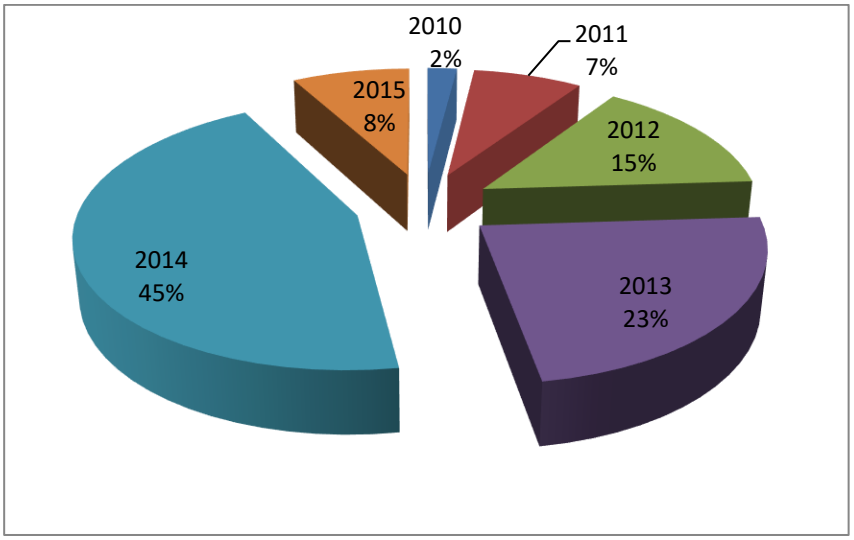

Figure 6 – Quantification of global researches conducted over the past five years.

It can be seen in Figure 6 that the number of researches related to solar source has been increasing significantly over the past five years. The year 2014 had the highest number of researches, representing 45% of the conducted, a sharp increase in 2010-2011 and 2013 to 2014. The percentage presented for 2015 is only related to researches that will be published in the future (prematurely informed yet), noting that if the growth rate is maintained, there will be a significant increase in the coming years.

3.1 Solar energy research in Asia

Figure 7 shows the share of the Asian continent countries in solar energy research over the past five years.

Figure 7 shows that countries that present a greater emphasis on research in the Asian continent coincide with the countries predominant in number of researches on a global scale. These countries (India, China and Malaysia) are responsible for 74% of research in solar energy in Asia. This relevance is significant because the Asian continent (shown in Figure 4) corresponds to 49% of the global research.

With regard to the application forms that solar energy is used in Asia, Figure 8 shows the prevalence of solar thermal energy.

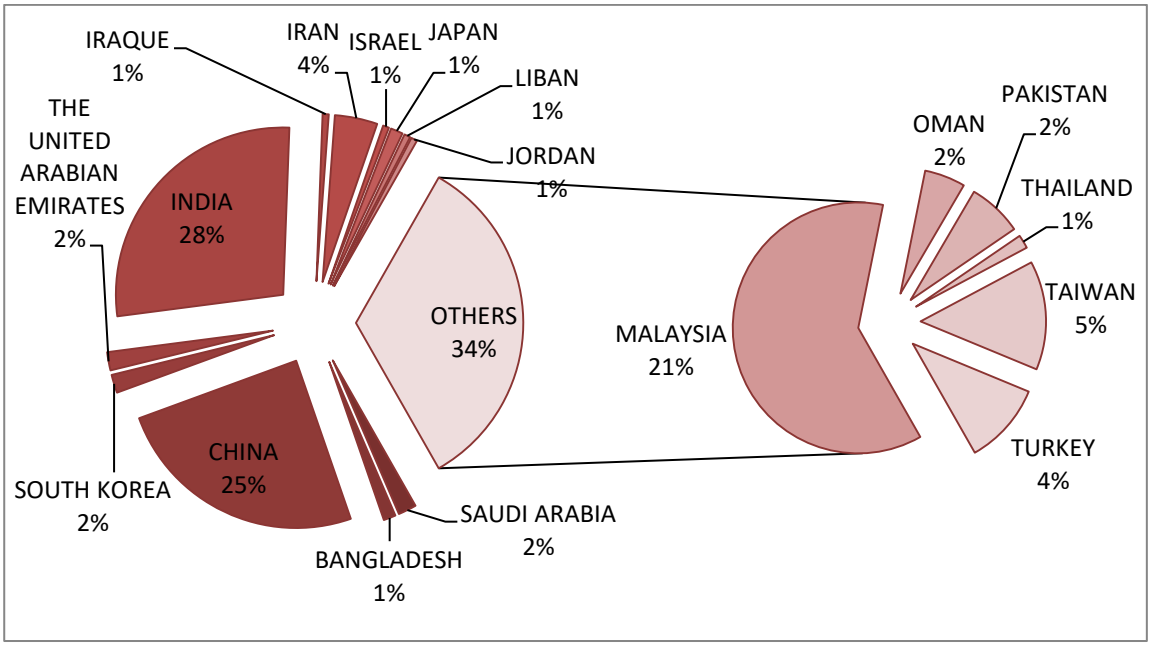

Figure 7 – Solar energy research in Asia.

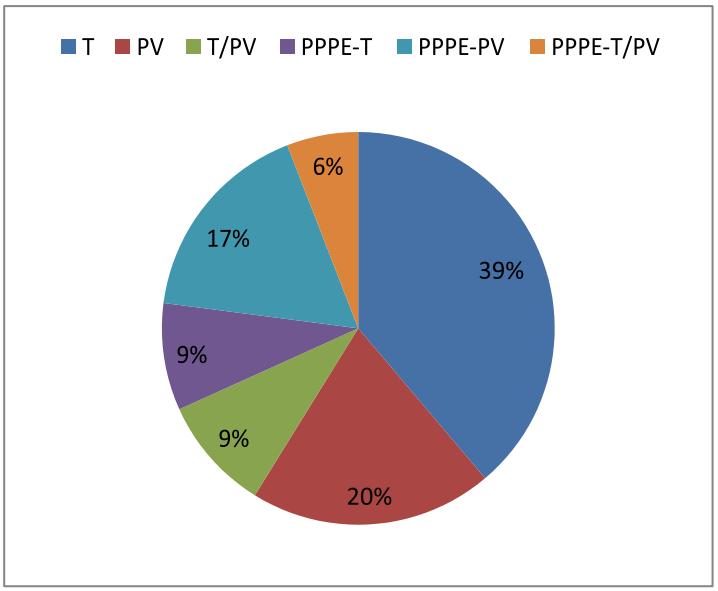

Figure 8 - Solar energy ways of application researched in Asia.

It can be noted in Figure 8 that the research in the thermal solar field is higher than in the photovoltaic one, representing almost half (~ 48%) of the continent, 37% of which relates to photovoltaic and 15% to both forms of application.

However, the data presented in the above chart suffer a strong influence from countries like India, China and Malaysia, in respect of the fact that they gained the first places in the global ranking of research in the solar energy field.

About the application of solar energy in India, solar thermal energy is the most used

and it is mainly used for heating water. According Veeraboina & Ratman (2012) India has a high potential for energy production from renewable sources development, and presents the highest intensities of solar energy present in Asia. Solar water heating has a huge scope in the domestic and industrial sector, especially in the textile industry, where hot water represents more than 70% of total energy demanded. The Indian government is in the first steps to promote and establish solar energy as a viable alternative source ahead of conventional energy sources (UMMADISINGU and SONI, 2011).

Photovoltaic solar energy in India, despite being below the research focused on thermal energy in Asia (Figure 8), will present in the future an important role in the energy matrix of the country (SHARMA et al., 2012).

Briefly, as there was a growing view in the global research of solar energy in the last few years, it is expected that this situation also reflects in Asia, representing approximately nearly half of the global research done in this field (~ 49%). Figure 9 shows this growth in recent years.

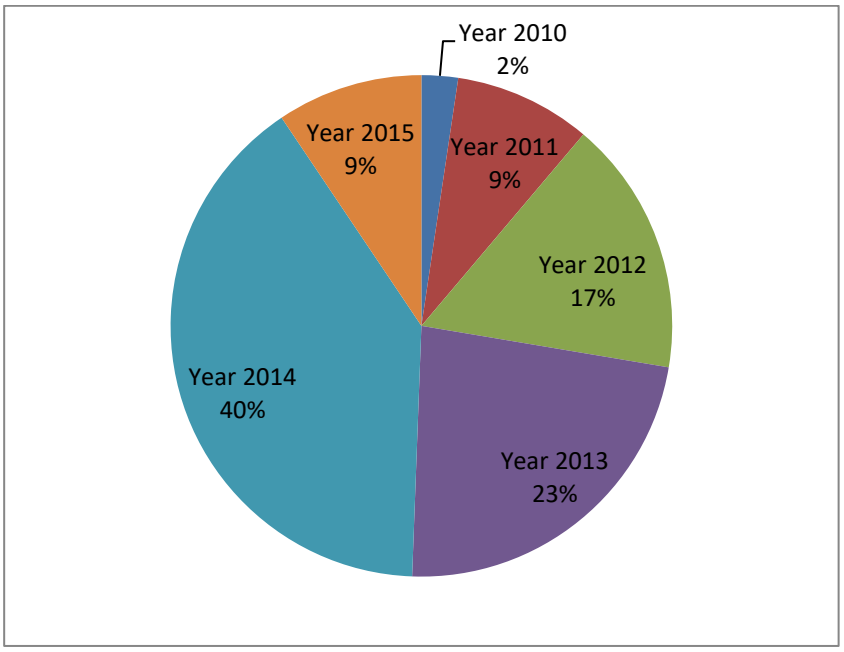

Figure 9 – Growing increase in research in Asia (2010-2015).

Note in Figure 9 that in 2014 the solar energy research showed 40% of its totality compared to previous years. This fact contributed significantly to global data as shown in Figure 6. Even in 2014, countries like India, China and Malaysia showed their predominance in solar energy studies.

3.2 Solar energy research in Europe

Countries that contributed to the research of solar energy in Europe are shown in Figure 10.

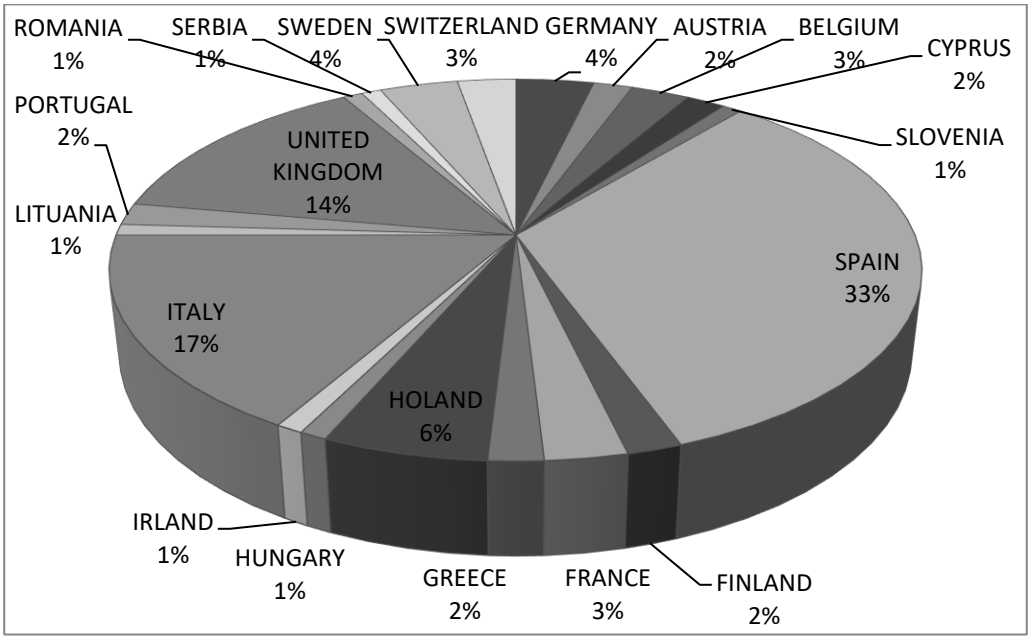

Figure 10 – Solar energy research in Europe.

The featured countries in Europe accounted for 64% of the research are a small number, represented by Spain, Italy and the UK. However, on the European continent solar energy different ways of application are spread more homogeneously (Figure 11).

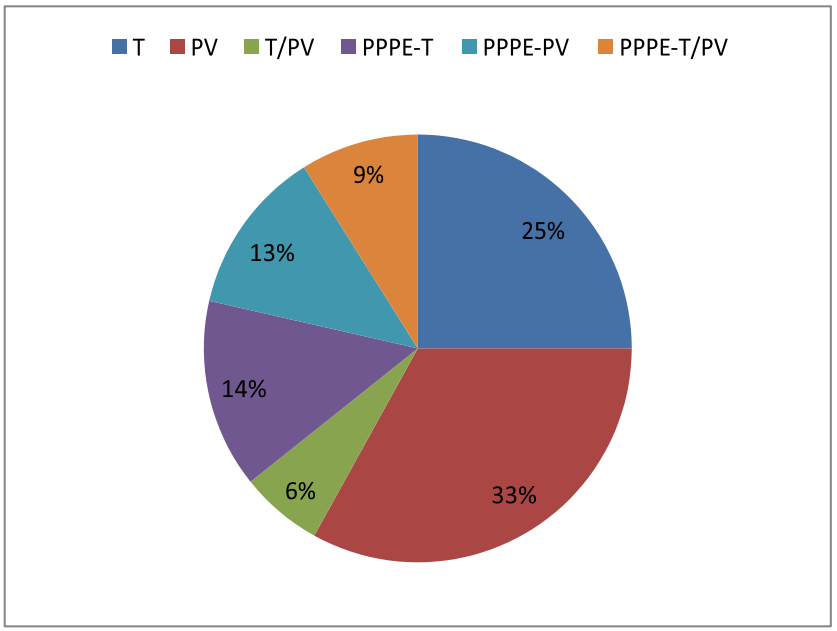

Figure 11 - Solar energy ways of application researched in Europe.

Despite forms of energy on the continent are well distributed, there is a slight difference of 6% between thermal and photovoltaic application. Presenting most of the research in Europe, Spain significantly contributes to this picture. According Talavera (TALAVERA et al., 2014) by the end of 2011, Spain had an installed capacity exceeding 4400 MW, which represented a contribution of 3% to the electricity demand. Still, possible increases in the electricity levy are under discussion, and this link to the photovoltaic market, evidence showing that technology can become profitable in Spain. Figure 12 shows the last five years quantification of research on solar energy sector for the European continent.

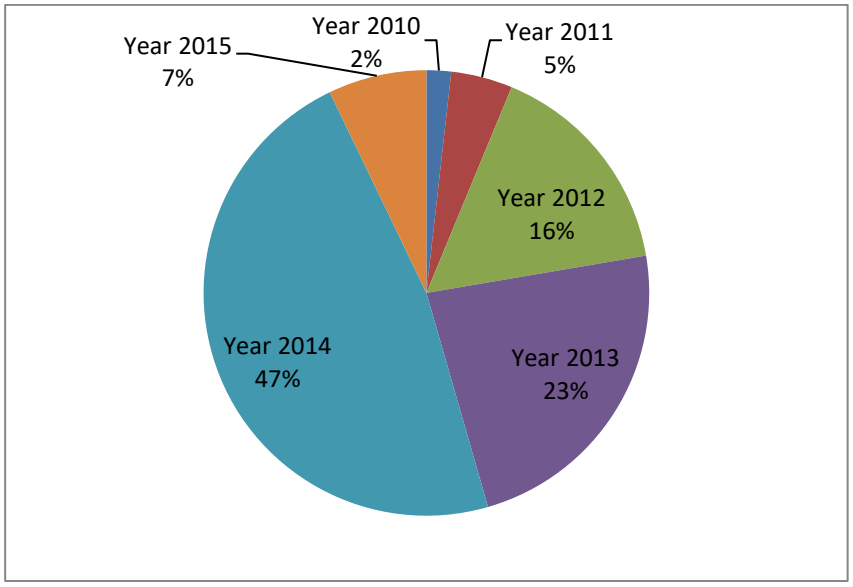

Figure 12 – Solar energy research of the last years in Europe.

As highlighted in the Asian continent, year 2014 in Europe also present the highest number of researches (47%), 7% more than in Asia. Furthermore, there was a decrease of 2% of future publications for 2015 compared to the same continent.

3.3 Solar energy research in North America

Figure 13 shows solar energy research in North America. Note that there is just a small portion of countries participating in the American solar energy research. There is a clear predominance of the United States (US) in the research done in recent years. According to the National Renewable Energy Laboratory of the United States, the CSP technology (Concentrator Solar Power) tends to become the largest renewable source of electricity generation of the country. Using this technology, an area of 23,418 square kilometers in the United States located where receives most solar radiation in the country can match the current capacity of electric power generation of 1067 GW (MILLS and MORGAN, 2008).

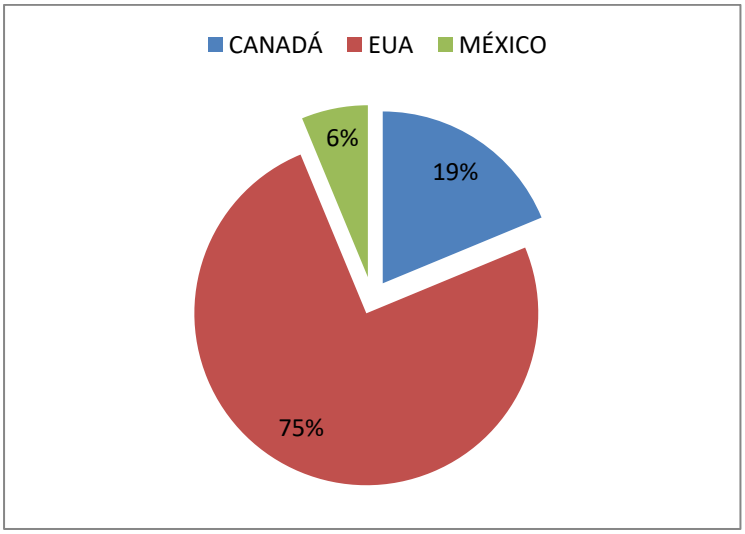

Figure 13 – Solar energy research in North America.

According Cassard et al. (2011), in the matter of solar water heating, the current US technology has the potential to save about 50-80% of the energy used for this application, depending on the region.

Figure 14 illustrates the ways of application most researched in North America.

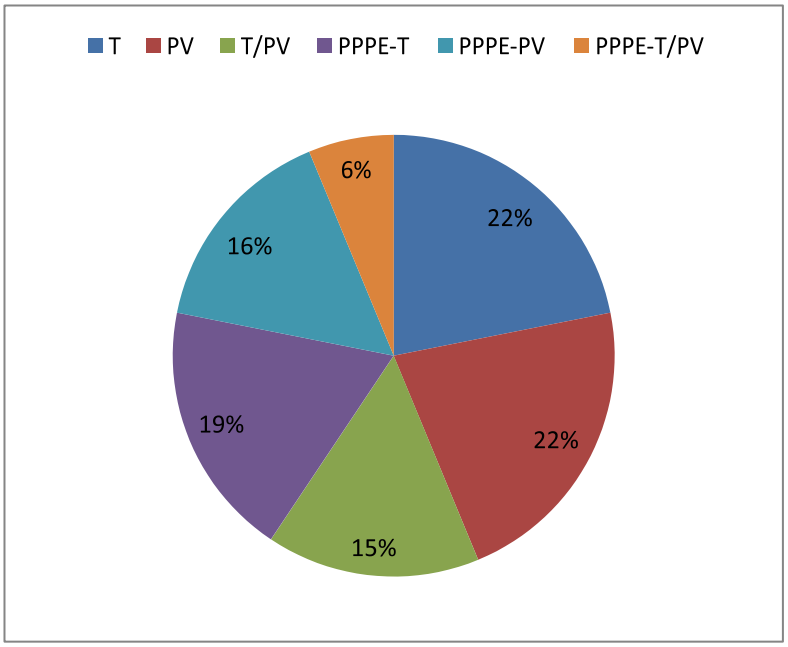

Figure 14 - Application forms of solar energy in North America.

Publications, about ways of application of North American solar energy T and PV, present an approximate index (both 22%), differing only if we count the themes of PPPE, resulting 41% in the thermal approach. According Timilsina *et al.* (2012), the North American market dominates with solar collectors with no cover (without glass) used for

swimming pools heating.

Figure 15 shows the last five years quantification of the US research on solar energy.

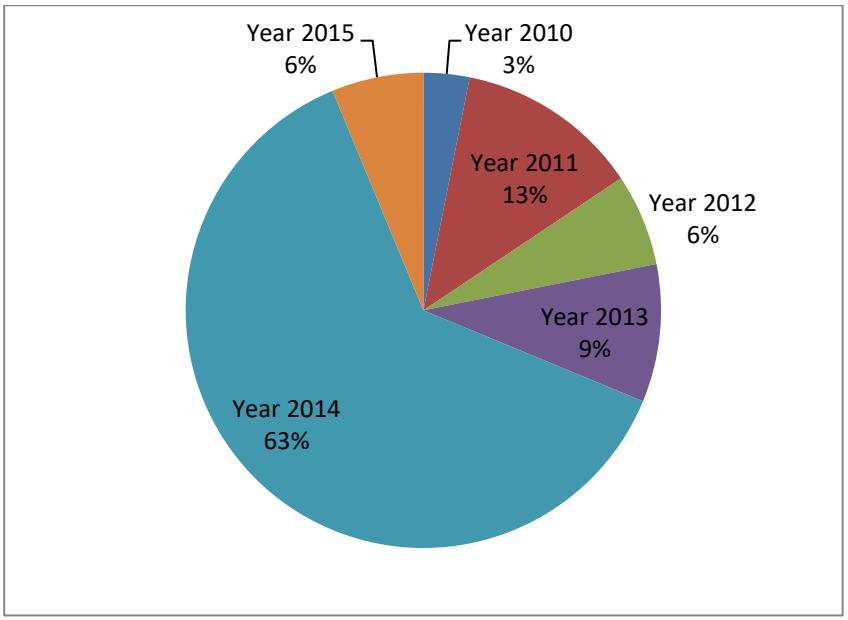

Figure 15 – Quantification of the North American research on solar energy (2010-2015).

Can be seen in Figure 15, the gap of 2014 compared to all other years. However, it is visible a drastic drop in the participation of the scientific community in 2012, which returns to rise in 2013-14. Still, the 64% rate (in 2014) exceeds the ones presented by Asia (40%) and Europe (47%), but we should remember that North America accounted for only 9% of the global research in solar energy against the predominance of Asia and Europe with 31 and 49%, respectively.

3.4 Solar energy research in Africa

The African countries that have conducted researches in the solar energy field in recent years are shown in Figure 16. It is also visible the proportion of contribution of each country.

According to Figure 16, the countries with the highest participation in solar energy research in Africa totaled 80% of which, 47% corresponds to Algeria, 19% Egypt and 14% Tunisia. Presenting almost half of the studies in Africa, the role of research in Algeria directly influences the research framework of the continent.

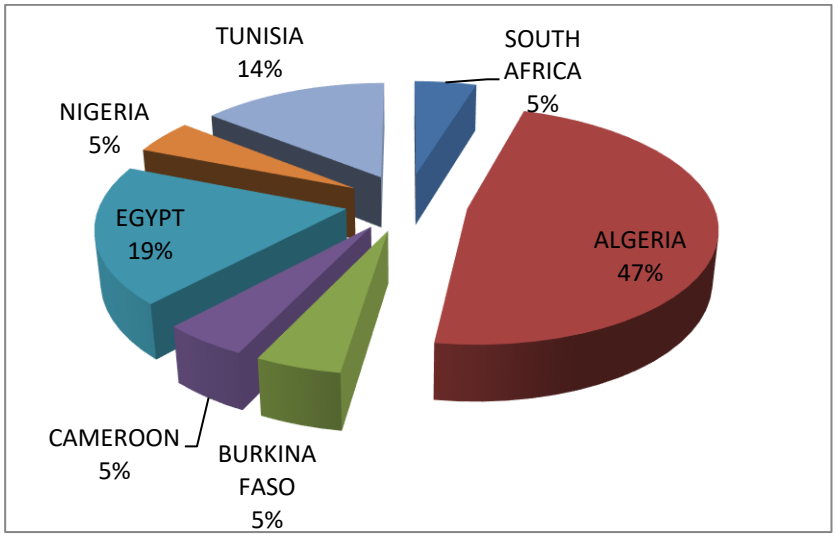

Figure 16 – Contributing countries in solar energy research in Africa.

Regarding solar energy, the geographical location of Algeria, in the region of the "Belt of the Sun" has many advantages due to weather conditions such as heat stroke throughout the year, low humidity, precipitation and plenty of flat unused land close to roads and transmission networks. These conditions are favorable to an extensive use of the enormous potential of solar energy. The solar radiation values range from 1700 $kWh.m^{-2}.year^{-1}$ North to 2650 $kWh.m^{-2}.year^{-1}$ in the south and the time-average of insolation on almost all the national territory exceeds 3000 hours, reaching up to 3500 hours in high plains and Sahara. Thus, Algeria is one of the countries with the highest levels of solar radiation in the world (BOUKELIA and MECIBAH, 2013).

Figure 17 shows solar energy ways of application researched in Africa.

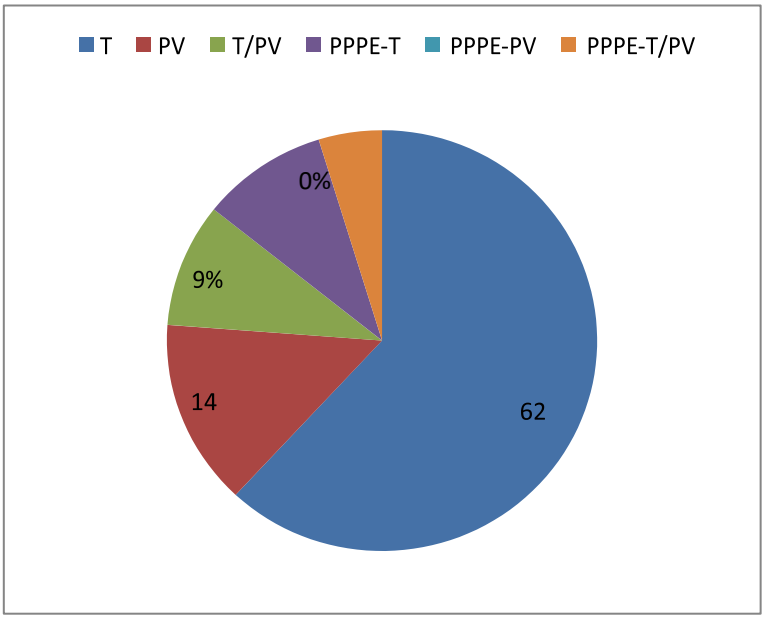

Figure 17 - Solar energy research approach in Africa.

Researchers conducted on solar thermal energy in Africa were strongly widespread, especially in 2014. On the other hand, the approach to PP E-PV has a null value, that is to say, that there is a lack of photovoltaic solar energy research on thermal solar energy.

The period focusing on the greater number of researches in Africa is shown in Figure 18.

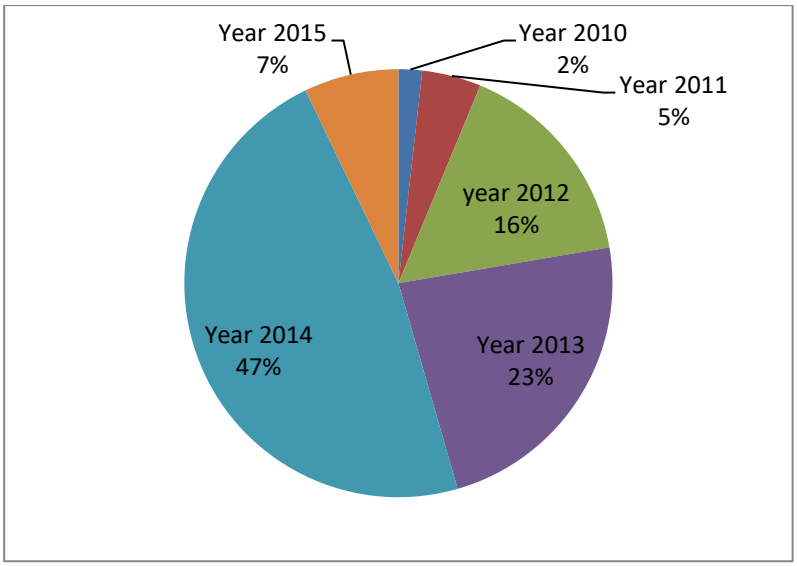

Figure 18 – Years most researched in Africa.

The graph in Figure 18 illustrates the annual increase in research in the solar energy field in Africa, which shows a similar growth in Europe and Asia, however, regarding 2014, the percentage in Africa showed a higher rate than Asia in the same year.

3.5 Solar energy research in South America

South America showed low participation in researches focusing on solar energy, accounting for only 2% of publications in the world. Figure 19 shows solar energy research in South America.

Besides presenting a low global participation, solar energy research in South America had the participation of a few countries such as: Brazil, Chile e Colombia. The country with the highest index was Brazil with 50% of research, which primarily focused on photovoltaic solar energy.

Considering energy development in Latin America, we can say that an industry sector that needs more re-engineering is the electrical distribution one. One of the common characteristics of the countries of this region (including Brazil), they have densely populated cities and a considerable percentage of the population is distributed along the fields presenting difficulties to access places due to the challenging geography (SILVEIRA et al., 2013).

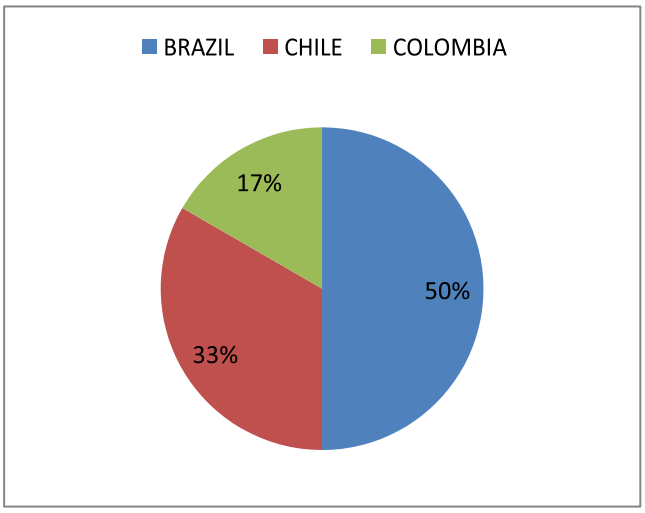

Figure 19 - Countries participating in solar energy research in South America.

According to the REN21 (2016), 5% of the population do not have access to grid electricity, considering Latin America and Caribbean, where most of them have low-income and are located in rural areas where the cost of electrical distribution networks is very high.

According to Silveira et al. (2013) Brazil has large areas with excellent intensity of solar radiation during most of the year, so that limitations on local installations of photovoltaic systems become minimum. In Brazil, some programs such as “Light for All”, an implementation program that mainly relies on the decentralized generation of stand-alone photovoltaic systems (DINIZ et al., 2011).

Figure 20 shows ways of application of solar energy in North America.

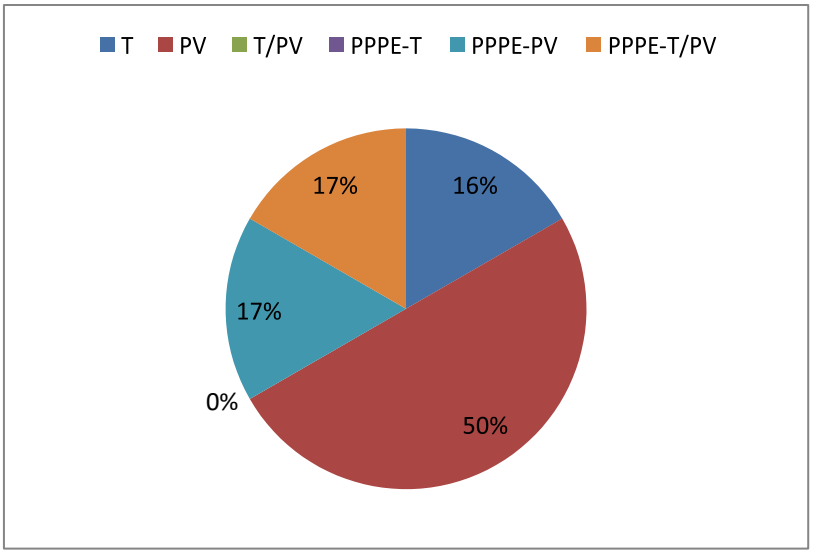

Figure 20 - Solar energy research approach in South America.

As can be seen from Figure 20, solar PV received increased attention in researches in South America. The use of photovoltaic systems in Brazil and around the world still depends on subsidies in order to achieve economic viability of keeping the current technology costs, not to mention the benefits of clean generation that this technology provides. Investments by developed countries with radiation levels lower than Brazil, are designed to generate production volumes that reduce 2.00 US $ .Wp^{-1} the cost for acquisition of solar panels (SILVEIRA et al., 2013).

Silveira *et al.* (2013) points out that such reduction can only be achieved depending on the volume of production, with an outlook for the coming years. Still, Brazil presents high levels of sunlight (1200 In^{-2}) compared with countries where technology has received higher investments, and photovoltaic technology has high chance to become competitive in the national scenery.

Figure 21 shows the proportion of work carried out in South America in the years 2010-2015.

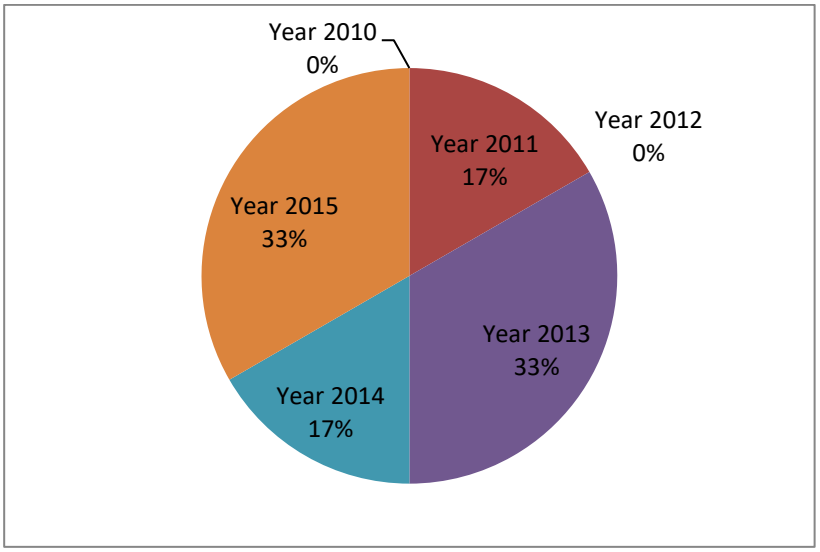

Figure 21 – Solar Energy Research in South America in the last five years.

Compared with the other continents, South America showed a low level in 2014 and was absent from publications in 2010 and 2012. However, for the years 2013 and 2015, increase over Asia, Europe, North America and Africa is very tangible. Thus there is a positive outlook on solar energy research in South America for 2015.

3.6 Solar energy research in Oceania

Solar energy research in Oceania is represented only by Australia. Figure 22 shows a comparison of the number of Oceania's publications (fully represented by Australia) compared with the African and South American continents.

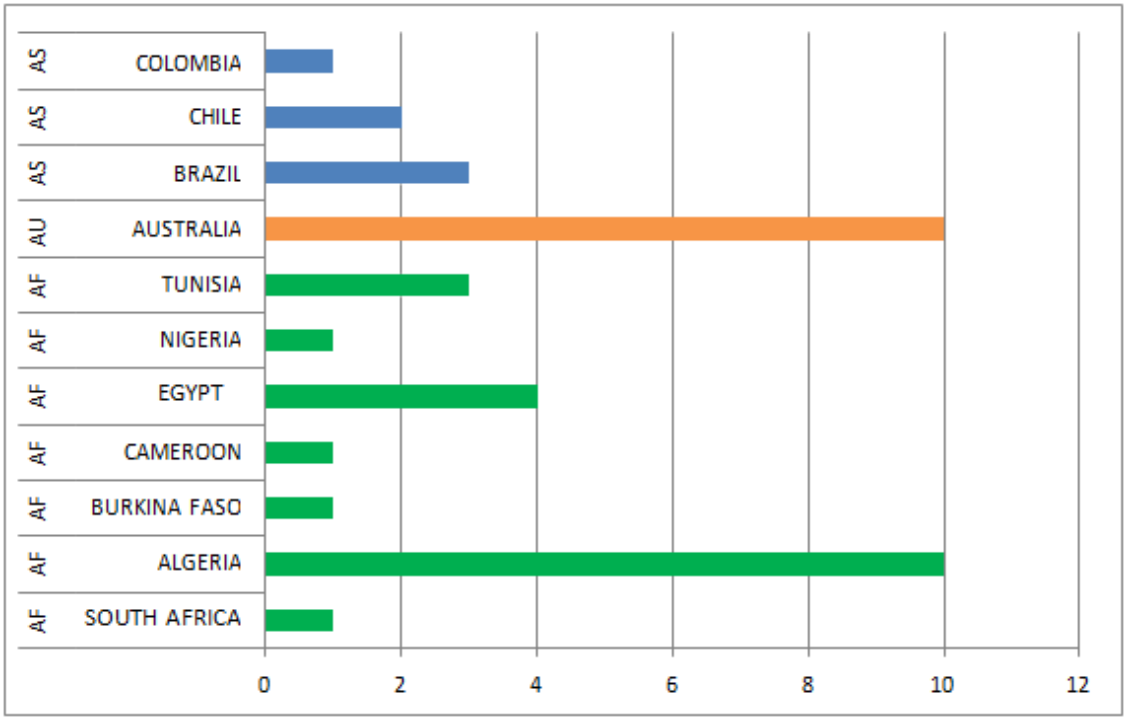

Figure 22 – Relationship between countries with lowest participation in the worldwide solar energy research.

Note in Figure 22 the similarity between Australia and Algeria regarding the research proportion, so that Australia (Oceania) had half of the research that North America had and exceeded with a minimum amount South America. In relation to the form of energy analyzed in the studies, solar thermal energy highlighted in the Oceania continent (Figure 23).

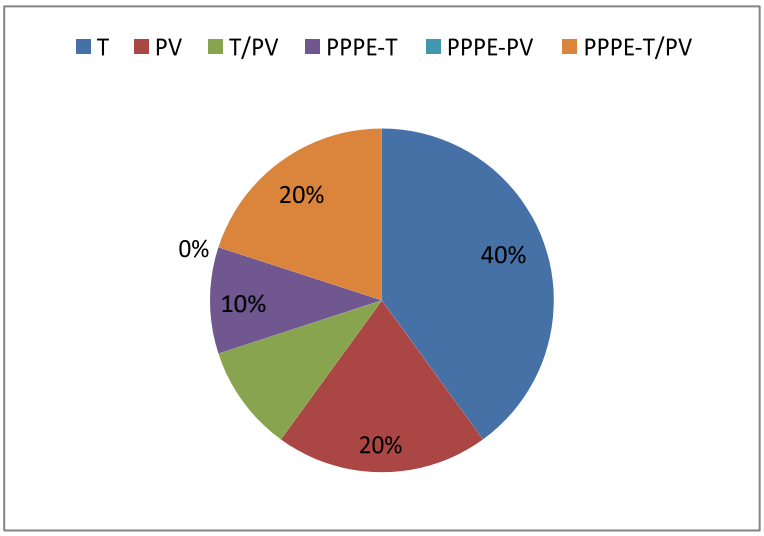

Fig. 23 - World solar energy types researched in Oceania.

According to Figure 23, the development of studies conducted in the solar thermal

field exceeds the research framework in Oceania. Presenting 100% of the research on the continent, Australia is responsible for this result. According Baniyounes (2013), solar energy has a great potential in Australia due to its atmosphere which is considered one of the sunniest of the world where there are large desert areas with low percentage of cloudiness and rain. According to Bahadori & Nanoha (2013) Australia has the highest average of solar radiation per square meter than other continents in the world, and even so solar energy represents only 2.315% of power generation (PV and thermal). In addition, the annual radiation burden on the Australian territory is approximately 58,000,000 PJ, namely 10,000 times the national annual energy consumption.

Solar thermal technology was launched and developed in Australia in 2011, with 704,459 solar water heating systems installed. This technology becomes the more common one in the use of renewable energy sources among Australians. However, there are other low temperature thermal applications such as agricultural products drying, solar ponds, and space heating (CLEAN ENERGY COUNCIL, 2011; LOVEGROVE and DENNIS, 2006).

Figure 24 shows solar energy research in Oceania in recent years.

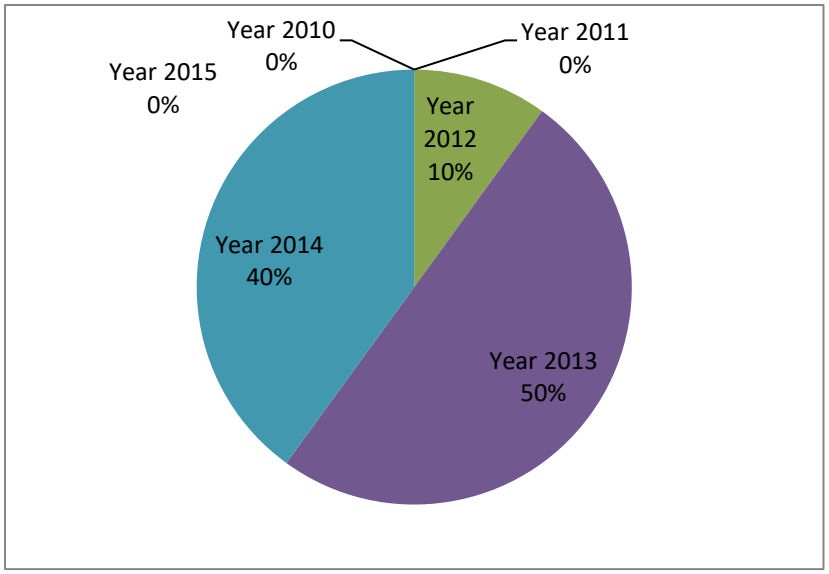

Figure 24 – Quantification of solar energy researches in Oceania between 2010 and 2015 (Australia).

Figure 24 shows the absence of solar energy research in Oceania for the years 2010, 2011 and 2015. On the other hand, the year 2013 Oceania showed predominant quantification of publications on solar energy compared to all other continents, offering 50% of it compared with the second place represented by South America (33%).

4. Final considerations

In this review, a global situation of solar energy was presented based on a number of publications from 2010 to 2015. Some countries, as China, had a significate number of publications while Germany, which is an important recognized player in all chain of the photovoltaic sector, did not showed relevance in terms of publications. This could be related to the economic situation of each one, where China had a quickly economic growth and modern development, using renewable energies to support the new energy demand and achieve a more appropriate energy consumption structure with the reduction of coal consumption, while Germany did not had a great chance in its energy demand.

According to data collected in the research and considering the variables it appears that:

i) Overall, the Asian continent was the one that presented the highest number of researches. The hegemony of researches on the continent is due to participation of the scientific community of countries like India, China and Malaysia, which account for 74% of the research done on the continent. China was the first country to break the threshold of $100 billion investment in renewable energies, and together with India increased their renewable energy targets in 2015. Some states in India promote renewable power deployment with the use of new metering policies and use of tendering, and various Pacific Islands introduced 100% renewable energy targets in 2015.

ii) Countries with the worldwide highest number of publications in the solar energy field were India, China, Spain, Malaysia and the United States totaling more than half of global research. Some European countries adopted new policies to have a minimum of 27% of renewable energy in final energy consumption by 2030, while many states in the U.S. expanded their existing Renewable Portfolio Standards (RPS), highlighting Hawaii with the first 100% RPS of the country.

iii) Research in solar energy sector had its main focus in the thermal generation field presenting 34% of rate in global terms than other ways of application;

iv) Solar energy research has considerably increased in the last five years, especially in 2014, when the highest number of publications totaled 45% of the global amount.

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