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SOLAR TRACKERS: WORLDWIDE MAP OF PERFORMANCES

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Abstract. *Photovoltaic solar energy systems represent a concrete alternative to the current used methods for electric energy generation based on the consumption of fossil-based fuels. In order to generate the maximum of electrical power while there is daylight, solar trackers were developed as well as photovoltaic modules positioning algorithms. This work reports a collection of data from experiments regarding to energy production using solar trackers in comparison to theirs fixed analogues, for worldwide geographical locations, plotted as a globe map. A total of 50 experiments were compiled, where 44 (88%) of them published after 2004. Although, different experiments took place in the same geographic location, they were differentiated and each result marked separately on the map. Combining all results for the 50 experiments the average gain for the single-axis trackers is 28% and for two axis trackers is 39% regarding fixed solar panels. Both values are within the theoretical expectation. The map presented here correlate experiments with solar trackers and geographic location, it can be a very interesting tool for researchers worldwide, allowing people to access information about working groups, results and experimental setups very quickly.*

Keywords: solar trackers, solar energy

1. INTRODUCTION

Photovoltaic solar energy production is a widespread known alternative to fossil fuels consumption, the amount of energy provided by the sun is enough to supply the ever-growing demand of human society. Unfortunately, associated to the photovoltaic cells efficiency (20%), the meteorological conditions and Earth´s movements reduce significantly the total electricity produced.

The solar trackers were developed in order to improve the energy production rates. These systems consist on an eletromechanical support that aligns the photovoltaic modules with the normal direction of the Sun rays. Compensating the apparent Sun movement across the sky, enhancing the electrical power generation in comparison to the fixed arrangements.

Since the first model of a solar tracker proposed in 1962 (Mousazadeh, *et al.*, 2009) up to the present days countless experiments were performed with many models of trackers all around the world. Today there is a variety of techniques for installing the positioning system and the trackers are classified regarding to the number of axes, their orientation and technology.

The results of each work depends on some factors, for example, the geographic location, the method used to track the Sun, the kind of tracker one have (passive or active), etc. Theoretical studies indicates that the gain related to the fixed system is about 20 to 30% for the single axis tracker and around 40% for the two axis tracker, both built with the same technology and submitted to the same meteorological conditions.

2. THE MAP OF PERFORMANCES

The scientific community has documented over the years a large variety of techniques and results regarding the use of solar trackers. Despite the fact that most papers are well known by researchers, so far there is no compilation including all of them, which would be a reference for future works.

Some reviews like Mousazadeh, *et al.* (2009) overviewed a good number of work and results, our goal is to expand their research and present the worldwide experiments in a map, where one can search for a given experiment in a given location, as well as check the density of works in a specific region.

In this work a high resolution world map was used for marking the experiments in each geographic position. It is displayed in a reduced scale in Fig. 1 and then magnified subsequently for detailed information. Each dot in the map is numbered, and each number represents a different scientific work that is detailed with its results according to the original paper in Tab. 1.

On the proposed map most of the dots have the same size, except for those representing a large number of experimental sites reported by one single paper. Those dots are larger but the numerical indication remains the same. A color code was used to indicate the kind of tracker implemented, the blue dots indicate single axis tracker, red is used for two axis tracker and black indicates different techniques, all reported experiments have a traditional fixed photoelectric system as reference.

In some works instead of photovoltaic modules the authors used radiometers, one attached to the tracker, the second placed on a fixed frame, thus the comparison is made regarding the total radiation detected by the devices as an alternative to the electrical power generated on solar panels. Nevertheless, the validity of the concept and the rigor of the experiments are unquestionable.

Some papers reporting about a large number of experimental stations placed on different geographic locations, has been treated differently. On those cases, instead of having one dot per station, we did chose have a single bigger dot nad one index number for the whole array.

Comparing all results reported on the 50 papers analyzed the mean value for the electric power generation efficiency gain for single axis trackers is about 28%, and for the two axis technologies is about 38%. The standard deviation for these means are 2,45% and 1.67%, respectfully.

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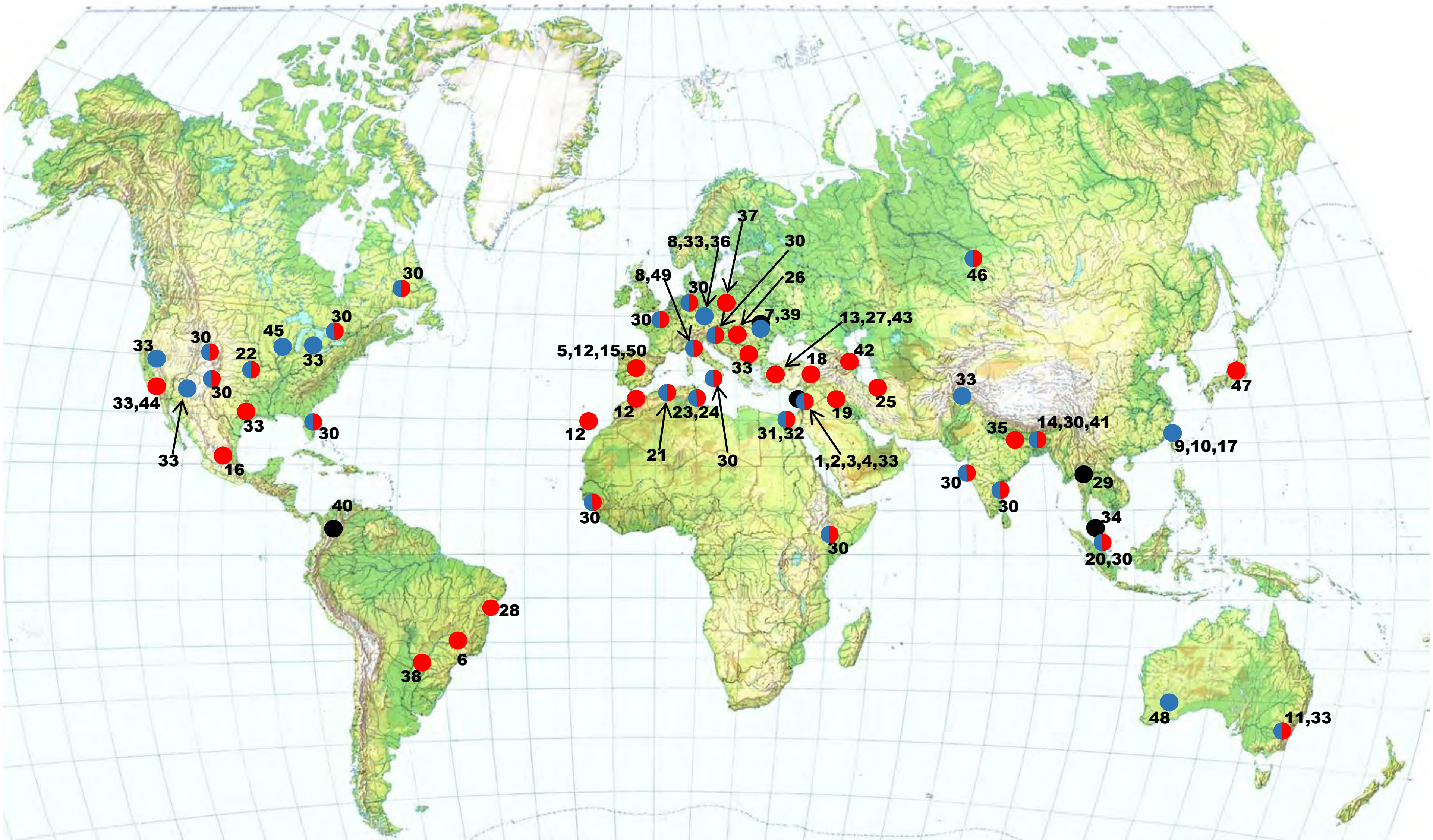

Table 1. Experiments papers marked on map.

Number	First Author´s Name	Year	Single Axis gain (%)	Two Axis gain (%)	Other Techniques gain (%)
1	Abdallah	2004a	26.41	43.87	34.43
2	Abdallah	2004b	-	41.34	-
3	Abu-khader	2008	-	-	30 – 45
4	Al-Mohamad	2004	20	-	-
5	Almonacid	2011	-	45.8	-
6	Alves	2008	-	53	-
7	Burduhos	2010	-	-	38
8	Chicco	2007	37.7 / 30.4	31.5	-
9	Chang	2009a	49.3	-	-
10	Chang	2009b	27.6	-	-
11	Chin	2011	12 - 15%	-	-
12	Cruz-Peragón	2011	-	30	-
13	Kivrak	2012	-	64	-
14	Ghosh	2010	22	25	-
15	Gómez-gil	2012	22.3	25.2	-
16	Pavel	2004	-	30	-
17	Huang	2011	23.6	-	-
18	Kacira	2004	-	34.6	-
19	Khalifa	1998	-	-	75
20	Khatib	2009	50-60	-	-
21	Koussa	2011	34.4 - 46.3	39-54	-
22	Lubitz	2011	29	34	-
23	Maatallah	2011	10.37	37	-
24	Rhif	2012	-	40	-
25	Mousazadeh	2011	-	30	-
26	Seme	2012	-	10 - 45	-
27	Sungur	2009	-	42.6	-
28	Da Silva	2011	-	39	-
29	Khlaichom	2007	-	-	7.1
30	Nann	1990	32.8	38.35	-
31	Helwa	2000	21	30	31
32	Shaltout	1995	-	-	40
33	Mousazadeh	2004	17.83	35.86	-
34	Afarulrazi	2011	-	19.72	-
35	Bajpai	2011	-	28.87	-
36	Colli	2012	12	-	-
37	Kaminski	2011	-	30.8	-
38	Kang	2011	-	30	-
39	Milea	2010	25	-	-
40	Pineda	2011	-	-	36.4
41	Samanta	2012	-	30 - 40	-
42	Taki	2011	-	33	-
43	Eke	2012	-	30.79	-
44	Gay	1982	-	40	-
45	Mosher	1977	31	-	-
46	Kitaeva	2012	23	32	-
47	Hu	2012		34.77	-
48	Liyanage	2011		-	-
49	Boicea	2010		34.5	-
50	Jaen	2009		51	-

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2.1 North, Central and South America

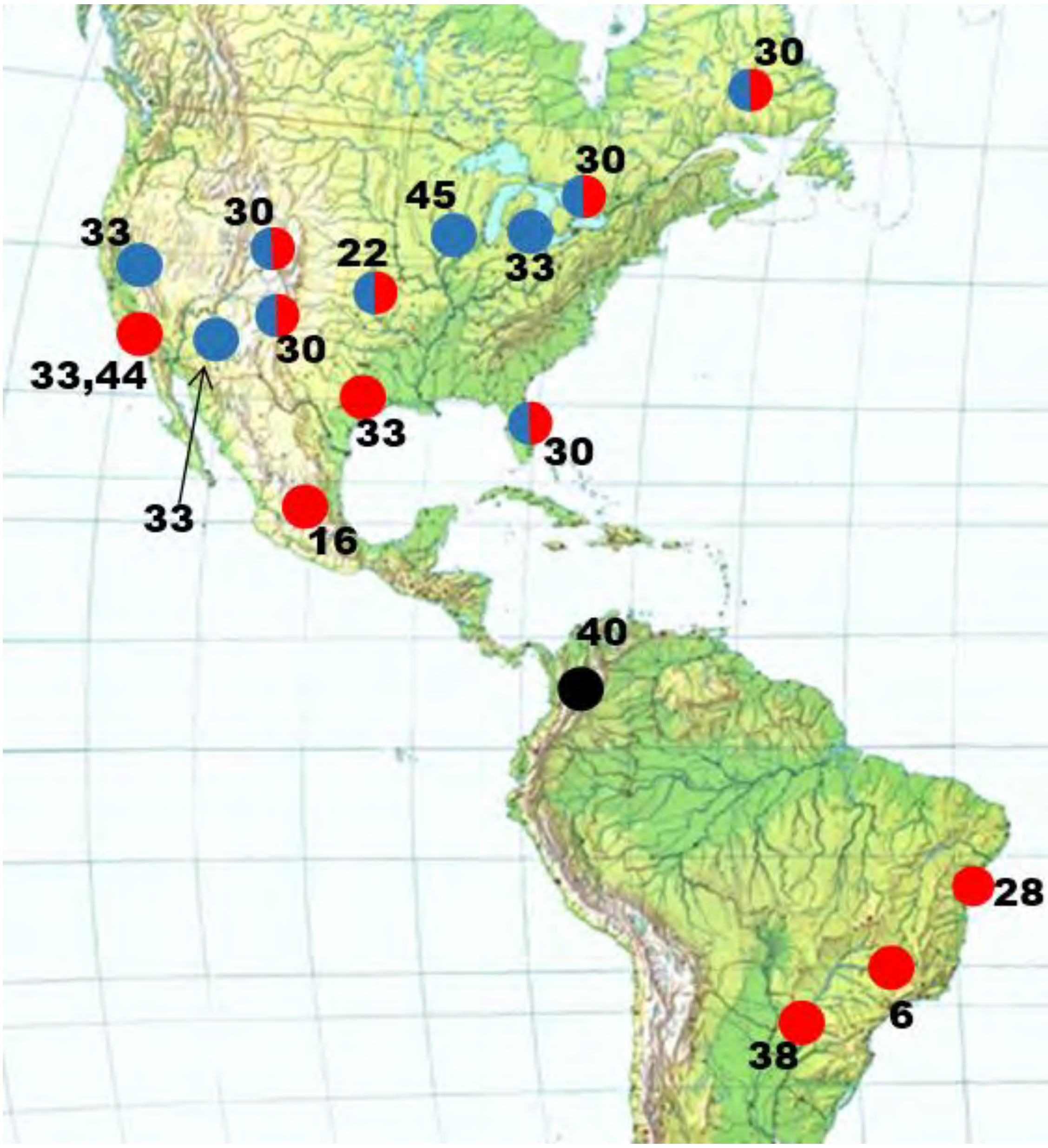

Figure 2. Detailing of the experiments marked in America.

Figure 2 shows a detailing of the American continent map. The work depicted as number 22 (Lubitz, 2011) contains more than 200 measuring stations spread across the United States of America. Among others studies performed on the same region, the work labeled as dot 22 is a clear sign of how developed the solar energy sector is in that country. Canada also appears in the map with some experiments realized near its major cities. Along with Europe these countries have already established large renewable energy databases and for decades have intensively investing in R&D.

In Latin America there are some groups developing solar energy research, but lately few papers are coming out in high impact journals or conferences. The countries of South and Central America, besides México, must invest more substantially in infrastructure for the development of renewable energies, especially on the photovoltaic sector, regarding the high irradiation areas and low latitudes occupied by these countries.

2.2 Africa, Europe and Middle East

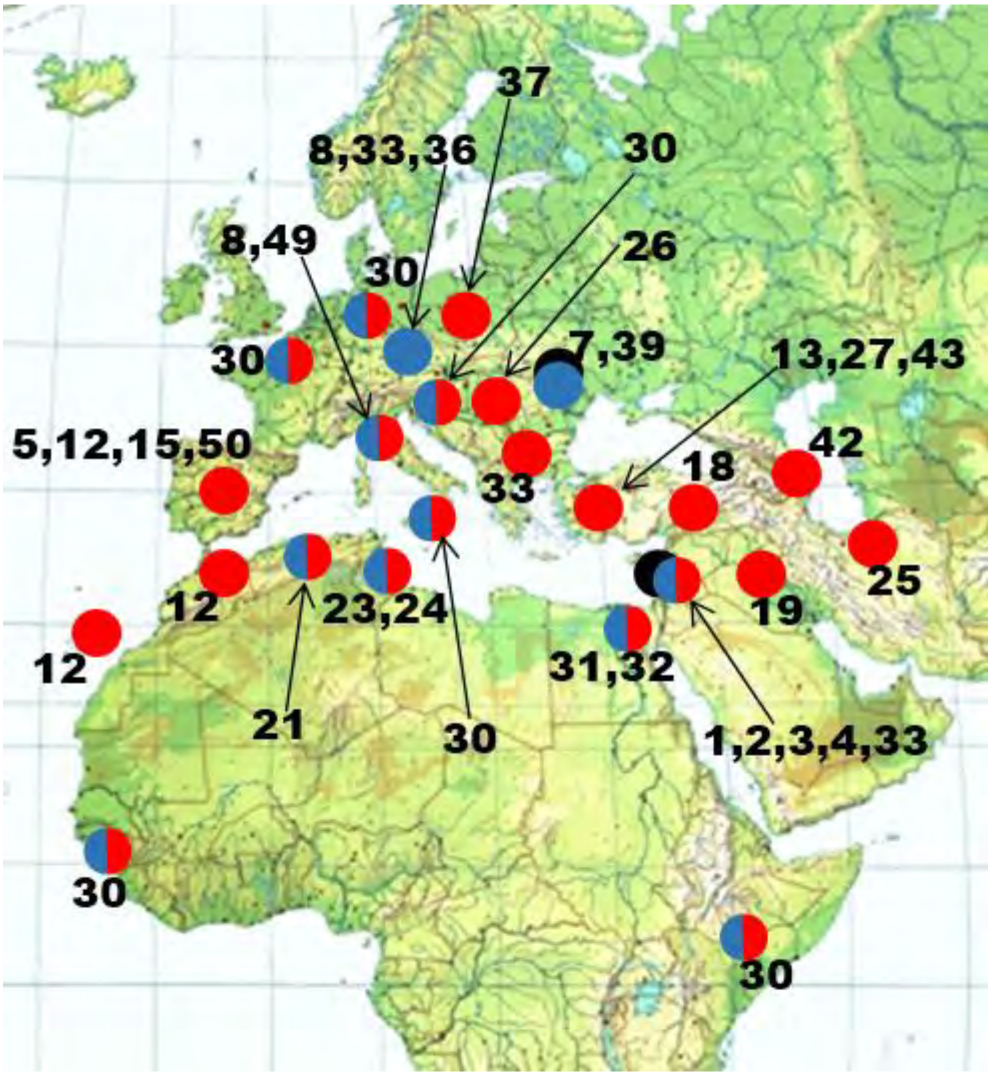

Figure 3. Detailing of the experiments marked in Africa, Europe and Middle East.

The highest density of experiments is found in Europe, as shown in Fig 3. As mentioned before, in Europe the renewable energy sector is consolidated and stands for a great deal in the sustainable strategy adopted by different countries. Following these guidelines, countries like Spain and Germany have entire power plants based on photovoltaic energy and promote huge research projects in several European cities, as signed by dot number 12 and 30 ((Cruz-Peragón, *et al.*, 2011) and (Nann, 1990)).

Recently, the Middle East has been occupying a prominent role in the photovoltaic energy research. This indicates an effort to develop alternatives for energy production in these countries and photovoltaic energy takes a major role in the process due to the good availability of Sun light, ready to be harnessed.

Unfortunately, Africa has only a few papers published in outstanding journals and conferences lately, with some of them being part of a bigger work, see dot 30 (Nann, 1990), the only experiment outside Saharan Africa. Clearly, the African continent must receive more investment, beyond the Sahara desert, in order to develop the photovoltaic energy sector, which could be of great help for economic and human development for the region as a whole.

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2.3 Asia and Oceania

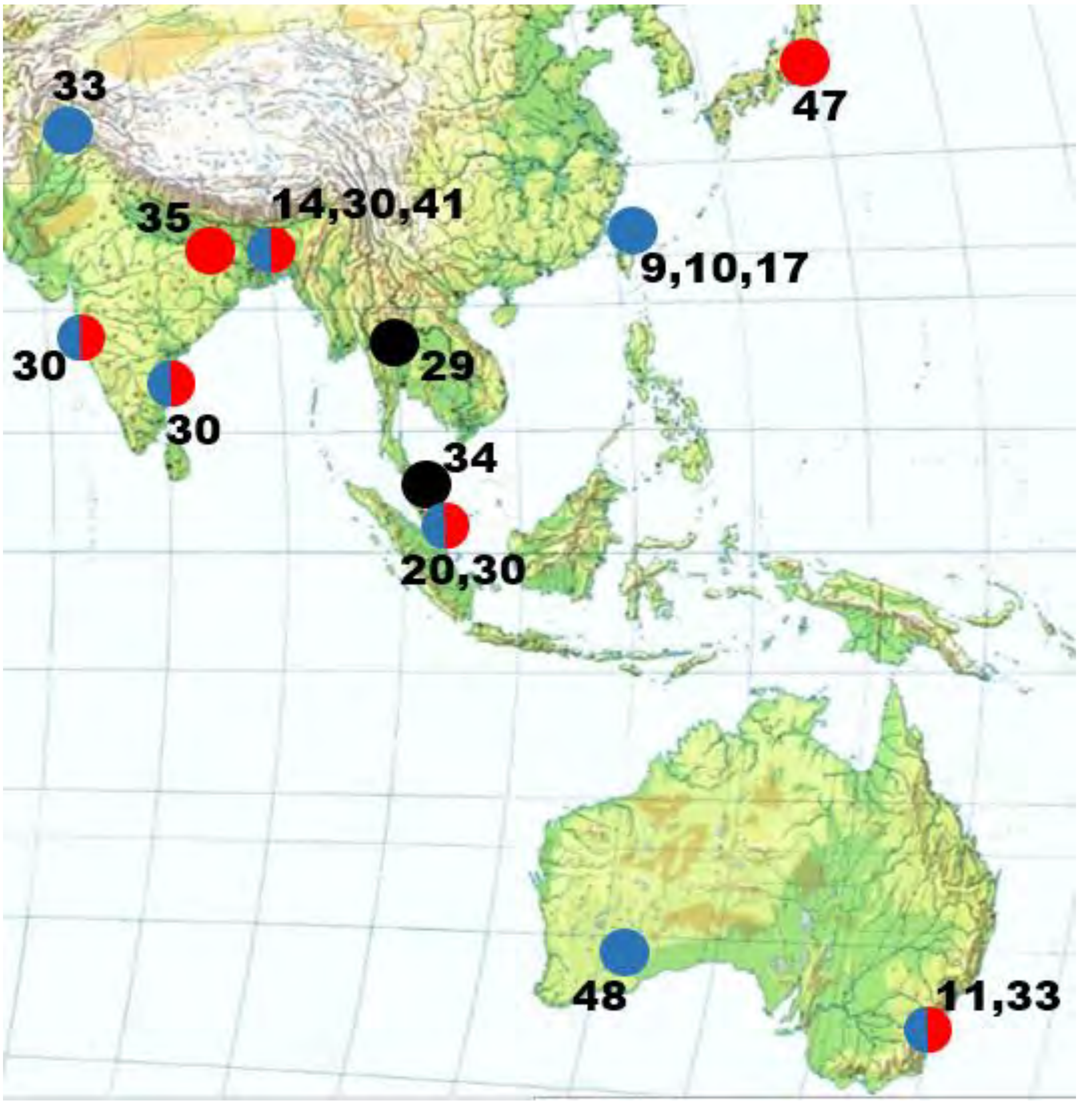

Figure 4. Detailing of the experiments marked in Asia and Oceania

Much like the scenario of the Middle East, in India and Asian Tigers, like Malaysia and Taiwan, there is a rising number of scientific papers being published over the last 5 years. The research groups in these countries shows intense activity with promising and innovative results, like the work doted by number 17 (Huang, *et al.*, 2011) in which were developed a one axis tracker with only 3 positions instead of a continuous following system, achieving satisfactory results.

The Japanese have already an extensive database and *know how* in the photovoltaic technology and their renewable energy sector is consolidated as a solar cell producer, so it is natural that their researches are focused in new methods and improvements for the already known technologies (Hu & Yachi, 2012).

The works that took place in Australia shows that there is initiative and interest on developing the photovoltaic energy sector, but more investment should be done in order to use all of the solar resource of the Australian outback.

3. CONCLUSIONS

The map presented here, correlating experiments regarding solar trackers and each geographical location, has been compiled from 50 published papers, collected from some of the most outstanding journals and conferences on renewable energy. It shows a clear correlation between developed scientific research groups, well established industry sector and the interest for renewable energy.

The combined mean value, for the ensemble of analyzed papers, for the efficiency gain of a single axis and a two axis tracker, in comparison to a fixed system falls within the theoretical expectation, equal

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to 28% and 38% respectively, and so does the standard deviation values, being 2.45% for single axis and 1.67% for two axis.

The map like representation proposed on this work does not aim to report all studies done so far, but it has the perspective to become a valuable tool to researchers and professionals worldwide, allowing people to quickly access information about different solar energy working groups, their results and experimental setups. Further information can be easily added to the map that can be updated once a year.

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