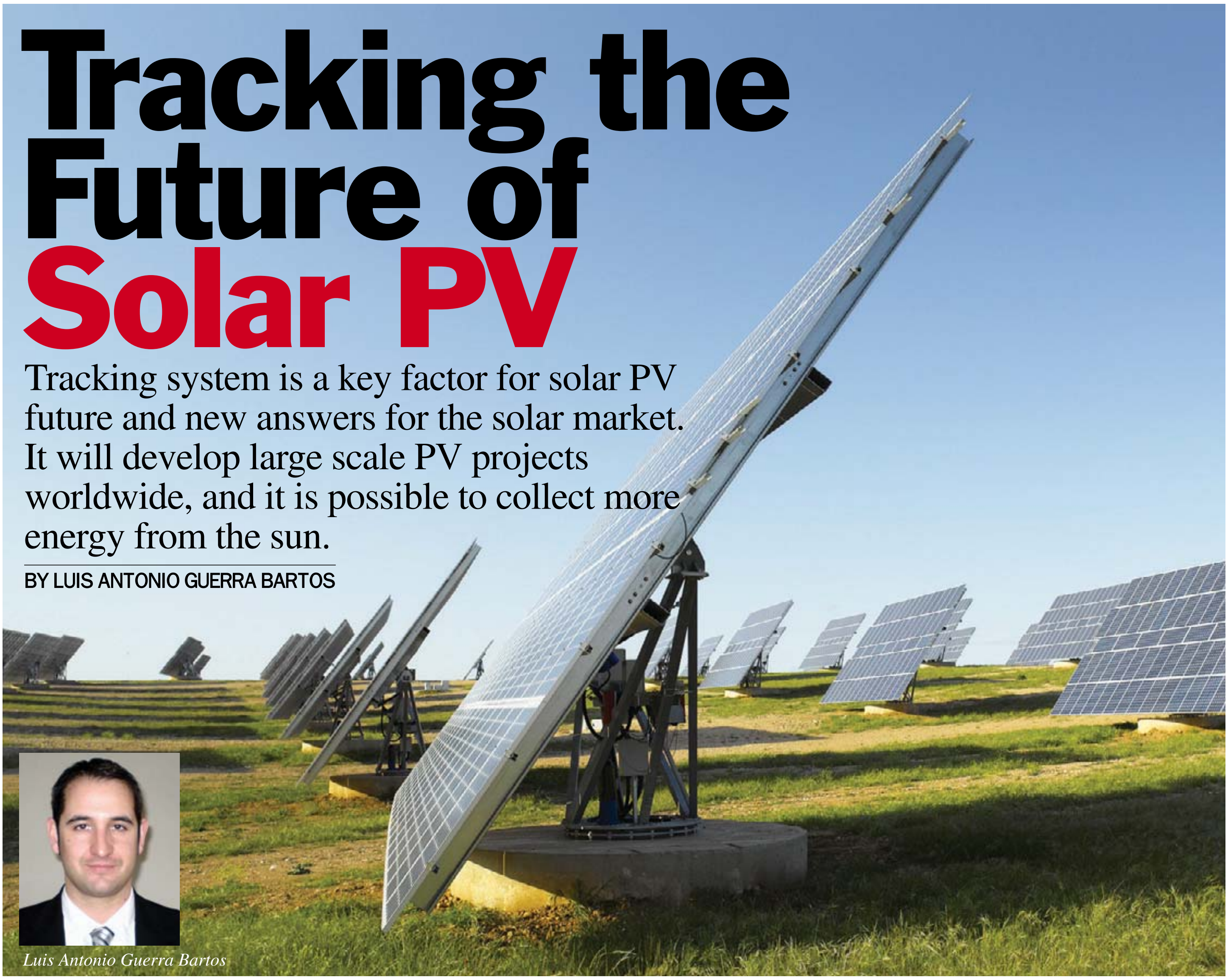

Tracking the Future of Solar PV

Tracking system is a key factor for solar PV future and new answers for the solar market. It will develop large scale PV projects worldwide, and it is possible to collect more energy from the sun.

BY LUIS ANTONIO GUERRA BARTOS

Luis Antonio Guerra Bartos

The photovoltaic effect remained a laboratory curiosity from 1839 until 1959, when the first silicon solar cell was developed at Bell Laboratories in 1954 by Chapin et al. It already had an efficiency of 6%, which was rapidly increased to 10%. The main application for many years was in space vehicle power supplies. Terrestrial application of Photovoltaics (PV) developed very slowly. Nevertheless, PV fascinated not only the researchers, but also the general public.

Its strong points are:

- Direct conversion of solar radiation into electricity,
- No mechanical moving parts, no noise,
- No high temperatures,
- No pollution,
- PV modules have a very long lifetime,
- The energy source, the sun, is free, ubiquitous, and inexhaustible,
- PV is a very flexible energy source, its power ranging from microwatts to megawatts.

MECASOLAR Flexible fixed systems

It's the most democratic technology because anybody could monopolize the energy that comes from the sun and is becoming more democratic from the economical point of view. Solar cell technology benefited greatly from the high standard of silicon technology developed originally for transis-

tors and later for integrated circuits. This applied also to the quality and availability of single crystal silicon of high perfection. In the first years, only Czochralski (Cz) grown single crystals were used for solar cells.

Nowadays, the panorama is far different cause at the end of 2008 worldwide more than 1,700 Photovoltaic (PV) power plants with a nominal capacity of more than 200 Kilowatts (kW) each were in operation. The cumulative power of these solar electric power plants according to figures of the solarserver's partner portal site, pvresources.com, exceeds 3,200 Megawatts (MW). More than 800 solar power plants with a capacity of more than one MW have been in operation or being tested at the end of the last year. According to preliminary data collected by pvresources 63% of the total capacity of utility-scale PV plants (>200 MW) were installed in Spain. Noteworthy market shares are held by Germany (650 MW, 20%), the U.S. (230 MW, 7%), Korea (scarcely 100 MW, 3%), Portugal (60 MW, 2%) and Italy (scarcely 60 MW, 2%). In Spain the installed PV capacity in the third and fourth quarter of 2008 reached one Gigawatt (GW). Compared with 2007 the capacity of utility-scale PV plants in Spain grew more than sevenfold. At the end of 2007 approximately 270 MW were connected to the grid, at the end of 2008 the cumulated capacity reached approximately 2,020 MW.

Czech Republic & France

In the European Community, a positive market development was visible also in the Czech Republic and in France. Multiple megawatt solar plants have been completed in the Czech Republic in 2008. A solar plant with a capacity of 7 MW was connected to the grid in France. Although Spain has been the unambiguous focus of market development, in Germany additional large-size plants have been completed as well.

U.S.A. PV Scenarios

Repower America Scenario A (Figure 2): Energy efficiency policies and programs reduce demand by 28%, nuclear and hydropower—neither of which emits CO_2—remain at current levels, America ramps up wind consistent with recent sectoral growth rates, solar thermal with storage is deployed at scale, and solar PV and geothermal grow at levels consistent with the projections of industry experts.

Repower America Scenario B (Figure 3): Like Scenario A, includes a mix of efficiency, renewables and existing generation, but assumes fossil fuel industries deploy approximately 20 large coal and natural gas power plants that capture and sequester their CO_2 emissions (these are known as coal and natural gas plants with CCS). Wind levels are reduced commensurate with the additional contribution from fossil power with CCS.

Continued solar PV growth at industry expected rates: Based on the average annual growth rate of 40% since 2000 and the recent announcements for gigawatt-scale solar PV projects in California, continue industry growth to achieve 3%-6% of the projected demand (or 4%-8% of the annual generation). At the lower end (Scenarios A and B), this is 65-75 GW, which is in the range of the CleanEdge 'Utility Solar Assessment' for 2020-2021. At the high end, it is 120-150 GW, which brings CleanEdge's forecast for those levels forward by three years.

In these scenarios, it is evident that tracking systems will be a key factor to developing large-scale PV-projects worldwide to reduce the installing times, improve the performance of the installation, and it's possible to collect more energy from the sun in comparison with fixed systems. In addition, it is a proven technology

Large-scale Power Plants Installed Worldwide by Country in 2008

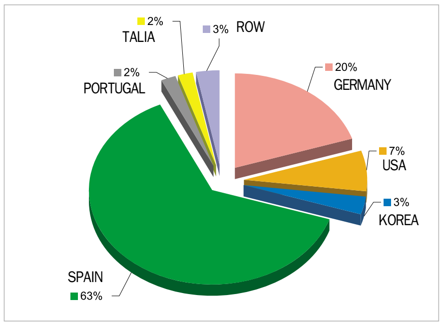

Figure 1. Large-scale power plants installed worldwide by country in 2008 (Source: MecaSolar)

Repower America Program Scenario A

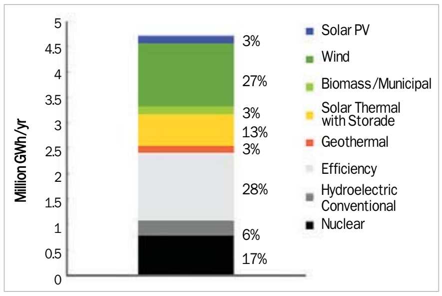

Figure 2. Repower America Program Scenario A (Source: Repoweramerica.org)

Repower America Program Scenario B

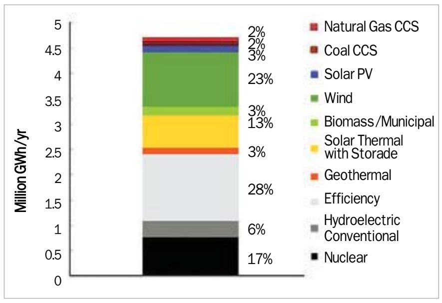

Figure 3. Repower America Program Scenario B (Source: Repoweramerica.org)

Large-scale Photovoltaic Power Plants—Number of Annually Installed Power Plants in Period from 1995 to 2007

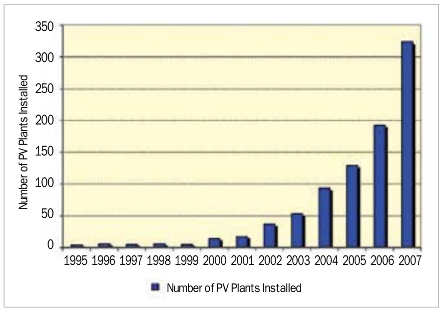

Figure 4. Total 880 large-scale PV plants worldwide over 200kWp, this figure shows that the global tendency is to build up large-scale PV plants. (Source: MecaSolar)

and low cost maintenance and energy consumption for solar tracking.

Maximizing Irradiation on the Collector

When designers front the design of a system with the capability of collecting sunlight, they must decide the way of mounting the system. The easiest way of mounting a PV system is to mount it horizontally, but of course, it's not the best way to optimize collection. The beam radiation component collected is proportional to the cosine of the angle between the incident beam and the normal to the plane of the collector.

The fraction of energy available to be collected will be between cos 'y' and the unity. The beam irradiance will be just a small fraction of the global irradiance in a highly diffuse environment.

It is possible to find multiple solution alternatives to horizontal mounting, and different companies offer multiple solutions with a wide range of prices to obtain more energy of the system.

As shown in the graph, to mount a PV system horizontally, the system should be horizontal at noon and only the radiation from the sun will be maximized. Therefore, the path through the atmosphere and corresponding are lowest air mass for the day.

Incident Solar Radiation Schema

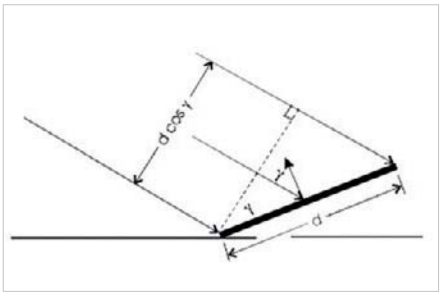

Figure 5. Incident solar radiation schema (Source: MecaSolar)

Horizon Line for America_Center (Lat. 36.8°N, long. 2.4°E, alt. 21m)

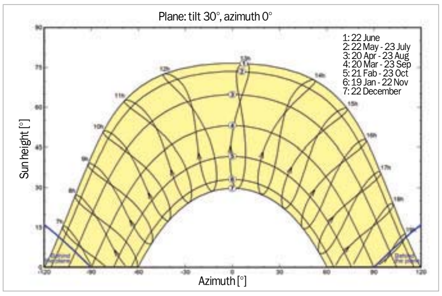

Figure 6. Horizon line drawing and shadows distribution (no shadowing) for an installation in Almeria (Spain), where the sun-path lines during the year a sun height daily distribution cab be observed. (Source: MecaSolar)

The performance of this horizontally mounted installation will be close to perpendicular for a period of approximately two hours because the sun travels through an angle of 15°per hour. Afterwards, the radiation received by the system decreases due to the increase in air mass, the angle between incident sunlight and the normal to the collector increases. The energy collected by the PV system decreases rapidly during the hours before 10 am and after 2 pm.

Let's observe the effect in the graph below (Figure 7):

Daily Energy Production Comparison between Different PV Solutions

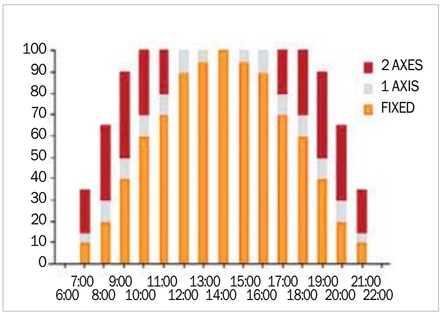

Figure 7. Daily energy production comparison between different PV solutions (Source: MecaSolar)

Let's observe the cumulative effect during a year month by month (Figure 8).

Cumulative Energy Production during a Year Comparison between Different PV Solutions

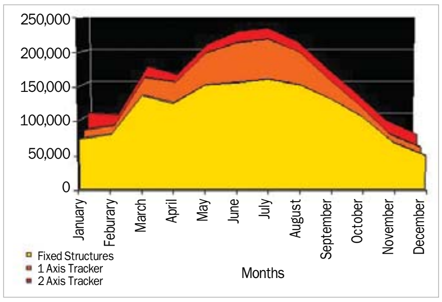

Figure 8. Cumulative energy production during a year comparison between different PV solutions (Source: MecaSolar)

During the installation of a tracking system, the incident irradiance is just affected by the increasing of the air mass as the sun approaches the horizon. Approximately 50% more of energy can be collected in the summer in a dry climate, but only about 20% more energy can be collected with a tracking system during winter months.

Depending on diffused light that a location receives, the amount of energy received defers for the same technology installed. For example, Phoenix in Arizona receives more diffused energy from the sun than Seattle in Washington, so they can collect about 35% more energy in the

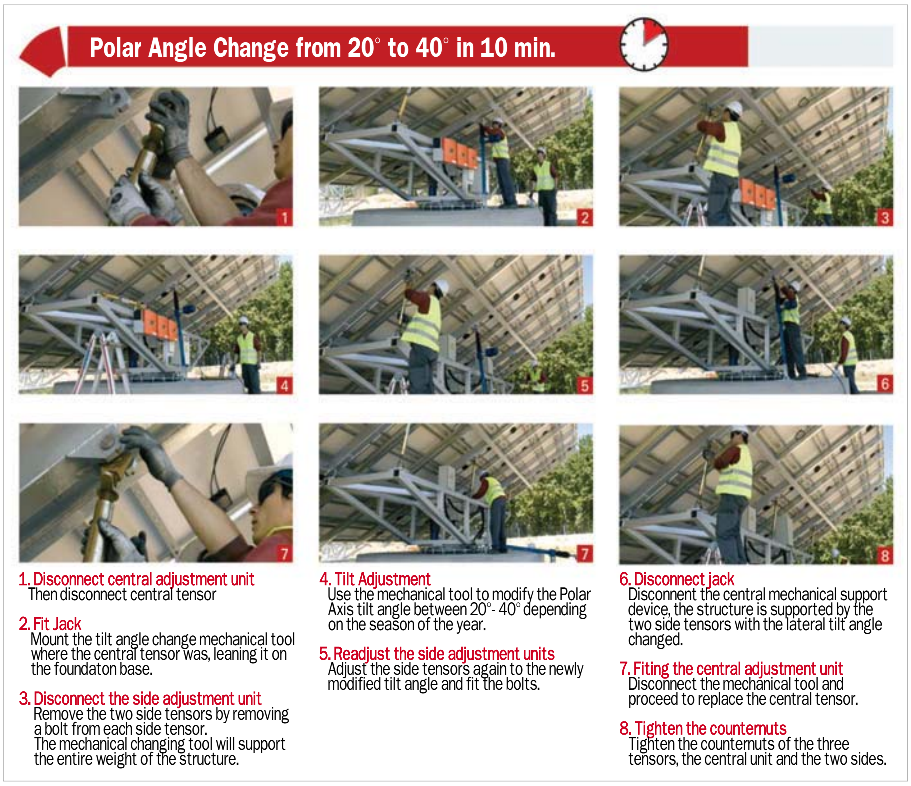

Figure 9. Quick and fast way to increment the production in 1 azimuth axis tracker MECASOLAR, changing the tilting angle (Source: MecaSolar)

Installation with Mecasolar 1 azimuth axis tracking system

Solar Irradiation Index, Ratios, and Production Comparison Worldwide between Different PV Solutions

Location	Lat ϕ	Body [Wh/m^2]	Clearness Index KTy	Ratios to global horizontal yearly irradiation					
				2 axis	1 az-axis	Fixed	Dif. 2 axis-fixed	Dif. 2 axis-1 Az axis	Dif. 1 axis Az-fixed
Ice-Island-Arctic 80	80	4261	0.58	2.75	2.54	1.67	64.67%	8.27%	52.10%
S. Petersburg-Russia 59,9	59.9	5703	0.453	1.72	1.64	1.18	45.76%	4.88%	38.98%
Hamburg-Germany 53,6	53.6	6437	0.412	1.49	1.42	1.11	34.23%	4.93%	27.93%
Freiburg-Germany 48	48	7075	0.428	1.42	1.36	1.07	32.71%	4.41%	27.10%
Nantes-France 47,2	47.2	7164	0.468	1.5	1.44	1.1	36.36%	4.17%	30.91%
Olympia-USA 46,6	46.6	7230	0.437	1.41	1.35	1.05	34.29%	4.44%	28.57%
Changchun-China 43,8	43.8	7531	0.51	1.6	1.53	1.16	37.93%	4.58%	31.90%
Sapporo-Japan 43	43	7615	0.421	1.41	1.35	1.09	29.36%	4.44%	23.85%
Madrid-Spain 40,4	40.4	7880	0.544	1.53	1.46	1.08	41.67%	4.79%	35.19%
Seoul-Korea 37,5	37.5	8161	0.44	1.39	1.32	1.07	29.91%	5.30%	23.36%
Albuquerque-USA 35	35	8391	0.687	1.66	1.55	1.09	52.29%	7.10%	42.20%
Djelfa-Algeria 34,6	34.6	8427	0.584	1.53	1.44	1.06	44.34%	6.25%	35.85%
El Paso-Mexico 31,5	31.5	8691	0.689	1.61	1.49	1.07	50.47%	8.05%	39.25%
Shanghai-China 31,2	31.2	8716	0.487	1.36	1.29	1.02	33.33%	5.43%	26.47%
Cairo-Egypt 30,6	30.6	8764	0.637	1.53	1.43	1.05	45.71%	6.99%	36.19%
Delhi-India 28,6	28.6	8919	0.63	1.56	1.44	1.07	45.79%	8.33%	34.58%
Karachi-Pakistan 24,8	24.8	9189	0.56	1.48	1.36	1.04	42.31%	8.82%	30.77%
Morelia-Mexico 19,7	19.7	9494	0.415	1.2	1.14	0.98	22.45%	5.26%	16.33%
Dakar-Senegal 14,7	14.7	9729	0.599	1.38	1.23	0.98	40.82%	12.20%	25.51%
Bangkok-Thailand 13,7	13.7	9768	0.49	1.27	1.16	0.98	29.59%	9.48%	18.37%
Claveria-Philippines 8,6	8.6	9924	0.513	1.27	1.13	0.95	33.68%	12.39%	18.95%
Colombo-Sri Lanka 6,9	6.9	9961	0.529	1.28	1.12	0.96	33.33%	14.29%	16.67%
Medellin-Colombia 6,2	6.2	9974	0.469	1.22	1.08	0.95	28.42%	12.96%	13.68%
Luanda-Angola -8,8	-8.8	9918	0.497	1.26	1.12	0.95	32.63%	12.50%	17.89%
El Alto-Bolivia -16,4	-16.4	9652	0.579	1.39	1.25	0.99	40.40%	11.20%	26.26%
Sao Paulo-Brazil -23,5	-23.5	9267	0.427	1.25	1.19	0.99	26.26%	5.04%	20.20%
Porto Alegre-Brazil -30	-30	8805	0.505	1.38	1.3	1.02	35.29%	6.15%	27.45%
Bariloche-Argentina -41,1	-41.1	7801	0.566	1.58	1.5	1.07	47.66%	5.33%	40.19%
Ushuaia-Argentina -55	-55	6263	0.402	1.62	1.55	1.19	36.13%	4.52%	30.25%
Little America-Antartic -78,2	-78.2	4306	0.577	2.67	2.48	1.55	72.26%	7.66%	60.00%
Average				1.524	1.422	1.084666667	39.34%	7.34%	29.90%

Table 1. Solar irradiation index, ratios, and production comparison worldwide between different PV solutions (Source: MecaSolar)

summer, but only 9% more energy in comparison with a fixed system, optimized in the winter.

Due to the use of a two axis tracking systems, it is more expensive than a fixed system, and both are the extremes in economical and performance ratios terms, it's possible to consider the single axis tracker which rotates in parallel to land plane and performs in good ratios. Moreover, the cost is nearly a fixed system. And if the 1 axis tracker mounts a PV system surface, it's possible to be manually adjusted several times a year, and the performance ratios are very close to a 2-axis tracker.

Depending on the use of the system, the orientation may also be seasonally dependant. A PV system used for irrigation during the summer will needs its collector oriented for optimal summer collection. However, if the system is used to feed the electrical consumptions of a mountain refuge during the winter, the collector must be optimized for these seasons, and the tilting angles will differ substantially from the optimum tilting angle for maximum output production along the whole year. A global company, it means, a company that is oriented to the global solar market, should provide systems that complies all the requirements of the different customers for all the countries worldwide and that could adapt to the special economical, technological, and social particularities of each country.

First of all, it is necessary to understand that a lot of conditions exist, especially if a company brings solutions worldwide. For example, the latitude of the project location, determines the available solar radiation, and the maximum power output reachable with each tracking system. The engineer that plans a PV system must keep in mind all this parameters to meet such economical, technical area for installation as well as location environment parameters.

In order to have a closer idea about the percentage of energy for each tracking system, see Table 1.

The energy output gain of a PV system depends on the latitude the system is installed and the solution used.

With 2 axis tracker systems, it's possible to collect the maximum energy from the sun, but at northern and southern locations the percentage becomes maximal and is equal for 1 axis tracker, keeping in mind that it has less performance than a 2 axis tracker.

Nevertheless, 1 axis tracker is cheaper and simpler than a 2 axis tracker, so a combination of factors will lead to choosing one technology or another.

It is possible to observe the data (Figure 10), and with 2 axis tracking system, you can gather 39.34% average more energy output than a fixed system. For 1 azimuth axis tracking system, the average energy increase is the 29.9 %.

In Figure 11, the energy output gain from a PV system depends on the type of installation (fixed system, 2 axis tracking system, 1 azimuth tracking system, etc.) and the latitude of the system location. For different locations, with same technology you can capture more energy, but installing tracking system is the best way to reach to the maximum. Naturally, there are too many factors that determine the technology (fixed systems or tracking, PV modules technology) used in a PV plant.

Among others, they are:

- Maturity of the PV market in the target country
- Existence of renewable governmental policies and the way they are articulated
- Latitude where the project will be installed
- Environmental and special requirements
- Special programs of banks to finance PV projects or particular requirements of the national bank of financing PV projects.
- Area available
- Solar radiation available in project location
- Existence of feed-in-tariff in the country where the project will be located
- Topography of the land where the project will be installed
- Assumable complexity of the systems
- Assumable maintenance
- Project finance
- Power evacuation capacity available
- Quality of evacuation lines of the country
- Electrical codes of the country

With actual market tendency of crystalline modules price descending, and the feed-in-tariff with yearly negative escalators in various countries like Spain and Italy, the PV systems market demands tracking systems to obtain maximum profitability from the installation, with the minimum price possible and with a preferably exiguous maintenance that allows to extract a little bit more from the photovoltaic

Energy Production Increase: Two Axis Tracking Compared to Fixed Mount at Local Optimum Tilt

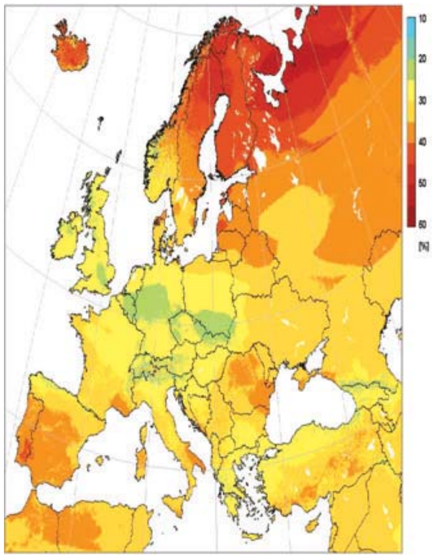

Figure 10. Energy production increase: Two axis tracking compared to fixed mount at local optimum tilt

From Huld, T., Šúri, M. and Dunlop, E.D. "Comparison of Potential Electricity Output from Fixed-Inclined and Two-Axis Tracking Photovoltaic Modules" Progress in Photovoltaics, 16:47-59, 2008 (Source: Huld, T. and Šuri, M.)

- Highest over 60° N (40-60%)
- Lowest British Isles, NW and Central Europe (20-30%)
- 30-40% Southern Europe represents highest absolute gain.

NEW 1 AZIMUTH AXIS TRACKER

What competitive advantages does new MECASOLAR 1 azimuth tracking system for the actual solar global scenario offer?

- Only a company that is involved in every area of solar business can provide solar market with suitable worldwide solutions because they understand the intrinsically problematic and technical necessities of every area. Due to the dynamic nature of solar market, the products and the characteristics of these, they must attend to the demands of this with the same rhythm and due to the flicking solar equipment device prices and alterative global market demands.
- Seeing the market evolution, the market demands different solutions to give the market the suitable option to maximize the ROI of the installation, and adapts to the requirements of the project, land availability, system-price, location, etc.
- The 1 azimuth axis tracker is the answer to meet economical and performance requirements with land occupation and price ratios close to a fixed systems and with performance ratios close to the optimal solution, the 2 axis tracker.
- To maximize the ROI of the installation, and when enough land is available, tracking systems maximize the return of investment and reduce the payback time. But imagine you can install a 1 azimuth tracking system at almost fixed system price, and you can obtain nearly the production of a two axis tracking system just adjusting the tilting of the PV-surface twice a year. This is the concept of the new 1 azimuth axis tracking system.
- Azimuth 1 axis tracker offers you the possibility to obtain more energy than a conventional 1 azimuth axis tracker adjusting manually twice a year the PV surface tilting in a 10 minute operation.
- Follows the philosophy that converts the MECASOLAR 2 axis tracker, in the most installed tracker due to the superficial foundation that gives the tracker the capability to adapt to the slopes of the land without terrain removal works so it's the most environmental respectful.
- New azimuth 1 axis tracker MECASOLAR MS-1E reduces the land occupation, about 2.51 hectares per 1 MW, due to the landscape shaped PV surface and due to their tracking system.
- Reduces the maintenance to nearly zero (similar to a fixed system) and the azimuth mechanics is derived from the successful MECASOLAR 2 axis tracking system that gives a proven reliability of the system.
- Reduces the energy consumption of the tracking system to less than a half for a 2 axis system (0.37 KWh/year).
- Reduces the concrete used for foundations.
- Reduces the time necessary to install the tracker because it is easier, and now it does not need a crane to lift the grid. It can be done with a common multipurpose forklift and all the modules could be assembled at horizontal position with no additional machinery because the total height is lower.
- Because of the intrinsic morphology of the tracker, this is more robust and owing the protection systems against high speed winds, and provides an additional reliability guarantee.
- Due to the designing of the structure oriented to be easily transportable, saving cost of freight, and oriented to be easily assembled, it has been possible to cut costs in machinery necessary for installation, times of installation, etc. The 1 axis tracker constitutes the response to a more mature market and the answer of a company that knows the problems and necessities in every area of solar business because the companies that integrate the group embrace the whole solar business.

Lambs are pasturing in a PV power plant in Fustinana (Navarra) with MECASOLAR trackers. The land hasn't been modified and the grass grows up freely, so it permits sharing of the use of the land. Due to the land hasn't been plowed up, the indigenous grass can grow up freely and this allows to feed the lambs.

Comparison of Energy Output between Different Tracking Systems

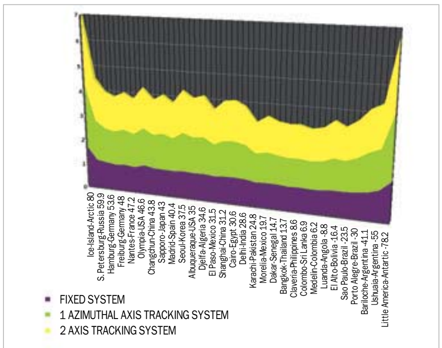

Figure 11. Graph that shows the different percentage of production obtained with each PV solution in each latitude. (Source: MecaSolar)

Different Energy Increase Comparing in Pairs with Different PV Solutions for Each Latitude

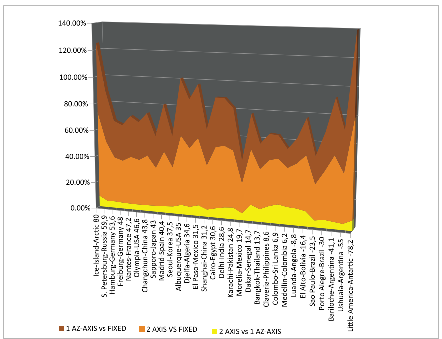

Figure 12. Graph where it is possible to appreciate different energy increase comparing in pairs with the different PV solutions for each latitude (Source: MecaSolar)

panels than a fixed systems with maximum ROI (Return on Investment).

Being aware of the market tendency and actual situation, a company provides solutions for market studying the technical and economical aspects that could bring the final customer a competitive advantage. The solar market was demanding a new product such as 1 azimuth axis tracker that could bring a quite good solution in terms of efficiency (nearly the maximum possible reachable with 2 axis tracker) with much tightened price and with the maintenance requirements, installation time and land occupation as fixed systems. Owing to the actual situation of the market, where some countries have feed-in-tariff since years ago, these are year-after-year decreasing and oblige promoters to offer the same profitability to final investors or customers of a PV power plant with a reduced feed-in-tariff. The promoters were asking for a system that could bring some more production than a fixed system at practically same cost.

A company that gives solution to the global solar market should bring the promoters the opportunity to obtain better ROIs with low installation times and with land occupation similar to fixed systems.

Most of the PV plants are installed on fields, some of them to give them a profitable use, others due to contamination to recover a land or to take advantage of lands. Otherwise, it will be recovered with difficulties. In any case, a PV installation must avoid as much as possible the excavations and the natural topography modification. A company that provides solar solutions must be conscience that it is a company that contributes to stopping climate change installing PV systems. Through this environmental conscience all the products are designed to avoid damages to the land and it is unnecessary to install any solution that excavates or removes land, avoiding modifying of the terrain that leads to an irreversible land erosion. Through the flexibility of their systems and the superficial foundation of the systems where no digging is necessary, they contribute to giving an additional advantage in comparison with other systems, and this contributes to obtaining an easier way the environment permits to install a power plant.

As the land is not modified to install the trackers or fixed systems, all the natural flora of the site is respected and allows the proprietary to share the use of this land for photovoltaic and cattle raising.

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