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Increasing the Efficiency of Solar Electric Power Utilization

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ABSTRACT

The relevance of the study is driven by the rapid development of solar energy and the search for opportunities to increase its efficiency in order to ensure a more stable energy supply for the population and improve the quality of life. **The objective:** to identify the key features of the global experience in using solar trackers for power generation. **Research methods:** mathematical analysis, empirical data analysis, systematization, investment analysis. **Findings:** this study examines various types of solar panels and their impact on the economic efficiency of solar energy projects. A review of relevant literature and scientific-practical studies confirms the versatility of solar trackers in different geographical and climatic zones. The study includes calculations of key investment attractiveness indicators for projects utilizing solar trackers and stationary systems, demonstrating the low efficiency of the latter. Key directions for the development of this technology have been identified, and recommendations for its improvement are provided. **Practical significance:** the main conclusion of this study may be useful for justifying the feasibility of using trackers at solar power plants and for exploring ways to improve the efficiency of solar generation.

Keywords: global economy; renewable energy sources; predictive analytics; solar trackers; investment analysis; international cooperation

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INTRODUCTION

The modern economy requires significant energy consumption for its development. This makes it necessary to find ways to provide energy from both traditional and renewable energy sources (RES). Nowadays, the fastest growing type of renewable energy sources has become the solar energy and by 2023: its share in the global production exceeds 5.5 per cent.[1] The Russian Federation considers the development of renewable energy sources as one of the top priority energy tasks. This is why it is important to study this issue taking into account the country's specifics and the possibility of applying global experience. Currently, Russia has a Renewable Energy Support Programme for the period of 2025–2035, according to which an additional 3.5 GW of solar power plants (SPP) are planned to start operating by the year of 2035.[2] This increases the relevance of studying this issue.

The rapid development of solar energy would be possible with permanent technological innovations implemented in the industry. One of them is the tracking systems, or solar trackers. Prior to 2008, all solar power plants were equipped with static or stationary modules that were oriented at a fixed angle and could not change their position to follow the sun. The main requirement for the installation of such panels is the direction of their inclination to the equator: towards the South in the northern hemisphere and the North in the southern hemisphere. This has resulted in significant losses due to weather conditions, season and other factors [1]. Besides, since the peak of energy production was only in the middle of the day, this would not ensure stability level and significant fluctuations in the market value of the energy were inevitable throughout the whole day. Nevertheless, the advantage of such panels is the capability to set a higher peak power, which increases the total energy generation per panel area. Besides, due to the shading effect between panel rows, the distance between these rows can be reduced by increasing the number of panels.

The first devices to overcome the problem of energy production losses due to the movement of the sun were invented in the 1980s. The so-to-say "East-West configuration" positioned solar panels so, that modules were installed very close together. This minimised the space between the panel rows and maximised output in areas with limited space (which is common for the Northern Europe). In addition, the sun rises low above the horizon in the northern latitudes, which allows to position the panels closer to buildings without shading them and closer to the ground, reducing the wind pressure effect. Unlike previous conventional solar modules, East-West modules provide much better stability of energy production throughout the day, significantly reducing the risks of inverter overloads at midday.

In 2008, photovoltaic panels began to be widely deployed. They can rotate throughout the daylight hours to track the sun's movement across the sky and maximise energy production. However, increasing the number of solar panels not only increases the economics of solar energy systems (SES), but also creates long rows of trackers that are not suitable for locations of limited territories. In addition, at low panel angles, some of the benefits of tracking systems are lost due to backward algorithms.[3]

In recent years, the problem of improving the economic return of solar energy projects has been scrutinised by many Russian scientists [2–4]. They analysed the problems of separate regions and the possibility of increasing production in various subjects of the country [5–7]. Foreign scholars also developed he technical and economic aspects of this issue. [11–13]. Despite the ambiguous attitude to solar trackers, notably, that the most important economic effect of their introduction, due to a sharp increase in the efficiency of the panel, is

[1] URL: https://rspp.ru/document/1/2/5/2502ae1262d70e4e020677e29ad60c23.pdf

[2] URL: https://rspp.ru/document/1/2/5/2502ae1262d70e4e020677e29ad60c23.pdf

[3] URL: https://www.woodmac.com/reports/power-markets-global-solar-pv-tracker-landscape-2023–150186928/

a significant reduction in the cost of electricity. Thus, truckers reduce operating costs and provide an opportunity to reinvest the released funds to upgrade facilities for its production. For this reason, the technology under consideration requires a more detailed study.

ASSESSING SOLAR TRACKER PERFORMANCE ACCORDING TO LEVELISED COST OF ENERGY

To determine this economic impact, it is necessary to compare the cost of electricity generated by solar energy systems with and without solar trackers. The most appropriate indicator for comparison is levelised cost of energy (LCOE). the normalized, or, in other words, levelised cost of electricity over the life of the generating asset (usually measured in US$/kWh). This indicator is much more accurate than cost per 1W, because it takes into account many different factors that are particularly important for a particular industry. In the context of the solar industry, the calculation of the normalised cost of electricity takes into account the following factors: panel cost, panel performance, system cost and maintenance cost. In this respect, the analysis of levelised cost of energy (LCOE) is best suited for both studying the dynamics of electricity costs in general and comparing them between different energy sources.

Table 1

Forecasted LCOE for Solar Panels Without Tracking (USD/MWh)

Country / Year	2022	2023	2024	2025	2026	2027
Argentina	74.06	50.69	40.48	34.58	31.80	29.71
United Kingdom	54.48	51.90	49.15	47.12	45.00	43.39
Germany	48.05	45.16	42.74	41.19	39.41	38.06
India	36.42	35.28	33.85	32.47	30.78	29.22
Indonesia	78.51	62.74	54.13	48.61	45.39	42.79
Spain	37.40	34.65	32.62	31.31	29.85	28.74
China	37.28	35.26	33.49	31.91	30.79	29.76
UAE	38.33	33.25	30.06	28.06	26.50	25.32
USA	47.66	42.20	39.97	35.56	34.53	33.13
Turkey	34.59	33.28	31.20	29.59	28.61	28.12
Philippines	83.87	66.90	57.48	51.45	48.06	45.32
France	39.31	36.93	34.96	33.70	32.25	31.14
Chile	32.40	28.88	26.53	24.99	23.76	22.83
SOUTH AFRICA	48.51	39.43	34.79	32.06	29.79	28.13
South Korea	82.37	71.80	64.62	60.20	56.79	54.17

Source: compiled by the author based on BloombergNEF forecasts: URL: https://about.bnef.com/blog/2h-2023-lcoe-update-an-uneven-recovery/

Since stationary solar panels have been deployed much earlier than trackers, they were geographically spread wider, despite the higher normalised electricity costs, due to lower efficiency and higher losses. In 2023, the normalised cost of electricity for non-tracking systems ranges from 28.88 US$/MWh in Chile to 71.8 US$/MWh in South Korea. Turkey, the United Arab Emirates and Spain are also among the leaders in terms of levelised cost of energy for stationary solar panels. It is worth noting, that despite the rather high indicator of levelised cost of energy in 2022–2023, according to Bloomberg forecasts, the indicator is expected to decrease significantly in 2024–2027, making it possible to reach cost-effective levels (compared to other energy sources) (*Table 1*).

Thus, countries such as Argentina (–59.88%), the Philippines (–45.96%) and Indonesia (–45.5%) are expected to achieve the highest cost reductions for non-tracking solar panels over the period. However, Argentina will be the leader in terms of change and also in absolute terms if the current forecast is met, with normalised costs decreasing from 74.06 to 29.71 US$/MWh over the 5-year period. Argentina will also lead the change in absolute terms if the current forecast is met, reducing normalised costs from 74.06 to 29.71 US$/MWh over 5 years (–US$ 44.34/MWh). For all countries using solar panels without tracking, the LCOE would decrease by an average of 32.9%. Although the data analysed represents a predicted development scenario, the dynamics of the last three years and increasing government support increase the probability of its realisation.

The normalised cost of electricity for solar panels with tracking is on average lower than for panels without tracking, but the geographical scope of their use is much smaller. At the end of 2023, LCOE values ranged from 26.3 (Chile) to 44.56 (Colombia). LCOE values range from 26.3 (Chile) to 44.56 (Colombia) US$/MWh. Spain, Turkey and Mexico also become leaders in reducing rationed costs. Similar to the LCOE dynamics for solar panels without tracking, trackers are also characterised by a stable decrease in normalised electricity costs in all countries during 2024–2027, according to Bloomberg forecasts (*Table 2*).

Table 2

Forecasted LCOE for Solar Panels With Tracking (USD/MWh)

Country / Year	2022	2023	2024	2025	2026	2027
Australia	47.68	38.51	33.65	30.68	28.47	26.78
Brazil	47.57	37.88	32.74	29.64	27.51	25.94
Spain	32.56	30.07	28.26	27.09	25.79	24.80
Colombia	53.91	44.56	39.46	36.18	33.77	31.93
Mexico	37.58	31.38	27.94	25.76	24.12	22.89
USA	42.45	38.38	35.52	31.83	30.94	29.76
Turkey	32.14	31.01	29.07	27.56	26.66	26.21
Chile	30.30	26.30	23.81	22.20	21.12	20.30
South Africa	41.98	34.13	30.11	27.74	25.81	24.38

Source: compiled by the author based on BloombergNEF forecasts: URL: https://about.bnef.com/blog/2h-2023-lcoe-update-an-uneven-recovery/

Brazil (–45.46%), Australia (–43.84%) and South Africa (–41.92%) will experience the largest decrease in LCOE for solar trackers, according to forecasts. At the same time, in absolute terms, if the forecast is correct, Colombia will have the best result (–21.62 US$/MWh). Meanwhile, Chile is expected to maintain its position as the country with the lowest LCOE in the whole list of leaders. On average for all countries, this indicator will fall by 35.1 per cent. Thus, the normalised cost of electricity for systems with tracking is lower both from the year of 2023 and throughout the forecast period to 2027. The current government policies of the countries under consideration and the dynamics of 2022–2023 allow us to make a conclusion that it is highly feasible that the projected values are quite realistic. It is particularly important to note that the significant difference in LCOE between fixed panels and trackers is also characteristic in each country under consideration. In the USA, for example, the LCOE in 2023 for the former is US$ 42.2/MWh, while the LCOE for the latter it was US$ 38.38 / MWh, another words, 9 per cent less. This indicator confirms the economic efficiency of solar trackers for the country's energy system.

At the same time, geographical, climatic, legislative and other peculiarities have become an important aspect. To analyse the normalised costs, the author has selected only the leading countries involved in electricity generation with the help of solar energy systems. Some other countries provide no publicly available information on energy costs, or their data vary significantly from region to region. To analyse the global experience with solar panels with and without tracking systems, the author of the study considered two countries from two different geographical regions in Asia and Africa.

RESULTS OF THE USE OF SOLAR TRACKERS IN SOUTH KOREA

South Korea actively developing solar energy was under study for the analysis among the Asia-Pacific (APAC) countries. Having ratified the Paris Agreement in 2016, South Korea set up the renewable energy sources share at 40 per cent of total public sector energy production, which caused some challenges for further increase of its capacity of total electricity generation. Since 2014, the country has pursued a policy of supporting the development of renewable energy sources, which has led to a rapid increase in the capacity of electricity generation. At the same time, solar power has become the national top priority source (*Fig. 1*).

Over the ten-year period (2013–2023), the cumulative installed capacity of solar energy systems increased by more than 20 times, meanwhile the other types of renewal energy systems remained at about the same level. This indicates that solar energy has become a priority energy source for the South Korean economy. The State support has greatly contributed to such a rapid growth: the government covered up to 80 per cent of installation costs. However, this only applies to the experience of stationary photovoltaic panels. Solar trackers are seldom visible in the country due to the high initial investment cost and lack of domestic technology research. In addition, Korean experts consider stationary systems more reliable from their maintenance point of view.

To overcome these drawbacks, it is required to run a continuous cost analysis of solar trackers for an improved generation of energy. In 2011 and 2017, South Korea carried out a research work. Initially, in theory local experts believed, that the cost of a tracked system and a conventional system could be the same [14]. The proposed solar panel system was quite small, so that it could be mounted on walls, which reduced the area required and the initial project investment. Later, economic aspects of installing photovoltaic panels were evaluated by comparing the investment performance of the projects.

According to the obtained results, depending on the season and geographical conditions, the use of solar trackers can contribute to the growth of energy production from 10 to 100 per cent, if compared to stationary panels [15]. Moreover, economic analyses confirm the superiority of tracking systems in terms of cost and environmental impact (*Fig. 2*).

Thus, we can make a conclusion, that the production capacity of solar trackers is significantly higher than those fixed solar systems operating at the most commonly used tilt angles (30–60°C), which confirms the relevance of this technology for South Korea.

POTENTIAL FOR THE USE OF SOLAR TRACKERS IN THE REPUBLIC OF GHANA

We made a research of this aspect for the Republic of Ghana, one of the largest per capita electricity consumers in sub-Saharan Africa. Unlike its neighbouring countries, Ghana has been able to open access to electricity for almost 80 per cent of the local population, the best indicator in West Africa. This was the decision of the government to start developing renewable energy, but it is worth noting, that access to electricity does not mean a stable and sustainable energy supply. An excellent solution to the energy problem is the solar energy: its costs are steadily decreasing. In 2023, the African Development Fund (ADF) awarded Ghana a grant of 27.39 million US dollars to develop renewable energy mini-grids, based particularly on the solar energy. Ghana will install 35 photovoltaic systems in 400 schools, 200 in health centres and 100 in housing and utilities. Besides this, public institutions, small and medium enterprises and some households will be able to install 12,000 such solar systems on their roofs, with a planned installed capacity of over 67 MW.[4]

Despite the support from the African Development Fund and Ghana's active policy to develop the growing the solar market, problems still exist in the sector: the country requires proper technical equipment, knowledge and

[4] URL: https://www.mordorintelligence.com/industry-reports/ghana-solar-energy-market

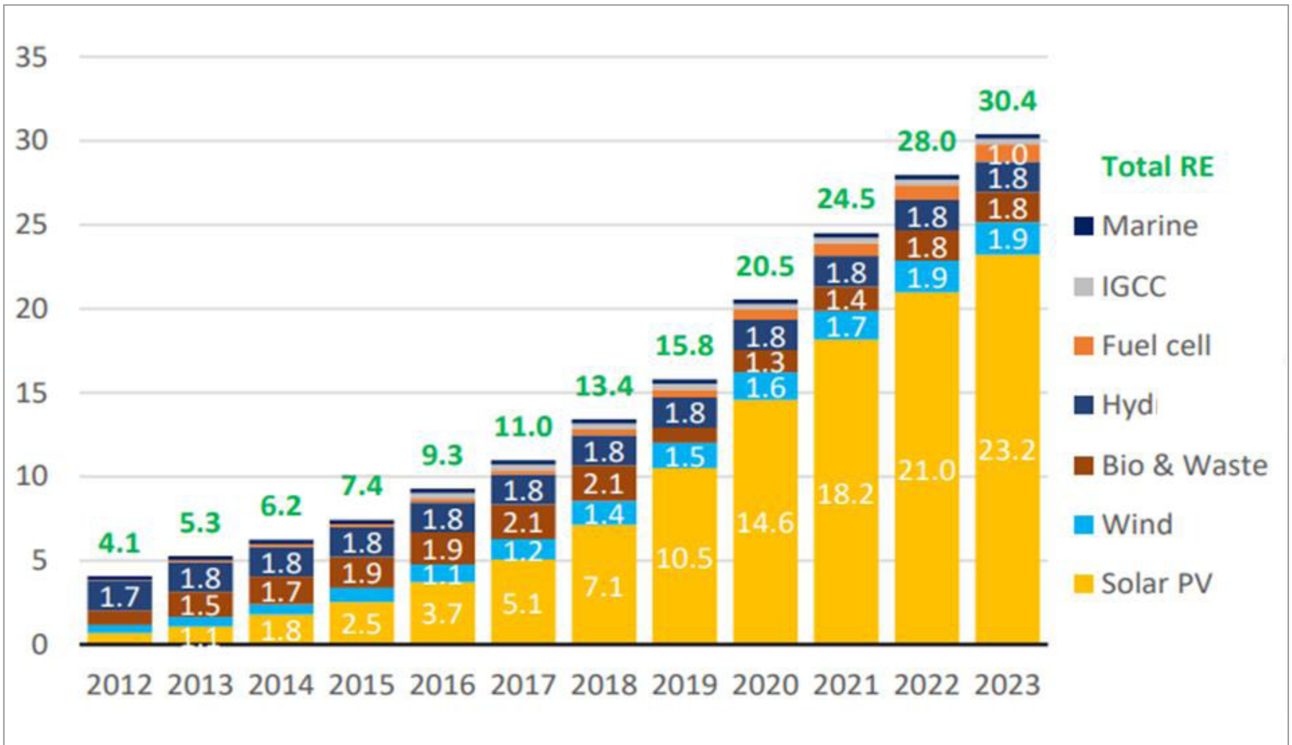

Fig. 1. **Dynamics of the Total Installed Capacity of Renewable Energy in South Korea, in GW**

Source: compiled by the author on the basis of: URL: https://www.renewable-ei.org/pdfdownload/activities/REI_SKoreaReport_202311_EN.pdf

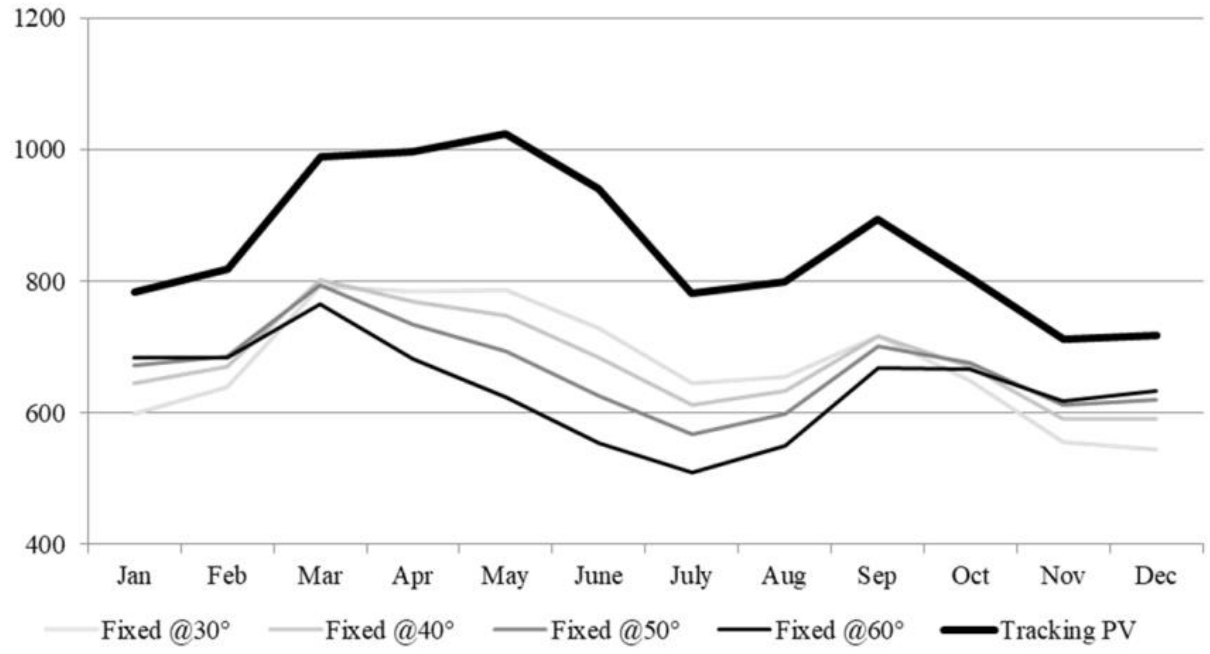

Fig. 2. **Electricity Production by Tracking Systems and Fixed Photovoltaic Panels in South Korea by Month, kW, 2023**

Source: compiled by the author on the basis of: URL: https://doi.org/10.3390/en16217338

skills that are still in short supply in the country. Many initiatives also lack funding due to the high cost of long-term solutions. Many products for photovoltaic systems are patented, interest rates are high and consumers lack the funds to invest in their own systems. Besides, after the installment of the panels, they require additional operating and maintenance costs. Hence, although the government supports the transition to renewable energy, proper legislation and regulations are still lacking in some areas. The government is aware of all these hindrances and is trying to find the ways to solve them, including by sharing experience and introducing the latest technologies.

The upgrading of solar panels with tracking systems can sparsely solve some of these problems. To assess their effectiveness, it is necessary to compare the investment indication of the same project using both systems. According to McKinsey, usually conventional solar trackers have been single-axis, horizontal or vertical. However, among the most common models have been dual-axis trackers, which move both horizontally and vertically, as well as multi-row trackers, which can accommodate multiple rows of solar panels. The latter systems make it possible to expand the capture of solar energy within the light day, thus maximising its output effect.

The process of fine-tuning of trackers' exposure required a whole complex of algorithms with various factors implemented in consideration: position of the sun, weather conditions, shading, etc5.[5] For the analysis of the solar power plant project in Ghana, experts made a research of both options of single-axis and dual-axis trackers. For comparison, the largest solar power plant in the Upper West region of the country was selected and for the indicators were used the payback period, net present value, greenhouse gas emission reduction, and energy production cost.

[5] URL: https://mckinseywell.com/products/solar-tracker-market-report-2023–2033

Table 3

Investment Performance Indicators of Solar Power Plants Using Fixed Panels and Solar Trackers

Tracker model / indicators	Payback period (in years)	Net present value (mln. US$)	Greenhouse gas emission (tonne/year)	Profit/ costs	Production costs of solar energy (in US$/kWh)
Fixed panels	17.1	−9.857	7127	0.24	0.151
Single-axis trackers	134	−4.564	8093	0.65	0.133
Dual-axis trackers	11.6	−3.660	22 762	0.72	0.13

Source: compiled by the author on the basis of: URL: https://www.vra.com/media/2020/pdd/35MWper cent20Solarper cent20Powerper cent20Projectper cent20-per cent20Upperper cent20Westper cent20Regionalper cent20Sitesper cent20-per cent20Stakeholderper cent20Engagementper cent20Plan.pdf

The total initial cost of all three projects was 43.12 million US dollars, including capital cost of 1.500 US$/kWh per each photoelectric module and an overall maintenance cost of 40 US$/year for all the three scenarios [16]. *Table 3* illustrates the results of the economic analysis for each scenario.

Based on the calculations in the *Table 3*, we can conclude, that there are absolute advantages for panels with solar trackers compared to fixed panels. The difference in indication from year to year is due to the difference in the intensity of solar exposure and the data on which is obtained using the tracking system. Particularly important is the reduced cost of the generated electricity, which mitigates the retail price of electricity to the public, and the reduction of greenhouse gas emissions, which will ensure that Ghana meets its Sustainable Development Goals.

CONCLUSIONS

Although solar power is the fastest growing source of renewable energy, a number of challenges require solution for its further development. One of them is the limited power generation due to the strong dependence on the light time of the day and the position of the solar panel. Most of all, this obstacle can be overcome by introducing tracking panels or trackers of the solar energy systems.

This article presents a comparative performance analysis, which shows that in the vast majority of countries under consideration, the normalised cost of expenditure for electricity generation with solar trackers is significantly lower. The result is a lower cost of electricity for the population, which contributes to improve the living standards of citizens and infrastructure.

In order to confirm the economic feasibility of introducing solar trackers despite high initial investments, the scientific research analyses the global experience of introducing this technology in South Korea and the Republic of Ghana.

Despite the Government support for solar energy development programmes, South Korea is experiencing serious problems in increasing solar energy generation. Stationary panels predominantly used in the power plant systems, cannot provide stable and constant power generation. In view of the country's limited land resources, solar trackers become a necessary technology for the further development of solar energy, especially considering the rainy summer seasons.

The situation is similar in the Republic of Ghana. Despite significant differences in geography and climate, the country needs likewise to develop solar power generation technologies to reduce energy costs for the population and provide electricity to the entire territory.

Three investment scenarios of solar energy systems are under consideration in a real-world case study: fixed panel, single-axis and dual-axis trackers. Based on the calculation of the net present value, the payback period, the energy production costs and the economic result of the project, the research has revealed, that the fixed systems are the most economically unviable. Thus, it is more feasible to use solar trackers. Taking into account the global experience in different geographical and climatic zones, it becomes a universal recommendation to implement such traceability solar energy systems in most countries of the world.

International cooperation makes an essential element for such a transition. The main driver for the further development to use solar energy in the near future is joint projects, the activity of international organisations, exhibitions and conferences, as well as intergovernmental meetings to exchange the proper experience. International cooperation has already contributed to development, introduction of advanced tracked solar systems with lower installation and maintenance costs. Some of them partially have been put into operation. An all-round extensive work of major organisations in the field of renewable energy has confirmed the importance of deployment of widespread tracker to sophisticate this technology.

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