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SOLAR ENERGY PRODUCTION: SPECIFICS OF ITS TERRITORIAL STRUCTURE AND MODERN GEOGRAPHICAL TRENDS

ABSTRACT. The study deals with the socio-economic geographical analysis of the solar energy production — one of the most rapidly developing industries of the world energy complex. The aim of the study is to identify and explain main features of the territorial structure of solar energy production and assess its role and place in the world. The paper also investigates the factors that affect the development of solar energy production itself as well as the deployment of individual solar panels or solar power stations. The study carried out is based on the review of datasets and official documents which enable to draw a conclusion that the result of an intensive development of solar energy production is its dynamic spatial expansion visible in the emergence of new poles of growth which largely changes the territorial structure of the industry, transforming it from a monocentric to polycentric.

KEY WORDS: renewable sources of energy, solar energy, photovoltaics, solar thermal energy

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INTRODUCTION

During the last few years solar energy production has evolved from an alternative to the main or even basic energy industry. More and more countries are considering solar energy production as a guarantee of national energy security, especially in the light of the worldwide transition to the concept of sustainable development. Undoubtedly, solar energy production is one of the most rapidly growing industries of the world energy complex. During the last few years its overall installed capacity increased by 5.8 times (Jäger-Waldau 2016). No other industry in the world, including telecommunications and computers, had such impressive growth. Great potential for the development of solar energy production is attributed to such global factors as the need to ensure national energy security, growing concern about the environmental consequences of the use of fossil energy sources, full scale innovative activity in the field of alternative energy sources and constant price reduction of electricity generated by solar power systems as a result of innovation and technological advancement. If 20 years ago 1 kWh cost 1 euro, now it costs 5-7 cents and sometimes even less (SolarPower Europe 2016). Moreover, solar energy production seems to be quite attractive to investors in terms of much lower capital and operating costs than traditional energy sources as well as being able to operate on-grid/grid-connected or off-grid.

What is more, solar energy production, being a relatively new phenomena, in its geographical context seems to break many conventional rules. Therefore, the aim of this article is to analyse the specifics of its territorial structure as well as the factors that affect the development and deployment of solar energy production. In order to do so several questions were raised and analysed accordingly: 1) brief analysis of the technical and economic characteristics of solar energy production as a complex of several subindustries; 2) identification of the main features and trends of the world solar energy production; 3) identification of the regional specifics of the development of the world photovoltaics and solar thermal energy (including concentrating solar energy systems (CSP)).

MATERIALS AND METHODS

The vast majority of the works dedicated to solar industry have mainly economic or technical context and cannot be applied to geographical matters, which makes this study unique as it is concentrated on the geographical specifics rather than the most traditional for this topic – economic ones. The data is fragmented due to the fact that solar energy production is still a very young industry, and as a result, there are no clear criteria for what kind of production might be attributed to solar industry, and there is no direct statistical information on the structural components of it. This article is based on the official statistical data and annual reports from international organizations engaged in solar energy field such as the International Energy Agency (IEA), SolarPower Europe (former European Photovoltaic Industry Association (EPIA)), European Solar Thermal electricity Association (ESTELA), National renewable energy laboratory (NREL), US Energy Information Administration (EIA), PV Insider, news-portal CSP today, GTM Research, etc. Therefore, the data accumulated and used for this research is valid and up-to-date. SolarPower Europe and ESTELA organizations update the yearly reports every June-July. After their release the existing authentic data bank created by the author is updated accordingly. The prices of different parts of solar modules are monitored every week so as to be able to notice the main trends. Moreover, many news sites are monitored once in two weeks period to gain data about the commission of new solar power stations. That is why every point in this article is hard born and is a result of a thorough research and consideration. The methods used are statistical and comparative analysis allowing studying the problem at hand from different angles.

RESULTS AND DISCUSSION

To start with, we need to clarify that solar energy production is in fact a combination of two subindustries: 1) solar thermal energy, represented by the technology of converting solar energy into heat (solar collectors) and technology of concentrating solar power (CSP) and its subsequent converting into electricity Solar concentrators are designed to generate electricity on a commercial scale, representing a new generation of solar collectors. They are collectors of a focusing type. Large mirrors concentrate sunlight to an extent that the water turns to steam, thus releasing enough energy to rotate the turbine (Mills 2004); 2) photovoltaics (PV) — the direct conversion of solar energy into electricity using devices containing solar cells made from semiconductor materials (for example, silicon) with special properties (the basic principle of photovoltaic cells is the appearance of the electrical current when exposed to light between two semiconductors with different electrical properties that are in contact with each other). Each of these subindustries has its own specifics and unique features of geographical distribution.

The development of the solar energy production in the world is accompanied by its spatial expansion. If in the early stages of the development of solar energy production its territorial structure had a pronounced «euromonocentric» character, the now happening process of the emergence of new poles of growth led to the appearance of a polycentric model of its territorial structure. In this model three main centres are distinguished: *European* — led by Germany (which for the past ten years has retained the status of world leader), Spain (the leader in concentrating solar energy), Italy and, more recently, Great Britain; *American* — with the United States and *Asian* — where the main poles of growth are two countries — China (since 2015, the world leader in total installed photovoltaic capacity (43 GW) and Japan (where, as a result of the shutdown of all operating nuclear reactors (in connection with the accident at the nuclear power plant Fukushima-1 in 2011) since 2012 there appears to take place a real «solar boom», designed to fill the deficit of energy capacity) (Akimova and Tikhotskaya 2014).

Along with the dynamic development of large centres, a mass of less significant ones appears, contributing to a change in the structure of the location of the industry's facilities. In the future, it is possible that these new centres will become the locomotive of the development of the world's solar energy production. In North America the «solar club», which until recently had only one member — the United States, was joined by Canada, in Europe – Germany, Italy, France and Spain were joined by the United Kingdom and Belgium, in the future this "club" can also welcome Bulgaria, Czech Republic and Romania.

In countries of South America and Africa, solar power has yet to become widespread, but in the long term these countries represent one of the main regions for the development of this industry due to the existence of high energy demand, high level of solar radiation over a large part of the territory and an environmental factor. For example, in Chile and South Africa, the total installed photovoltaic capacity has already exceeded 1 GW.

Despite the spatial expansion, solar energy production is characterized by a high degree of territorial concentration at various levels, which shows in the dominance of individual countries and their regions. For example, at the level of macroregions – 45% of photovoltaic capacity is concentrated in Europe, 73% of solar thermal (without CSP (concentrated solar power)) — in the Asia-Pacific region, 50% of concentrated solar power – in Europe.

At country level there appears to be a similar situation: the leader in photovoltaics is China, which accounts for 19% of total power capacity, in solar thermal — China (about 70%), in concentrated solar power — Spain (50%).

Nevertheless, the main trend of recent years in photovoltaics is the shaping up of a small group of leading countries while leveling up the intercountry differences within this group. Thus, China accounts for about 19% of the world's global photovoltaic power, but Germany, which is in the second place, lags only slightly behind — 17% of global capacity, Japan has 15% and the United States 11%. This trend in photovoltaics is confirmed by the calculated Herfindahl-Hirschman index for a set of countries with total installed photovoltaic capacity of more than 1 GW — 1124, which indicates a moderate degree of concentration on this market, the emergence of new players and the gradual expansion of the industry beyond the main centres of its origin.

Solar thermal (STE) and concentrating solar energy (CSP) production, on the contrary, have a very high index value — 5028 for STE, 3659 for CSP.

This trend is particularly noticeable at the in-country level, where the core is formed by 3-4 regions, in some cases 1-2. For example, Gansu, Qinghai, Jiangsu, Inner Mongolia in China (Fig. 1), California, North Carolina and Arizona in the USA (Fig. 2, 6), Extremadura and Andalusia in Spain (Fig.

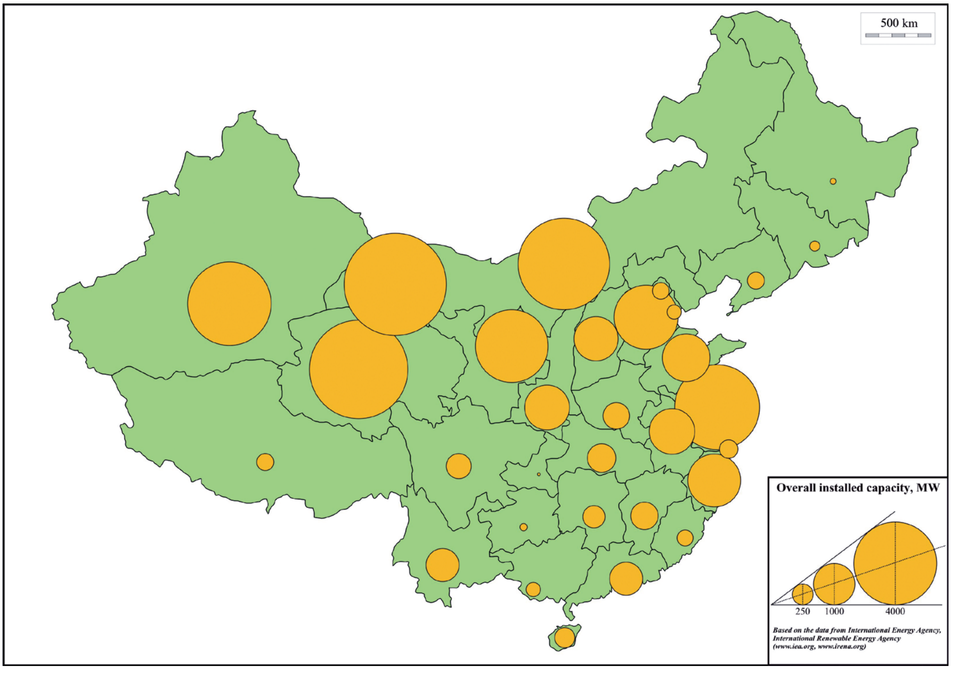

Fig. 1. Photovoltaics in China

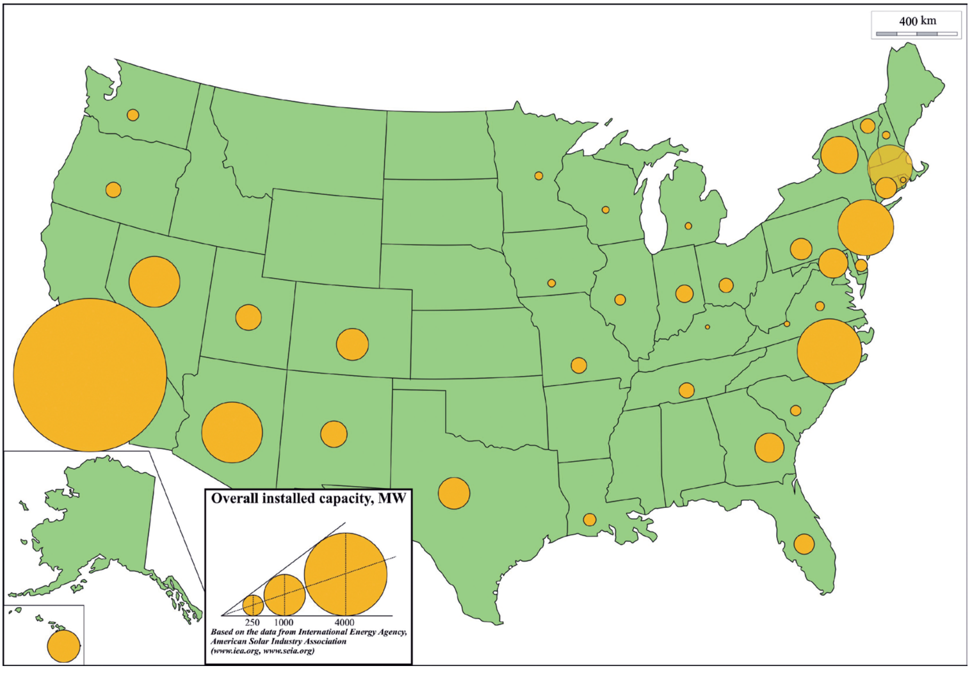

Fig. 2. Photovoltaics in the USA

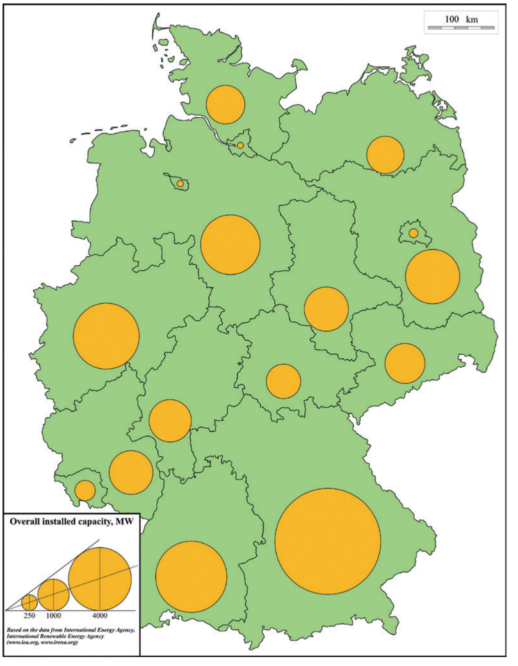

Fig. 3. Photovoltaics in Germany

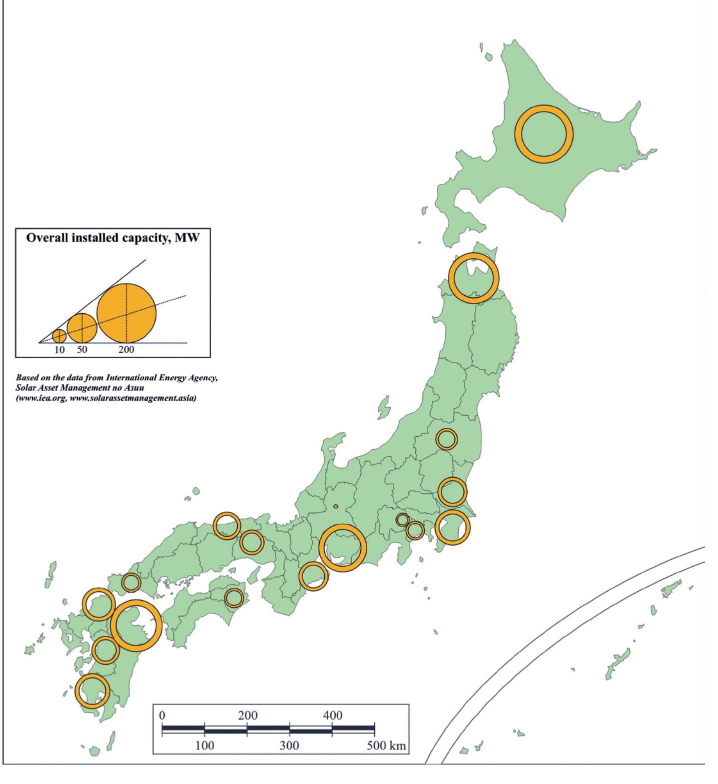

Fig. 4. Photovoltaics in Japan

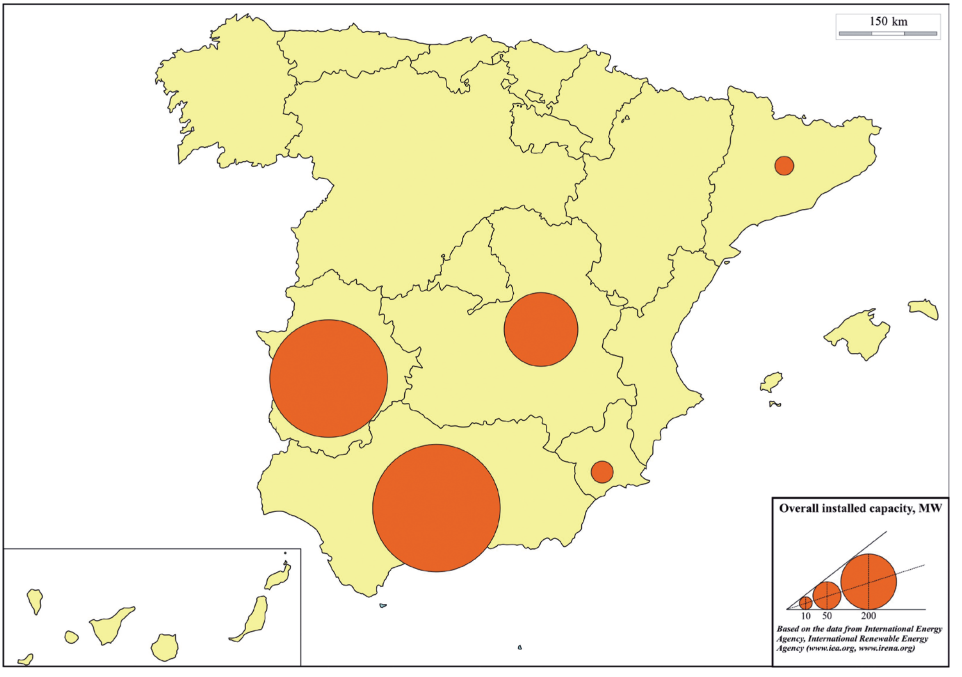

Fig. 5. Concentrated solar energy production in Spain

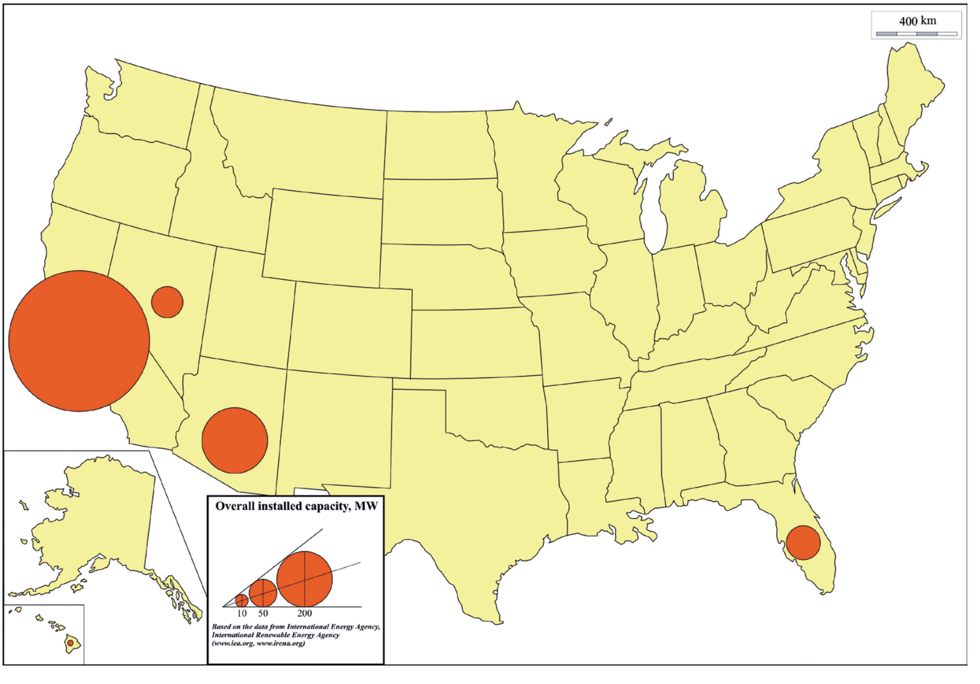

Fig. 6. Concentrated solar energy production in the USA

5), Bavaria, Baden-Württemberg and North Rhine-Westphalia in Germany (Fig. 3), Oita, Aichi, Aomori and Hokkaido in Japan (Fig. 4), etc.

A profound complex research revealed that nowadays the most important feature of the territorial development of solar energy production is its rapid development in Asian countries, so to say "drift to the East". During the period 2012-2015 share of Asian countries in the world photovoltaic capacity increased from <20% to 38%, and in solar thermal power — from 68% to 74%, while the share of European countries fell significantly from 69% to 42% and from 17% to 11%, respectively. A similar change in the "development vector" was observed in the production of components and equipment for the industry, as well as in the service sector (design, monitoring, advertising, etc.), i.e. in sectors where often the same companies operate. Now the main centre is China, with which fiercely compete European and American companies. Unsurprisingly China occupies a leading position due to the fact that the solar technology, that first appeared in the developed countries of Europe and the United States, in Chinese version is much cheaper (the price difference is 20-25%), which is due to the following factors:

• *economies of scale*. Chinese plants have significantly higher production capacity and output than the plants of other countries. The largest plant that produces solar modules in China has a capacity of 3.2 GW, while the largest plant in Europe and the US — only 650 MW.

• *proximity to suppliers of cheap raw materials*. Leading Chinese companies were the first to use local suppliers of cheap raw materials, which made it possible to reduce the cost of materials compared to other competitors in the world.

• *specialization in the production of standard modules*. Chinese companies give preference to the production of standard basic products (multicrystalline modules with a size of 60x60). In comparison, Western and Japanese companies have historically operated in the market segments, providing a larger range of sizes and technologies of solar modules.

As a result, China accounts for more than 60% of the world's production of photovoltaic cells, 70% of solar modules. It can be assumed that the producers of solar modules in China will soon force out all other producers on the market due to the collapse of prices for their products (Masson et al. 2014; Greentech Media Research 2015; PV Insider 2015).Therefore, European and American companies have nothing else to do but search for new high-tech solutions to overcome this situation, for example, by specializing in the production of thin-film solar modules with a lower conversion efficiency, but also with less capital costs.

Europe and the United States still retain their leading positions on the polysilicon market, as its production is extremely complicated technological process (Bernreuter 2014; Platzer 2012). Taking into consideration the decline in the price of polysilicon, China still cannot produce both high-quality and cheap product at the same time, as a consequence, cannot ensure the production of polysilicon in sufficient volume to also dominate in this production segment.

China is the undisputed leader on the solar collector market. Surprisingly, it specialises in the production of the most sophisticated and technologically advanced, while Europe and the United States are actively developing the production of the simplest and the cheapest flat solar thermal collectors. This is due to the fact that European and American companies cannot withstand price competition with China in the production of technologically complex collectors, which, due to their technical characteristics, are most effective for use in China itself (in addition, they have lower requirements of financial investments during their life cycle compared with gas analogs, which predetermines their popularity in the country) (Mauthner and Weiss 2015; European solar thermal electricity association 2016).

Concentrated solar energy production is still very young and the leaders on the global market are yet to be settled and vary depending on the technology used and design applied. In general, we can conclude that at the moment only two countries retain leading positions — Spain and the United States (Renewables 2016; CSP Today 2016), the companies of those have a very high level of vertical integration due to the high capital investments of CSP systems. The domination of these countries can be put down to the complexity of the technology and, as a consequence, the necessity to have a strong technological base and R & D centers specialized in this segment of the solar energy production. Nevertheless, concentrating solar energy production is a promising sector for developing countries. The reasons are economic and geographical. Concentrating solar energy production is most effective when placed in areas of the tropical belt with a high level of solar radiation, it benefits from economies of scale and does not need expensive photovoltaic materials.

It was determined that there is no single determining factor of location, acting for each country. Determinative factor varies from country to country, in accordance with the socio-economic and political specifics of these countries. It should be recognized that there are a number of different factors: the cost of other energy sources, population density, national energy pricing strategies, geographic location (latitude), the structure of government subsidies, global trends, etc. — and each of them plays its role. For example, due to the still relatively high cost of solar electricity, institutional factors play a big role in the development of solar energy production: the political climate in the country, the desire or unwillingness of the authorities to promote the development of the industry, the level of awareness of the population about this technology, etc. In all countries with high level of the development of solar energy production the state support measures are used to improve the competitiveness and investment attractiveness of the industry. The most common measures to support and encourage the development of solar energy production in the European Union and the United States include: 1) an obligation to establish a fixed tariff for electricity generated by solar installations; 2) subsidies for every kilowatt * hour of electricity generated (in the form of tax rebates or direct payments); 3) investment subsidies (grants, loans, favorable tax incentives) to compensate for the high capital investments in the construction of renewable energy facilities, such as solar energy production; 4) establishing a standard that obliges manufacturers or distributors of electrical energy to produce a certain percentage of renewable energy. Such measures are widely used in the European Union; 5) measures to encourage investors by facilitating access to credit at a reduced rate; 6) setting goals of public commissioning of solar power by 2020 and 2030 and the targets for the development of a certain percentage of electricity from alternative sources by a certain year; development and adoption of a financial support programme to achieve its goals; 7) unlimited connection to networks of local solar energy production facilities etc (Couture and Gagnon 2009; Mendonça 2007).

Nevertheless, there is one single factor for each country, which played a decisive role in the development of solar energy production, and is not necessarily the most obvious one. For example, solar radiation is no longer a decisive factor for the development of photovoltaics due to the evolution of solar technologies, which allows solar modules to generate electricity even when it is cloudy by using both direct and scattered solar radiation. In addition, hybrid plants can always be used. At the same time, it should be noted that within one of subindustries of solar energy production for different sectors (industrial and individual) factors can be different.

1) The consumer, demand, high incomes of the population — played a decisive role in the development of individual solar energy production in the countries of the European region (the United Kingdom, Italy, Belgium, France, Germany, Czech Republic, Austria, Switzerland), as well as in Israel;

2) State policies — contributed to the development of individual solar power in India, Japan, industrial — in Bulgaria, Romania and Germany;

3) The existence of national material and production base, as well as the need for the electrification of rural and hard-to-reach remote areas — China, Canada, Turkey, Mexico, Brazil (all — individual solar energy production);

4) External influence (energy crises, collapse in other sectors of the fuel and energy complex) — the USA (all segments of solar energy production), Japan (industrial solar energy production);

5) Availability of sparsely populated areas with high levels of solar radiation — industrial solar energy production — Spain, Chile, Morocco, Algeria, China.

CONCLUSION

The study presents novel comprehensive geographical analysis of world solar energy production, in which special focus was given to its territorial structure.

1. This study proved that solar energy production is indeed one of the most promising industries of the world energy complex. In just 5 years — from 2010 to 2015 — its global capacity increased almost 6 times (in comparison: wind power — by 2,2, bioenergy — 1,7 geothermal — 1,2 times).

2. Accelerated development of solar energy production is predetermined by: a) enormous power, inexhaustibility and general availability of solar energy, b) high ecological safety of the industry, c) constant and rapid improvement of its economy (solar modules have fallen in price by more than 250 times since 1977, the price of solar kilowatt-hour from 2010 by 4 times, etc.).

3. The combination of traditional resource vector (using the energy coming from the Sun) and new technologies has allowed solar energy production to compete with traditional hydrocarbon energy and gradually start winning state and individual consumer preferences, thus beating its main competitor — wind energy. At the moment, the geography and development of solar energy production cannot be viewed solely through the prism of its placement and the balance of power in relation to the finished product — a solar installation. Solar energy production — is a single set of industries from mining to installing solar panels that performs a fundamental function in society — the production of heat and electricity of solar origin.

4. The result of active development of solar energy production is its dynamic spatial expansion transforming its territorial structure from monocentric to polycentric with three main centers: Europe (Germany, Spain, Italy, the UK), North America (USA) and Asia (Japan and China).

5. An important feature of the territorial development of the world's solar energy production is its rapid growth in Asian countries (in China, Japan and South Korea) — the so-called «drift to the East".

6. However, a high level of territorial concentration is still present, that manifests itself in the domination of a small number of countries and their regions. For example, at the intra-country level, the nucleus is formed by only 3-4 regions, sometimes just 1-2.

7. At the same time, there is no single, common for all countries, location factor at the mesolevel. Depending on the socio-economic and political specifics of the country, the determining location factor also changes.

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