Assessment of the potential of photovoltaic power resources on all continents.

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Abstract. Evaluating the development potential of large-scale PV power base is of great value in supporting the construction of Global Energy Interconnection (GEI) and meeting global electricity needs by supplying clean energy. This paper analysed the characteristics of global solar resources and summarized the current status of global key large-scale PV power base. The analysis model of development potential, annual theory generation and full load hours was established based on the facts of capacity per square meter, global horizontal irradiation and geographical conditions. The development potential of large-scale PV power base of all continents was studied by applying the evaluating system of global PV power base. The results showed that the solar power development bases in Asia are mainly concentrated in western China, Israel, Jordan, Saudi Arabia, and the United Arab Emirates in the Middle East.

1. Introduction

Solar power generation has a large space for technological innovation and development prospects, and will play an active role in the construction of the global energy Internet. Photovoltaic power generation has obvious advantages in reducing power generation costs and achieving large-scale commercial applications [1]. In recent years, the rapid development of global photovoltaic power generation has become the main force for the growth of new energy. As of the end of 2017, global photovoltaic power generation capacity reached 400 million kilowatts, accounting for less than 1% of theoretical development potential, and there is still much room for development in the future [2, 3].

According to the global distribution of solar energy resources, solar power development bases in Asia are mainly concentrated in western China, Israel, Jordan, Saudi Arabia, and the United Arab Emirates in the Middle East. European solar power development bases are mainly concentrated in southern Europe, distributed in Italy, Greece, Turkey, Germany and so on. North American solar power development bases are concentrated in the southwestern United States. South American solar power development bases are mainly concentrated in the Atacama Desert area at the border between Peru and Chile. Africa's solar power development bases are mainly concentrated in the Sahara Desert and areas north of North Africa, and Ethiopia, Sudan, Kenya and other countries and regions in East Africa. Oceania solar power development bases are mainly concentrated in the northern region of Australia [3-5].

At present, solar resource assessment databases and systems based on satellite remote sensing data that are widely used around world include the SolarGIS solar resource assessment system developed by...
GeoModel, the Heliosat-3 system of MineParisTech, and obtained from the inversion of images by the European Geostationary Satellite (Meteosat). HelioClim dataset, European sunshine and solar radiation dataset (Satel-Light), etc. The World Environment Agency (GEF) launched the Solar and Wind Energy Assessment (SWERA) project in 2001 [6-7]. This project was implemented by UNEP in conjunction with 25 partners worldwide and adopted the form of demonstration projects. By 2006, demonstration studies have been carried out in 13 countries and the distribution of solar energy resources in these countries has been drawn. The project calculates the solar irradiance on the ground through the satellite cloud map, and then draws the distribution map of solar energy resources. The accuracy of the resource distribution map is 10km × 10km. In China, the China Meteorological Administration estimates solar radiation based on observation data from meteorological stations, and presents a division of solar energy resources in China. The country is divided into five categories according to the amount of solar radiation received [8-10]. Because the distribution of meteorological stations in China is dense in the east and scarce in the west, most of the regions with abundant solar energy resources in China are concentrated in the west. The estimation based on the observation data of meteorological stations cannot meet the needs of solar energy development and utilization.

With reference to existing solar resource assessment methods, and methods and models for photovoltaic power station base development, establish an analysis model for the development potential of photovoltaic power stations, and use an independently developed global large-scale photovoltaic power station development potential assessment system to study the development of photovoltaic power station bases in North Africa and the southwestern United States. Exploiting potential.

2. Development potential analysis model of photovoltaic power plant base

The potential evaluation model of photovoltaic power plant development mainly includes the theoretical installed capacity of photovoltaic power plant bases, annual theoretical power generation, and utilization hours.

(1) Development of installed theory

The development of photovoltaic power stations is greatly affected by terrain and geomorphology. In order to calculate the theoretical development of installed photovoltaic power plants, the non-developed area must be excluded, and then the unit area installation method is used for calculation. The specific formula is as follows:

\[ E_s = S \times P_s \] (1)

In the formula: \( E_s \) — the development volume of photovoltaic power station technology in the s area.

\( S \) — The installable area of photovoltaic power plants. Accurate calculation needs to exclude non-installable areas (including mountains, rivers, hubbles, geological disaster areas, nature reserves, etc.), and roughly calculate the total area of available bases multiplied by the installable area ratio. Generally, it can be assumed as 3% -5%.

\( P_s \) — The installed capacity of photovoltaic power plants per unit area in the s area is generally 25-30w/m² according to actual engineering conditions.

(2) Annual theoretical power generation and utilization hours

The formula for estimating the annual power generation of photovoltaic power stations is as follows:

\[ W_s = E_s \times \tau_s \times \eta \] (2)

In the formula: \( W_s \) — the annual power generation of photovoltaic power stations in the area, in kilowatt hours;

\( E_s \) — The theoretical development volume of photovoltaic power stations in the s area, in megawatts;
\[ \tau_s \] — The annual peak solar time of solar energy in the region, which is the total annual solar radiation in the region;

\[ \eta \] — Photovoltaic power plant system efficiency is related to inverter efficiency, fouling efficiency, and battery efficiency, and is generally about 0.7 to 0.9.

The annual theoretical power generation hours of photovoltaic power stations in the area \( s \) is the total theoretical annual power generation of photovoltaic power stations in the area divided by the total development volume. The specific formula is as follows:

\[
H_s = \frac{W_s}{E_s}
\]  

(3)

3. Analysis and Planning of Photovoltaic Power Resource Potential on All Continents

3.1. Analysis and Planning of Photovoltaic Power Resource Potential of Europe

The potential of solar power development in Europe is about 10.9 billion kilowatts. Among them, Germany, Italy and other countries currently have solar power development potential of 4.37 billion kilowatts, accounting for 40% of the potential of solar energy development in Europe. According to the remaining 5% of the development, the scale of solar power generation in Europe in 2030 and 2050 will reach 7.6 and 1.84 billion kilowatts, respectively.

Table 1. Potential and scale of solar energy development in Europe and major countries (Unit: 10 MW)

| Country          | Installed capacity at the end of 2017 | Development potential | Remaining development | Development scale by the end of 2020 | Development scale by the end of 2030 | Development scale by the end of 2050 |
|------------------|--------------------------------------|-----------------------|-----------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Europe           | 11177                                | 1094000               | 1083000               | 22007                               | 76157                               | 184457                              |
| Germany          | 4240                                 | 74000                 | 70000                 | 4940                                | 8440                                | 15440                               |
| Italy            | 1970                                 | 56000                 | 54000                 | 2510                                | 5210                                | 10610                               |
| United Kingdom   | 1279                                 | 55000                 | 53000                 | 1809                                | 4459                                | 9759                                |
| France           | 820                                  | 106000                | 105000                | 1870                                | 7120                                | 17620                               |
| Spain            | 728                                  | 86000                 | 85000                 | 1578                                | 5828                                | 14328                               |
| Belgium          | 357                                  | 6000                  | 6000                  | 417                                 | 717                                 | 1317                                |
| Greece           | 260                                  | 22000                 | 22000                 | 480                                 | 1580                                | 3780                                |
| Netherlands      | 259                                  | 8000                  | 8000                  | 339                                 | 739                                 | 1539                                |
| Czech Republic   | 206                                  | 16000                 | 16000                 | 366                                 | 1166                                | 2766                                |
| Switzerland      | 192                                  | 9000                  | 9000                  | 282                                 | 732                                 | 1632                                |

3.2. Analysis and Planning of Photovoltaic Power Resource Potential of Africa

The potential for solar power development in Africa is about 40.9 billion kilowatts. Among them, South Africa, Algeria, and other top ten countries currently have 11.968 billion kilowatts solar power development potentials, accounting for 29% of European solar development potential. Considering that the solar bases in the African region have great development potential, according to the calculation of the remaining 5% of the development volume, the scale of African solar power development in 2030 and the end of 2050 will reach 250 and 2.29 billion kilowatts, respectively.
Table 2. Potential and scale of solar energy development in Africa and major countries (Unit: 10 MW)

| Country    | Installed capacity at the end of 2017 | Development potential | Remaining development | Development scale by the end of 2020 | Development scale by the end of 2030 | Development scale by the end of 2050 |
|------------|--------------------------------------|-----------------------|-----------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| Africa     | 358                                  | 4092500               | 4092100               | 4450                                 | 24911                                | 229516                                |
| South Africa | 201.4                                | 181500               | 181300               | 383                                  | 1289                                | 10354                                |
| South Africa | 42.5                                 | 343900               | 343900               | 386                                  | 2106                                | 19301                                |
| Morocco    | 20.5                                 | 89000                | 89000                | 110                                  | 555                                 | 5005                                 |
| Reunion Island  | 18.9                                | 79000                | 79000                | 98                                   | 493                                 | 4443                                 |
| Egypt      | 11.6                                 | 145300               | 145300               | 157                                  | 883                                 | 8148                                 |
| Senegal    | 8.5                                  | 26200                | 26200                | 35                                   | 166                                 | 1476                                 |
| Mauritania | 8.5                                  | 146800               | 146800               | 155                                  | 889                                 | 8229                                 |
| Uganda     | 4.6                                  | 32200                | 32200                | 37                                   | 198                                 | 1808                                 |
| Burkina Faso | 4.4                                | 36400                | 36400                | 41                                   | 223                                 | 2043                                 |
| Namibia    | 3.7                                  | 116500               | 116500               | 120                                  | 703                                 | 6528                                 |

3.3. Analysis and Planning of Photovoltaic Power Resource Potential of Asia
The potential for solar power development in Asia is approximately 65.8 billion kilowatts, of which the total solar development potential of major countries such as China and Japan reaches 17.27 billion kilowatts, accounting for 26% of the potential for solar development in Asia. According to the calculation of 1% to 10% of the remaining development volume, the development scale of European solar power generation in 2030 and the end of 2050 will reach 18.5 and 8.41 billion kilowatts, respectively.

Table 3. Potential and scale of solar energy development in Asia and major countries (Unit: 10 MW)

| Country | Installed capacity at the end of 2017 | Development potential | Remaining development | Development scale by the end of 2020 | Development scale by the end of 2030 | Development scale by the end of 2050 |
|---------|--------------------------------------|-----------------------|-----------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| Asia    | 21122                                | 6581000               | 6559878               | 119520                               | 185119                               | 841107                               |
| China   | 13065                                | 1129200               | 1116135               | 24226                                | 40968                                | 208388                               |
| Japan   | 4860                                 | 65400                | 60540                | 6071                                 | 12125                                | 24233                                |
| India   | 1928                                 | 447200               | 445273               | 8607                                 | 35323                                | 102114                               |
| Korea   | 560                                  | 16000                | 15440               | 869                                  | 2413                                 | 5501                                 |
| Thailand | 270                                  | 69200                | 68930               | 1304                                  | 8197                                 | 21983                                |

3.4. Analysis and Planning of Photovoltaic Power Resource Potential of America
The potential for solar power development in the Americas is approximately 54.7 billion kilowatts, of which the solar development potential of major countries such as the United States and Canada totals 39.35 billion kilowatts, accounting for 72% of the potential for solar energy development in the Americas. Based on the 5% of the remaining development volume, the development scale of solar power generation in the Americas in 2030 and the end of 2050 reached 28.4 and 5.58 billion kilowatts, respectively.
Table 4. Potential and scale of solar energy development in America and major countries (Unit: 10 MW)

| Country  | Installed capacity at the end of 2017 | Development potential | Remaining development | Development scale by the end of 2020 | Development scale by the end of 2030 | Development scale by the end of 2050 |
|----------|--------------------------------------|-----------------------|----------------------|------------------------------------|------------------------------------|------------------------------------|
| America  | 5013                                 | 5476500               | 5471487              | 10484                              | 284059                             | 557633                             |
| United States | 4289                         | 1410500               | 1406211              | 7101                               | 77412                              | 147722                             |
| Canada   | 294                                  | 1296300               | 1296006              | 1590                               | 66390                              | 131190                             |
| Chile    | 218                                  | 843000                | 84082                | 302                                | 4506                               | 8711                               |
| Brazil   | 110                                  | 1144000               | 1143890              | 1254                               | 58448                              | 115643                             |

3.5. Analysis and Planning of Photovoltaic Power Resource Potential of Oceania

Oceania’s solar power development potential is approximately 12.4 billion kilowatts, of which Australia and New Zealand’s solar development potential totals 11.68 billion kilowatts, accounting for 95% of Oceania’s solar development potential. Based on 1% of the remaining development volume, the scale of solar energy development in Oceania in 2030 and the end of 2050 will reach 140 and 760 million kilowatts, respectively.

Table 5. Potential and scale of solar energy development in Oceania and major countries (Unit: 10 MW)

| Country         | Installed capacity at the end of 2017 | Development potential | Remaining development | Development scale by the end of 2020 | Development scale by the end of 2030 | Development scale by the end of 2050 |
|-----------------|--------------------------------------|-----------------------|----------------------|------------------------------------|------------------------------------|------------------------------------|
| Oceania         | 658                                  | 1239700               | 1239042              | 1897                               | 14287                              | 76240                              |
| Australia, New Zealand | 642                          | 1120400               | 1119758              | 1762                               | 12959                              | 68947                              |
|                 | 7                                   | 483000                | 48293                | 55                                 | 538                                | 2953                               |

4. Conclusion

The solar power development bases in Asia are mainly concentrated in western China, Israel, Jordan, Saudi Arabia, and the United Arab Emirates in the Middle East. The theoretical development potential of the 10 selected bases exceeds 2.3 billion kilowatts; the European solar power development bases are mainly concentrated in southern Europe, distributed in Italy, Greece, Turkey, Germany, etc., the theoretical development potential of the six selected bases exceeds 150 million kilowatts; the solar power development bases in the Americas are mainly concentrated in the southwestern United States, and Atacá, which borders Peru and Chile. In the Ma Desert, the selected 11 bases have a theoretical development potential of more than 1.8 billion kilowatts; the African solar power development bases are mainly concentrated in the Sahara Desert in North Africa and the north, and South Africa and other regions. 100 million kilowatts; Oceania solar power development bases are mainly concentrated in the northern region of Australia. The theoretical development potential of the four selected bases exceeds 1.1 billion kilowatts.

In terms of calculation of development potential, the unit area of a unified photovoltaic power station can be exploited. In the future, we will further combine the development characteristics of different regions to accurately give the developable unit area of photovoltaic power plants in different countries, which can more accurately evaluate the development potential of photovoltaic power plants. In terms of upgrading the evaluation system, a complete set of evaluation index systems will be established in the future to evaluate the feasibility of building large-scale photovoltaic power plants around the world and provide more accurate solutions for site selection.
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