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ORIGINAL PAPER

Innovation of renewable energy generation technologies at a regional level in China: a study based on patent data analysis

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Abstract This paper is a pioneer study which examines the innovation of renewable energy generation technologies based on residential patent applications in 30 regions of China between 2006 and 2015. Wind power, solar energy, geothermal energy, ocean energy, hydro power, and biomass & waste energy are the subject technologies for this analysis. Different indicators such as absolute numbers, growth rates and revealed technology advantages are used to measure the various green innovation dynamics in different regions. The results show that some regions with a higher number of patent applications or growth rates did not show stronger technological advantage (specialization) in such technologies. On the other hand, the region of Inner Mongolia shows a very strong specialization but with a much smaller number of patent applications.

Keywords Renewable energy generation technologies · Patent applications · Innovation indicators · Revealed technology advantage · Chinese regions

1 Introduction

China has become the world's second largest consumer of energy and will overtake the US as the world's leading energy consumer in three to five years. As the world's largest emitter of carbon dioxide, China will face increasing international pressure to cut emissions. China's goal will be to vigorously develop renewable energy industries in order to mitigate future energy and environmental problems, and this will be an

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important breakthrough contributing to China's ability to fulfill commitments to the international community.

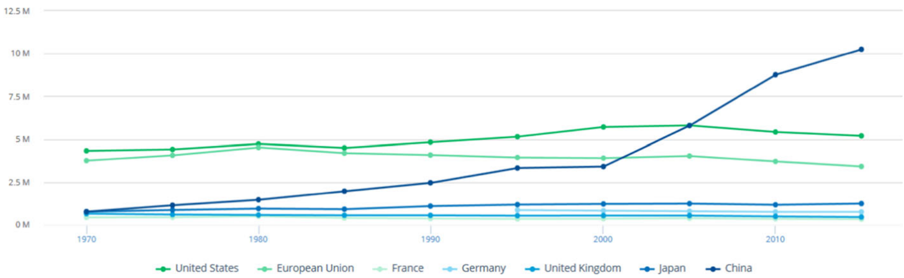
The National Energy Commission will take the lead in the development of national energy strategic planning. National energy strategic planning will guide the development of medium and long-term energy construction, covering a time period which is expected to exceed more than 20 years. The national energy strategic plan will focus on adjusting the diversified development of energy structures and the development of new energy, nuclear and biomass energy, water, wind, and so on.

China's total energy consumption has, for many years, been amongst the highest in the world. China's annual primary energy consumption accounted for more than 90%, while the utilization rate of wind energy, solar energy, biomass and other renewable energies is still low. During the 12th Five Year Plan (FYP) period, the renewable energy industry was included as a key support of sustainable development and green growth. However, in China there is not only national policy support, local governments have also developed a lot of preferential policies to encourage enterprises to develop renewable energy industries and technologies.

In this paper, Section 2 presents some background information; Section 3 explains why patents were chosen as an indicator of technological innovation and concludes with a review of the literature; Sections 4 and 5 explain the methodologies applied and the database, respectively; Results will be shown in Section 6, while Section 7 concludes and presents ideas for future research.

2 Background of economic and innovation developments of Chinese regions

China has been experiencing a high speed of economic growth for several decades and has now become the largest developing country, the largest coal consuming country and the largest emitter of greenhouse gases. Figure 1 shows the Total CO2 emissions of major emitters in 1970–2013, China's growth rate was the highest among the world's major economies. China's CO2 emissions have grown dramatically since it started on its fast industrialization path and after it joined the World Trade Organization (WTO) in 2003. In 2007, China's carbon emissions surpassed that of the USA. In 2012, China's carbon emissions were almost equivalent to the carbon emissions of both the U.S. and

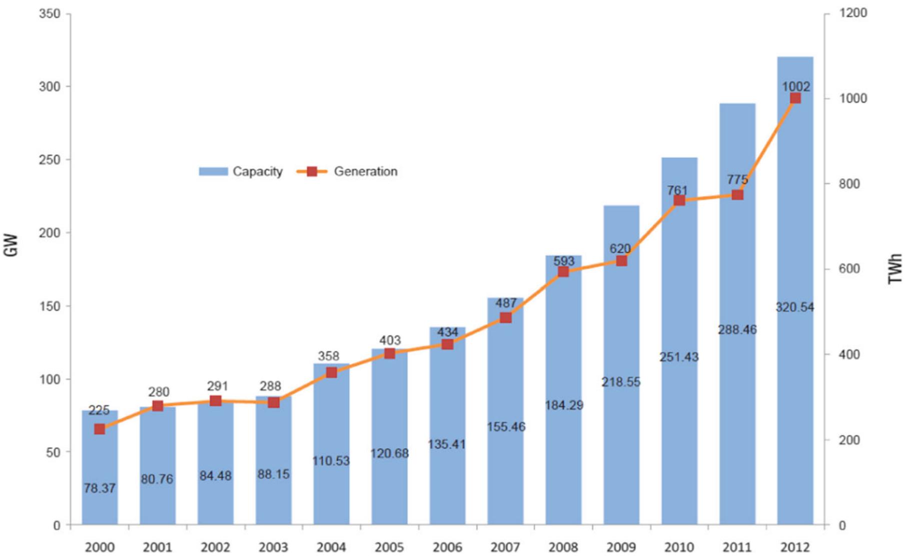


Source: World Development Indicators

Fig. 1 Total CO2 emissions of major emitters in 1970–2013 (kt) the EU-27 combined. Therefore, China faces more pressing and difficult challenges in the process of renewable energy transformation.

Due to the depletion of traditional energy resources and the destruction of the environment, the international community has reached a consensus on the need for the development of the renewable resources. In keeping with this, the Renewable Energy Law was promulgated in 2006, which represents the framework policy which lays out the general conditions for renewable energy to become a more important energy source in the People's Republic of China and is implemented nationwide. It covers all modern forms of renewable energy, i.e. wind, solar, water, biomass, geothermal and ocean energy. Figure 2 presents both China's renewable energy capacity and power generation from 2000 to 2012. Obviously, green growth and sustainable development are becoming the most important targets of the blueprints of the future both nationally and regionally. From a macro perspective, the renewable energy industry is a strategic emerging industry which will become the new engine of economic transformation. According to the plan from the National Development and Reform Committee (NDRC), by 2020, China's renewable energy power generation installed capacity will reach 290 million kilowatts, accounting for about 17% of the total installed capacity. Among them, nuclear power installed capacity will reach 70 million kilowatts, wind power installed capacity will reach nearly 150 million kilowatts, solar power installed capacity will reach 20 million kilowatts and biomass power generation installed capacity will reach 30 million kilowatts. It is foreseeable that China's renewable energy industry development prospects will be very broad.

Innovation is a key element of national power. A country's ability to develop new inventions or methods of production is always accompanied by the creation of wealth, leading in turn to higher technologies and fostering further innovation through the



Source: China Renewable Energy Outline 2012

Fig. 2 China's renewable energy capacity and power generation development of derivative products. China, as the leading developing country, has made huge progress in terms of technological innovation. Figure 3 shows the total number of patent applications at the patent offices of selected leading innovative countries. As we can see, in 2010, the total patent applications in China has surpassed the Japanese total amount; in 2011, China passed the USA and became the world's leading patent application country. According to data from the World Intellectual Property Organization (WIPO), in 2014, China processed 34.6% of all patent applications in the world. With over 920,000 total applications, China processed 160% more applications than the United States and 285% more applications than Japan.

After 20 years of rapid development, the eastern coastal areas have entered the industrial take-off stage, adopting a leading role in the country. A market economy system has been basically formed quickly with the international market under the rules of the WTO. The three regions with most economically developed economic and metropolitan areas are: The Pearl River Delta, with Guangzhou, Shenzhen and Zhuhai as the center, the Yangtze River Delta, with Shanghai as the center, and the Bohai Economic Rim, with Beijing and Tianjin as the center districts. These three regions have created a regional development miracle. Figure 4 shows the Gross Regional Product (GRP) (Yuan/person) in 2014. One can see clearly that Guangdong province, Jiangsu province and Shandong province are in the leading positions with GRP values of 67.80 billion Yuan, 65.08 billion Yuan and 59.43 billion Yuan, respectively. The Per Capita Gross Regional Product(yuan/dollar) of each region is showed in the Appendix.

Figure 5 presents the Gross Regional Product (Yuan) per capita, basic statistics on the R&D activities of industrial enterprises above a designated size (here, one million Yuan) and the number of patent applications in all regions in China in 2014. Guangdong, Jiangsu and Shandong stand for the top 3 provinces in terms of the gross regional product value (67,809 Yuan, 65,088 Yuan and 59,426 Yuan, respectively). Jiangsu, Guangdong and Shandong account for the top 3 provinces for R&D expenditure (137,653.78 million Yuan, 137,528.69 million Yuan and 117,554.82 million Yuan, respectively). Regarding the number of patent applicants, Jiangsu and Guangdong still remain in the top 2 positions with the number of 421,907 and

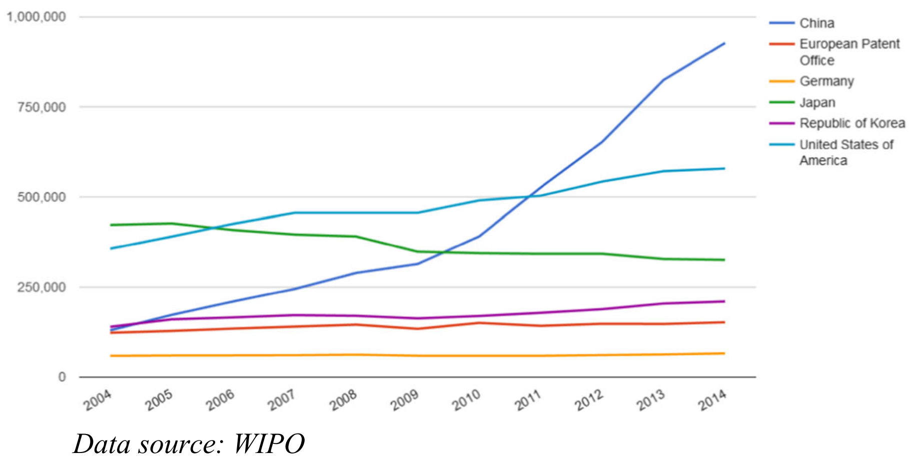


Fig. 3 Total national patent applications for top selected innovative countries

Data source: National Bureau of Statistics of China

Fig. 4 Gross Regional Product (100 million Yuan) in all regions in China, 2014

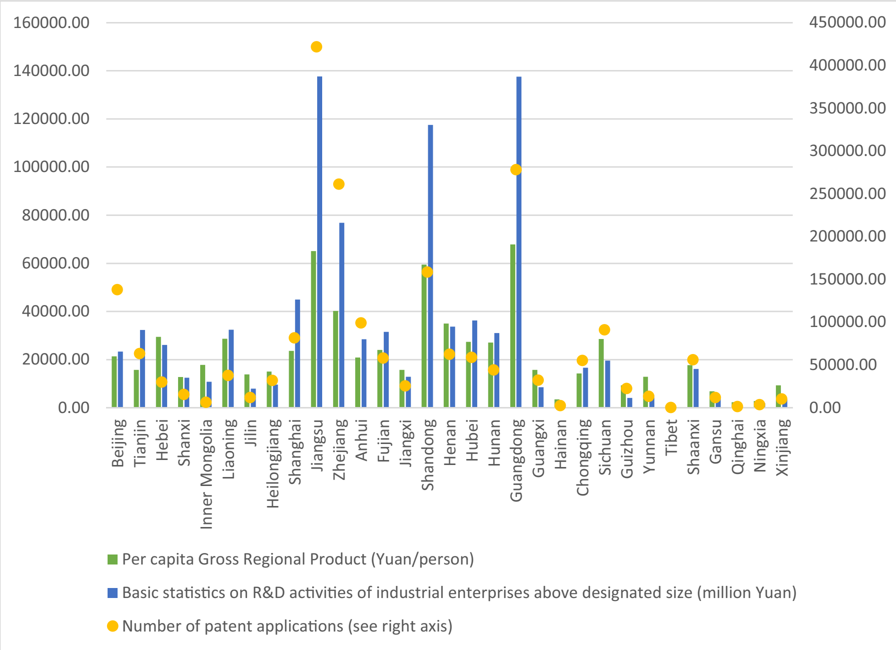
278,358, respectively. Zhejiang, on the other hand, is ranked in third position for patent applications and fourth for both GRP per capita and R&D expenditure. Shandong ranked no. 4 (158,619) in this field.

Su and Chen (2014) argue that green innovation is key to realizing the goal of a transition to green growth. The implementation of green innovations will effectively reinforce the impetus for green growth. Thus, renewable energy generation technologies (REGT) in particular are the crucial driving force for the further step of green development.

Welfens (2014) mentions green innovations are not easy to launch since innovation risks and costs are often high thus established. Helm et al. (2014) make some statistical comparisons regarding patent filings for selected renewable energy technologies during the time periods of 1975–2005 and 2006–2011 among countries. It is quite obvious to see that China accounted for the highest percentage of patent filings in relation to these technologies during the second time period (Fig. 6).

3 Patents as indicators for measuring technology innovation

Griliches (1990) defined patents thusly: A patent is a document, issued by an authorized government agency, granting the right to exclude anyone else from the production or use of a specific new device, apparatus, or process for a stated number years.

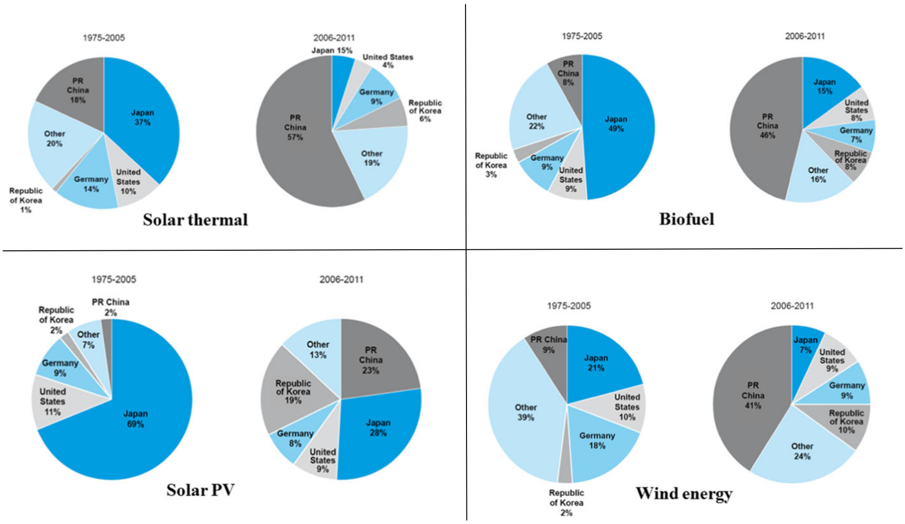


Data source: National Bureau of Statistics of China

Fig. 5 Per capita Gross Regional Product (Yuan), basic statistics on R&D activities of industrial enterprises above a designated size (million Yuan) and the number of patent applications in all regions in China (see *right axis*), 2014

Although rudimentary to some, one might ask about the different types of patent in China. There are, in fact, three different types of patent available in China: invention patent, utility model and design patent. Compared to the utility model and design patent, the invention patent has a longer (3–5 years) application process until it is granted, while the other two are normally granted within 1 year. In keeping with the difficulty in obtaining an invention patent, the duration of protection granted by that instrument is 20 years, while the other forms of patent only offer protection for 10 years.

Technological innovation is always discussed by researchers and politicians as being one of the most important elements for strengthening a nation's international status or a firm's competiveness. A number of measuring methods, such as research and development (R&D) expenditure or the number of scientific personnel, exist in the academic literature. After Griliches (1990) published his work: "Patent statistics as economic indicators: A survey" in 1990, patent data has become more and more popular for use as an indicator of measuring innovation dynamics on both a national level (macro-level), which indicates the output R&D process plus input to production and value-added, and a firm level (micro-level), which indicates the current status of technological knowledge plus the market value of the patent itself. Haščič and Migotto (2015) find that patent data provides a wealth of information on the nature of the invention, the inventor(s) and the applicant, and that the data itself is readily available (if not always in a convenient format) and discrete (and thus well suited for the development of indicators).



Source: Helm et al., 2014

Fig. 6 Office of first filing for selected renewable technologies in selected countries

A great many studies use patent data to analyze innovation, particularly in the field of green growth and renewable energy. For instance, Johnstone et al. (2008) explore the development of renewable energy technologies by using a panel of patent data from 25 OECD countries, they look at innovations for five renewable energy technologies: wind, solar, geothermal, electricity from biomass, and ocean power. Their data show rapid growth in wind and solar energy patent activity, particularly since the mid-1990s. Much of this innovation corresponds to policies enacted following the Kyoto Protocol. Innovation with respect to biomass and ocean energy is also growing, but from a very low base. In contrast, there has been little innovation in the area of geothermal energy since the 1970s. Popp et al. (2011) also use patent data for analyzing wind, solar photovoltaic, geothermal, and electricity from biomass & waste across 26 OECD countries from 1991 to 2004. They find that technological advances do lead to greater investment, but the effect is small. Environmental policy appears more important, as countries which have ratified the Kyoto Protocol invest more in renewable capacity. Investment in other carbon-free energy sources, such as hydro and nuclear power, serves as a substitute for investment in renewable energy. There are plenty of other studies which measure innovation in different fields using patent data, but the majority are generally focused at the country level. Of course, while a national innovation study is very important and effective for informing future strategy and development, fundamentally speaking, any national innovation behavior is shaped by regional innovation dynamics. The concept of the national innovation system, which developed spontaneously from Listian nationalism elements and Schumpeterian innovation theory, was first introduced by Freeman (1987) and then, in 1992, the concept of the regional innovation system was first introduced in Cooke (1992) in the paper: “Regional Innovation Systems: Competitive Regulation in the New Europe”. Asheima and Coenen (2005) defined the regional innovation system as the institutional infrastructure supporting innovation within the production structure of a region. Following the report "Welcoming the era of knowledge economy and constructing the national innovation system", from the Chinese Academy of Science (CAS), China began to construct the regional innovation system through a number of national and regional development strategies and plans. CAS, which provides advisory and appraisal services on issues stemming from the national economy, social development, and science and technology progress, has around 68,000 employees and includes 104 institutions distributed thirteen regional branches in Beijing, Shenyang (Liaoning Province), Changchun (Jilin Province), Shanghai, Nanjing (Jiangsu Province), Wuhan (Hubei Province), Guangzhou (Guangdong Province), Chengdu (Sichuan Province), Kunming (Yunnan Province), Xi'an (Shaanxi Province), Lanzhou (Gansu Province), Hefei (Anhui Province) and Xinjiang Province.

4 Methodologies of measuring technological specialization using patent data

Patent data are collected for analysis and comparison at the national, regional or firm level. The most popular indicators used by economists are:

- Revealed Technological Advantage Index (RTA);
- Relative Patent Advantage Index (RPA);
- Revealed Patent Advantage Index (RPA*);
- Patent Share (PS);
- Relative Patent Position Index (RPP);
- C20 Concentration Index;
- Gini Concentration Index;
- RTA in its most important technological field (RTAMIT);
- Patent Share in a country's most important technology field (PSMIT).

The most frequently used indicator of technological specialization is RTA. It was first developed by Balassa (Balassa 1965), and later adopted by different authors in the literature in order to measure the technological advantages of different countries and firms in given technological areas. The OECD defines RTA as follows: RTA provides an indication of the relative specialization of a given country in selected technological domains and is based on patent applications filed under the Patent Cooperation Treaty. It is defined as a country's share of patents in a particular technology field divided by the country's share in all patent fields:

$$RTA_{ij} = \frac{P_{ij} \Big/ \sum_j P_{ij}}{\sum_i P_{ij} \Big/ \sum_{ij} P_{ij}} \quad (1)$$

Where *RTAij* is the Revealed Technological Advantage Index in the area of technology *i* for country *j*. *Pij* is the number of patents relating to technology *i* among the national applications in a patent office; $\sum_j P_{ij}$ is the total number of patents from all j countries in the technological area i in a patent office; $\sum_i P_{ij}$ is the number of patents of applicants from country j in all i technological areas in a patent office and $\sum_{ij} P_{ij}$ is the total number of patents from all j countries in all i technological areas in a patent office. The index is equal to zero when the country holds no patents in a given sector; is equal to 1 when the country's share in the sector equals its share in all fields (no specialization); and above 1 when a positive specialization is observed.

Relative patent advantage is defined for every country i and every technology field j, the RPA is calculated according to:

$$RPA_{ij} = 100 \times \tanh\ln\left(\frac{P_{ij} / \sum_j P_{ij}}{\sum_i P_{ij} / \sum_{ij} P_{ij}}\right) \tag{2}$$

Equation (2) indicates values between −100 (extremely weak specialization) and +100 (extremely strong specialization). Walz and Schleich (2009) also used this method to examine the relative patent activity of climate policy-related technologies among different countries.

Grupp (Grupp 1990) introduced the Revealed Patent Advantage (RPA*) Index as following:

$$RPA^*_{ij} = \left(RTA_{ij}{}^2 - 1\right) / \left(RTA_{ij}{}^2 + 1\right) \tag{3}$$

The results of RTA could range from 0 to infinity, i.e. vary between 0 and 1 in the absence of specialization and between 1 and infinity in the presence of competitive advantage. Khramova et al. (2013) and Frietsch et al. (2010) mentioned that in order to avoid such an uneven distribution of values of the relatively neutral position between these two options, RPA* is created to normalize the RTA. Thus, the resulting index characterizes the symmetric distribution of identifying technological advantages. Positive values point to the fact that the technology has a higher weighting in the portfolio of the country than its weighting in the world. Negative values indicate specialization below the average.

In this paper, RTA, RPA and RPA* will be calculated for the 29 regions in China with the accumulated data from 2006 to 2015. For the selected technologies of solar energy and wind power average growth rates from 2006 to 2010 and 2011 to 2015, respectively, are also calculated.

5 The data

The International Patent Classification(IPC)system is developed by the WIPO, and is a hierarchical system which classifies more than 70,000 technological groups and subgroups. Johnstone et al. (2008) identified the six groups of renewable energy generation technologies, which includes wind power, solar energy, geothermal energy, ocean energy, hydro power and biomass & waste energy, as follows:

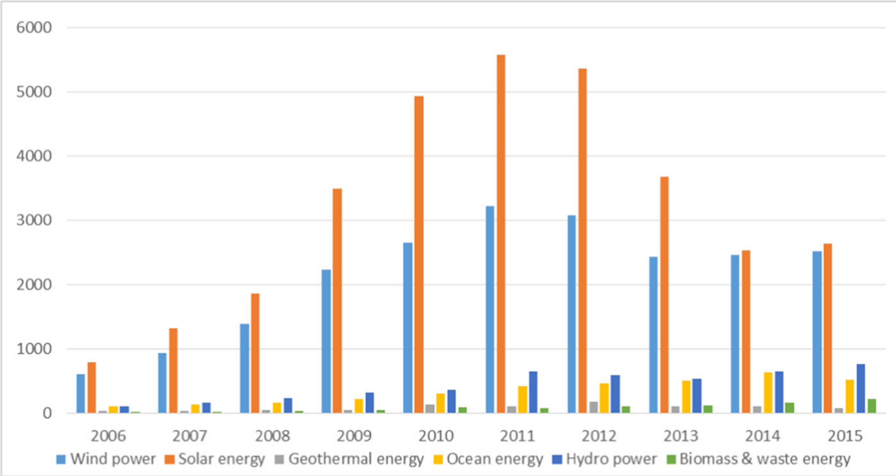
Wind power	
Wind motors with rotation axis substantially in wind direction	F03D1
Wind motors with rotation axis substantially at right angle to wind direction	F03D3
Other wind motors	F03D5
Controlling wind motors	F03D7
Adaptations of wind motors for special use;	F03D9
Details, component parts, or accessories not provided for in, or of interest apart from, the other groups of this subclass	F03D11
Solar energy	
Use of solar heat, e.g. solar heat collectors	F24 J2
Devices for producing mechanical power from solar energy	F03G6
Aspects of roofing for energy collecting devices – e.g. including solar panels	E04D13/18
Devices consisting of a plurality of semiconductor components sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation – specially adapted for the conversion of the energy of such radiation into electrical energy	H01L27/142
Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation – adapted as conversion devices	H01L31/04–078
Generators in which light radiation is directly converted into electrical energy	H02N6
Geothermal energy	
Devices for producing mechanical power from geothermal energy	F03G4
Mechanical-power-producing mechanisms – using pressure differences or thermal differences occurring in nature	F03G7/04
Production or use of heat, not derived from combustion – using natural or geothermal heat	F24 J3
Ocean energy	
Tide or wave power plants	E02B9/08
Submerged units incorporating electric generators or motors characterized by using wave or tide energy	F03B13/10–26
Mechanical-power-producing mechanisms – using ocean thermal energy conversion	F03G7/05
Hydro power	
Water-power plants; Layout, construction or equipment, methods of, or apparatus for	E02B9 AND NOT E02B9/08
Machines or engines for liquids of reaction type	F03B3 AND NOT F03B13/10–26
Water wheels	F03B7 AND NOT F03B13/10–26
Power stations or aggregates of water-storage type; Machine or engine aggregates in dams or the like	F03B13/06–08 AND NOT F03B13/10–26
Controlling machines or engines for liquids	F03B15 AND NOT F03B13/10–26
Biomass & waste energy	
	C10L5/40–48

Wind power	
Solid fuels essentially based on materials of non-mineral origin – animal or vegetable substances; sewage, town, or house refuse; industrial residues or waste materials	
Plants or engines characterized by use of industrial or other waste gases	F01 K25/14
Engines or plants operating on gaseous fuel generated from solid fuel, e.g. wood	F02B43/08
Incineration of waste - recuperation of heat	F23G5/46
Liquid carbonaceous fuels Gaseous fuels Solid fuels AND Dumping solid waste Destroying solid waste or transforming solid waste into something useful or harmless Incineration of waste; Incinerator constructions Incinerators or other apparatus specially adapted for consuming specific waste	(C10L1 OR C10L3 OR C10L5) AND (B09B1 OR B09B3 OR F23G5 OR F23G7)
Plants for converting heat or fluid energy into mechanical energy; use of waste heat Use of waste heat of combustion engines – Profiting from waste heat of combustion engines Machines, plant, or systems, using particular sources of energy – using waste heat, e.g. from internal-combustion engines AND Incineration of waste; Incinerator constructions Incinerators or other apparatus specially adapted for consuming specific waste or low grade fuels, e.g. chemicals	(F01 K27 OR F02G5 OR F25B27/02) AND (F23G5 OR F23G7)

To build the database, patent applications for all three kinds of REGT from 2006 to 2015 for 30 regions (Tibet, Hong Kong, Macau and Taiwan are excluded due to lack of data) in China are considered. Patent applications related to these technologies are searched for using their IPC codes as above from the Incopat patent information platform. The resulting dataset contains 51,572 patent applications received domestically

6 Results

Figure 7 and Fig. 8 show the total REGT patent applications and the regional REGT patent applications in China from 2006 to 2015, respectively. One can see from Fig. 7 that solar energy and wind power both account for an extremely large proportion of applications. The applications relating to these two technologies increased rapidly from 2006 to 2010, the period of the 11th Five Year Plan (FYP), and reached a peak 2011. From then on, the number of total applications for both solar energy and wind power decreased slightly in 2012 and dramatically in 2013. The numbers for 2014 and 2015 remained relatively steady. The other four technologies: geothermal energy, ocean energy, hydro power and biomass & waste energy - all represented very small proportion of total applications but one can clearly see that the growth rates are increasing over time. From a regional perspective, Jiangsu, Zhejiang and Beijing occupied the top

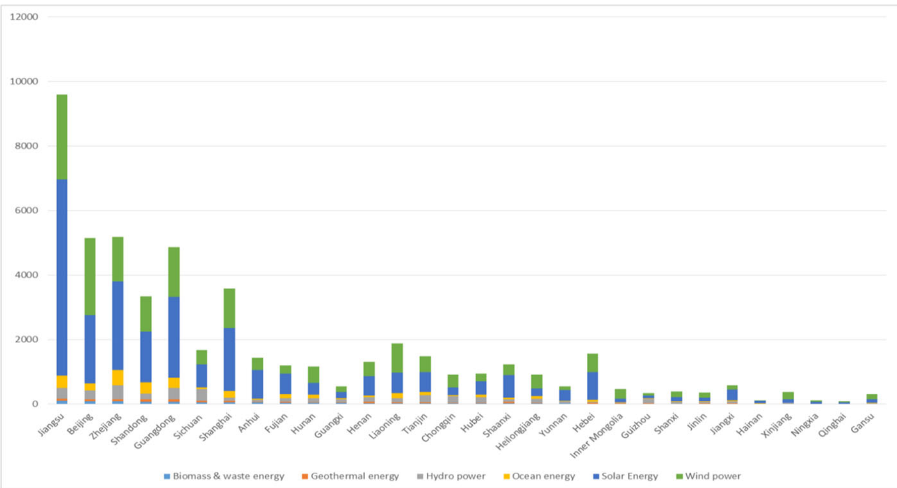


Data source: Incopat

Fig. 7 Total REGT patent applications in China from 2006 to 2015

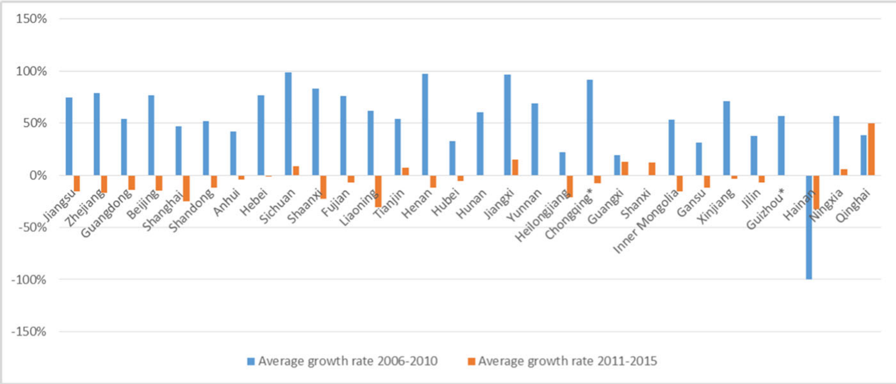
three positions with 9592, 5180 and 5156 applications, respectively. Hainan, Ningxia and Qinghai are the weakest regions in these technologies with the number of applications being only 118, 109 and 81, respectively.

Figure 9 and Fig. 10 show the average growth rate of solar energy technology and wind power technology patent applications during the periods 2006–2010 and 2011–2015, respectively. As previously mentioned, the average growth rate of solar energy technology between 2005 and 2010 reached a very high level, with the growth rate for 19 regions exceeding 50%, almost all of the regions (excluding Hainan) showed positive growth in this period. However, from 2011 to 2015, only 7 regions enjoyed a positive growth rate but with very small numbers, except for Qinghai whose average



Data source: Incopat

Fig. 8 Regional REGT patent applications in China from 2006 to 2015

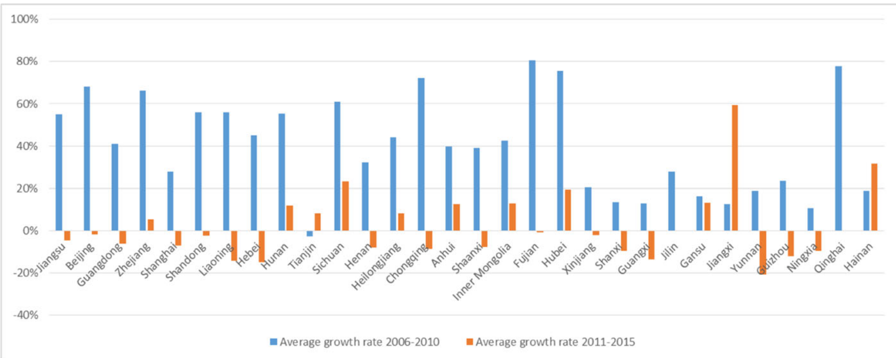


Data source: Incopat, author's own calculations

Fig. 9 Average growth rate of solar energy technology patent applications of 2006–2010 and 2011–2015. *Average growth rate from 2007 to 2010 since there were 0 patent applications in 2006

number is almost 50%. Only six regions show positive growth rate for both periods. With regard to wind power technology, the situation is a little bit better but still broadly similar (Fig. 10), 16 regions show an average growth rate of more than 40% during the 11th FYP period, while 30 regions had positive numbers, only Tianjin had a negative result. During the 12th FYP period, 11 regions continued to enjoy positive growth. 10 regions show a positive growth rate for both periods.

Figure 11 shows the RTA, RPA and RPA* results from the 31 regions by using the accumulated REGT patent applications and total patent applications between 2006 and 2010. There are six regions, namely Shandong province, Guangdong province, Anhui province, Guangxi province, Hebei province and Chongqing municipality, which have negative results. Anhui province had the lowest number which means Anhui was the least innovative region in the REGT. On the other hand, the most innovative regions in REGT are the Inner Mongolia Autonomous region, Qinghai province and Hebei province.



Data source: Incopat, author's own calculations

Fig. 10 Average growth rate of wind power technology patent applications 2006–2010 and 2011–2015

	RTA	RPA	RPA*
Jiangsu	1,485871485	37,65224681	0,376522468
Beijing	1,351620861	29,25059634	0,292505963
Zhejiang	1,119066851	11,20230112	0,112023011
Shandong	0,940533986	-6,123079992	-0,0612308
Guangdong	0,871219954	-13,69940163	-0,136994016
Sichuan	1,116399994	10,96663753	0,109666375
Shanghai	1,35211767	29,28419825	0,292841982
Anhui	0,739788851	-29,25845665	-0,292584566
Fujian	1,095945926	9,136236585	0,091362366
Hunan	1,249036126	21,87778443	0,218777844
Guangxi	0,9538679	-4,71949993	-0,047194999
Henan	1,111516469	10,53330978	0,105333098
Liaoning	1,56367562	41,94622008	0,419462201
Tianjin	1,234201551	20,73725354	0,207372535
Chongqing	0,921172429	-8,192401986	-0,08192402
Hubei	0,90241811	-10,23180148	-0,102318015
Shaanxi	1,212765333	19,0545491	0,190545491
Heilongjiang	1,336383523	28,2104533	0,282104533
Yunnan	1,610521583	44,34828708	0,443482871
Hebei	2,201963988	65,80404758	0,658040476
Inner Mongolia	3,022641404	80,26905328	0,802690533
Guizhou	1,168796459	15,47218873	0,154721887
Shanxi	1,060319038	5,850296029	0,05850296
Jinlin	1,036996504	3,631258464	0,036312585
Jiangxi	1,550209694	41,23092007	0,412309201
Hainan	1,610779364	44,36114317	0,443611432
Xinjiang	1,983310964	59,46101294	0,594610129
Ningxia	1,710519031	49,05594757	0,490559476
Qinghai	2,700500829	75,88241635	0,758824163
Gansu	1,414957699	33,38008477	0,333800848

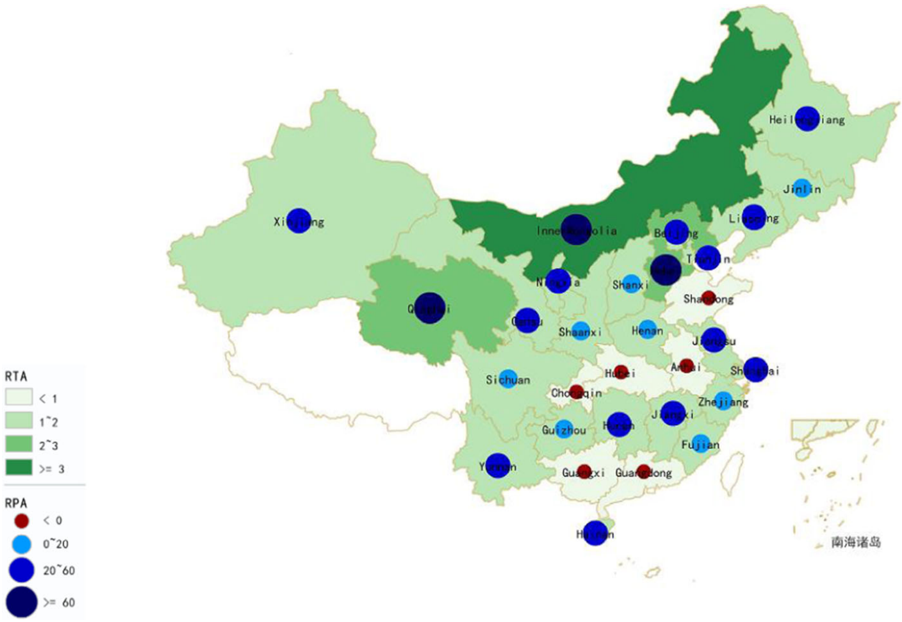
Data source: Incopat, author's own calculation

Fig. 11 RTA, RPA and RPA* of REGT in different regions, 2006–2010

Figures 12 and 13 show more intuitive images based on the above calculation results with regional total REGT patent applications in China and Calculated regional RTA and RPA from 2006 to 2015. If one compares these two maps, it is noticeable that both Guangdong province and Shandong province, which ranked in the second tier in total patents applications, have negative (read no) specialization in this field. On the other hand, both Inner Mongolia and Qinghai show very strong specialization but the total number of applicants' are quite small. In Inner Mongolia, wind power technologies accounted for more than 60% of the total number and in Qinghai province solar energy technology's share is also over 60%.

Data source: Incopat, author's own calculations

Fig. 12 Regional total REGT patent applications in China from 2006 to 2015



Data source: Incopat, author's own calculations

Fig. 13 Calculated regional RTA and RPA from 2006 to 2015

7 Conclusion

As one can see, leading regions in terms of the number of both patent applications and REGT patent applications, such as Guangdong and Shandong provinces, do not show evidence of a specialization in these renewable fields, while other innovative regions, such as Jiangsu and Zhejiang provinces, did show evidence of a positive specialization in REGT but with relatively weak advantage levels. In China, both central government and local government should do more to promote innovation processes in these four regions. Moreover, against the background of high per capita income and strong R&D input levels, these four regions should consider developing high-tech technologies such as new materials and energy efficiency technologies.

On the other hand, some western regions like Inner Mongolia or Gansu province, which are strategically and economically important due to their richness in natural resources and their special geographical positions, should focus further on both solar and wind energy technology innovation. Smart grid-related technologies should be considered for long-term energy and electricity distribution.

7.1 Directions for future research

This study presents mostly descriptive results and does not examine in detail nor explain the drivers of innovation. Furthermore, how REGT transfer occurs and among the regions in China is also not studied. Thus, in a future study, the two aforementioned points will be considered in order to complement this descriptive study with econometric analyses. Another strand of future research should be to include the role of foreign inventions and FDI respectively.

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Appendix

Database: Annual by Province

Indicators: Per Capita Gross Regional Product(yuan/dollar)

Year: LATEST20

Region	2014	2013	2012	2011	2010	2009	2008	2007	2006
Beijing	28.327,20	26.646,40	24.808,56	23.290,93	22.319,73	20.211,35	20.415,00	20.112,45	17.406,82
Tianjin	29.810,48	28.182,71	26.424,56	24.304,91	22.059,23	18.893,12	18.567,90	16.054,22	14.402,60
Hebei	11.326,91	10.954,11	10.375,50	9.688,82	8.663,64	7.421,80	7.276,35	6.580,32	5.940,23
Shanxi	9.934,84	9.849,10	9.537,15	8.943,81	7.942,88	6.498,19	6.807,85	5.958,84	4.959,93

Database: Annual by Province

Indicators: Per Capita Gross Regional Product(yuan/dollar)

Year: LATEST20

Region	2014	2013	2012	2011	2010	2009	2008	2007	2006
Inner Mongo	20.126,35	19.097,97	18.118,55	16.535,65	14.308,55	11.997,28	11.037,99	8.875,84	7.048,87
Liaoning	18.470,54	17.453,83	16.066,08	14.478,04	12.799,94	10.612,62	10.047,17	8.720,55	7.665,96
Jilin	14.209,63	13.352,48	12.312,82	10.969,77	9.549,41	8.029,89	7.445,71	6.486,95	5.494,02
Heilongjiang	11.112,18	10.612,89	10.127,91	9.360,81	8.182,53	6.777,48	6.881,92	6.218,21	5.720,11
Shanghai	27.583,57	25.617,40	24.212,42	23.548,20	22.990,03	20.883,15	21.187,72	20.763,39	20.151,20
Jiangsu	23.193,77	21.214,53	19.383,72	17.766,69	15.968,57	13.361,41	12.666,67	11.324,30	10.086,15
Zhejiang	20.680,45	19.370,78	17.973,34	16.899,32	15.627,38	13.237,32	13.107,00	12.274,43	11.140,65
Anhui	9.752,12	9.009,29	8.165,63	7.318,60	6.312,48	4.954,11	4.573,60	4.029,12	3.531,65
Fujian	17.980,74	16.369,65	14.963,98	13.513,12	12.095,80	10,095,71	9.419,12	8.561,58	7.437,41
Jiangxi	9.822,66	8.989,30	8.167,90	7.458,64	6.422,79	5.234,00	5.033,24	4.458,50	3.754,92
Shandong	17.246,18	16.014,92	14.681,79	13.501,14	12.422,48	10.837,56	10.426,08	9.238,29	8.279,18
Henan	10.501,98	9.631,48	8.933,35	8.174,84	7.387,73	6.218,90	6.071,86	5.358,77	4.669,13
Hubei	13.355,52	12.056,87	10.939,31	9.753,85	8.433,36	6.846,92	6.286,17	5.483,94	4.623,77
Hunan	11.408,22	10.400,62	9.495,18	8.522,53	7.470,23	6.167,87	5.744,54	4.976,24	4.159,63
Guangdong	17.979,89	16.563,34	15.341,75	14.491,44	13.519,49	11.907,00	11.914,53	11.135,21	9.872,36
Guangxi	9.373,94	8.654,56	7.927,40	7.223,62	6.110,31	4.844,50	4.638,18	4.108,77	3.600,56
Hainan	11.026,63	10.040,26	9.182,36	8.242,44	7.201,87	5.813,41	5.600,19	4.994,31	4.447,96
Chongqing	13.555,24	12.168,64	11.036,30	9.840,27	8.339,68	6.920,29	6.486,23	5.565,26	4.373,07
Sichuan	9.951,27	9.182,71	8.397,05	7.453,79	6.401,33	5.235,21	4.905,03	4.338,35	3.708,16
Guizhou	7.489,24	6.517,74	5.589,90	4.681,40	3.964,64	3.312,50	3.119,66	2.636,55	2.021,80
Yunnan	7.723,51	7.128,94	6.294,67	5.494,87	4.760,35	4.087,86	3.979,11	3.550.54	3.150,84
Tibet	8.286,69	7.411,60	6.504,82	5.726,47	5.145,66	4.531,40	4.301,36	4.043,84	3.655,41
Shaanxi	13.294,33	12.138,80	10.937,04	9.544,78	8.199,76	6.626,51	6.236,15	5.202,81	4.135,72
Gansu	7.488,10	6.908,50	6.233,13	5.588,99	4.869,45	4.006,34	3.931,94	3.552,21	3.076,30
Qinghai	11.238,24	10.381,48	9.410,38	8.420,42	7.287,70	5.873,79	5.831,28	4.855,09	4.132,56
Ningxia	11.850,99	11.152,31	10.321,61	9.424,70	8.117,26	6.575,18	6.207,34	5.067,60	4143,46
Xinjiang	11.515,01	10.572,35	9.584,80	8.581,57	7.565,43	6.021,14	6.266,86	5.689,09	5.228,90

National Bureau of Statistics

ppp exchange rate from OECD

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