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Industrial Arrangement of Large-scale, Non-grid-connected Wind Power Industrial Zones in Coastal Areas of China

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Abstract: Constructing an industrial system for a large-scale, non-grid-connected wind power industry is a key step towards the diverse utilization of wind power. However, wind power exploitation is not only a technical challenge but an industrial problem as well. The objective of this study is to introduce a concept of large-scale, non-grid-connected wind power (LSNGCWP) industrial zones and establish an evaluation model to assess their industrial arrangement. The data of wind energy, industry, nature resources and socio-economy were collected in this study. Using spatial overlay analysis of geographic information system, this study proposes a spatial arrangement of the LSNGCWP industrial zones in the coastal areas of China, which could be summarized as the ′one line and three circles′ structure, which will contribute to the optimization of the industrial structure, advance the wind power technology, coordinate the multi-industrial cooperation, and upgrade the industrial transformation of China′s coastal areas.

Keywords: coastal areas in China; wind energy resources; large-scale non-grid-connected; wind power industry; industrial arrangement

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1 Introduction

Resources for wind energy have recently undergone a rapid development in China. By 2007, there had been 159 wind power plants in China, with a total installed capacity of 1.03×10^7 KW (Fang, 2007). Between 1986 and 2007, the wind power installed capacity in the country increased at an annual growth of 428.95%, which is overwhelmingly higher than the average growth rate of the world (25.8%). Although the exploration of wind energy resources and the scale of wind power industry are increasing, it must be noted that wind power contributes less than 10% to the power network, which remains a challenge in the field of wind power generation. In response to this problem, the innovative concept of non-grid-connected wind power is raised by Chinese researchers (Gu, 2006).

Through searching in ELSEVIER database, few related literature on the applied research of non-grid-connected wind power industry has been found. Most of the abroad researchers are carrying out studies basing on the traditional viewpoint of grid-connected wind power (Brammeier, 1996; Akhmatov and knudsen, 2002; Lennart *et a1*., 2007; WWEA, 2009). Along with the development of wind energy industry in China, some researchers believed that traditional power industry is faced up with some challenges and effective solutions are significant (Xi and Ji, 2001; Kang and Gao, 2006; Wang, 2008). Based on analysis of wind energy in China (Xue and Zhu, 2001) and experience abroad (Xing and Chen, 2006), many studies have been conducted on large-scale non-grid-connected wind power (LSNGCWP). Some researchers have made a comprehensive description of LSNGCWP systems (Gu, 2006; Gu, 2008a), whereas certain technical issues related to LSNGCWP were examined (Li and Zhang, 2008; Lin

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and Yang, 2008; Tu *et al*., 2009; Zhang and Zhou, 2009). Along with wind power development, the principles and framework for constructing a non-grid-connected wind power industrial system were brought up (Gu, 2008b), which is significant for the applied research of LSNGCWP. Huang *et al*. (2008) made a wind power industry layout based on non-grid-connection pattern. Liu and Huang (2008) researched the arrangement of LSNGCWP and high-energy industry. Furthermore, after conducting the applied research of wind power and indicating the problem during wind energy developing, the development and future direction of LSNGCWP in the northwestern and central China were discussed (Guo and Li, 2006; Li, 2008; Liu, 2008). Moreover, the application of large-scale wind power used in energy-intensive industries including nonferrous metallurgy and salt chemical industries has been previously analyzed from an economic perspective, and Probit model has been applied to making a coupling arrangement of energy-intensive industries and LSNGCWP (Lin and Fang, 2008). The literature suggests that more research is warranted in the areas of technology and industrialization of LSNGCWP.

The coastal areas have developed rapidly ever since the reform and opening up policy of China, leading to high energy demand and serious environmental pollution. To curtail energy use and sewage discharge, many enterprises have been restricted in growth, and some had to face the reality of being eliminated through competition. However, at this time, wind energy generation in coastal areas is not yet undertaking a large-scale development. If the LSNGCWP can be used for energy-intensive industries, it will optimize the energy structure and help keep coastal areas develop at high speed. Therefore, the research on LSNGCWP in coastal areas is significant and promising but unfortunately limited. The objective of this study is to make an attempt on the arrangement of LSNGCWP in the coastal areas of China.

2 Conceptions

2.1 LSNGCWP

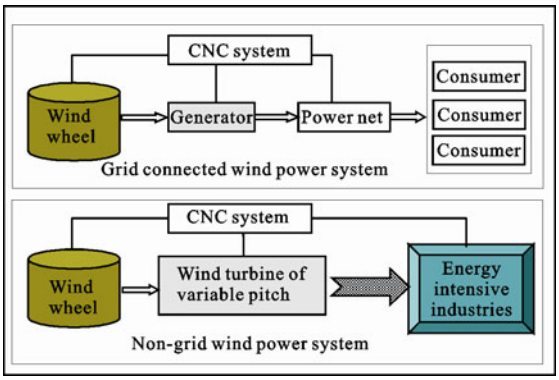
Wind power grid integration is currently the only option for a large-scale wind industry. LSNGCWP research have opened up new ways of diversified wind power generation and utilization. The establishment of LSNG CWP industrial system will tightly integrate both the upstream and downstream wind industries, including many kinds of energy-intensive industries and their related service industries, such as wind farm operation, project financing, and insurance. The foundation of large-scale industrial zones will promote the regional economic development and reduce the cost for the enterprises.

Due to the instability of wind resources and the operational characteristics of wind power units, implementing the frequency modulation as well as the voltage regulation, and controlling the power vibration of the system in the same way as conventional power generation are difficult. The increase in wind power in proportion to the total power capacity weakens the capability of adjusting and controlling the power network. Once a breakdown incident occurs in the power network, it will aggravate the incident and even trigger the collapse of voltage, with the technological problem remaining unresolved. In addition, with the conventional way of constructing wind power systems, wind energy resources can not become a substitute to fossil fuel energy at a large scale, even if there is a significant decline in the price of wind power. To solve the problem mentioned above, Gu (2008a) proposed an innovative idea of utilizing an LSNGCWP system, which received funding support from the Major State Basic Research Development Program of China (973).

The LSNGCWP means that the terminal load of the wind power system is no longer the traditional single network. Instead, it can be directly applied to a series of highly-efficient industries and other special areas adaptable to the characteristic of wind power or mainly applied to a large-scale wind power farm with 0.5–10 GW power quantity. Different from the traditional wind power system, the LSNGCWP system does away with the limitations of traditional power networks (Fig. 1). The development of the LSNGCWP system is not only related to the development of new non-grid-connected wind power turbines but also to the high energy consumption industries in terms of their requirements, prospects, choices, and overall arrangements. Therefore, based on these principles and fundamental concept, an LSNGCWP system is not only a technical challenge but an industrial challenge as well.

2.2 LSNGCWP industry

The wind power industry generally refers to various sectors involved in the comprehensive exploitation of



CNC system means computerized numerical control system

Fig. 1 Comparison of grid-connected and non-grid-connected wind power systems

wind energy resources. From the traditional perspective, these sectors include research, customer service, wind turbine manufacturing, field construction and installation businesses, and electric power maintenance. The industrial chain of LSNGCWP can be divided into three main parts: the R&D departments and manufacturing-related industries of new non-grid-connected wind power turbine in the upstream; the wind power industries in the midstream, which include wind power, wind farm installation, and maintenance; and power-consuming industries in the downstream, which consist mainly of electrolytic aluminum and copper smelting industries, chlorine-alkali industries, coal-to-methanol industries, and other heavy chemical industries.

Compared with the traditional wind power industries, the following advantages of non-grid-connected wind power industry can be concluded.

First of all, being a new strategic industry, the non-grid-connected wind power industry has worldwide significance in terms of innovation and applicability. Related industries were also created, such as the wind turbine and parts manufacturing industry formed in support of the development of the LSNGCWP system, and the low emission energy-intensive industries powered by non-grid-connected wind energy.

Second, the non-grid-connected wind power industry extends industrial chains. The development of non-grid-connected wind power industry should consider the industrial energy consumption, which is quite different from the case of traditional power industries. This means that the construction of non-grid-connected wind power must make arrangements for some derivative industries, thus creating a longer industrial chain.

Third, the non-grid-connected wind power industry is a low-carbon industry. In the industrial chain for non-grid wind power, the upstream and midstream industries are typical low-emission industries. Furthermore, the large-scale wind power generation can substitute for the fossil fuel previously needed by energy-intensive industries, resulting in a significant reduction in the total amount and intensity of carbon emissions from related industries.

2.3 LSNGCWP industrial zones

Due to its many advantages over the traditional wind power industry, the non-grid-connected wind power industry should be arranged in advance in the context of a low carbon economy. To fulfill the purpose of conserving energy and reducing carbon emissions, the development of nonferrous metals, the salt chemical industry, and the coal chemical industry will be restricted even if they are urgently required. The coordination between the utilization of LSNGCWP and the optimization of energy-intensive industries will not only settle the power use after the construction of LSNGCWP, which accelerates the adjustment of energy-intensive industries, but will also contribute to maintaining the momentum of rapid economic growth while keeping a low-carbon development of coastal areas, which are still dominated by the heavy chemical industry. Creating industrial zones is effective in organizing industries in large-scale regions. Thus, constructing the first LSNGCWP industrial zone in the coastal areas of China is feasible and necessary.

As an industry-intensive area in a certain geographical space, an industrial zone is generally established along an infrastructure (e.g., a railway, highway, waterway, or pipeline) and is usually based on the industrial agglomeration around central cities or transportation hubs. Based on the distribution of wind resources and reliance on the central cities, the LSNGCWP industrial zone will assemble the machinery and spare parts manufacturing and the construction and maintenance of wind farms, salt industry, nonferrous metallurgy, and coal chemical industry together in accordance with the technical and economic links between these industries. In this case, the LSNGCWP industries will be intensively distributed along the coast and infrastructure lines. The spatial model of LSNGCWP industrial zones in the coastal area is presented in Fig. 2.

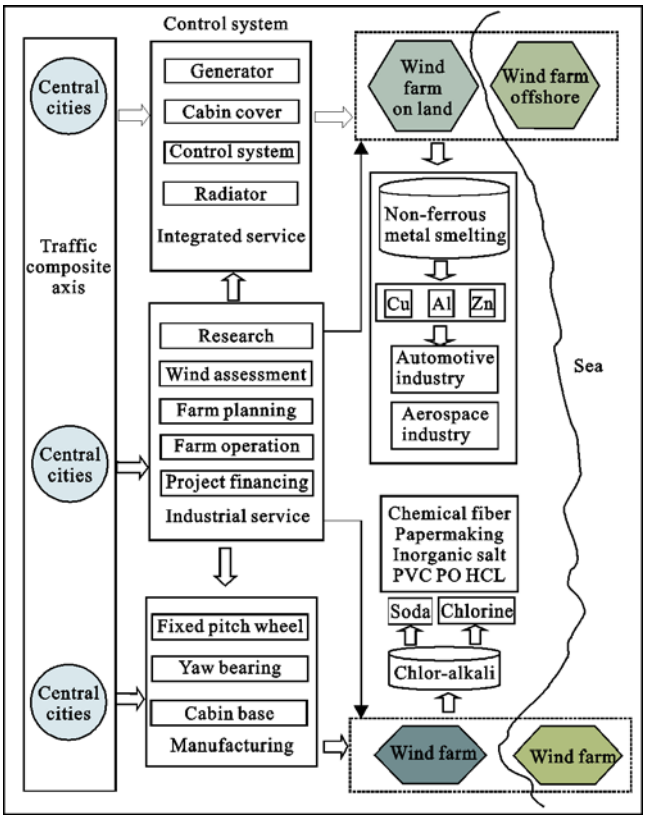


Fig. 2 Spatial model of LSNGCWP industrial zones in coastal areas

3 Materials and Methods

3.1 Study area

According to *China Marine Statistical Yearbook*, a coastal area is an area with a coastline. The coastal areas in the mainland of China include nine provinces, one autonomous region, two special administrative regions, and two municipality-cities with administrative division standards. Considering the data accessibility, 11 coastal areas were chosen as the target subjects: Zhejiang Province, Shanghai Municipality, Jiangsu Province, Shandong Province, Tianjin Municipality, Hebei Province, Liaoning Province, Fujian Province, Guangdong Province, Hainan Province, and Guangxi Zhuang Autonomous Region.

The total area of study regions is 1.27×10^8 km^2. The population and gross domestic product in 2009 in China′s coastal areas were 4.9×10^8 and 2.07×10^9 yuan (RMB), respectively. The wind energy resources in the coastal areas can be divided into land-based wind energy and off-shore wind energy. The coastal areas do not only have the biggest wind resource belt of the terrestrial area, which is made up of coastal zones and inland areas, but also the offshore wind energy resource belt, which is mainly composed of areas within 20 km from the sea coast. Thus, China′s coastal areas are rich in wind energy resources. Furthermore, the coastal areas have a high demand for nonferrous metals, chemical products, and other industrial raw materials used in industrialization processes, which demand high energy consumption due to the fact that they are still in the process of industrialization. Taking the caustic soda industry as an example, the production reached 1.13×10^7 tons in the coastal areas in 2008, accounting for 61.22% of the national output. Consequently, the coastal areas have a basic market that needs the LSNGCWP industrial zone development.

3.2 Data sources

In order to make a quantitative analysis, this study placed importance on data collecting, which is mainly concerned with wind energy, industry, nature resources and socio-economy. Three kinds of data were used in this study: 1) wind energy resource data from literature, such as the available wind intensity and hours of available wind, college electronics ranking, *etc*. (Li, 2005; Liu *et al*., 2007; Wu, 2008); 2) socio-economic data including deposits in the whole society taken from China Statistical Yearbook of 2008 (NBSC, 2009) and China Industry Statistical Yearbook of 2008 (NBSC, 2009), such as the general manufacture percentage in China and the special manufacture percentage in China, machinery and electric equipment output in China, bauxite (raw coal, crude salt, copper) amount, Electrolytic Aluminum (electrolytic coppers, soda, methanol) output, regional power consume amount, GDP, deposits in the whole society, *etc*.; 3) qualitative assessment of data from experts, such as bauxite (raw coal, crude salt, copper) availability, Electrolytic Aluminum (electrolytic coppers, soda, methanol) demand, big city position in the whole country.

3.3 Index system and weight

The arrangement of LSNGCWP industrial zones is a technical process of arranging the wind power industry chain in coastal areas, with considerations for the distribution of wind energy resources, the structure of the city, and the current situation and plan for the transport system, focusing on the arrangement of wind energy-

intensive industries. And it is crucial to convert the factors of industrial distribution to quantitative evaluation. As such, this paper constructs an index system to evaluate the arrangement in accordance with non-grid- connected wind power consuming industries, non-grid-connected wind power manufacturing industries, non-grid-connected wind power services industries respectively by the method of progressive analysis of factors, in which non-grid-connected wind power consuming industries mainly consist of four industry sectors: 1) wind power & electrolytic aluminum; 2) wind power & electrolytic coppers; 3) wind power & chlor-alkali; and 4) wind power & methanol. The indicator system of each industry sector is different in grade-three indexes which are determined by Delphi method. The indexes and weights are shown in Table 1.

Table 1 Evaluation indicator system for distribution of large-scale non-grid-connected wind power industries in coastal areas

Types of industries	Grade-two indexes	Grade-three indexes
Wind power consuming industries (wind power & electrolytic aluminum, wind power & electrolytic coppers, wind power & chlor-alkali and wind power & methanol)	Wind energy resource capabilities (0.5)	Available wind intensity (0.5) Hours of available wind (0.5)
	Resources base (0.2)	Bauxite (raw coal, crude salt, copper) amount (0.6) Bauxite (raw coal, crude salt, copper) availability (0.4)
	Development perspective (0.2)	Electrolytic aluminum (electrolytic coppers, soda, methanol) output (0.5) Electrolytic aluminum (electrolytic coppers, soda, methanol) demand (0.5)
	Development risk (0.1)	Regional power consume amount (0.6) GDP (0.4)
Wind power manufacturing industries	Present industrial base (0.3)	The number of wind enterprise
	Manufacturing base (0.5)	General manufacture percentage in China (0.4) Special manufacture percentage in China (0.3) Machinery and electric equipment output in China (0.3)
	Wind energy resource capabilities (0.2)	Available wind intensity (0.5) Hours of available wind (0.5)
Wind power services industries	City development base (0.4)	Big city number (0.6) Big city Position in the whole country (0.4)
	Human resources and technology (0.3)	College electronics ranking (0.6) The number of wind power research institute (0.4)
	Financial support (0.3)	Deposits in the whole society

3.4 Evaluation model of industrial arrangement of LSNGCWP

To arrange a LSNGCWP industry in the coastal areas, this paper introduces an integrated assessment model for industrial arrangement.

$$p_{E-A}^{i}=\sum_{k=1}^{4}f(B_k)=\sum_{j=1}^{2}\omega_j\Phi_j+\sum_{j=3}^{4}\omega_j\Phi_j+\sum_{j=5}^{6}\omega_j\Phi_j+\sum_{j=7}^{8}\omega_j\Phi_j \tag{1}$$

$$p_{E-C}^{i}=\sum_{k=1}^{4}f(B_k)=\sum_{j=1}^{2}\omega_j\Phi_j+\sum_{j=3}^{4}\omega_j\Phi_j+\sum_{j=5}^{6}\omega_j\Phi_j+\sum_{j=7}^{8}\omega_j\Phi_j \tag{2}$$

$$p_{C-A}^{i}=\sum_{k=1}^{4}f(B_k)=\sum_{j=1}^{2}\omega_j\Phi_j+\sum_{j=3}^{4}\omega_j\Phi_j+\sum_{j=5}^{6}\omega_j\Phi_j+\sum_{j=7}^{8}\omega_j\Phi_j \tag{3}$$

$$p_{ME}^{i}=\sum_{k=1}^{4}f(B_k)=\sum_{j=1}^{2}\omega_j\Phi_j+\sum_{j=3}^{4}\omega_j\Phi_j+\sum_{j=5}^{6}\omega_j\Phi_j+\sum_{j=7}^{8}\omega_j\Phi_j \tag{4}$$

$$p_{MA}^{i}=\sum_{k=1}^{3}f(B_k)=\sum_{j=1}^{1}\omega_j\Phi_j+\sum_{j=2}^{4}\omega_j\Phi_j+\sum_{j=5}^{6}\omega_j\Phi_j \tag{5}$$

$$p_{R-S}^{i}=\sum_{k=1}^{3}f(B_k)=\sum_{j=1}^{2}\omega_j\Phi_j+\sum_{j=3}^{4}\omega_j\Phi_j+\sum_{j=5}^{5}\omega_j\Phi_j \tag{6}$$

$$\Phi_j=\frac{e_j-m_j}{M_j-m_j}=\begin{cases}1 & e_j\geq M_j\\ \dfrac{e_j-m_j}{M_j-m_j} & m_j<e_j<M_j\\ 0 & e_j\leq m_j\end{cases} \tag{7}$$

where, $p_{E\text{-}A}^{i}$, $p_{E\text{-}C}^{i}$, $p_{C\text{-}A}^{i}$, and p_{ME}^{i}, represent the assessment value of wind power & electrolytic aluminum, wind power & electrolytic coppers, wind power & chlor-alkali and wind power & methanol being arranged in

place i respectively; p^i_{MA} and $p^i_{R\text{-}S}$ are the assessment value of non-grid-connected wind power manufacturing industries and non-grid-connected wind power services industries in place i; k is the number of Grade-two indexes, B_k is the assessment value of grade-two indexes; ω_j is the weight of index j; Φ_j is the fuzzy subordinative degree influencing index j, varying between 0 to 1; e_j is the exact value of index j; M_j, m_j are the maximum and the minimum of the jth index.

3.5 Accomplishment of industrial arrangement of LSNGCWP

This study imports the comprehensive evaluation indexes into GIS spatial database and visualizes the evaluation result by linking with topological data. On the basis of data, it outputs the industrial distribution evaluation graphics on non-grid-connected wind power manufacturing industries, non-grid-connected wind power services and non-grid-connected wind power consuming industries, which includes wind power & electrolytic aluminum, wind power & electrolytic coppers, wind power & chlor-alkali and wind power & methanol. Overlaying the spatial graphics by GIS technique and refer to existing development axes, this study determines the industrial distribution area, and accomplishes the industrial arrangement of large-scale, non-grid-connected wind power industrial zones.

4 Spatial Arrangements of LSNGCWP Industries in Coastal Areas

4.1 Result of assessment index system for LSNGCWP industrial zones

All the data were standardized according to Equation 7 and the assessment value of LSNGCWP industry arrangement were calculated according to equations 1 to 6 in the 11 coastal areas, as shown in Table 2.

4.2 Spatial arrangement of LSNGCWP industrial zones

Based on the results in Table 2, a spatial overlay analysis using the geographic information system technology was made, and the visualization of this idea is presented in Fig. 3. Based on the analysis above, the spatial arrangement of the LSNGCWP industrial zones in coastal areas can be designed as shown in Fig. 4, summarized as the ″one line and three circles″ structure. According to the spatial structure, it is feasible to organize the LSNGCWP industrial zones in such a way that the coastal areas can accommodate the development of the LSNGCWP industry, avoid the risks, and still be able to establish the industry progressively.

The term ″one line″ refers to the coastal composite development axis that includes the coast-island zone, the off-shore zone, and the highway connecting the coastal areas. This line will be the foundation for the LSNGCWP industrial zones and become a venue for thriving industries. The ″three circles″ refers to the Pearl River Delta LSNGCWP industrial base region, which includes seven cities of Guangdong Province, such as Guangzhou, Zhongshan, Foshan, Dongguan, Shenzhen, *etc*.; the Yangtze River delta LSNGCWP industrial base region, which includes Zhejiang Province, Jiangsu Province, and Shanghai Municipality; and the Bohai Bay Rim LSNGCWP industrial base region, which includes Shandong, Hebei, and Liaoning provinces.

The industries arranged in the Yangtze River delta LSNGCWP industrial base region includes wind power & electrolytic aluminum, wind power & chlor-alkali,

Table 2 Value of assessment index system for arrangement of LSNGCWP industrial zones in coastal areas of mainland of China

	Wind power & electrolytic aluminum	Wind power & electrolytic coppers	Wind power & chlor-alkali	Wind power & methanol	Wind power manufacturing industries	Wind power services industries
Tianjin	0.327	0.000	0.653	0.000	0.000	0.000
Hebei	0.653	0.353	0.728	0.644	0.621	0.000
Liaoning	0.531	0.565	0.000	0.535	0.728	0.535
Shanghai	0.000	0.000	0.000	0.000	0.000	0.817
Jiangsu	0.515	0.000	0.864	0.000	0.821	0.535
Zhejiang	0.625	0.324	0.505	0.532	0.654	0.000
Fujian	0.425	0.734	0.000	0.000	0.000	0.000
Shandong	0.621	0.565	0.772	0.767	0.000	0.000
Guangdong	0.534	0.658	0.557	0.512	0.000	0.438
Guangxi	0.827	0.471	0.000	0.645	0.000	0.000
Hainan	0.000	0.000	0.000	0.000	0.000	0.000

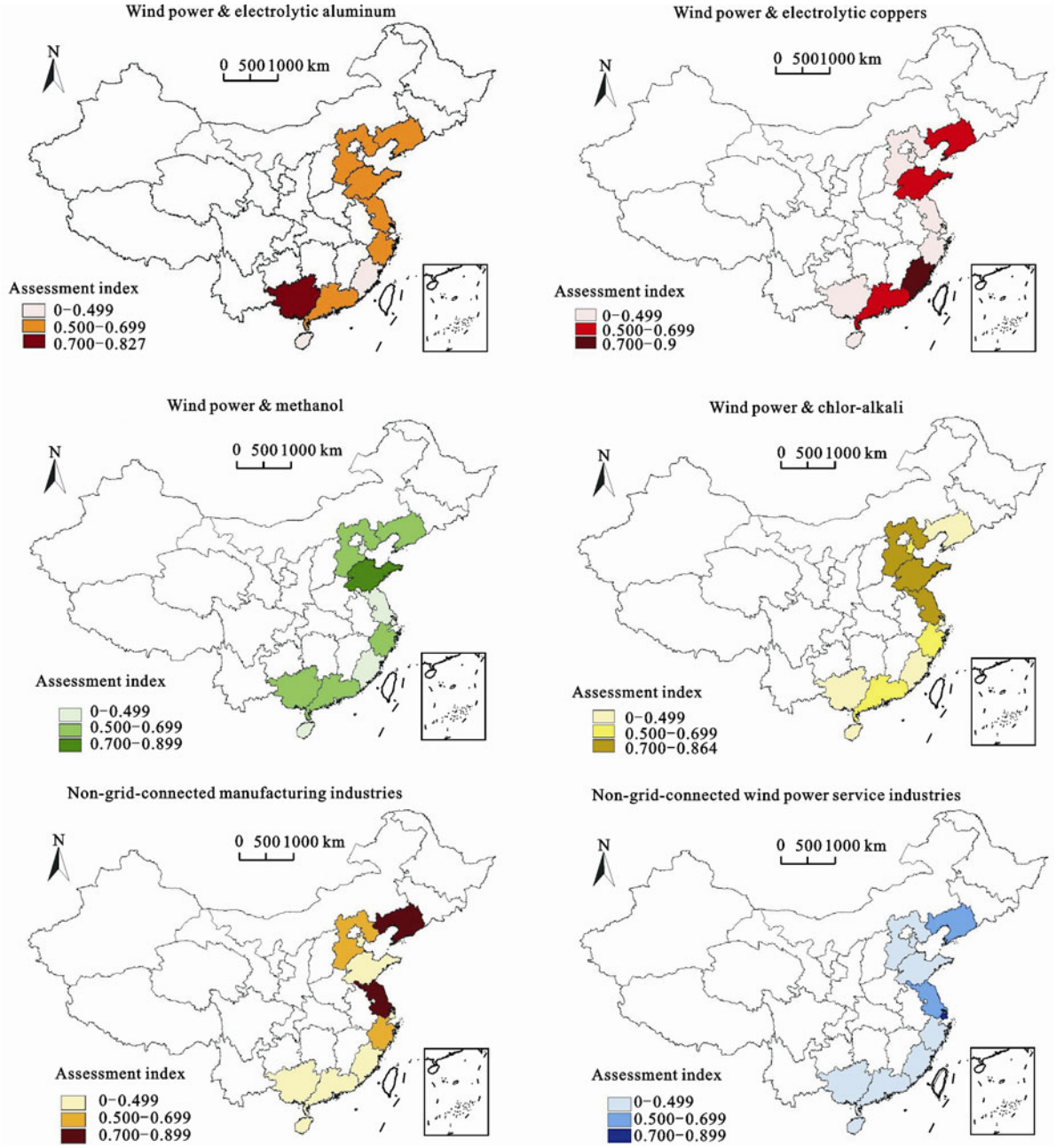
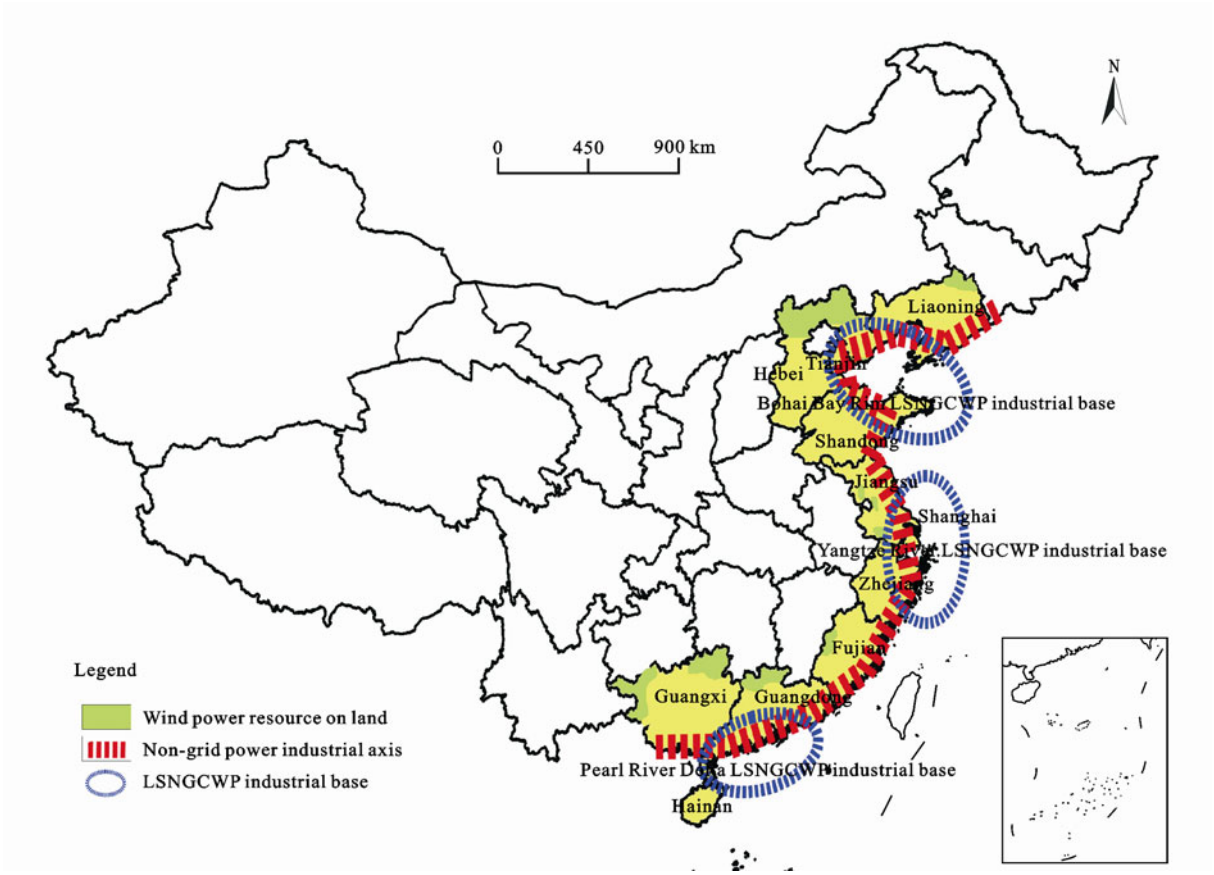


Fig. 3 Spatial analysis of arrangement of LSNGCWP industrial zones in coastal areas of mainland of China

non-grid-connected wind power manufacturing industries, non-grid-connected wind power services industries. Based on this arrangement, the industries planned to be in the coastal areas of northern Jiangsu are two electrolytic aluminum plants of 1.0×10^5 t/yr, one ion membrane caustic soda plant of 4.0×10^5 t/yr, and one PVC production base of 4.0×10^5 t/yr. Relying on the regional advantages in economy, finance, and technology, Shanghai will focus on modern services, such as wind farm project assessment, wind energy resources survey, non-grid-connected wind power technology, and non-grid-connected wind power finance and insurance. The areas of Nanjing, Nantong, Hangzhou, Ningbo, and other places will prioritize the development of non-grid-connected wind power technology research and the development of equipment manufacturing and other industries. Wenzhou and Taizhou will advance wind power-caustic soda and wind power-copper industries, among others.

The Pearl River Delta LSNGCWP industrial base re-



LSNGCWP means large-scale, non-grid-connected wind power

Fig. 4 Spatial arrangements of LSNGCWP industries in coastal areas

gion is generally arranged into three parts: the electrolytic aluminum base of 2.0×10^5 t/yr relying on wind farms and the national hub port in Shantou and Zhanjiang, the chlor-alkali chemical industry base of 8.0×10^5 t/yr relying on the wind farms in Huizhou, Shantou, and Zhanjiang, and the electrolytic copper industries relying on the wind farms in Shanwei and Yangjiang.

The Bohai Bay Rim LSNGCWP industrial base region composes of the southern Liaoning and eastern Liaoning peninsula, and the northwestern Hebei and eastern Shandong peninsula. By virtue of the Dalian deep-sea port and the advantages of existing industries, some carbon-free and energy-intensive industries, such as electrolytic aluminum and methanol, will be established. The wind power industry base in northwestern Hebei will rely on the wind power energy resources in Zhangjiakou and Chengde to develop chlor-alkali and methanol industries. The Shandong peninsula will primarily promote the chlor-alkali, electrolytic aluminum, electrolytic coppers, coal methanol, and other energy-intensive industries.

5 Discussion and Conclusions

The metallurgical and chemical industries, such as nonferrous metal smelting and salt chemical industries, provide the basic raw materials needed for industrialization in China. However, they also consume huge amounts of fossil fuel energy. The electrolytic aluminum and chlor-alkali productions consume 5% and 1.5% of national annual energy output, respectively. Therefore, using non-grid-connected wind power as a substitute for thermal power is practical and meaningful to be able to conserve energy and reduce carbon emission.

According to the evaluation results of arrangement of LSNGCWP industrial zones in coastal areas of mainland of China, non-grid-connected wind power consuming industries should be arranged in Hebei, Liaoning, Zhejiang, Guangdong and Jiangsu provinces, non-grid-connected wind power manufacturing industries should

develop in Hebei, Zhejiang, Jiangsu and Liaoning provinces, and non-grid-connected wind power services industries should be arranged in Shanghai Municipality, Jiangsu and Liaoning provinces. Therefore, these areas in coastal areas should take the ′one line and three circles′ structure as the framework and choose the superior areas as the primary development zones.

In addition, the coordinated development of LSNG CWP and energy-intensive industries has been provided with resources and market fundamentals. Although there are promising prospects for the non-grid-connected wind power industry, there are still some crucial scientific problems that need to be resolved.

To promote the progressive development of LSNG CWP in coastal areas, the following aspects should be studied further. First, there should be focus on the selection of wind power consuming industries in a wider range. Second, studying how the LSNGCWP technology can aid in the industrialization process is necessary. Lastly, the large-scale development and utilization of wind energy resources in off-shore areas should be studied further, such as the supporting structure of off-shore wind turbine, the measurement and assessment of off-shore wind energy resources, the technical specification system of off-shore wind power, and the research and development of large wind turbines.

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