sustainability

MDPI

Article

Study on the Evolution Mechanism and Development Forecasting of China's Power Supply Structure Clean Development

Xiaohua Song, Xubei Zhang *, Yun Long and Yiwei Guo

School of Economic and Management, North China Electric Power University, Beijing 102206, China; sxh@ncepu.edu.cn (X.S.); longyun@ncepu.edu.cn (Y.L.); guoyiwei@ncepu.edu.cn (Y.G.)

* Correspondence: xb.zj@ncepu.edu.cn

Academic Editor: Tomonobu Senjyu

Received: 31 October 2016; Accepted: 26 January 2017; Published: 5 February 2017

Abstract: The clean development of China's power supply structure has become a crucial strategic problem for the low-carbon, green development of Chinese society. Considering the subsistent developments of optimized allocation of energy resources and efficient utilization, the urgent need to solve environmental pollution, and the continuously promoted power market-oriented reform, further study of China's power structure clean development has certain theoretical value. Based on the data analysis, this paper analyzes the key factors that influence the evolution process of the structure with the help of system dynamics theory and carries out comprehensive assessments after the construction of the structure evaluation system. Additionally, a forecasting model of the power supply structure development based on the Vector Autoregressive Model (VAR) has been put forward to forecast the future structure. Through the research of policy review and scenario analysis, the paths and directions of structure optimization are proposed. In this paper, the system dynamics, vector autoregressive model (VAR), policy mining, and scenario analysis methods are combined to systematically demonstrate the evolution of China's power structure, and predict the future direction of development. This research may provide a methodological and practical reference for the analysis of China's power supply structure optimization development and for theoretical studies.

Keywords: China's power supply structure; clean development; evolutionary analysis; forecasting research; System Dynamics(SD); Vector Autoregressive Model (VAR)

1. Introduction

Although China has a wealth of energy resources, coal is still the main source of energy production. The long-term coal-fired electricity production and consumption has led to a high proportion of coal in the energy system. Coal accounted for 64% of China's total energy consumption in 2015, and 60% of China's electricity is supplied by coal currently. Power structure clean development issues, such as haze and other prominent environmental problems, the overcapacity of coal-fired power generation, and the low proportion of renewable energy consumption have become constraints on China's energy revolution and low-carbon development.

In recent years, the Chinese renewable energy construction scale has expanded unceasingly, which provides effective support for the development and optimization of the power source structure. However, due to the time-variability, uncontrollability, and the intermittent nature of renewable energy, China has experienced a huge waste of electric energy, poor coordination of regional power development, and production problems with peak load regulation and grid stability. Power construction is fast but inefficient. National Energy Board data show that in the first half of 2016, 32.3 billion kWh of wind power was abandoned. Therefore, the optimal allocation of energy resources and the utilization efficiency still needs to be greatly improved. China has clearly put forward the crucial development goal of promoting the rational development and utilization of renewable energy in the 13th Five Year Plan [1]. It is necessary to use technological innovation and management to improve the power source structure of China and to support the supply side reform of the power sector.

The evolution of the power structure is a long-term, dynamic, complex, and interactive process. The system structure is influenced by various factors such as socio-economic development, industrial policy formulation, and technological innovation. A clean low-carbon power source structure is the inevitable trend of China's future development. With the continuous reform of China's supply side and the deepening of power system reform under the comprehensive control of internal and external factors, China must deal with the prominent issues of total quantity control, structural optimization, coordinated development between the main bodies, and government integration with the market.

In this paper, based on data mining of the process of China's power supply structure, we present in-depth studies of the evolution mechanism and the key influence factors, construct a clean development forecasting model of the power supply structure, and put forward the optimized development path. These studies can provide theoretical support and practical references for the overall optimization of the power supply structure and its green and efficient harmonious development in China.

2. Literature Review

In the context of clean development, single power development, the driving force of power supply structure adjustment, and the methods of structure analysis are the main research directions in the existing literature.

Thermal power occupies a dominant position in China's power structure, which has posed a challenge for the clean development of the power industry [2], so that clean energy still has a long way to go toward China's power supply structure clean development. Peggy and Kenneth [3] argued that China's over-investment in thermal power capacity has resulted in an abnormal development of the overall power industry. Murata et al. [4] studied the benefits of the Clean Development Mechanism (CDM) in China on energy conservation and emission reduction. Menegaki et al. [5] believe that renewable energy sources that can hedge the risks of traditional energy price volatility are critical to China's sustainable development. The increase in clean energy generation makes China's irrational power structure gradually move towards a rational and stable structure [6]. Feng et al. [7] expounded the status and development of wind power installations in China, the distribution of wind resources, and the distribution of large-scale wind power installations, and concluded that China's wind power has great potential. In the process of expanding renewable energy, the resulting problems are increasingly significant. Because the use of renewable energy technology is not fully mature, Siddiqui et al. [8] confirmed that a significant amount of R&D investment to reduce costs by promoting technological advances has reduced the market competitiveness of renewable energy sources compared to traditional fossil fuels. After analyzing the development of distributed power generation from the aspects of the power system, technology, and economic obstacles, Liu et al. [9] pointed out that there are still many problems such as high cost, excessively high selling price, poor regulating ability, and insufficient consumption space with regards to renewable energy in China.

The evolution of the power supply structure may be affected by multiple factors such as resource conditions, system optimization, and environmental protection [10]. El-Kordy's research suggested that externalities and environmental costs need to be considered when installing new power generators [11]. Gong et al. [12] believed that Environmental Dynamic Models are important tools for understanding and predicting the impacts of global and environmental changes due to natural or anthropogenic factors. John et al. [13] demonstrated that the carbon intensity is strongly related to energy intensity, type, and structure by using the Laspeyres model. Hirstet al. [14] explored the key role of low-carbon factors in power plans from the perspective of policy and technology. At the same time, politics has increasingly become a decisive factor in the direction and speed of the development of individual energy sources, especially renewable energy [15]. The policies promulgated by the government guide the direction of power structure change [16]. In the case of the electricity market not being mature, the Chinese government began to guide the conversion of the power supply structure, vigorously promoting renewable energy development [17].

In the analysis of the power supply structure, the existing literature has deeply studied many methods and models. Steenhof et al. [18] constructed a relatively complete evaluation index system of China's power structure optimization and used fuzzy pattern recognition, principal component analysis, and other methods to analyze the degree of optimization in order to provide a more intuitive basis for power supply structure adjustment decisions. Cai et al. [19] used the Long-range Energy Alternatives Planning System (LEAP) modelto predict and analyze the future power supply structure of China, and concluded that replacing coal-fired power plants with more efficient nuclear power is the future development trend in China. At present, there are three kinds of models commonly used in research: (1) Systematic models such as the System Dynamics(SD) model, gray system prediction model, and the Artificial Neural Network(ANN) model [20]; (2) Inheritance structure models, such as the LEAP model; (3) Hybrid class models. The System dynamics(SD) model was first proposed by the American scholar Forrester in the early 1950s [21], and it can solve problems of a complex system with high order and nonlinear multiple feedback, so it has been widely used in the energy research field [22]. Hosseini et al. [23] analyzed the future trend of conventional and unconventional oil production and capacity expansion rates using a system dynamics approach. Alexander et al. [24] evaluated Mekong Delta adaptation strategies with system dynamics modeling. Bowen Xiao et al. [25] used the method of system dynamics to analyze the current situation of natural gas power generation, influencing factors, and the development trend of installed capacity. The Vector Autoregressive Model (VAR) model based on economic theory can be used to predict the dynamic relationship between energy and the economy because it can provide a more accurate forecast value [26]. Bin et al. [27] used the Vector Autoregressive model to analyze the influencing factors of the changes in carbon dioxide emissions in China's iron and steel industry.

The related research has described the change of the single power and the whole power supply structures, and analyzed the development trend of the power supply structure with the combination of economic and environmental factors. At present, there are few studies on the analysis of the evolution mechanism and evaluative features of the power supply structure. Studies on the integration of power supply structure adjustment with new market changes and new policies and regulations are still sorely lacking. In this paper, based on the analysis of China's power supply structure clean evolution and forecasting model construction, we analyzed the new situation and its complex environment, and proposed the optimization of China's power supply structure development, in order to provide a reference for the analysis and optimization of China's power supply structure clean development.

3. Methodology

3.1. Research System

In this paper, as shown in Figure 1, the evolution of China's power supply structure and the trend of clean development will be analyzed in depth. Based on the analysis of the current situation and the complex environment of the power supply structure in China, we constructed an analysis system of the power structure evolution mechanism based on system dynamics, and extracted the key influence factors for the clean development of the power supply structure. This method of data analysis is used to build a comprehensive evaluation system. The VAR model is used to establish the forecasting model of China's power supply structure development. The key influence factors extracted by system dynamics are added to the model and the empirical analysis is carried out using the data of the last 20 years. Since policy is uncertain and hard to quantify, the paper is devoted to the analysis of this factor, which is not included in the VAR model construction. After the analysis of the policy, the scenario hypothesis is put forward to optimize the development goal and path of the power supply structure in the near future. Finally, the corresponding policy recommendations are presented.

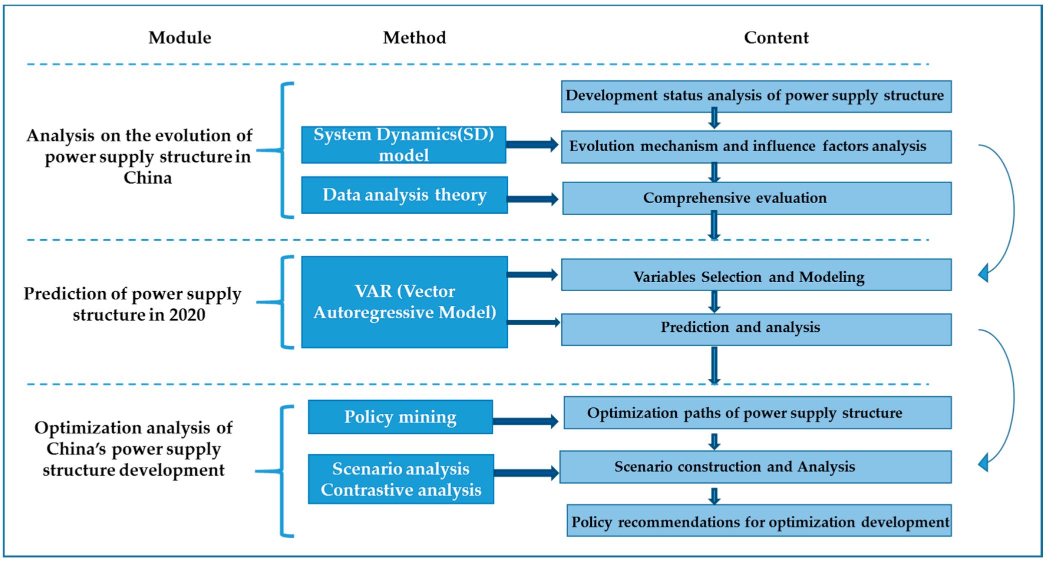


Figure 1. Framework diagram of the paper ideas.

3.2. Methods

3.2.1. System Dynamics Analysis

The system dynamics analysis method is the basis of this paper, for constructing the analysis model of the power structure evolution mechanism, which was firstly initiated by Professor Forrester from the USA in the 1950s [28]. The pivotal view of system dynamics is that the system is composed of units, units of movement, and information. The system is called the unity of structure and function, with integrity, correlation, hierarchy, stability, similarity, and purpose. The motion of the elements leads to a certain causal relationship between the elements, which can be illustrated by a feedback loop. Some or all of the feedback loops in the system together constitute the basic structure of the system. When changes of two units are in the same direction, this expression is called positive feedback motion and the opposite is called negative feedback motion. For example, the growth of the installed capacity of thermal power adds to the emission of pollutants such as sulfur dioxide, which results in high pollution treatment costs. Enterprises will expand clean energy production to avoid the high cost of social pollution control, so the generation of clean energy will increase. The feedback relationship between the variables formed by the transfer of this unit movement is the basis for the analysis of the power supply structure evolution in China. If the cause is represented by C, R is the result, and the direction of causality is represented by the semicircular arc, then the causal feedback relationship between C and R can be expressed as Figure 2.

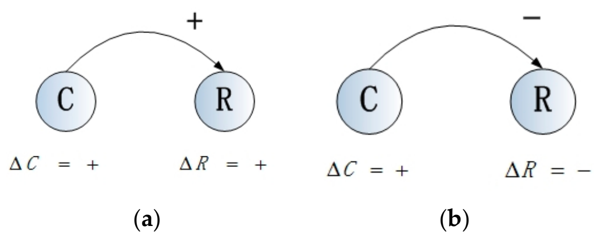


Figure 2. Causality in two kinds of feedbacks. (**a**) Positive feedback; (**b**) Negative feedback.

Figure 2a shows positive causal feedback, while Figure 2b exhibits negative causal feedback. The causal feedback loop, which is used to explain the inner development of things, is formed by linking the open causal feedback relations end to end. The power structure system is also composed of many different feedback loops, the internal mechanism of which is complex and coordinated. In this paper, the system dynamics model is used to mine the internal relations of the evolution of China's power supply structure, so as to analyze the structure of the system and the logical relationship among the elements effectively.

3.2.2. Vector Autoregressive Model (VAR)

Vector autoregressive models are commonly used to explore the correlation of time series systems and the dynamic effects of random disturbances on the system. The VAR method avoids the requirements of the structured model by constructing each endogenous variable as a function of the hysteresis value of all endogenous variables in the system. Consequently, the univariate autoregressive model is extended to autoregressive models composed of multiple time series variables. The time variation of the installed capacity of the single power supply type within the power supply system is suitable for building a VAR model. When it is necessary to analyze three or more time series, the model fully reveals its superiority.

The mathematical expression of the VAR (p) model with regressive lag order p is:

$$y_t = \Phi_1 y_{t-1} + \cdots + \Phi_j y_{t-j} + c + \varepsilon_t \tag{1}$$

In the expression: t represents the length of the time series, t = 1, 2 , . . . , n; Φ_j is an n × n matrix of autoregressive coefficients, j = 1, 2, ..., p; c represents one (n × 1) vector of the constant term, and ε_t is a (n × 1) white noise vector, which is characterized by:

$$E(\varepsilon_t) = 0 \tag{2}$$

$$E(\varepsilon_t \varepsilon_\tau) = \begin{cases} \Omega \; t = \tau \\ 0 \; t \neq \tau \end{cases} \tag{3}$$

where Ω is a (n × n) symmetric positive definite matrix.

4. Evolution of China's Power Supply Structure Clean Development

Power structure adjustment should not only meet the requirements of the system power consumption and load level, but should also ensure the security, stability, and economic operation of the power system. Therefore, the evolution of the power structure is a long-term, dynamic, complex, and interactive process, which is influenced by the characteristics of the power system and the national economic development, power demand, technical level, resource endowment, and government policy. Studies on the evolution mechanism must take the influence of multiple factors such as the power system, economy, and environment into account, with the purpose of grasping the power structure evolution direction and trend accurately.

4.1. Analysis of the Current Situation of the Power Supply Structure in China

China has been committed to the optimization of the power structure adjustment, but thermal power still dominates the power supply structure (Figure 3). Nuclear power, hydropower, wind power, solar power, and other renewable energy sources have been developed to a certain extent. Fossil fuel energy generation occupies 65.93% of the power supply structure. Coal is still the main fossil fuel energy source for power generation; its proportion is still as high as 59.01%. The share of gas-fired and oil-fired power generation is small. Regarding non-fossil fuel power generation, the highest proportion comes from hydropower. Pumped storage power is also developing in certain areas. Wind power has become the third largest power supply source in China.

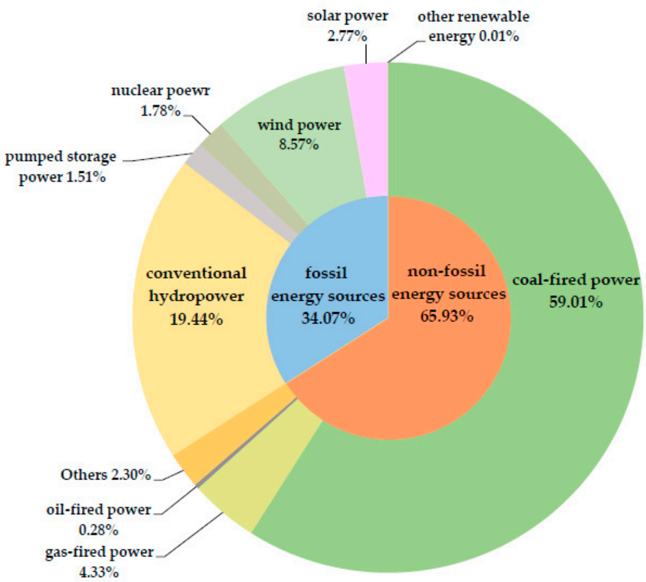


Figure 3. China's power supply structure in 2015 (data is from China's National Energy Administration [29]).

In the overall context of clean development, the proportion of thermal power in China's power supply structure shows a downward trend. At the same time, there is strong momentum in the development of renewable energy. Thermal power has the natural advantages of availability, economy, and safety, while renewable energy power generation has problems of instability and dissipation. Therefore, China's thermal power-based power supply structure has not changed for a long time. In recent years, with the guidance of China's national policy and the rising level of marketization, the rapid development of clean energy is moving the power supply structure in the direction of clean evolution.

4.2. Analysis of the Clean Evolution Mechanism of China's Power Supply Structure Based on the System Dynamics Method

System dynamics is applicable to the dynamic behavior of complex feedback systems and is widely used in the study of social economic systems. It emphasizes the interrelationship and interaction between the system and the environment. The behavior pattern and characteristics of the system are mainly rooted in its internal dynamic structure and feedback mechanism. The research object is the power supply structure system in China. The evolution of the power supply structure is the result of a series of factors interacting with each other, which is consistent with the law of cause and effect. There are multiple feedbacks within the power system, and many of the complex interdependencies cannot be described linearly. Therefore, the construction of the power structure evolution mechanism analysis system founded on system dynamics helps to clarify the main influencing factors of the evolution of the power structure, and sort out the system structure and the logical relationship of elements.

In the evolution of China's power structure, the environmental factors of carbon emissions and environmental pollution are significant in restricting the expansion of thermal power. The power system stability and power generation cost, which are determined by the characteristics of the power system, have a negative causal relationship with the increase of the proportion of renewable energy power generation. Consequently, this paper analyzes the interaction between the power supply system and three subsystems: the whole electric power system, environment, and policy. After considering the interaction mechanism among the subsystems, the power system evolution mechanism analysis system is constructed, as shown in Figure 4.

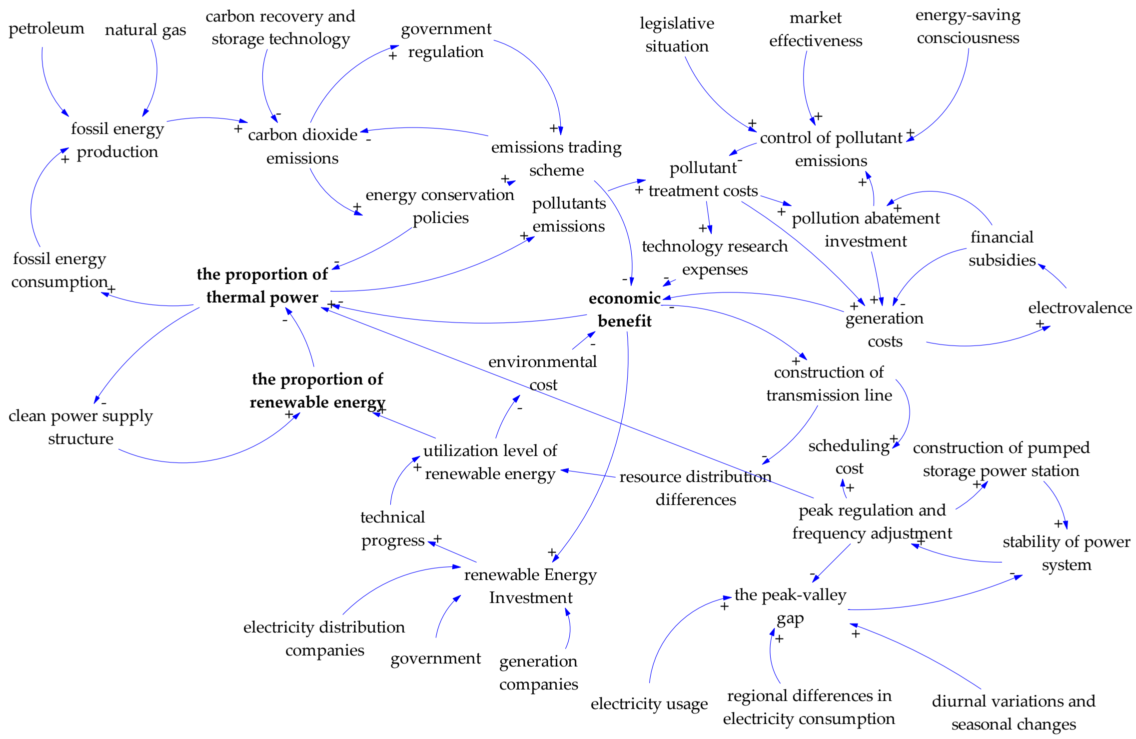


Figure 4. Analysis of China's power supply structure evolution mechanism.

Through the analysis of the causal diagram of system dynamics, it is found that in the process of evolution, the integration of the power system itself determines that the thermal power, with strong peaking capacity, can occupy the basic position in the power supply structure. Additionally, it is difficult to improve the proportion of renewable energy in the short term because of low on-grid energy and backward transmission facilities. Although thermal power has basic advantages, its development is controlled by government-led carbon emissions trading and environmental costs. The increase of the economic benefit brought by the government's compensation for renewable energy has become the main driving force of its development. The increase in the share of renewable energy has benefited greatly from the gradual increase in the level of utilization and from the acceleration of the grid construction, to a certain degree.

Thus, under the guidance of environmental pressure, policy, and the power system itself, the key to thermal power development is to **reduce energy consumption** and **pollutant emissions** in order to achieve cleaner production.

Under the support of the policy to understand the regional and user differences, rational distribution, accelerating the **construction of the power grid infrastructure** is important for breakthroughs in renewable energy. It is the fastest way to realize breakthrough development of renewable energy, by a rational power generation layout and by promoting grid infrastructure construction after mastering the regional and user differences.

4.3. Comprehensive Evaluation of China's Power Supply Structure Clean Development

In this paper, the evolution of China's power structure from 1952 to 2015 is analyzed from two dimensions: time and space. Data processing and computational analysis help us to further explore the evolution characteristics and build a comprehensive evaluation system of the clean development of China's power supply structure, as shown in Figure 5 below.

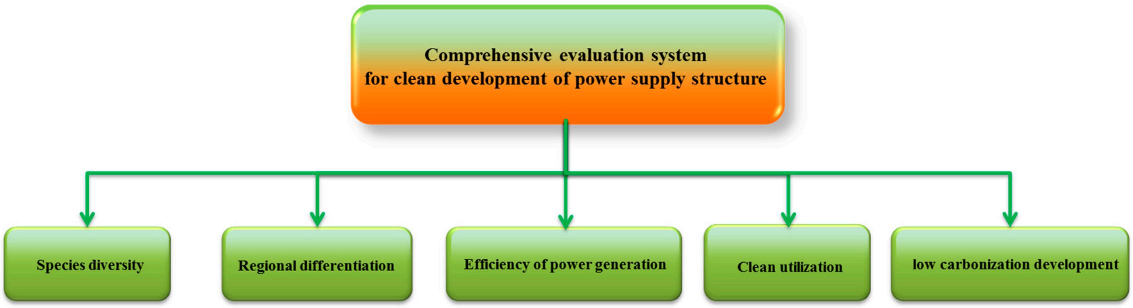


Figure 5. Comprehensive evaluation system of the clean development of China's power supply structure.

4.3.1. Evaluation of Diversity

The types of power supply are increasingly diversified in China. In the early 1970s, as shown in Figure 6, China's power industry relied solely on thermal power and hydropower. Today, thermal power, nuclear power, and various types of renewable energy jointly constitute China's power supply system. With the further maturation of technology, biomass, tidal energy, geothermal energy, and other types of renewable energy sources also began to generate electricity. Diversification is the best choice to change China's over-reliance on coal and to ensure the safety and stability of the power supply under the influence of environmental and policy factors. Competition among different types of power supply, such as thermal power and renewable energy, stimulates the transformation of the power supply structure to one that is clean and highly efficient.

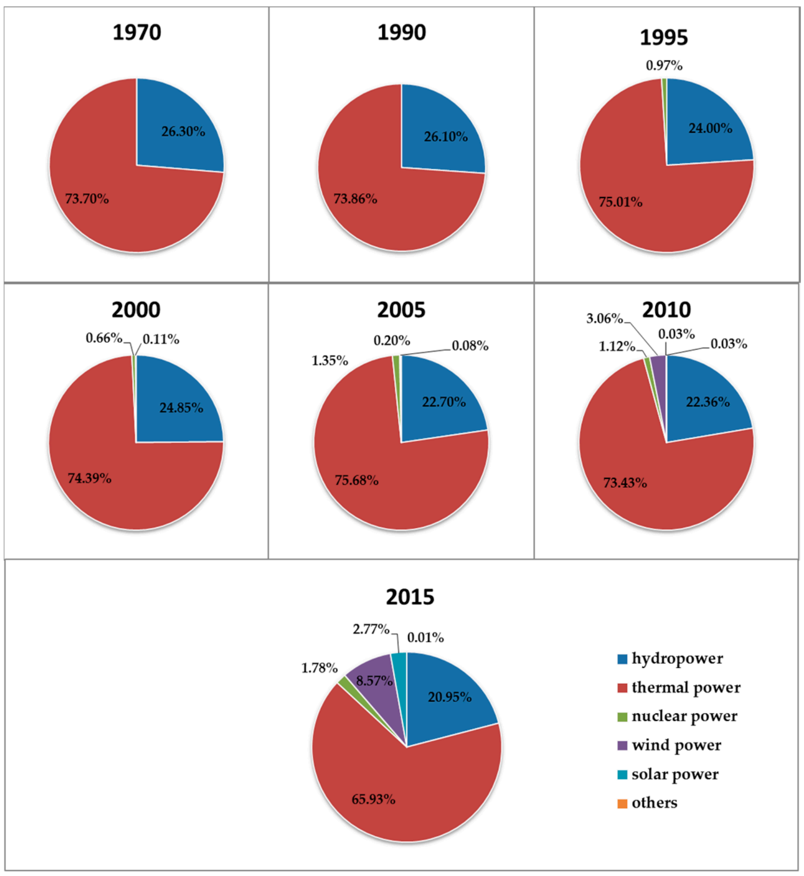


Figure 6. Comparison of China's power supply structure in different years (data is from China's Electric Power Yearbook [30,31]).

4.3.2. Evaluation of Distribution Rationality

Resource development, environmental pollution, policy, and other factors make the regional power structure differentiation become increasingly prominent. As shown in Figure 7, in the initial stage of evolution, the vast majority of regions have only two types of power supply, and thermal power occupied the dominant position. The diversification of the power supply has promoted the development of new energy sources in different regions. The diversity of resources widened the regional power supply structure differences. In coal-rich areas such as Shanxi Province, thermal power has the absolute dominant position, while the southwestern region is dominated by hydropower. The regional distribution of a single power supply also shows a distinct character. For example, under the influence of the Fukushima disaster and other factors, China's nuclear power installed capacity is limited to coastal areas due to prudence and safety considerations. Solar power generation is mainly concentrated in the northwestern region on account of solar energy resource constraints.

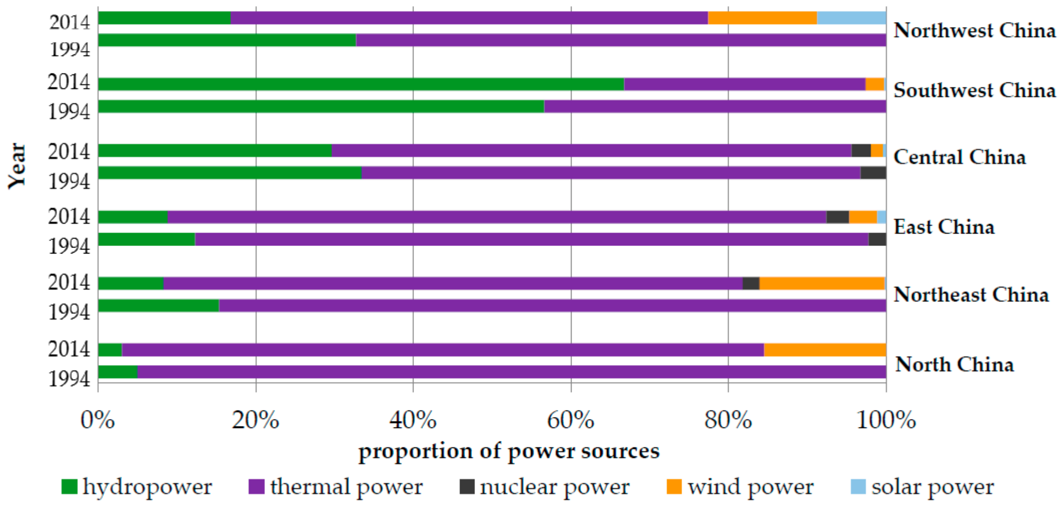


Figure 7. Comparison of regional distribution in China's power supply structure development (data is from China's National Energy Administration [32,33]).

4.3.3. Evaluation of Energy Efficiency

The direct result of the power structure evolution is the promotion of both single power generation efficiency and the whole operation efficiency of the electric power system. An efficient and reasonable power structure should not only be able to meet the electricity demand, but should also maintain reasonable and stable operation of the power system as a whole, so that the supply side and demand side can gain maximum benefits. From the power system operation point of view, the optimal standard of the power supply structure does not exist. However, there is still room for the optimization of the power supply structure within a single power supply. Further optimization of the structure adjustment could do better in fitting the characteristics of the low load, medium load and peak load while continuously improving the power generation efficiency and benefits. The replacement of inefficient thermal power generation units, the development of efficient energy sources such as nuclear power, and the construction of peaking power source are driving the power structure towards the direction of business-like evolution. As shown in Figure 8, under the request of clean development, the proportion of large units of thermal power increased significantly while the power consumption rate and the station service power consumption decreased rapidly. The power generation efficiency has been gradually improved. The imperative increase in the proportion of pumped storage and other peak power set China's power system operation on a mature and efficient development path.

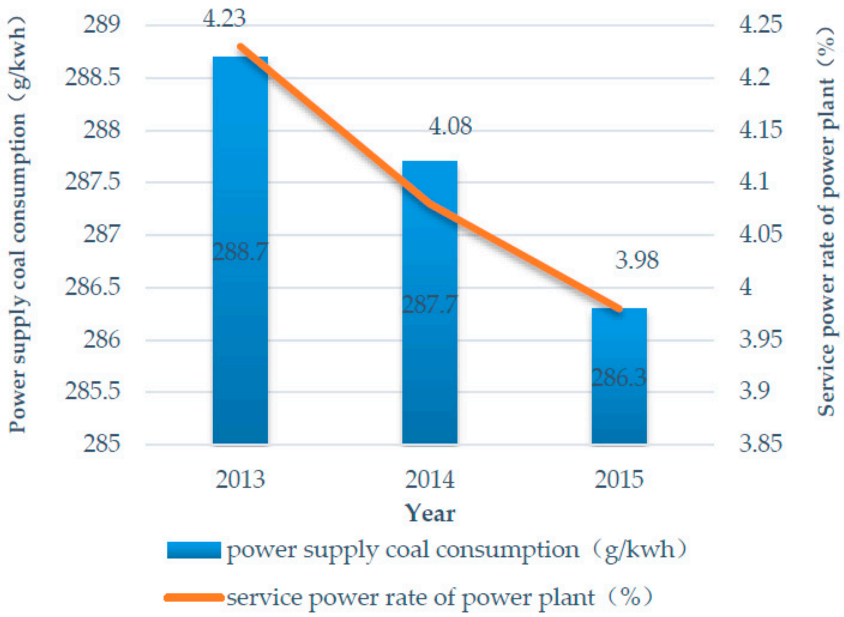


Figure 8. Efficiency indicators of 1000 MW thermal power unit from 2013–2015 (data is from China's Electric Power Yearbook [30,31]).

4.3.4. Evaluation of Clean Utilization

Based on carbon emissions and pollutant emissions incentives, the clean development of China's power path is reflected by two aspects: the clean use of fossil fuels and the positive development of non-fossil fuel energy sources.

The resistance to the clean development of China's power structure mainly comes from coal-fired power generation. From the trend of the evolution of China's power structure, as shown in Figure 9, the proportion of natural gas and methane in thermal power generation increased year after year, and clean production technologies such as the flue gas desulfurization (FGD) method was gradually popularized. As shown in Figure 9, the proportion of clean energy in the power supply structure also showed an upward trend. With the gradual maturation of power generation technology, the renewable energy industry has developed rapidly. Renewable energy, as well as nuclear power with non-pollutant emissions, are the main forces in the clean evolution of China's power supply structure.

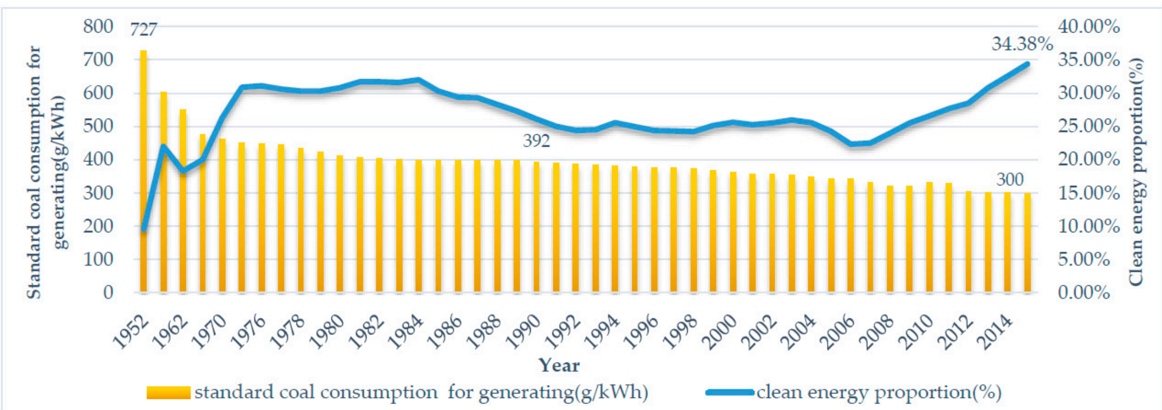


Figure 9. Standard coal consumption and share of clean energy in China's power generation (data is from China's Electricity Yearbook [30]).

4.3.5. Evaluation of Low Carbonization Development

Under the requirement of sustainable development, low carbonization is the inevitable result of the power structure evolution. Clean utilization and species diversity contributes to the low-carbon transformation of the power supply structure. China's power industry made great efforts to change from the energy-intensive traditional industrial model to a low-carbon mode. Rapid development of the low carbon power supply (especially wind power and solar power) facilitated the boost of the renewable energy proportion.

With the support of national policy, wind power and solar power generation had amazing growth. As shown in Figure 10, after the explosive growth in the early stages of development, the growth rate gradually flattened because of the increasingly saturated wind power marketand the rationality of development. In addition to wind power and solar power generation, the types of renewable energy power generation are increasingly diversified, including direct combustion of agricultural waste, power generation by garbage incineration, cogeneration, biogas, gasification, and biomass power generation. These power generation methods not only became mature technologies, but also made great progress in cost reduction and the promotion of economic efficiency. Many new energy power stations have good performance and have made outstanding contributions to reduce pollutant and carbon emissions from power generation.

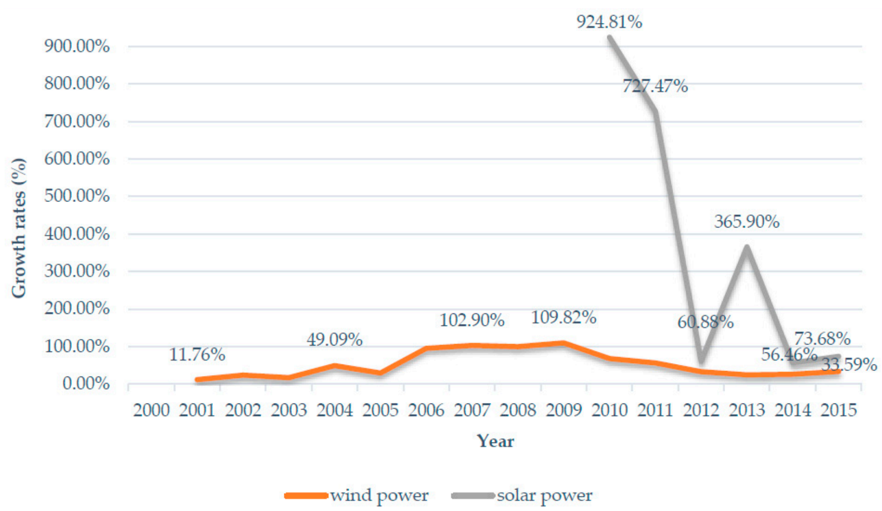


Figure 10. Growth of major renewable energy sources in China (2000–2015) (data is from China's National Energy Administration [34]).

5. Prediction of the Power Structure Evolution Trend Based on the VAR Model

5.1. VAR Model Establishment

Considering the power supply structure as a whole, under the interaction of the power system, environmental pressure, and policy, the development of various power sources has interactive influence. The variation of the installed capacity of one type of power supply may be directly or indirectly influenced by the installed capacity of the last period or the last several periods. It is appropriate to analyze and predict the power supply structure of China by using the Vector Autoregressive Model(VAR), which is suitable for multiple time series variables. One of the applications of the unconstrained VAR model is to make predictions. The VAR model regards every endogenous variable as a function of the hysteresis of all the endogenous variables in the system. Based on this model, the evolution trend of the power supply structure in the future is predicted.

The system dynamics analysis of the evolution of the power supply structure in Section 4.2 shows that the key factors affecting the development of thermal power are energy consumption, pollutants, and carbon dioxide emissions. The acceleration of grid infrastructure construction is an important way to promote the proportion of renewable energy in the power supply structure. For the sake of data validity, integrity, and completeness, as shown in Table 1, this paper selected the proportion of five primary power supply types and influence factors from 1994 to 2015 to build the model. Figure 11 shows the raw data of the proportion of the main power sources. Prior to 2005, there was no separate statistics on coal-fired power generation and gas-fired power generation. Therefore, the thermal power data in this paper include both coal-fired and gas-fired power generation.

Table 1. Variables selection.

Year	Variables Names	Measuring Units	Variable Symbols	N
1996–2015	the proportion of thermal power	%	W_1	20
	the proportion of hydropower	%	W_2	
	the proportion of nuclear power	%	W_3	
	the proportion of wind power	%	W_4	
	the proportion of solar power	%	W_5	
	standard coal consumption(coal-fired generation)	g/(kW·h)	E_1	
	annual investment of power grid	billion yuan	E_2	
	annual carbon dioxide emissions	million tons	E_3	

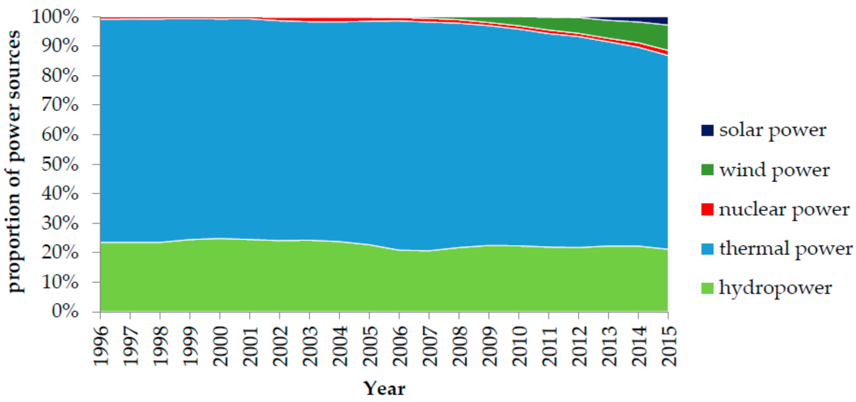


Figure 11. Changes of the proportions of the main power sources from 1996 to 2015 (data is from China's Electric Power Yearbook [30]).

The share of geothermal power generation, marine energy, and other new energy sources in China's current power supply structure is still very small. Therefore, we can assume that hydropower, thermal power, nuclear power, wind power, and solar power constitute the overall power supply structure, namely:

$$w_1 + w_2 + w_3 + w_4 + w_5 = 1 \tag{4}$$

In order to eliminate heteroscedasticity of the time series and guarantee the data's stability, this paper preprocesses each variable in advance. There are a lot of missing values for the data of previous years, since wind power and solar power generation started much later. The missing values are altered to constants ζ, which are sufficiently small so that the conversion of data will not change the trend of the original time series. Then, we take the logarithm of all data. After the completion of data pre-processing, Augmented Dickey-Fuller tests are used to check whether each series has a trend.

Upon inspection, the original sequences are non-stationary. It is necessary to test the stationarity of the first difference of the series. The results of the first difference Augmented Dickey-Fuller (ADF) test are shown in Table 2. After the first difference, the time series are stationary series except for W_1 and E_3. The prerequisite for constructing the VAR model is that the time series is homogeneous. Thus, this paper builds the model with six sequences, excluding the two variables W_1 and E_3. The cointegration test is carried out in the next step because of the nonstationarity of the original data. Results are presented in Table 3.

Table 2. Results of the first difference Augmented Dickey-Fuller (ADF)test at 5% level.

Series	ADF *t*-Statistic	Prob.	Leg Length	Stationarity
W_1	−1.535155	0.4958	0	Non-stationary
W_2	−4.343612	0.0034	1	Stationary
W_3	−3.251002	0.0317	0	Stationary
W_4	−4.249909	0.0039	0	Stationary
W_5	−3.133713	0.0401	0	Stationary
E_1	−5.780225	0.0002	1	Stationary
E_2	−3.780571	0.0123	3	Stationary
E_3	−1.360259	0.5803	0	Non-stationary

Table 3. Unrestricted cointegration rank test.

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5% Critical Value	Prob.
None *	0.993074	94.47585	40.07757	0.0000
At most 1 *	0.987748	83.63914	33.87687	0.0000
At most 2 *	0.841758	35.02892	27.58434	0.0046
At most 3	0.659100	20.44715	21.13162	0.0621
At most 4	0.431467	10.72922	14.26460	0.1683
At most 5	0.163358	3.388818	3.841466	0.0656

Notes: * Denotes rejection of the hypothesis at the 0.05 level.

The trace test indicates no more than three cointegrating equations at the 0.05 level. This is likely to be associated with a small amount of sample data and does not affect the construction of the VAR model [35]. As shown in Table 4, the optimal lag order of the VAR model is 2, by the principle of the minimum Akaike Information Criterion(AIC) and Schwarz Criterion(SC).

Table 4. Vector Autoregressive Model (VAR) lag order selection.

Lag	AIC	SC
0	−6.116586	−5.818342
1	−6.352325	−4.264617
2	−14.09063	−10.21346

The VAR (2) model is constructed as Table 5.

Table 5. VAR (2) model coefficient matrix.

	W_2	W_3	W_4	W_5	E_1	E_2
W_2(1)	1.049026	−1.283851	−5.176256	−7.110045	0.275014	3.195738
W_2(-2)	−0.539673	3.914823	−3.235774	14.41504	0.353436	−3.842315
W_3(-1)	0.047249	0.699818	−0.259935	−0.586071	0.024584	−0.919362
W_3(-2)	−0.101284	−0.398884	2.096625	−1.045495	−0.087339	0.053323
W_4(-1)	0.014071	−0.066653	−0.244075	0.292642	0.002302	−0.211251
W_4(-2)	−0.03549	−0.12981	0.255988	0.329940	−0.013385	−0.243074
W_5(-1)	0.014367	0.160528	0.297816	−0.01652	−0.019799	−0.062399
W_5(-2)	−0.027906	−0.21765	0.280529	0.334601	−0.015083	0.027896
E_1(-1)	−0.91967	−8.843629	3.979128	2.044497	−0.217903	4.616790
E_1(-2)	0.811793	−0.427889	−11.49752	−8.042921	−0.083813	1.826295
E_2(-1)	−0.045558	−0.435968	2.140392	−0.776267	−0.082883	−0.27316
E_2(-2)	−0.022952	0.102758	1.276162	0.852739	−0.031316	0.146463
C	0.015892	0.044282	−0.679188	0.152316	0.022505	0.400879

A sufficient and necessary condition for a stable VAR model is that all eigenvalues are within the unit circle. Figure 12 indicates that no root lies outside the unit circle. VAR (2) satisfies the stability condition which can be applied in the power supply structure prediction. The model fitting degree, R2, is greater than 70%.

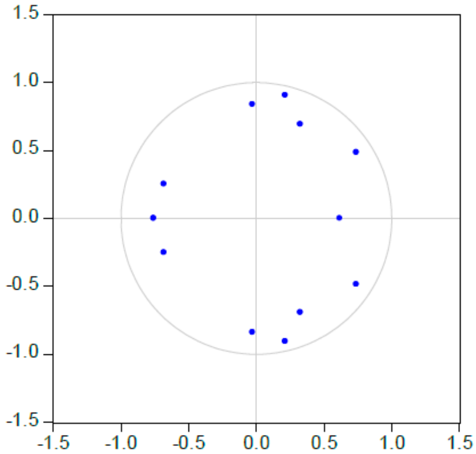
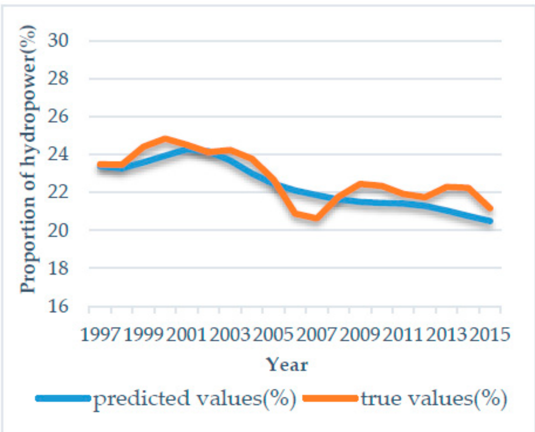


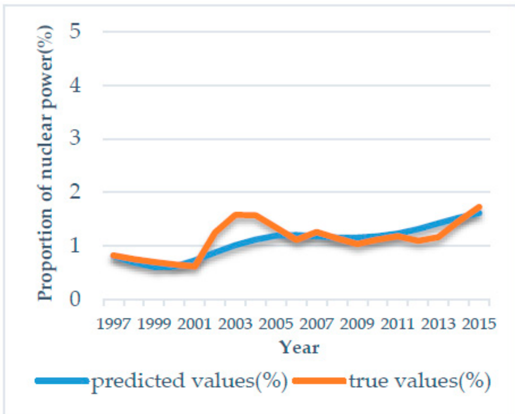
Figure 12. Inverse roots distribution diagram of the Auto Regression(AR)characteristic polynomial.

Through the VAR (2) model, we obtain the growth rate of each time series in the next five years, to calculate the predicted value. Comparison of the predicted values and the real values can help us to understand the accuracy of the model (Figure 13). The curves of the VAR (2) model fit the trend of each time series well, but it is smoother than the real value curves, which is consistent with common sense. Because the proportion of the various types of power supply may be subject to the macroeconomic environment, policies, and other uncontrollable factors, their volatility is relatively large.

In a word, the model is credible. Analysis of the forecast results will be presented in Section 5.2. From the trend of the time series evolution, W_3 may increase slowly. W_2 and E_1 may show a downward trend in the next five years, while W_4, W_5, and E_2 show a more obvious growth trend.

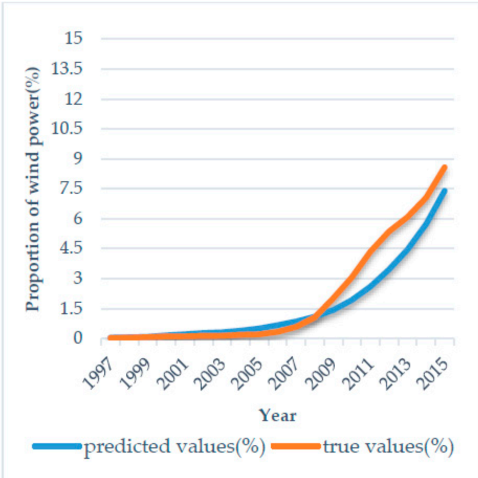


(**a**) W_2

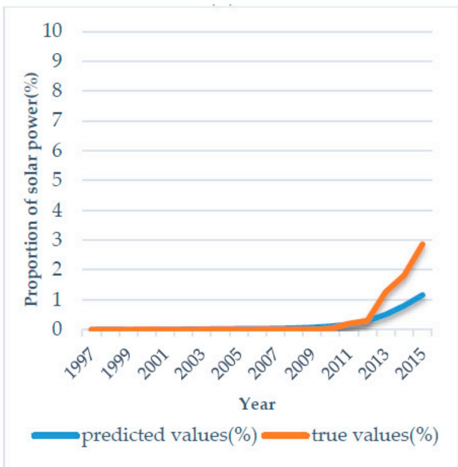


(**b**) W_3

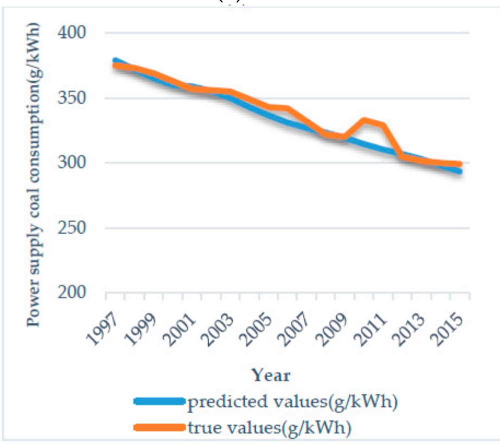
Figure 13. *Cont.*



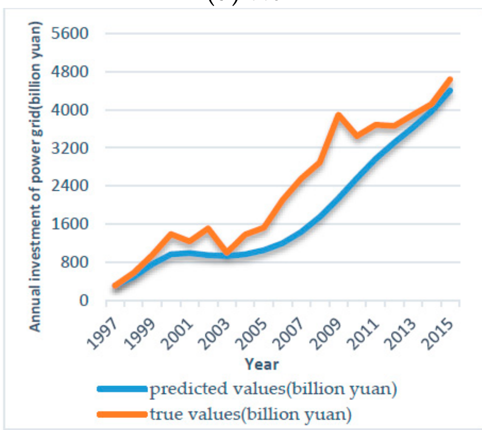
(c) W4



(d) W5



(e) E1



(f) E2

Figure 13. Fitting analysis of predicted values and true values. (**a**) The contrast between predicted values and true values of W_2; (**b**) The contrast between predicted values and true values of W_3; (**c**) The contrast between predicted values and true values of W_4; (**d**) The contrast between predicted values and true values of W_5; (**e**) The contrast between predicted values and true values of E_1; (**f**) The contrast between predicted values and true values of E_2.

5.2. Forecasting Results Analysis

In this paper, we construct the stable VAR (2) model to forecast the power structure of China in 2020, and the results are shown in Figure 14.

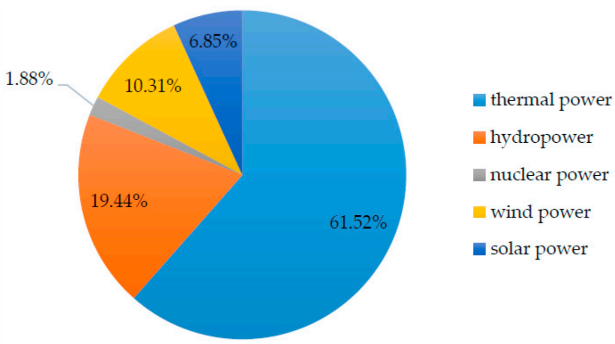


Figure 14. Forecast of China's Power Supply Structure in 2020.

The proportion of thermal power generation in 2020 will be lower than 62%; it falls by 4.13% compared with that of 2015. However, thermal power still occupies the main position in the power supply structure, which will pose huge challenges to carbon dioxide reductions and haze governance in China. Nuclear power development is relatively conservative. Compared with 2015, its share rises only 0.15%. Hydropower, wind power, and other renewable energy sources in 2020 account for 36.6% in the power supply structure. Within five years, it increases by about 4%. This is a considerable improvement, because renewable energy accounted for only 25% in 2010. Among the renewable energy sources, only the proportion of hydropower may slightly decline. China's hydropower development started relatively early, so it's potential is insufficient compared with new energy sources such as wind power. Wind power remains as China's third major power supply. The proportion of solar power has also been greatly improved. If the issue of renewable energy reception is better resolved, its proportion may grow faster.

Overall, in the next five years, China's power supply structure will move in the direction of clean and low-carbon production, which presents a more obvious optimization.

6. Optimization Analysis of China's Power Supply Structure Clean Evolution Based on Policy Guidance

Policy usually plays an important guiding role in the evolution of the power supply structure [36]. The results from the analysis of the evolution mechanism indicated that policy has been one of the important driving factors in the evolution of the power supply structure in China. Power development policy will have a direct or indirect impact on the installed capacity of various power supply types. In particular, coercive and restraining policies for the power supply structure adjustment are particularly effective. Because of the long construction period of large-scale power projects, it is necessary to make adjustments to the structure and the overall arrangement in advance, in order to avoid huge wastes of investment and resources. Policy planning will help to meet the power supply in a more economical, clean, and efficient way, and support the healthy development of the national economy. Policy is not suitable for further data modeling since it is difficult to quantify.

In this section, firstly, the paper discusses the recent power supply policy in China, and then carries out the optimized scenario analysis. Finally, the paper analyzes and summarizes the future direction of China's power supply structure under the influence of policy factors, compared with the VAR forecasting results.

6.1. Power Supply Structure Optimization Path under the Policy Guidance

Various types of policies, such as macroeconomic policies, national development plans, and industrial policies will have an impact on the further optimization of the power structure [37]. The research range focuses on electric power planning in the 13th Five-Year Plan and policies enacted by China's National Energy Administration the National Development and Reform Commission in the last two years. Through combing and analyzing these policies, the power supply structure optimization path under policy guidance can be presented.

As shown in the Table 6, electric power planning conveys a clear signal to the directions of main power sources development from 2016 to 2020. The overall development of thermal power may be inhibited. Gas-fired power shows higher levels of government support than for coal-fired power. China is still cautious about nuclear power. Safety is the priority in the development process. Renewable energy development is strongly encouraged by the state. The positive hydropower development under the premise of environmental protection is affirmed. Planning stresses that wind power should be focused on both the development and decentralized development. On the contrary, solar energy should focus on distributed development.

Table 6. Power sources development guidelines in the 13th Five-Year electric power plan.

Power Sources		Development Guidelines in Next Five Years
Thermal power	Coal-fired power	transformation and upgrading of coal-fired power in order to achieve the efficient, clean, and sustainable development of whole thermal power
	Gas-fired power	orderly development of natural gas power generation, and accelerated construction of distributed gas-fired generation
Hydropower		Positive hydropower development under the prerequisite of ecological priority and resettlement
Nuclear power		safety development of nuclear power in coastal areas
Wind power		integrated planning, parallel developmentof centralized and decentralized wind farms, the joint development of land-based wind power and offshore wind power
Solar power		decentralized development, the realization of local absorption, technological progress and cost reduction
others		adjust measures to the local conditions

Combining the policy analysis, we can draw the main optimization path of the power structure under the policy guidance. As shown in Figure 15, the policy mainly promotes the optimization of the power supply structure through the power system and through industrial development. Clean energy utilization of fossil fuel energy, the optimization of the power source internal structure, and the upgrading of the renewable energy absorption capacity are the main guiding directions of the policy in the measures regarding electric power systems. Suppression of new coal-fired power plants and the upgrading of coal-fired units will promote the clean and efficient development of thermal power. Recently, the gradual seriousness of renewable energy curtailment made the government begin to pay more attention to its orderly development. Peaking powers such as pumped storage power are valued as unprecedented. The strong capacity of peak shaving will promote grid-connected generation and consumption of renewable energy. Improvement of energy storage technology on the user-side and electricity usage will all contribute to the stability of the power grid. From the industrial point of view, technological innovation and capital will stimulate the rapid development of the new energy industry. Ultimately, these will help to further optimize the power supply structure.

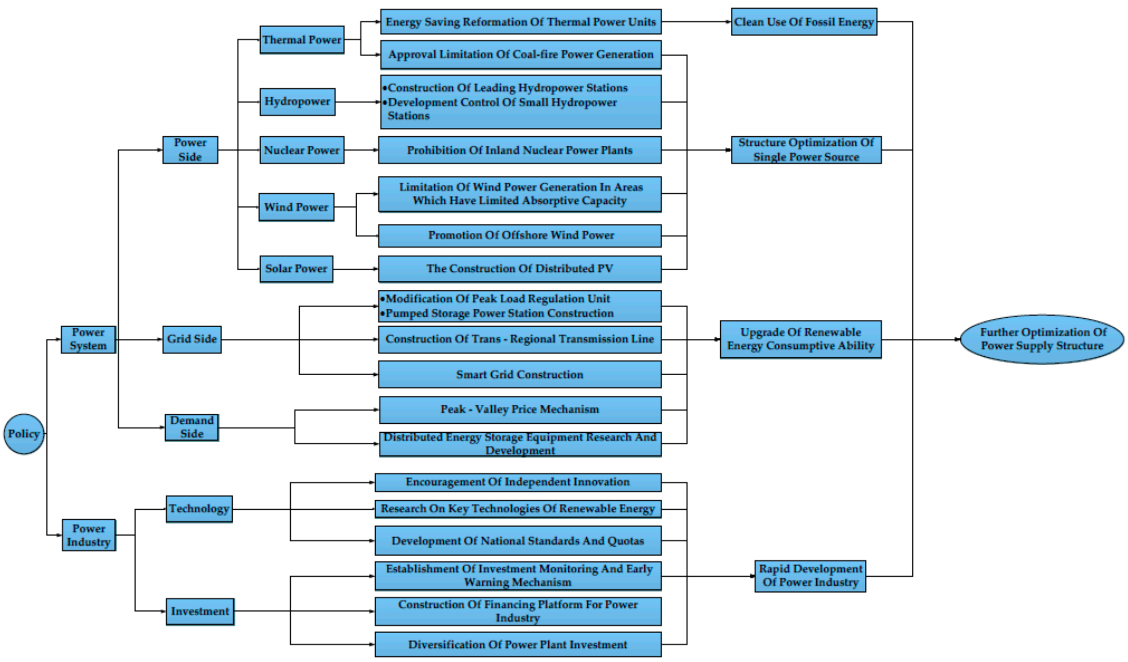


Figure 15. Power supply structure optimization paths under the policy guidance.

6.2. Prospect of China's Power Supply Structure Optimization in 2020 Based on Scenario Analysis

Scenario analysis which combines qualitative analysis with quantitative analysis can be used to predict and analyze the direction of the power supply structure optimization under the policy guidance. It recognizes the diversity of outcomes. The analysis of system dynamics indicates that carbon emission is also an important factor affecting the evolution of the power supply structure. Because of the non-stationarity of the carbon emission data, this paper does not include it in the construction of the VAR model. With the establishment of the unified national carbon trading market in 2017, low-carbon development becomes even more urgent for the whole power system. Based on the analysis of policy, the paper constructs two scenarios to analyze the development of the power supply structure in 2020. Carbon emission is the key distinguishing factor of the scenario assumptions. The expected rate of increase for each power supply is shown in Table 7.

Table 7. The growth rate settings for different scenarios.

Power Sources	① Average Annual Growth Rate in 2010–2015	② Growth Rate in Baseline Scenario	Growth Rate in the Enhanced Low-Carbon Scenario
Coal-fired power	6.27%	4.10%	②
Gas-fired power	19.13%	10.80%	②
Conventional hydropower	8.15%	2.80%	①
Pumped-storage power	6.39%	11.70%	②
Nuclear power	19.67%	16.50%	②
Wind power	34.29%	9.90%	(① + ②)/2
Solar power	168.67%	21.20%	②

(1) Baseline Scenario

This scenario set is in reference to the 13th Five-Year electric power plan. Planning is very crucial and indispensable pilot work. According to the load forecasting of a certain period of time, it can systematically consider the coordination among all kinds of power sources on the premise of meeting the demand of power load growth and various constraints. Therefore, it has scientific and practical value for research. In this scenario, by 2020, China's economy will maintain steady and moderate growth. There will be more emphasis on quality and efficiency, as well as the evolution of the power supply structure. The growth rates of this scenario are based on the targets set forth for electric power planning of the 13th Five-Year Plan published by the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA).

(2) The Enhanced Low-Carbon Scenario

After the start of the national carbon emissions trading market in 2017, the cost of carbon emissions will force an adjustment for the power enterprises which generating power from fossil fuels. Renewable energy may have a larger preponderance than ever before. We assume that the carbon dioxide emissions constraint in this scenario is stronger than for the baseline scenario. It is estimated that the growth rate of thermal power generation with large carbon emissions will continue to slow down, and zero-emission conventional hydropower and wind power will develop rapidly. Nuclear power and pumped storage power are vulnerable to the impact of this policy, therefore, they will have moderate growth. Blind investment and expansion of renewable energy will result in a large amount of abandoned electricity. As shown in Table 7, this paper makes some adjustments to their growth rates [38].

Based on the installed capacity of each power source in 2015 and different growth rates, this paper calculates the optimal power supply structure individually in 2020. The results are presented in Table 8.

Table 8. Comparison of the prediction results in different scenarios.

Power Sources		VAR Prediction Results	Baseline Scenario	The Enhanced Low-Carbon Scenario
Thermal power	Coal-fired power	61.52%	55.00%	45.12%
	Gas-fired power		5.50%	4.52%
Hydropower	Conventional hydropower	19.44%	17.00%	18.02%
	Pumped-storage power		2.00%	1.64%
Nuclear power		1.88%	2.90%	2.38%
Wind power		10.31%	10.50%	23.21%
Solar power		6.85%	5.50%	4.50%

In the enhanced low-carbon scenario, the share of thermal power is lower than in the baseline scenario. The proportion of hydropower is essentially flat. However, there are differences in the internal structure of hydropower. Conventional hydropower in the enhanced low-carbon scenario occupies a larger proportion. The growth of wind power is far beyond the plan expectations when taking the carbon emissions factor into account. On the contrary, the development of solar energy may be quite slow.

We can add the VAR model prediction results to the comparative analysis. Thermal power is still the most important power source in China among the three scenarios. Similarly, the thermal power proportion has a significant decline compared with 2015. The lowest proportion of thermal power appears in the enhanced low-carbon scenario. The proportion of hydropower in the three scenarios is relatively close. Wind power in the enhanced low-carbon scenario shows a substantial increase.

In conclusion, under the influence of multiple factors such as carbon dioxide emissions and policy, the share of thermal power will decrease significantly in the next five years while the proportion of clean energy will rise rapidly. Clean development and low carbonization of the power supply structure will deepen.

7. Suggestions on Clean Development of the Power Supply Structure in China

Through the analysis of the evolution of the power supply structure, prediction, and optimization, the diversification and cleanliness of the power supply structure in China is improved under the policy guidance, but there is still a gap regarding the optimization target. The power industry is a comprehensive one across all walks of life. It thus requires higher levels of policy coordination and a rational layout to drive the efficient allocation of resources within the industry. In the face of huge environmental pressure and the weak growth of power demand in China, the method of making a more rational and scientific adjustment of the power structure still remains a great problem. Combined with the optimization paths, this paper puts forward the following policy recommendations:

7.1. Promote Well-Rounded Industrial Innovation

At present, China needs to promote ideological innovation, technological innovation, and management innovation regarding the low efficiency of the power generation industry caused by insufficient electricity demand and excess supply. Conventional wisdom holds that consumption is determined by production. This concept should be changed in order to control the blind expansion of installed capacity. Key technological innovations such as special high-voltage transmission technology, high-efficiency photovoltaic cells, low-cost photothermal generators, large-capacity inverters, and micro-inverters should also be strengthened in various industries to reduce operating costs while improving the power generation efficiency. The innovations and breakthroughs of new technology can promote the technological innovation of the whole industry chain. In terms of fossil fuel energy generation, it is feasible to raise efficiency by optimizing the control technology and the unit supply structure, as well as establishing a diversified development concept. These changes will bring new vitality to the industry. Industrial business model innovation is also crucial. China should implement the "go-out" strategy of hydropower, thermal power, nuclear power, and grid projects to drive the export trade of related equipment, technology and services, and strengthen technical exchanges.

7.2. Impel the Coordinated Development of the Power Supply

The key of power structure optimization focuses on how to coordinate large-scale clean energy centralization and improve overall power system efficiency. The application of large grid-connected renewable energy puts forward higher requirements of peak regulation and reliable operation. Promoting the construction of the energy interconnection is essential for the fleet development of the electric power industry. The energy interconnection involves a great many sectors such as power generation, transmission and distribution, electricity sales, and use. With the help of power electronic technology and information technology, it is easy to realize the interconnection of energy sources and information flows of various centralized power supplies, distributed power supplies, energy storage devices, and electric power units. It is obvious that the energy interconnection can rationally allocate energy resources to solve the problem of new grid-connected energy sources so as to achieve the purpose of promoting the coordinated development of fossil fuel energy and renewable energy. The power generation side can use the energy trading platform to carry out on-line electricity trading, reselling, and other services to prevent the waste of electricity which will facilitate better demand-side management.

7.3. Deepen the Power System Reform and Strengthen Policy Support for Clean Development

In order to allow the market to play a decisive role in the allocation of resources, the government should continue to deepen the new round of power system reform. In addition to the public welfare of electricity, purchase prices and grid-connection prices should be formed by the market. China should actively promote the marketization of electricity prices on the power generation side and the sales side, and separate the transmission and distribution price from the generation and sale tariffs to establish a huge four-in-one power market including power capacity, electric energy, auxiliary services, and the renewable energy quota market. The introduction of financing and project modes of operation including contract energy management, energy saving leasing, and carbon trading is necessary. The government should improve the renewable energy price policy and subsidy policy, as well as separate the benchmark price and financial subsidy of coal-fired power generation in order to meet the needs of the current market-oriented power reform. At present, the development of new energy industries rely on government subsidies. Therefore, it may be helpful to change the current situation by changing a differential subsidy into a fixed subsidy and by promoting a quota system and a green certificate trading mechanism. The analysis of supply and demand resources and environmental costs should be included in policy-making so as to improve the accuracy and scientificity of the policy. The most important thing is that the government should make clear the direction of the implementation of policies, to ensure the continuity and stability of policies. The use of financial and tax incentives and other means can be used for the development of power to provide policy support. The use of fiscal and tax incentives and other means should be encouraged in order to provide policy support for power development.

7.4. Summary

To promote the efficient use of non-fossil fuel energy installations and the rapid development of renewable energy, scientific planning and energy-saving scheduling of various power sources are important missions of the policy for the requirements of clean energy development. Industrial innovation, the coordinated development of various power sources, and policy support are important driving forces to activate the development potential of the power industry. This paper argues that China's power structure will be further optimized if the government can do better in these areas.

Acknowledgments: This study is supported by the National Natural Science Foundation of China (NSFC) (71501071), the China Postdoctoral Science Foundation (2014M550937), the Ministry of Education in China Project of Humanities and Social Sciences (14JF005), and the Fundamental Research Funds for the Central Universities.

Author Contributions: All the authors have made their own contributions to the paper. Xiaohua Song and Xubei Zhang conceived and designed the overall framework of this paper; Yun Long and Yiwei Guo conducted a preliminary data analysis; Xubei Zhang performed the experiments and wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chen, Q.X.; Kang, C.Q.; Ming, H.; Wang, Z.Y.; Xia, Q.; Xu, G.X. Assessing the low-carbon effects of inter-regional energy delivery in China's electricity sector. *Renew. Sustain. Energy Rev.* **2014**, *32*, 671–683. [CrossRef]
2. Khanna, N.Z.; Zhou, N.; Fridley, D.; Ke, J. Quantifying the potential impacts of China's power-sector policies on coal input and CO_2 emissions through 2050: A bottom-up perspective. *Util. Policy* **2016**, *41*, 1–11. [CrossRef]
3. Peggy, M.; Kenneth, B.K. Modeling tools to evaluate China's future energy system—A review of the Chinese perspective. *Energy* **2014**, *69*, 132–143.
4. Murata, A.; Liang, J.; Eto, R.; Tokimatsu, K.; Okajima, K.; Uchiyama, Y. Environmental co-benefits of the promotion of renewable power generation in China and India through clean development mechanisms. *Renew. Energy* **2016**, *87*, 120–129. [CrossRef]
5. Menegaki, A. Valuation for renewable energy: A comparative Review. *Renew. Sustain. Energy Rev.* **2008**, *129*, 2422–2437. [CrossRef]
6. Yuan, X.L.; Zuo, J. Transition to low carbon energy policies in China—from the five-year plan perspective. *Energy Policy* **2011**, *39*, 3855–3859. [CrossRef]
7. Feng, Y.; Lin, H.Y.; Ho, S.L.; Yan, J.H.; Dong, J.N.; Fang, S.H.; Huang, Y.K. Overview of wind power generation in China: Status and development. *Renew. Sustain. Energy Rev.* **2015**, *50*, 847–858. [CrossRef]
8. Siddiqui, A.S.; Marnay, C.; Wiser, R.H. Real options valuation of US federal renewable energy research, development, demonstration, and deployment. *Energy Policy* **2007**, *35*, 265–279. [CrossRef]
9. Liu, P.; Tan, S.K. Comparison of policies for wind power development in China and abroad. *Procedia Eng.* **2011**, *16*, 163–169. [CrossRef]
10. Ge, J.N.; Gao, Y.; Zhai, H.Q.; Ye, C. Preliminary Exploration of Optimizing Energy Structure of Power Generation of Shanghai in New Period. *East China Electr. Power* **2010**, *38*, 1582–1585.
11. EI-Kordy, M.N.; Badr, M.A.; Abed, K.A.; lbrahim, S.M.A. Economical evaluation of electricity generation considering externalities. *Renew. Energy* **2002**, *25*, 317–328. [CrossRef]
12. Gong, W.; Duan, Q.Y.; Li, J.D.; Wang, C.; Di, Z.H.; Ye, A.Z.; Miao, C.Y.; Dai, Y.J. An Intercomparison of Sampling Methods for Uncertainty Quantification of Environmental Dynamic Models. *J. Environ. Inf.* **2016**, *28*, 11–24.
13. Ebohon, O.J.; Ikeme, A.J. Decomposition analysis of CO_2 emission intensity between oil-producing and non-oil-producing sub-Saharan African countries. *Energy Policy* **2006**, *34*, 3599–3611. [CrossRef]
14. Hirst, E.; Hild, J. The value of wind energy as a function of wind capacity. *Electr. J.* **2004**, *17*, 11–20. [CrossRef]
15. Wang, Y.; Li, N.; Li, J. Media coverage and government policy of nuclear power in the People's Republic of China. *Prog. Nucl. Energy* **2014**, *77*, 214–223. [CrossRef]
16. Zhao, Z.Y.; Zuo, J.; Fan, L.L.; Zillante, G. Impacts of renewable energy regulations on the structure of power generation in China—A critical analysis. *Renew. Energy* **2011**, *36*, 24–30. [CrossRef]
17. Du, L.M.; Mao, J.; Shi, J.C. Assessing the impact of regulatory reforms on China's electricity generation industry. *Energy Policy* **2009**, *37*, 712–720. [CrossRef]
18. Paul, A.; Steenhof, W.F. Scenario development in China's electricity sector. *Technol. Forecast. Soc. Chang.* **2007**, *74*, 779–797.
19. Cai, L.; Guo, J.; Zhu, L. China's Future Power Structure Analysis Based on LEAP. *Energy Sources A Recov. Util. Environ. Eff.* **2013**, *35*, 2113–2122. [CrossRef]
20. Carolin, M.M.; Fernandez, E. Analysis of wind power generation and prediction using ANN: A case study. *Renew Energy* **2008**, *33*, 986–992. [CrossRef]

21. Forrester, J.W. *Urban Dynamics*; The MIT Press: Cambridge, MA, USA, 1969; pp. 2–62.
22. Stave, K. Participatory system dynamics modeling for sustain-able environmental management: Observations from four cases. *Sustainability* **2010**, *2*, 2762–2784. [CrossRef]
23. Hosseini, S.H.; Hamed, S.G. A study on the future of unconventional oil development under different oil price scenarios: A system dynamics approach. *Energy Policy* **2016**, *91*, 64–74. [CrossRef]
24. Chapman, A.; Darby, S. Evaluating sustainable adaptation strategies for vulnerable mega-deltas using system dynamics modelling: Rice agriculture in the Mekong Delta's An Giang Province, Vietnam. *Sci. Total Environ.* **2016**, *559*, 326–338. [CrossRef] [PubMed]
25. Xiao, B.W.; Niu, D.X.; Guo, X.D. Can natural gas-fired power generation break through the dilemma in China? A system dynamics analysis. *J. Clean. Prod.* **2016**, *137*, 1191–1204. [CrossRef]
26. Liu, X.; Mao, G.; Ren, J.; Li, R.Y.M.; Guo, J.H.; Zhang, L. How might China achieve its 2020 emissions target? A scenario analysis of energy consumption and CO_2 emissions using the system dynamics model. *Clean Prod.* **2015**, *103*, 401–410. [CrossRef]
27. Xu, B.; Lin, B. Assessing CO_2, emissions in China's iron and steel industry: A dynamic vector autoregression model. *Appl. Energy* **2016**, *161*, 375–386. [CrossRef]
28. Forrester, J.W. *Industrial Dynamics*; Productivity Press: Cambridge, MA, USA, 1961; pp. 2–36.
29. National Energy Administration. The Utilization Hours of 6000 Kilowatts and above Nation-Wide Power Plants in the Year of 2015. Available online: http://www.nea.gov.cn/2016-01/29/c_135056890.htm (accessed on 29 January 2016).
30. Editorial Board of China Electric Power Yearbook. *China Electric Power Yearbook (2015)*; China Electric Power Press: Beijing, China, 2016.
31. Editorial Board of China Electric Power Yearbook. *China Electric Power Yearbook (2014)*; China Electric Power Press: Beijing, China, 2014.
32. Who Installed the Country's Largest Capacity in 2014? Available online: http://news.bjx.com.cn/html/20151126/685222-2.shtml (accessed on 26 November 2015).
33. Editorial Board of China Electric Power Yearbook. *China Electric Power Yearbook(1994)*; China Electric Power Press: Beijing, China, 1996.
34. Department of Energy Statistics National Bureau of Statistics. *China Energy Statistical Yearbook (2015)*; China statistics Press: Beijing, China, 2015.
35. Wang, Y.; Guo, J.E.; Xi, Y.M. Study on the Dynamic Relationship Between Economic Growth and China Energy Based on CointegrationAnalysisand Impulse Response Function. *China Popul. Resour. Environ.* **2008**, *18*, 56–61.
36. Hassan, Q.U.; Seong, B.S. How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. *Energy Policy* **2010**, *38*, 2216–2224.
37. Liu, L.Q.; Liu, C.X.; Wang, J.S. Deliberating on renewable and sustainable energy policies in China. *Renew. Sustain. Energy Rev.* **2013**, *17*, 191–198. [CrossRef]
38. Zhao, Z.Y.; Chen, Y.L.; Chang, R.D. How to stimulate renewable energy power generation effectively?—China's incentive approaches and lessons. *Renew. Energy* **2016**, *92*, 147–156. [CrossRef]