Carbon Emission Accounting Model and Multi-dimensional Evaluation of Power System with High Proportion of New Energy

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Abstract. The construction of novel power system with high proportion of new energy is considered to be an important way to achieve carbon reduction. In this paper, the carbon emission accounting model and multi-dimensional evaluation are proposed to promote the establishment of power system with high proportion of new energy. Firstly, the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) carbon emission accounting model is established in this paper to analyze the influencing factors of energy carbon emission in a certain region. Then the basic characteristics of the novel power system with new energy is presented. Finally, the multi-dimensional evaluation model of power system with high proportion of new energy is put forward to clearly assess the construction process of the novel power system.

Keywords: Novel power system, new energy, carbon emission accounting, multi-dimensional evaluation

1. Introduction
Recently, building a novel power system with new energy as the main body is an important carrier and platform for the power industry to practice the goal of "double carbon" [1-2]. Clean, low carbon, safety and high efficiency are the core requirements of energy system and power system, and also the basic development orientation of novel power system with new energy as the main body in the future [3]. In the construction process of the novel power system, a large number of new technologies and new business forms will be spawned, and the "source network load" ecology of the power system will change significantly [4-5]. At the energy production end, a diversified clean energy supply system will be formed, with wind power, photovoltaic power, hydropower and other new energy power as the main supply, and the function of fossil energy power becomes the guarantee and support for the bottom. On the power grid side, ac-dc hybrid large power grid and various forms of power grid coexist. Besides, the level of electrification on the load side will be greatly improved, and the energy consumption mode is developing towards multi-energy complementation and source-load interaction [6-7]. Therefore, how to study and construct the multi-dimensional evaluation system and implementation path method of the novel power system according to the regional development stage and its own characteristics plays an important role in the realization of the goal of "double carbon".

At present, the carbon emissions of countries in the world are at different stages, which can be roughly divided into four types. Emissions in developed countries such as Britain, France and the United States peaked in the 1970s and 1980s and are now in a post-peak decline stage. Emissions from emerging countries such as India are rising. There are also a large number of developing and
agricultural countries where emissions associated with rapid economic and social development have yet to kick in. Some members of the European Union have taken the lead in pledging to be carbon neutral by 2050. From the historical relationship between carbon emission and economic growth in major developed countries, the development degree of a country is closely related to the cumulative carbon emission per capita [8-10]. For China, the cumulative carbon emission per capita is far lower than that of major developed countries, and also less than the global average. Our pursuit of carbon neutrality by 2060 is far more difficult than that of developed countries.

In this paper, the carbon emission accounting model and multi-dimensional evaluation are proposed to promote the establishment of power system with high proportion of new energy. Firstly, the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) carbon emission accounting model is established in this paper to analyze the influencing factors of energy carbon emission in a certain region. Then the basic characteristics of the novel power system with new energy is presented. Finally, the multi-dimensional evaluation model of power system with high proportion of new energy is put forward to clearly assess the construction process of the novel power system.

2. Carbon Emission Accounting Model Establishment

According to the economic development stage, energy consumption and carbon emission status, and comprehensively considering the economic and social development goals, carbon emission intensity control goals and other factors, the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) carbon emission accounting model is established in this paper to analyze the influencing factors of energy carbon emission in a certain region, and to study and forecast the energy carbon emission and peak time of 2020-2060 in different scenarios.

Firstly, the STIRPAT theoretical model is adopted to construct the econometric model of influencing factors of carbon emission, while the qualitative screening of driving factors that affects carbon emissions can be obtained. Then the panel data for econometric regression analysis of carbon emission are available. The driving factors that affects carbon emissions are firstly analyzed as following.

(a) Urbanization. According to current studies, urbanization refers to the process of rural population transferring to cities and towns in the process of economic development. In existing studies, urbanization level is usually represented by the ratio of urban population to regional total population. From the perspective of the development process of countries around the world, urbanization development is an inevitable stage in the process of industrialization development. In the process of urbanization development, a series of environmental problems are often accompanied, so the level of urbanization is also an important factor of carbon emissions. From the perspective of economic theory, the higher the level of urbanization development is, the larger the scales of population gathered in the city are, which requires a large amount of public infrastructure to meet the demand of urban population increase, resulting in increased energy consumption of the city, and then the carbon emissions are increased. But there is a theory that the improvement of urbanization level is beneficial to reducing carbon emissions. At present, most cities in China are in the process of rapid urbanization development. The impact of urbanization level on carbon emissions needs further discussion and analysis.

(b) Industrial structure. Industrial structure is not only an important component of regional social and economic development, but also a major factor affecting carbon emissions. However, due to different industrial development modes, industrial structure has different effects on carbon emissions. The primary industry dominated by traditional agriculture has low energy demand, and its positive impact on carbon emissions can be ignored basically. On the contrary, the development of some industries in the primary industry, such as forestry, will be conducive to the increase of carbon sinks and play a role in inhibiting carbon emissions. As the pillar industry of national economic development, the secondary industry is mainly dominated by industry, which is basically energy-intensive industry. The increase of its industrial structure will obviously promote the increase of
carbon emissions. The technology-intensive and knowledge-intensive service industries belong to low carbon industry, the impact is not big for carbon emissions, while some of the tertiary industry, such as transportation industry will indirectly cause the increase of carbon emissions, but on the whole, the development of the third industry will not result in carbon emissions increased significantly.

(c) Energy intensity. Energy is the most important factor of production to drive economic growth, but also the main cause of carbon dioxide emissions. Energy intensity represents the ratio of energy consumption to economic output value, and is a standard to measure the energy utilization level and energy technology level of a country or region. On the one hand, energy intensity directly reflects the dependence of economic growth on energy consumption. On the other hand, it indirectly reflects the development level of technology in economic development, and is a comprehensive manifestation of the development level of carbon emission reduction technology. The lower the energy intensity is, the lower the corresponding carbon emissions will be reduced. In the future, how to effectively control energy consumption intensity will become the key to achieve the reduction of total carbon emissions.

According to the above analysis, the carbon emission accounting STRIPAT model is given in figure 1. The STRIPAT model is proposed by Dietz and Rosa [11], which is given as

$$X = x_1 \cdot X_p^{x_2} \cdot X_A^{x_3} \cdot X_T^{x_4} \cdot x_5$$

(1)

where $X$ is the carbon emission accounting amount; $X_p$, $X_A$ and $X_T$ are the influence factor variables; $x_1$ represents the constant term; $x_2$, $x_3$ and $x_4$ represent the environmental impact elasticity of each variable; $x_5$ is the error term. In order to eliminate the possible heterogeneity, the natural logarithm form is taken for all variables, and it has

$$\ln X = \ln x_1 + x_2 \ln X_p + x_3 \ln X_A + x_4 \ln X_T + \ln x_5$$

(2)

In order to test the relationship between urbanization level and carbon emissions, the variable of urbanization level can be decomposed into the primary and peaceful terms. And since there is a big correlation between urbanization and economic level, the environmental Kuznets curve shows that the environmental impact and economic growth between the "inverted U" relationship. Therefore, in order to eliminate the influence of the relationship to the urbanization level caused by economic level and the carbon emissions, the economy rich degree can be incorporated. The carbon emission accounting of some area through STRIPAT model is then shown in figure 2.

![Carbon Emission Accounting STRIPAT Model](image.png)

**Figure 1.** Carbon emission accounting STRIPAT model.
According to the national goal of "dual carbon" and the power development plan, it is expected to basically complete the construction of a novel power system by 2035 and complete the construction of a novel power system by 2050. The period from 2021 to 2035 is the construction period, while the new energy installations will gradually become the largest power source, and conventional power sources will gradually be transformed into regulatory and support power sources. The power system maintains a high moment of inertia and ac synchronous operation characteristics, while the ac and dc grid, large grid and micro grid coordinately develop. The scale of system energy storage and demand response continues to expand, and the power output and power load of the generator set are initially decoupled. The period from 2036-2060 is the mature period, while the new energy has gradually become the main power supply. Thermal power gradually achieves net zero emission through CCUS technology and becomes a long period regulation power source. The distributed power supply, microgrid, AC/DC network and large power grid show integrative development. The energy storage of the system is fully applied, and the output of the generator set and the electricity load are gradually fully decoupled.

3. Multi-dimensional Evaluation Model of Power System with High Proportion of New Energy

The novel power system with new energy as the main body is an important part of clean, low-carbon, safe and efficient energy system, which has the following characteristics:

(a) Clean and low-carbon. It is necessary to form a clean-dominated and electricity-centered energy supply and consumption system, which is aimed to realize diversified, clean and low-carbon energy on the production side, and efficient and reduced electricity on the consumption side.

(b) Safe and controllable. New energy should be able to provide active support, and distributed microgrids should be measurable and controllable. Besides, the large power grids should have a reasonable scale and strong structure. A security defense system should be established to make the system more resilient, resilient and self-healing.

(c) Flexible and efficient. The power generation side and the load side have strong adjustment ability, and the power grid side have strong resource allocation ability, so as to realize the mutual exchange and flexible conversion of all kinds of energy, and improve the overall efficiency.

(d) Open and interactive. The power grid adapts to all kinds of new technologies, new equipment and large-scale access of multiple loads. Market players of all types participate extensively, compete fully and respond actively in the novel power system.

(e) Smart and friendly. The new electric power system has the characteristics of high digitalization, intelligence and network, realizing the intelligent coordination and control of the massive dispersed objects of power generation, supply and use, and realizing the friendly cooperation of source network, load and storage.

According to the above analysis, the multi-dimensional evaluation model of power system with high proportion of new energy is shown as below.
3.1. Clean and Low-carbon Evaluation Index

The future novel power system will be from the deterministic adjustable and controllable conventional power supply dominated, with the security and stability of synchronous generator support system as the main responsibility, gradually evolved to the new energy generation installation dominated by strong uncertainty and random fluctuation, and finally realized the new energy generation dominated, and at the same time became the main responsibility to support the security and stability of power system. It is expected that by 2060, the installed and generating capacity of new energy will account for about 63% and 59% respectively, and conventional power sources will become important regulating power sources. Therefore, the index system of clean and low-carbon is constructed as follows in table 1:

| Index                                      | Explanation                                           |
|--------------------------------------------|-------------------------------------------------------|
| Installed capacity of new energy (million kW) | Total installed capacity of new energy                |
| Proportion of new energy                   | Installed capacity/total installed capacity            |
| Generating capacity of new energy          | Generating capacity of new energy power station       |
| Proportion of new energy generation        | power generation of new energy stations /Total power generation |
| Photovoltaic installed capacity (GW)       | Sum of distributed and centralized photovoltaic installed capacity |
| Photovoltaic power generation              | Total photovoltaic power generation                   |
| Wind power installed capacity (MW)         | Sum of distributed and centralized wind power installed capacity |
| Wind power generation                      | Wind farm generation                                  |
| Utilization rate of new energy Generation (%) | The percentage of the actual generation of new energy in the theoretical generation |
| Transmission capacity of outgoing section of new energy (million kW) | The maximum outgoing capacity of new energy resources through transmission channels |
| Proportion of non-fossil energy in primary energy consumption (%) | Non-fossil energy consumption/Total primary energy consumption |

3.2. Safe and Controllable Evaluation Index

It is needed to build a novel power system security and stability control system. That is to say, it should be able to grasp the basic theory and stability mechanism of novel power system, build a power grid simulation platform characterized by multi-time scale, platforming and intelligence, and master the operation characteristics of "double high" power system. Building a new type of power system fault prevention system can help to build a new generation of independent and controllable substation secondary system, promote the standardized application of safety devices, consolidate and improve the "three lines of defense." Besides, combined with the new IT technology, the construction of a new generation of dispatching technology support system "human-machine integration, open group intelligence, multi-level coordination, independent control" can be realized. Therefore, the safe and controllable evaluation index is constructed as follows in table 2:
Table 2. Safe and controllable evaluation index.

| Index | Explanation |
|-------|-------------|
| Power supply reliability rate | Total hours of the power supply period/hours during statistical period |
| Power grid security and the level of control technology | Refers to the power grid safety operation control ability of ultra-high voltage and large-scale multi-terminal flexible direct feed AC-DC hybrid system. Power generation/electricity consumption. The index is the ratio of electricity consumption to electricity consumption. Usually, the higher the index is, the higher the local power guarantee ability is. On the contrary, the lower the index is, the lower the local power guarantee capability is. |
| Power security capability | Safety spare adjustment capacity |

3.3. Flexible and Efficient Evaluation Index

The power generation side and the load side should have strong regulation capability, and the power grid side has strong resource allocation capability, which enables all kinds of energy to be interconnected, mutually beneficial and flexibly converted to improve overall efficiency. The balance mode of power system will change from real-time balance mode to imperfect source load real-time balance mode with larger time and space scale. The physical form of power system will be changed from mechanical electromagnetic system dominated by synchronous generator to power semiconductor/ferromagnetic component hybrid system dominated by power electronic equipment and synchronous machine. The dynamic characteristics of power system will change from weak coupling to strong coupling between electromechanical and electromagnetic transient processes. In accordance with the requirements of national policies, the construction of power side energy storage will be vigorously supported to actively serve the development of user side energy storage, and provide technical consultation and grid connection services. Therefore, the flexible and efficient index system is constructed as follows in table 3:

Table 3. Flexible and efficient evaluation index.

| Index | Explanation |
|-------|-------------|
| New energy storage capacity (million kW) | New energy storage includes pumped storage and electrochemical storage capacity |
| Adjustable load capacity (million kw) | Sum of adjustable load power |
| System economic regulation capacity (MW) | Adjustable generation power and adjustable load capacity |
| Demand-side response ratio | Demand-side response load/total load capacity |
| Distributed condenser | Distributed condenser access capacity |
| Completion rate of flexible transformation of thermal power units | Number of thermal power units that have completed flexible transformation/total regional thermal power units |
3.4. Open and Interactive Evaluation Index
At the level of power grid structure, the transmission and distribution one-way hierarchical multi-level structure network is transformed to multiple bidirectional hybrid hierarchical network. From the perspective of transmission network form, the main transmission mode is from AC bone to grid frame and DC long-distance transmission to the interconnection between AC power grid and DC network. From the terminal network form, power supply network and energy network interconnect with each other. Also, it needs to promote the introduction of demand-response support policies and market mechanisms to reasonably distribute costs and benefits through market mechanisms. A new distribution dispatching system adapted to the development of distributed power supply will also be constructed. Besides, we will promote the application of 5G+ smart power grid regulation, meet the demand for dispatching and communication of massive distributed power supplies, and realize coordinated control of charge and storage resources of wide-area source networks. Therefore, the open and interactive index system is constructed as follows in table 4:

| Open and interactive | Index                                      | Explanation                                                                 |
|----------------------|--------------------------------------------|----------------------------------------------------------------------------|
|                      | Distributed power supply permeability      | Distributed power supply capacity/rated power distribution network capacity |
|                      | Grid-connected microgrid access rate       | Number of microgrids connected to large power grids/number of microgrids   |
|                      | Installed capacity of distributed new energy (MW) | Total installed capacity of distributed power                              |
|                      | Big data Load Annual electricity consumption | Annual electricity consumption of data center load                         |
|                      | The universal service level of new energy vehicles | Represents the service coverage and convenience level of new energy vehicles in the region, which is measured by secondary indicators |
|                      | Integrated energy service business development index | Represents the overall development level of integrated energy service business |
|                      | The user side interaction service index     | Represents the power grid side and user side interaction ability           |

3.5. Smart and Friendly Evaluation Index
It is necessary to increase the deployment of intelligent terminals in medium voltage distribution network, the construction of distribution communication network and the practicality of distribution automation, and extend to low voltage distribution network to greatly improve observability, measurability and controllability. At the same time, we should promote the application of new energy storage and demand side response, and improve the regulation and adaptability of the distribution network through multi-energy complementarity and integrated control technology of source network, charge and storage, and promote the balance of electricity and quantity in different levels, classification and clustering. By 2025, a safe, reliable, green, intelligent, flexible, interactive, economical and efficient smart distribution network will be basically completed. The smart and friendly index system is constructed as follows in table 5:
Table 5. Smart and friendly evaluation index.

| Index                                      | Explanation                                      |
|-------------------------------------------|--------------------------------------------------|
| New energy intelligent prediction accuracy| New energy actual power/predicted power           |
| Distributed energy intelligent forecast accuracy| Distributed energy actual power/forecast power  |
| Promotion rate of new energy cloud platform| Promotion and popularity of new energy cloud platform |
| Intelligent Terminal Deployment Rate       | Number of intelligent terminals/Number of all terminals |
| Intelligent prediction accuracy of power grid load| Actual power/predicted power                      |
| The intelligent level of power grid       | Represents the intelligent development level of power grid in the region, and is measured by secondary indicators |

4. Conclusion

In this paper, the carbon emission accounting model and multi-dimensional evaluation are proposed to promote the establishment of power system with high proportion of new energy. Firstly, the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) carbon emission accounting model is established in this paper to analyze the influencing factors of energy carbon emission in a certain region. Then the basic characteristics of the novel power system with new energy is presented. Finally, the multi-dimensional evaluation model of power system with high proportion of new energy is put forward to clearly assess the construction process of the novel power system.

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