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A review of the carbon emission factor method's application to power system accounting

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Abstract. Adopting low-carbon power technologies is a crucial step in the power sector's sustainable growth. Macro data statistics that are transformed based on primary energy consumption make up the majority of the carbon emissions statistics used in the current research. The applicability of such technologies is constrained, and they do not reveal the features of carbon emissions from the power system. The three widely used methods of carbon emission detection are listed by the review method in this paper. Additionally, a novel concept of combining carbon emission analysis and power system power flow calculation is discussed, the concept of power system carbon emission flow is proposed, the significance of power system carbon emission research is highlighted by combining specific data, and finally the application field and research direction of power system carbon emission are discussed. The carbon emission data released by the International Energy Agency in 2023, due to the impact of the new crown epidemic, the carbon emission in 2020 will be reduced, but it will rebound to the pre-epidemic level in 2021.

Keywords: carbon emission monitoring, tributary carbon flow, tributary carbon flow rate, node carbon potential, electricity-carbon coupling.

1. Introduction

Innovation and development, which entails the revision of production patterns and is integral to national rights and interests, are at the heart of low-carbon development [1-2]. Global carbon dioxide emissions from energy will rise by 0.9%, or 321 metric tons, in 2022. Studying the issue of carbon emissions is vital [3]. The approach used to compute and count carbon emissions at the moment begins with macro data and bases the results on energy use. The simplicity of this mathematical procedure is a benefit. The low-carbon characteristics of the power system cannot be represented by calculating carbon emissions alone due to research and development in the low-carbon energy sector.

This article uses the review method to extract and synthesize reliable papers in the field of carbon emission research. It then lists three carbon emission detection methods that are more prevalent in the prior art, defines and analyzes the characteristics of carbon emission flow in the power system, and proposes a new technology that is used in conjunction with specific data to examine the potential applications of carbon emission flow in the power system. It is crucial to comprehend and examine the carbon emissions in the electricity system from a new perspective in order to more organically link their characteristics with the idea of low-carbon development.

2. Overview of carbon emissions monitoring methodology

Based on the technique of data collecting and the accuracy of accounting data, international carbon measurement methods can currently be simply separated into Intergovernmental Panel on Climate Change (IPCC) emission factor method, measure method and material balance method. The emission factor approach is currently the most widely used accounting technique in the entire world. The reliable measurement of carbon emissions is possible using either the material balance method or the IPCC emission factor method.

2.1. IPCC emission factor method

The emission factor is the greenhouse gas emission coefficient that describes how much is produced or consumed per unit, such as the amount of CO_2 emitted when burning fossil fuels, the amount of CO2 emitted while buying and using energy, etc. The Emission Factor Method, the most popular carbon emission accounting technique globally, is explained in detail in the booklet. It is a result of data on the degree of energy activity, emission variables, and fuel carbon oxidation rate. The following calculation formula:

$$E = \sum_{i=1,2,3,\ldots,m} A_{D,i} E_{F,i} O_{F,i} \tag{1}$$

Among them, E represents the totality of CO_2 emissions, in units of tone; AD,i represents the use of the first fuel, TJ; $E_{F,i}$ is the first fuel's emission factor, measured as CO_2, and $O_{F,i}$ is the first fuel's carbon oxidation rate, in units of % [4].

2.2. Measure method

The Measure Method uses the Continuous Emission Monitoring System (CMS) to directly measure the flow rate, flow rate, concentration, and other exhaust gas parameters in order to calculate the total gas emissions. The following calculation formula:

$$E_n = \sum_{p=1}^{\infty} F_p C_{C,p} \tag{2}$$

In the formula, CC, P is the measured carbon content of the fuel in the time period P, in units of %. Extraction sampling and direct measurement are two techniques used in coal-fired power plants for flue gas sampling. Direct measurement is primarily used in domestic power plants. Point measurement and line measurement are the two different categories of direct measurement techniques. To test the CO_2 concentration via point measurement, attach the sensor to the probe's tip and insert the probe straight into the flue. Linear online measurement involves installing the sensor and probe directly on the flue or chimney and measuring the measured object over a long distance using spectral analysis technology or laser technology [5].

2.3. Material balance method

Material Balance Method is a mass balance. The amount of material input into the system is equal to the amount of material output out of the system when the system boundary is specified. The following calculation formula:

$$\sum G_{in} = \sum G_{pro} + \sum G_{out} \tag{3}$$

In the formula, G_{in} is the sum of the input materials, t; G_{pro} is the sum of the products obtained, in units of tone ; G_{out} is the sum of the loss of materials and products, in units of tone.

Carbon balancing is mostly used in coal-fired power plants' material balance methods. The carbon emissions are computed using information on the carbon content of coal, fly ash, and slag. A model for calculating the CO_2 emissions from the coal combustion and desulfurization processes is then constructed. The intensity of carbon emissions is carbon emissions. Although the model is very straightforward, errors were made in the collection of calculation data and the outcomes. The effect of the industrial power system on the unit's carbon emissions is not taken into account [5].

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3. Carbon emissions from the power system

As a fundamental idea, the power system's carbon emission flow will result in a number of new concepts and indicators that form the cornerstone of the power system's carbon emission generation.

Emission Stream Analysis's theoretical underpinnings. All indicators that are connected to the power system's carbon emission flow in this study are collectively referred to as carbon flow indicators.

Power plants release carbon emissions into the atmosphere on the surface, while in reality, electricity customers absorb carbon emissions through carbon emission streams, as shown in Figure 1:

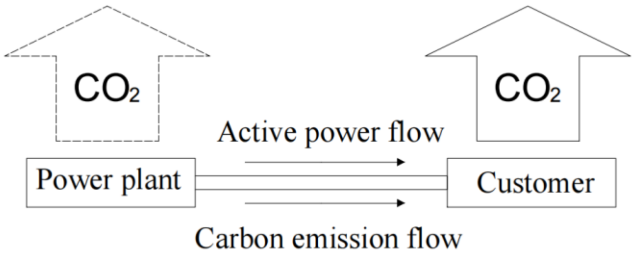

Figure 1. Illustration of carbon emission flow in power system.

3.1. Carbon emission flow

The carbon emission flow in the power system begins at the power plant (power plant node), enters the system by using the grid electricity from the power plant, travels via the power grid while following the system trend, and eventually arrives at the consumer terminal (load node) on the user side.In essence, carbon emissions are produced when energy users absorb carbon streams and release them into the atmosphere through power plants [6, 7].

3.2. Theoretical basis of carbon emission flow in power system

As a fundamental idea, the power system's carbon emission flow will result in a number of new concepts and indicators that form the cornerstone of the power system's carbon emission generation. Emission Stream Analysis's theoretical underpinnings. All indicators that are connected to the power system's carbon emission flow in this study are collectively referred to as carbon flow indicators.

3.2.1. Branch carbon emission flow and carbon emission flow rate. Branch carbon emission flow, which describes the size of the carbon flow on the branch, is the most fundamental physical quantity to quantify the carbon flow. It is represented by the letter F. Branch carbon flow is the total quantity of carbon emissions brought on by the carbon flow and tidal current passing through a branch over the course of a particular amount of time.

The definition of the branch carbon emission flow rate is: the branch's carbon flow rate through the current per unit time, denoted by the symbol R, which is numerically equal to the derivative of the branch's carbon flow with respect to time and is typically expressed in tCO_2/h or $kgCO_2/s$. [8];

$$R = \frac{dF}{dt} \tag{4}$$

3.2.2. Branch carbon emission flow intensity and nodal carbon intensity. For research purposes, it is required to combine the carbon emission flow with the power flow since the power flow affects the power system's carbon emission flow. Given that the active power flow in the power system primarily affects the carbon emission, the branch carbon emission flow intensity is defined as the proportion of the active power flow to the carbon flow rate in any branch of the power system represented by ρ:

$$\rho = \frac{R}{P} \tag{5}$$

The branch carbon flow density varies with the system's power flow since the active power flow and branch carbon flow rate both refer to instantaneous values. For simplicity, the average branch carbon flow density, also known as the average carbon flow density, is further discussed. [8].

$$\overline{\rho} = \frac{\int Rdt}{\int Pdt} = \frac{R}{P} \tag{6}$$

Define the nodal carbon intensity of the power system, denoted by the symbol e, based on the carbon flow density. The following formula represents the node n's node carbon potential:

$$e_n = \frac{\sum_{i\in N^+} P_i \, \rho_i}{\sum_{i\in N^+} P_i} = \frac{\sum_{i\in N^+} R_i}{\sum_{i\in N^+} P_i} \tag{7}$$

In the formula: N^+ is the collection of all branches connected to node n with power flow flowing into node n; i is the branch number.

The relationship between power flow analysis and carbon emission analysis can be summarized [8], as shown in Figure 2:

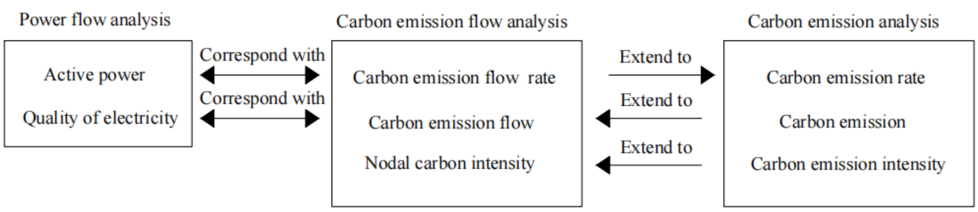

Figure 2. Relationship among related indices.

4. Algorithm research based on carbon flow tracking

4.1. Disadvantages of traditional methods

The following are drawbacks of conventional carbon footprint measuring methods for widespread use: It is challenging to reflect the level of renewable energy consumption on the user side and to apply to the carbon footprint tracking of large-scale renewable energy systems. The inability to immediately compute carbon tracking data. It is challenging to balance the real-time dynamic properties of power and carbon emissions in the power system.

4.2. Improvement measures

In view of the above shortcomings, some scholars have made corresponding improvements:

Reinforcement learning apply to the carbon footprint tracking of large-scale renewable energy systems. Transfer Learning is a sub-direction in the field of machine learning. The issue of large-scale tracking can be resolved if the machine can solve type A problems very well and then solve type B problems that are comparable to type A problems faster and better.

Reinforcement learning reflect the level of renewable energy consumption on the user side. Based on the power system flow data between the user's own load and the power generation side, reinforcement learning can calculate real-time carbon emissions. future carbon emission data can be trained using machine learning, For example: Grey Pridiction GM(1,1),Ridge Regression, Linear Regression and K-means.

Reinforcement learning Effectively increase the rate of calculating carbon tracking. Assuming that the carbon footprint needs to go through N systems, if in order to use dynamic programming to solve the carbon footprint tracking problem, you need to define state, action, system dynamic,as shown below: state:(i,V),i represents the system where it is located, V represents the system it has passed through action j, Indicates the next system to go system dynamic:(j,V) →(j,V ∪{j}) stage cost:d(i,j) The distance from system i to system j Value function: $J^*_k(i,V)$ The minimum distance that the current system i is in and passes through all systems in the set V only once. After the definition is completed, it is the recursive formula of dynamic programming. Let s be the source of carbon emissions:

$$J_0^*(s,[s]) = 0 \tag{8}$$

$$J_{k+1}^*(i, V \cup \{i\}) = \min_{j \in V}\{d(i,j) + J_k^*(j,V)\} \tag{9}$$

Reinforcement learning balance the real-time dynamic properties of power and carbon emissions in the power system. Reinforcement learning actually originated from dynamic programming, and dynamic programming and reinforcement learning solve a dynamic optimization problem or a sequence optimization problem. Since reinforcement learning inherits the basic framework of dynamic programming and Markov decision process, reinforcement learning still has some theoretical guarantees of traditional dynamic programming and Markov decision process.

5. CO_2 emissions in 2022

This part divides CO2 emissions into two broad categories: conventional energy and renewable energy, and discusses the reasons for this change in emissions.

5.1. Non-renewable energy

The increase in emissions in 2022 was influenced by certain difficulties. Of the 321 Mt CO_2 rise, 60 Mt CO_2 can be attributed to the need for cooling and heating during severe weather, and another 55 Mt CO_2 can be linked to the shutdown of nuclear power facilities.The CO_2 emissions from coal increased by 1.6% or 243 Mt during the global energy transition, well above the average growth rate over the previous ten years and coming in at 15.5 Gt.

Natural gas emissions dropped by 1.6%, or 118 Mt.Gas emissions were significantly reduced, by roughly 13.5%, in Europe. Likewise, the Asia-Pacific area experienced 1.8% decreases that were unprecedented.

Oil-related CO_2 emissions increased by 2.5% or 268 Mt to 11.2 Gt more than coal-related emissions.

5.2. Renewable energy

Power produced by wind and solar PV beat that from gas or nuclear sources for the first time.

For instance, emissions rose by 0.8%, or 36 Mt. The largest increase in emissions was seen in the building sector as a result of the extreme temperatures. The greatest emissions reductions came from the production of electricity and heat as a result of the tremendous increase of solar and wind energy as well as the conversion of coal to gas. While many other countries reduced their use of natural gas, the United States saw an increase of 89 Mt in CO2 emissions from gas as it was necessary to meet the peak power demand during summer heat waves. [9].

6. Conclusion

The notion of power system carbon emission flow is suggested in this work, which also covers a novel method of fusing carbon emission analysis with power system power flow calculation. The new crown epidemic's effects will cause a decrease in carbon emissions in 2020, but they will return to their pre-epidemic levels in 2021, according to data on carbon emissions released by the International Energy Agency in 2023. These data demonstrate the value of investigating this sort of carbon emission research methodology, particularly the carbon emissions of the electricity system, which make up the majority of it and provide a more accurate picture of the current state of carbon emissions.The International Energy Agency's data and the idea of carbon emission flow in the power system are briefly presented in this review study. This strategy has not yet been applied to particular circumstances. The intelligent AI model can be used in future studies to more precisely study power using the carbon model.

References

[1] Qixin CHEN, Chongqing KANG, Qing XIA, et al. Key low carbon factors in the evolution of

power decarbonization and their impacts on generation expansion planning[J]. Automation of Electric Power Systems, 2009, 33(15): 18-23.
[2] IPCC. Intergovernmental panel for climate change: fourth assessment report[R]. Cambridge, UK: Cambridge University, 2007.
[3] Hong-Shuo YAN, Xian-Chun TAN, An ZENG, Ling-Si KONG,Advances in Climate Change Research Volume 14, Issue 1, February 2023, Pages 23-31.
[4] Yiqing Wang. (2015). Application of IPCC emission factor method in fishery carbon emission reduction assessment. Modern Agricultural Science and Technology (20),165-166+182.
[5] Ping ping WANG, Yongchun ZHAO, Junying ZHANG, et al. Research progress on carbon measurement methods for coal-fired power plants under the dual carbon goal[J]. Clean Coal Technology, 2022, 28(10):170-183.DOI:10.13226/j.issn.1006-6772.HK22090601.
[6] Carbon flows: the emissions omitted-the usual figures ignorethe role of trade in the world's carbon economy [EB/OL]. [2011-04-28]. http://www. economist.com/node/18618451.
[7] ATKINSON G, HAMILTON K, RUTA G, et al. Trade invirtual carbon: empirical results and implications for policy[J]. Global Environmental Change, 2011, 21: 563-574.
[8] Tianrui ZHOU, Chongqing KANG, Qianyao XU, Qixin CHEN. Preliminary study on carbon emission flow analysis theory of power system[J]. Automation of Electric Power Systems, 2012, 36(07): 38-43+85.
[9] International energy agency [C], CO_2 Emissions in 2022,2023 https://www.iea.org/reports/-co2-emissions-in-2022.