The Origin and Accuracy Assessment of Carbon Emission Factors for Electric Carbon Meters

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Abstract

This paper introduces the application and accuracy issues of electricity carbon meters in the context of carbon emission factors. First, it presents the fundamental concepts of electricity carbon meters and their prospective applications regarding carbon emission factors. By comparing various literature and sources, it examines the origin and accuracy concerns associated with carbon emission factors for electricity carbon meters. Furthermore, it raises critical questions regarding these carbon emission factors and proposes corresponding solutions.

Full Text

Preamble

Title: On the Origin and Accuracy Evaluation of Carbon Emission Factors for Electric Carbon Meters

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Abstract: This paper addresses the application and accuracy concerns of carbon emission factors in electric carbon meters. It begins by introducing the fundamental concept of electric carbon meters and their prospective applications in carbon emission accounting. Through a comparative analysis of diverse literature and data sources, the paper investigates the origins and accuracy issues associated with carbon emission factors used in these devices. Finally, it raises critical questions regarding these factors and proposes corresponding solutions.

Keywords: electric carbon meter, carbon emissions
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Introduction

In August 2023, an online report titled *"Jiangsu Pilots 'Electric Carbon Meter' Application"* (hereinafter referred to as Article A) was published, followed on December 1 by another report: *"Shanghai Electric Power Research Institute Develops and Applies Carbon Emission Meter to Calculate Real-Time Carbon Emission Factors and Obtain Precise Carbon Emission Data"* (hereinafter referred to as Article B). These reports indicate that a new type of electric carbon meter, created by adding a "carbon emission factor function module" to the foundation of State Grid's smart IoT meters, holds promising prospects for widespread application and has attracted considerable industry attention. Simultaneously, through comprehensive analysis, this paper raises several questions regarding the origin and accuracy of carbon emission factors employed in electric carbon meters and proposes solutions.

1. The Origin and Accuracy of Electric Carbon Meter Carbon Emission Factors

1.1 Article A Analysis

Article A states that "electric carbon meters can be installed and applied at power plants, transmission networks, and the consumption side." The operational principle involves real-time acquisition of electrical parameters, with measured data transmitted to a server that calculates the carbon emission factor, which is then used with electricity consumption to determine carbon emissions. In a pilot application at Kunshan Tianyang New Materials Company, the electric carbon meter displayed not only current, voltage, and cumulative electricity consumption data, but also real-time scrolling cumulative carbon emissions: for an electricity consumption of 51,300 kWh, carbon emissions were 29 tonnes, yielding a calculated carbon emission factor of 0.565 tCO_2/MWh.

However, Article A fails to explicitly clarify the traceability relationships between carbon emission factors at power plants, transmission networks, and consumption sides. Nor does it explain the origin or accuracy of the 0.565 tCO_2/MWh emission factor used for the Kunshan Tianyang Company's electric carbon meter.

1.2 Article B Analysis

In 2023, the Shanghai Electric Power Research Institute collaborated with Weisheng Group to develop a carbon emission meter capable of real-time measurement. This device can display real-time carbon emissions, historical carbon emissions, real-time carbon emission factors for the park, and further breakdown carbon emissions and related electricity data by equipment and floor level on the backend. The meter's design is based on the Shanghai electric power industry standard T/SEPA2-2022 *Regional Distribution Network Carbon Emission Accounting Specification*.

The carbon dioxide emission factor calculation formula specified in this standard is:

$$EF_i = CC_i \times OF_i \times \frac{44}{12}$$

where EF_i is the CO_2 emission factor for the i-th fossil fuel (tCO_2/GJ), CC_i is the carbon content per unit calorific value of the i-th fossil fuel (tCO_2/GJ), and OF_i is the carbon oxidation rate of the i-th fossil fuel (%).

Regarding carbon emission factor acquisition, the standard stipulates that factors should be calculated based on those published by the national competent authorities for the corresponding regional power grid, or provincial grid carbon emission factors may be adopted.

Several observations emerge from this analysis. First, Article B's carbon emission factor uses units of tCO_2/GJ, whereas Article A's electric carbon meter employs tCO_2/MWh—an important distinction. The tCO_2/GJ factor in Article B represents average CO_2 emission factors for China's regional power grids, researched and published by national authorities based on total generation, total fuel consumption, and calorific values of all power plants in the regional grid. In contrast, the tCO_2/MWh factor discussed in this paper adopts the power supply-carbon emission factor approach. This paper's proposed origin and accuracy evaluation of carbon emission factors uses tCO_2/MWh as the standard unit.

Second, the coefficient 44/12 in Article B's formula originates from molecular weights: a CO_2 molecule consists of two oxygen atoms and one carbon atom connected by covalent bonds. Carbon has an atomic weight of 12, oxygen 16, giving CO_2 a molecular weight of 44. Thus, one unit of carbon produces 3.666 times its weight in CO_2 when combusted.

Third, Article B reasonably proposes using provincial grid carbon emission factors at the consumption side, representing a sound approach for sourcing consumption-side factors. However, Article B does not address accuracy evaluation of carbon emission factors across power plants, transmission networks, and consumption sides.

1.3 Article C Analysis

On October 31, 2023, the Huaneng Carbon Neutrality Research Institute released the report *Research on Carbon Dioxide Emission Factors of China's Regional Power Grids (2023)* (hereinafter referred to as Article C). This report was jointly completed by the Huaneng Carbon Neutrality Research Institute, the Environmental Planning Institute of the Ministry of Ecology and Environment, and other organizations, and derives from the Chinese Academy of Engineering's branded project "Research on Several Major Issues Concerning China's Carbon Peak and Carbon Neutrality."

The report establishes that regional power grid CO_2 emission factors are fundamental parameters for accurately accounting for indirect emissions from electricity consumption and serve as critical metrics for quantitative analysis and promotion of consumption-side carbon emission reductions. Using a balance analysis method based on provincial grid generation data, inter-provincial power exchange data, and medium-to-long-term power development plans, the report constructs a provincial grid production simulation optimization model. Through scenario analysis, it investigates CO_2 emission factors for regional and provincial power grids from 2020 to 2035.

The findings reveal that China's provincial grid emission factors are generally high in the northeast and low in the southwest. Provinces with high grid emission factors are concentrated in Northeast and North China, where coal power dominates the generation mix; in 2020, these grid emission factors reached 841 gCO_2/kWh and 1,000 gCO_2/kWh, respectively. Conversely, regions with lower emission factors are primarily in Southwest China, where hydropower dominates the power structure; in 2020, Sichuan and Yunnan's grid emission factors were 117 gCO_2/kWh and 146 gCO_2/kWh, respectively. Under new energy policy scenarios from 2020 to 2035, provincial grid emission factors are projected to decline by an average of 43%.

Article C's authoritative research report on China's regional power grid CO_2 emission factors clearly indicates that provincial grid carbon emission factors will serve as the traceability source for transmission-side and consumption-side carbon emission factors, encompassing the entire chain from power plants to transmission to consumption. Power generation from generating units represents direct CO_2 emissions, while transmission and consumption sides represent indirect emissions. Consequently, accuracy evaluation of transmission-side and consumption-side carbon emission factors primarily depends on accuracy evaluation of the power supply-carbon emission factor of generating units.

1.4 Provincial Grid Carbon Emission Factor Calculation and Accuracy Evaluation

A provincial grid integrates multiple power sources, including power supply from numerous generating units, inter-provincial grid exchange, and remote ultra-high voltage (UHV) line inputs. A weighted average algorithm is appropriate for calculating provincial grid carbon emission factors.

The numerator of the equation includes: (1) total carbon emissions from multiple generating units (tCO_2), where each unit's carbon emissions equal its power supply (MWh) multiplied by its carbon emission factor (tCO_2/MWh); (2) carbon emissions from inter-provincial grid exchange ($\pm$) (tCO_2); and (3) carbon emissions from remote UHV line inputs (tCO_2). The denominator is the total provincial grid power supply (MWh), comprising: (1) power supply from multiple generating units (MWh); (2) inter-provincial grid exchange (±) (MWh); and (3) remote UHV line inputs (MWh).

For accuracy evaluation, a full-process measurement method can be applied to sampled units' CO_2 emission factors. Additionally, transmission and distribution line loss rates affect consumption-side carbon emission factors. As previously mentioned, Kunshan Tianyang Company's electric carbon meter displayed a carbon emission factor of 0.565 tCO_2/MWh. With a transmission and distribution line loss rate of 6%, tracing this back to the provincial grid carbon emission factor yields 0.565 tCO_2/MWh × 94% = 0.531 tCO_2/MWh.

2. Proposal: Full-Process Measurement Method for Accuracy Evaluation of Coal-Fired Unit Carbon Emission Factors

This section presents a full-process measurement method using a monthly calculation cycle, illustrated with parameters from a 300 MW coal-fired unit.

Coal Weighing: Generating units consume various coals including bituminous, anthracite, and lignite. Raw coal weighing error is denoted as e_1. For example, monthly consumption of bituminous coal for a 300 MW unit was weighed at 72.502 tonnes.

Coal Quality Testing: This involves two key measurements. First, calorific value determination uses units of MJ/kg (megajoules per kilogram) or the engineering unit kcal/kg, with a conversion factor of 4.186 (1 kcal/kg = 4.186 kJ/kg). Bituminous coal typically has a calorific value of 25–35 MJ/kg (5,972–8,361 kcal/kg), while lignite ranges from 8.38–16.76 MJ/kg (2,001.9–4,003.8 kcal/kg). Measurement error for calorific value is e_2. In the example, the 300 MW unit's bituminous coal calorific value was measured at 25 MJ/kg.

Second, fixed carbon and carbon content determination: Fixed carbon refers to the residue after removing moisture and ash, containing carbon plus small amounts of sulfur and hydrocarbons. Carbon content is measured on a dry, ash-free basis, typically ranging from 60–80% for coal. Carbon content measurement error is e_3. The example 300 MW unit's bituminous coal carbon content was measured at 72.5%.

Power Supply Calculation: Generating unit power supply equals power generation minus auxiliary power consumption. Measurement errors include generation metering error e_4, auxiliary power metering error e_5, and auxiliary power rate deviation e_6. For the example 300 MW unit, monthly generation was 216 MWh with an auxiliary power rate of 6%, yielding monthly power supply of 203.04 MWh. The unit's main parameters include: rated voltage 18 kV, rated current 10,997 A, rated capacity 342.86 MVA, rated active power 300 MW, rated power factor 0.875, 3-phase, 50 Hz.

Coal Consumption Rate Measurement and Standard Coal Consump-

tion Calculation: The power generation coal consumption rate measures coal consumed per kWh of electricity produced, expressed as g/kWh or kg/MWh. For the example unit, monthly generation of 216 MWh consumed 72.502 tonnes of 25 MJ/kg bituminous coal, resulting in a generation coal consumption rate of 335.66 kg/MWh.

When measuring coal consumption, different coals with varying calorific values must be converted to standard coal equivalent, defined as having a calorific value of 29.27 MJ/kg (7,000 kcal/kg). The resulting consumption rate is called the standard coal consumption rate. The example unit's generation standard coal consumption rate converts to 286.69 kg/MWh. The power supply standard coal consumption rate, a key economic and technical indicator for power plants, equals the generation standard coal consumption rate divided by (1 - auxiliary power rate). For the 300 MW unit, the power supply standard coal consumption rate is 305 kg/MWh.

Standard Coal Consumption and CO_2 Emissions Calculation: Monthly standard coal consumption for power supply equals the power supply standard coal consumption rate multiplied by monthly power supply. For the example: 0.305 t/MWh × 203.04 MWh = 61.92 tonnes.

Theoretical CO_2 emissions from standard coal are calculated based on elemental molecular weights: one tonne of standard coal emits 2.66–2.72 tonnes of CO_2, meaning each unit weight of standard coal produces 2.66–2.72 times its weight in CO_2. The 2.66 factor corresponds to 72.5% carbon content, while 2.72 corresponds to 74.18% carbon content. For the example 300 MW unit with 72.5% carbon content, one tonne of standard coal produces 2.66 tonnes of CO_2.

Direct CO_2 Emission Measurement: Fixed measurement equipment installed at the power plant stack or emission point can directly measure CO_2 emissions. This involves: (1) CO_2 concentration measurement using a CO_2 analyzer (error e_7); (2) flue gas velocity monitoring using ultrasonic flow meters (error e_8); and (3) stack area measurement (error e_9). Monthly CO_2 emission volume (m^3) equals flue gas flow rate (m^3/h) × CO_2 concentration (ppm) × emission duration (720 h/month).

Final Emission Factor Calculation: The generating unit's power supply-CO_2 emission factor (t/MWh) equals monthly standard coal CO_2 emissions (t) divided by monthly power supply (MWh). For the example 300 MW unit: 164.7 t CO_2 ÷ 203.04 MWh = 0.811 t/MWh.

Conclusion

The widespread application of electric carbon meters constitutes a systematic engineering challenge. The system comprises consumption-side carbon emission factors for electric carbon meters, transmission line loss rates for transmission-side factors, and generating unit power supply-carbon emission factors and provincial grid carbon emission factors—including factors for multiple generating units, inter-provincial grid exchange (±), and remote UHV line inputs. While electricity consumption and transmission represent indirect carbon emissions, only power generation constitutes direct emissions. Therefore, promoting electric carbon meters requires demonstrating the traceability and accuracy of the entire provincial grid carbon emission factor system. The rational and complete calculation of provincial grid carbon emission factors and full-process measurement verification of coal-fired unit carbon emission factors represent key technical issues for future electric carbon meter deployment.

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Note: Figure translations are in progress. See original paper for figures.