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RESEARCH ON ENTERPRISE CARBON EMISSION ACCOUNTING SYSTEM BASED ON WEATHER FORECASTING AND MACHINE LEARNING

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Abstract. This study integrates weather forecasting and machine learning to propose a new method for corporate carbon emission accounting and management. First, set up a weather data acquisition system to obtain real-time and future 15-day weather forecast data; Then use the carbon emission calculation method to monitor and calculate the energy consumption and carbon dioxide emissions in the production process of the enterprise in real time; Then, with the help of machine learning algorithms such as neural networks, a prediction model is built based on historical data to analyze and predict the impact of different factors on carbon emissions. Finally, through data analysis and cost forecasting, we provide reliable carbon cost prediction and management services for enterprises, help enterprises adjust production plans, improve production efficiency, and formulate scientific and effective emission reduction strategies. This method significantly improves the accuracy and stability of carbon emission forecasting, and has important practical significance for enterprise carbon cost accounting and management, which can help enterprises reduce environmental risks and costs, and provide new ideas and methods for enterprise carbon emission management and sustainable development.

Keywords: weather forecasting; Machine learning; carbon emission accounting; Management; Cost forecasting.

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АУА РАЙЫН БОЛЖАУ ЖӘНЕ МАШИНАЛЫҚ ОҚЫТУҒА НЕГІЗДЕЛГЕН КӘСІПОРЫННЫҢ КӨМІРТЕК ШЫҒАРЫНДЫЛАРЫН ЕСЕПКЕ АЛУ ЖҮЙЕСІН ЗЕРТТЕУ

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Аннотация. Бұл зерттеуде ауа райын болжау мен машиналық оқыту біріктіріліп, корпоративтік көміртек шығарындыларын есепке алу және басқарудың жаңа тәсілі ұсынылады. Алдымен нақты уақыт режимінде және алдағы 15 тәулікке арналған ауа райы деректерін алуға мүмкіндік беретін метеодеректерді жинау жүйесі орнатылады. Кейін кәсіпорынның өндірістік үдерістеріндегі энергия тұтынуы мен көмірқышқыл газы (CO_2) шығарындылары нақты уақыт режимінде мониторинг жасалып, көміртек шығарындыларын есептеу әдістемесімен есептеледі. Бұдан соң нейрондық желілер сияқты машиналық оқыту алгоритмдерінің көмегімен тарихи деректер негізінде әртүрлі факторлардың шығарындыларға әсерін талдап, болжайтын болжамдық модель құрылады. Соңында деректерді талдау және шығындарды болжау арқылы кәсіпорындарға көміртек құнын (carbon cost) болжау және басқару бойынша сенімді қызметтер көрсетіледі, бұл өндірістік жоспарларды түзетуге, өндіріс тиімділігін арттыруға және шығарындыларды төмендетудің ғылыми әрі тиімді стратегияларын әзірлеуге жәрдемдеседі. Ұсынылған әдіс көміртек шығарындыларын болжаудың дәлдігі мен тұрақтылығын айтарлықтай арттырады және кәсіпорынның көміртек құнын есепке алу мен басқару үшін маңызды практикалық мәнге ие: ол экологиялық тәуекелдер мен шығындарды азайтуға көмектеседі және көміртек шығарындыларын басқару мен орнықты дамуға жаңа идеялар мен тәсілдер ұсынады.

Түйін сөздер: ауа райын болжау; машиналық оқыту; көміртек шығарындыларын есепке алу; басқару; шығындарды болжау.

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ИССЛЕДОВАНИЕ СИСТЕМЫ УЧЕТА УГЛЕРОДНЫХ ВЫБРОСОВ ПРЕДПРИЯТИЯ НА ОСНОВЕ ПРОГНОЗИРОВАНИЯ ПОГОДЫ И МАШИННОГО ОБУЧЕНИЯ

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Аннотация. В данном исследовании интегрируются прогнозирование погоды и методы машинного обучения для предложения нового подхода к корпоративному учёту и управлению углеродными выбросами. Сначала развёртывается система получения метеоданных для сбора погодной информации в реальном времени и 15-дневного прогноза. Затем с использованием методики расчёта углеродных выбросов в реальном времени осуществляются мониторинг и вычисление энергопотребления и выбросов диоксида углерода (CO_2) в производственных процессах предприятия. Далее при помощи алгоритмов машинного обучения, таких как нейронные сети, на основе исторических данных строится прогностическая модель для анализа и прогнозирования влияния различных факторов на объём выбросов. Наконец, с опорой на анализ данных и прогнозирование затрат предоставляются надёжные услуги по прогнозированию и управлению углеродными затратами, что помогает предприятиям корректировать производственные планы, повышать эффективность и разрабатывать научно обоснованные и эффективные стратегии снижения выбросов. Предложенный метод существенно повышает точность и устойчивость прогнозирования углеродных выбросов и имеет важное практическое значение для учёта и управления углеродными затратами предприятия: он помогает снижать экологические риски и издержки, а также предлагает новые идеи и методы управления углеродными выбросами и устойчивого развития.

Ключевые слова: прогнозирование погоды; машинное обучение; учёт углеродных выбросов; управление; прогнозирование затрат.

Introduction. The impact of global warming is huge, and carbon emissions are one of the main causes. In order to achieve sustainable development, many countries have set carbon emission caps to encourage enterprises to reduce emissions. Corporate carbon emissions are related to energy consumption and type, and accurate calculation is of great significance for formulating emission reduction strategies. However, the traditional carbon emission calculation method has a large investment in manpower and material resources and is not accurate, which limits the implementation of emission reduction strategies.

Weather forecasting realizes weather prediction with the help of meteorological and geological information, which has been integrated into daily life, and the accuracy is constantly improving. Machine learning is increasingly widely used to mine the value of data and predict trends using computer algorithms and statistical theories.

Climate change is a serious global problem, and human activities are the main triggers, and reducing carbon emissions has become an international consensus. As a major energy consumer and greenhouse gas emitter, enterprises have made outstanding contributions to carbon emissions in large industrial countries. Therefore, it is important to scientifically calculate and manage the carbon emissions of enterprises, which is related to ecological and socio-economic development. At present, various fields are actively exploring the path of low-carbon economy, and the problem of corporate carbon emissions needs to be solved urgently.

The research on corporate carbon emission management at home and abroad focuses on carbon footprint calculation and management, the establishment and promotion of carbon trading market, and the openness and transparency of carbon emission data (Yang, et al, 2024). However, there are many problems with traditional methods, such as high energy consumption of carbon footprint calculation, difficulty in unified management of carbon trading markets, and easy concealment and falsification of carbon emission data.

At present, the measurement, management and reduction of corporate carbon emissions mainly use statistical algorithm-based methods, the former relies on a large amount of historical data and is susceptible to external interference, and model-based methods, the latter has high data requirements. The application of weather forecasting and machine learning technologies is expected to make up for the shortcomings of these two methods and improve the accuracy of measurement and management.

Theorical Framework

The traditional carbon emission accounting methods mainly include the combustion method, which estimates carbon dioxide emissions based on energy consumption, and the process analysis method, which calculates carbon dioxide emissions according to energy consumption, and the latter calculates according to the production process and raw material use (Wei, et al, 2024). Carbon reduction management strategies include energy substitution, process improvement, and resource optimization, etc., and can be evaluated by reducing energy consumption and optimizing production processes to reduce carbon emissions, and their effects can be evaluated with the help of an indicator system.

Weather forecast data is available through weather forecasting websites or API interfaces, covering key meteorological parameters, processed and cleaned for carbon accounting. Weather factors have a significant impact on corporate carbon emissions, such as temperature affecting energy consumption and humidity affecting chemical reactions. Machine learning algorithms, such as decision trees and support vector machines, are widely used in carbon emission management, which can build models to predict carbon emissions, and can also provide optimization and decision support for carbon emission reduction strategies, helping enterprises determine the best emission reduction plan. Combining weather forecast data with traditional accounting methods and using machine learning algorithms can more accurately predict carbon emissions and formulate effective emission reduction strategies for enterprises.

Carbon emission monitoring collects data such as energy consumption and emission sources with the help of sensors and monitoring equipment, and then analyzes, processes and interprets them. Enterprises should follow the requirements of scoping, accurate data, standardized format, and improved transparency in the preparation of carbon emission reports, and comprehensive and accurate reports can help enterprises manage carbon emissions (Zheyu, et al, 2024). Using data visualization tools to display carbon emission trends and compare data from different time periods and other enterprises can assist enterprises in scientific decision-making and efficient management of carbon emissions.

Clean energy technologies are the key to reducing carbon emissions, and solar, wind, and hydro can replace traditional fossil fuels, and large-scale promotion can significantly reduce carbon emissions. Energy efficiency and energy-saving technologies are widely used in buildings, transportation, and industry to reduce energy consumption without compromising service levels by improving thermal insulation, promoting electric vehicles, and optimizing production processes. Carbon capture and carbon storage technology captures carbon dioxide through chemical absorption, physical adsorption, etc., and sequesters it through underground storage or conversion and utilization (Chen, et al, 2024). New materials and low-carbon technology innovations bring new opportunities, new battery and energy storage technologies help the development of electric vehicles, and new materials improve solar energy efficiency, providing more options for reducing carbon emissions.

Materials and methods

Driven by the "dual carbon" goal, enterprises involved in carbon quotas and carbon tariffs are facing pressure on carbon management, and it is urgent to comprehensively verify the total amount of carbon emissions and establish a carbon cost management system. The power industry accounts for a high proportion of carbon emissions, and due to the influence of new energy power generation, the carbon emission factor fluctuates violently due to meteorological factors such as sunshine and wind speed, which brings uncertainty to carbon cost management (Li, et al, 2024).

This study combines weather forecast data with electricity carbon emission factors, and uses machine learning algorithms to calculate and predict real-time power carbon emission factors in the next 15 days, providing a scientific basis for enterprise carbon cost management and emission reduction.

In order to meet the needs of enterprises, a carbon emission monitoring information system is designed, and its design ideas and framework are shown in Figure 1. The system provides a visual representation of the past, current, and 15-day daily and hourly carbon emissions of electricity consumers. Enterprises can use this data to predict and analyze carbon emission costs on the same day and in the next 15 days, and obtain reliable carbon emission forecasting and management services in combination with production processes and plans. In addition, the system can help companies adjust production plans, increase or decrease production loads, and support decision-making (Li, et al, 2024).

The long-term operation of the monitoring system will help enterprises reduce costs, improve efficiency, and formulate more scientific and effective emission reduction plans. The research results are of great significance for enterprises to achieve carbon emission reduction, improve resource utilization efficiency, and formulate sustainable development strategies.

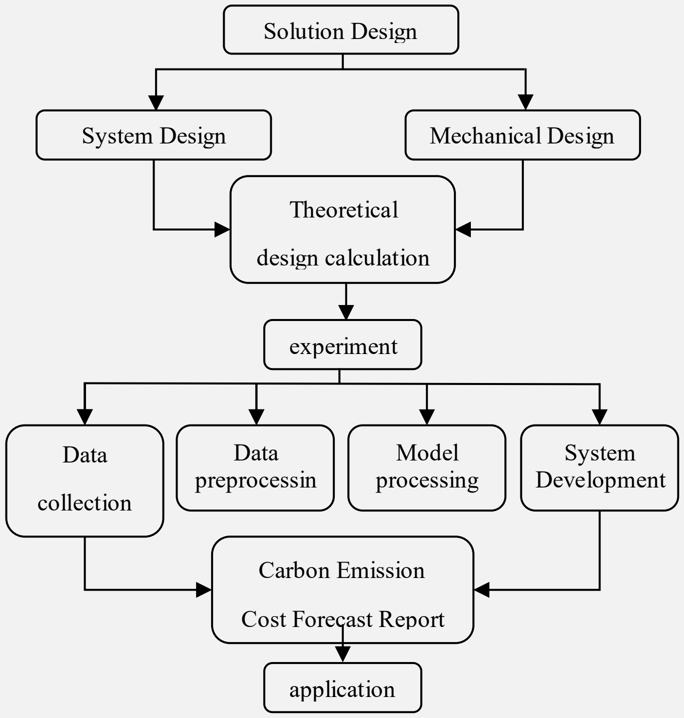

Figure 1: System design ideas and frameworks

The system collects data from multiple data sources such as meteorological bureaus, equipment sensors, and production sites, stores them in cloud databases, and cleans, converts, and standardizes pre-processing to meet the needs of subsequent model construction and analysis.

Meteorological data covers temperature, humidity, wind speed, precipitation and other parameters, analyzes their impact through historical data and machine learning algorithms, extracts key eigenvalues, and analyzes the correlation between meteorological factors and carbon emissions through statistical methods, so as to establish a prediction model suitable for enterprises to predict future meteorological conditions. Production data includes equipment usage, production process, energy consumption, pollutant emissions, etc., and analyzes these factors based on historical data and machine learning algorithms to predict future production processes and energy consumption. Real-time equipment data involves machine status, energy consumption details, flow meter and pressure gauge readings, etc., with the help of on-site sensors and equipment interfaces for real-time monitoring, combined with historical data to generate real-time operating charts and statistics.

The collected data needs to be cleaned, invalid and missing data removed, converted into a unified standard format, and then standardized to conform to specific distribution rules, such as normal distribution. This article uses daily weather forecast data, which can be obtained from meteorological websites or meteorological bureaus, where temperature, humidity, wind speed, rainfall and other information are essential for enterprise carbon emission accounting and management (Li, et al, 2024).

Corporate carbon emissions are generated by a combination of factors such as energy consumption, transportation and logistics, waste disposal, and chemical use. By measuring and tracking the carbon emissions of each link of the company's production activities, it identifies the peak period and emission sources of carbon emissions, and provides a scientific basis for enterprises to formulate emission reduction measures.

Based on the carbon emission factors that have been analyzed, we can build a carbon emission model based on weather forecasting and machine learning techniques (Mao, et al, 2024). The model can input weather forecast data and carbon emission factors in the production activities of the enterprise, and process and analyze the data in the model, and finally output the carbon emissions of the enterprise. The specific design steps of the model are as follows:

First, we need to preprocess weather forecast data and carbon emission factors. For weather forecast data, it is first necessary to standardize its format, such as unifying the date and time format. For carbon emission factors, we can use a standardized approach, that is, the values of multiple variables are scaled to the same range (Cui, et al, 2024).

Feature engineering is the process of transforming raw data into a collection of features that a model can recognize and utilize. In this paper, we feed weather forecast data and carbon emissions into the model as features. In terms of feature selection, we can use correlation coefficient analysis, principal component analysis and other techniques to screen out features with high correlation with carbon emissions (Chao, et al, 2024).

According to the results of feature engineering, we can choose machine learning algorithms suitable for enterprise carbon emission accounting, such as linear regression, decision trees, random forests, etc., for training. During the training process, we can use techniques such as cross-validation and grid search to improve the accuracy and generalization performance of the model.

The data used is the historical data of the city-level city where the enterprise is located, and the data collection interval is 5min, in which the weather indicators include irradiance, wind speed, humidity, temperature and other indicators, which are set as input indicators, and the power carbon emission factor at the corresponding time is the output index Using 80% of the local data for the whole year of 2022 as the initial dataset, the BP neural network model was trained. The other 20% of the data is used as the test set to test the accuracy of the model. The trend of carbon emission factors in Anhui Province in 2022 is shown in Figure 2.

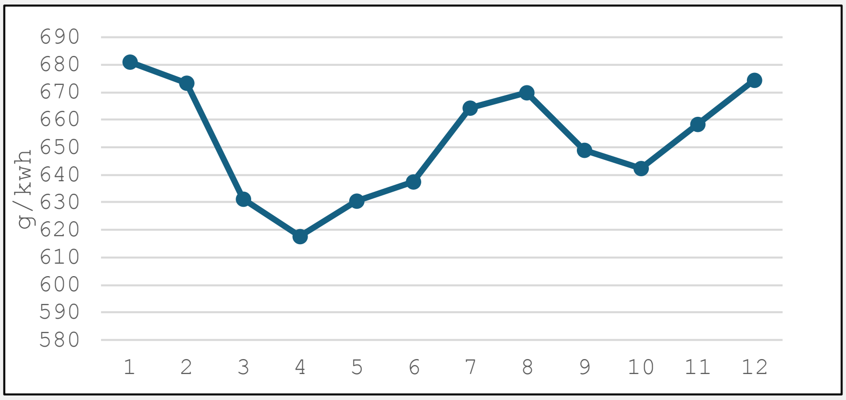

Figure 2: The trend of carbon emission factors in Anhui Province in 2022

The test dataset is fed into the trained model to evaluate the prediction performance of the model. Figure 3 shows the dynamic carbon emission factor for 24 hours in the future. The predicted dynamic carbon emission factors for the next 15 days are shown in Figure 4.

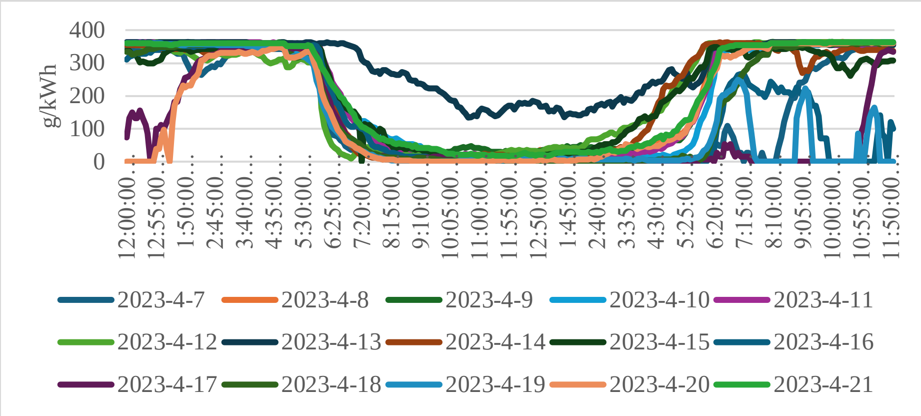

Fig. 3 The dynamic carbon emission factor for 24 hours in the future is predicted

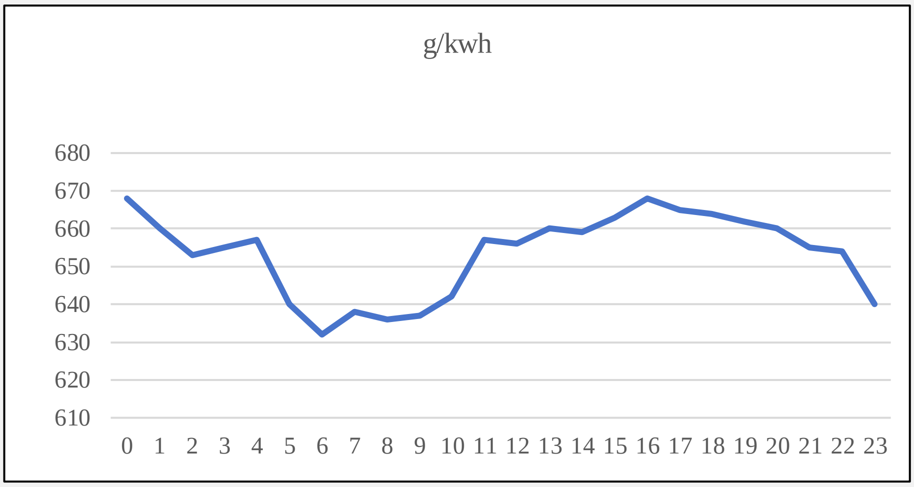

Figure 4: Predicted dynamic carbon emission factors for the next 15 days

In carbon emission accounting based on weather forecasting and machine learning, it is necessary to identify the correlation of model prediction results, identify the weather factors that mainly affect carbon emissions, and then design strategies to improve, control or reduce carbon emissions. Focus on model limitations and sources of error, such as the accuracy of weather forecast data.

This accounting method can help companies accurately measure carbon emissions, take effective control measures to reduce emissions, improve efficiency and reduce costs, and also help companies identify and track carbon footprints and set strategic goals that are in line with government regulations and market competition (Li, et al, 2024).

However, there are potential limitations to this approach. Weather forecast data may be inaccurate or updated late, resulting in increased error in the results; At the same time, it relies on large amounts of corporate energy use and weather condition data, which can affect the accuracy of the results if the data is incomplete or incorrect.

Weather forecasting and machine learning-based enterprise carbon cost forecasting needs to consider weather data acquisition, carbon emission calculation, machine learning modeling, and data analysis and cost forecasting. The working principle of the prediction system is shown in Figure 5.

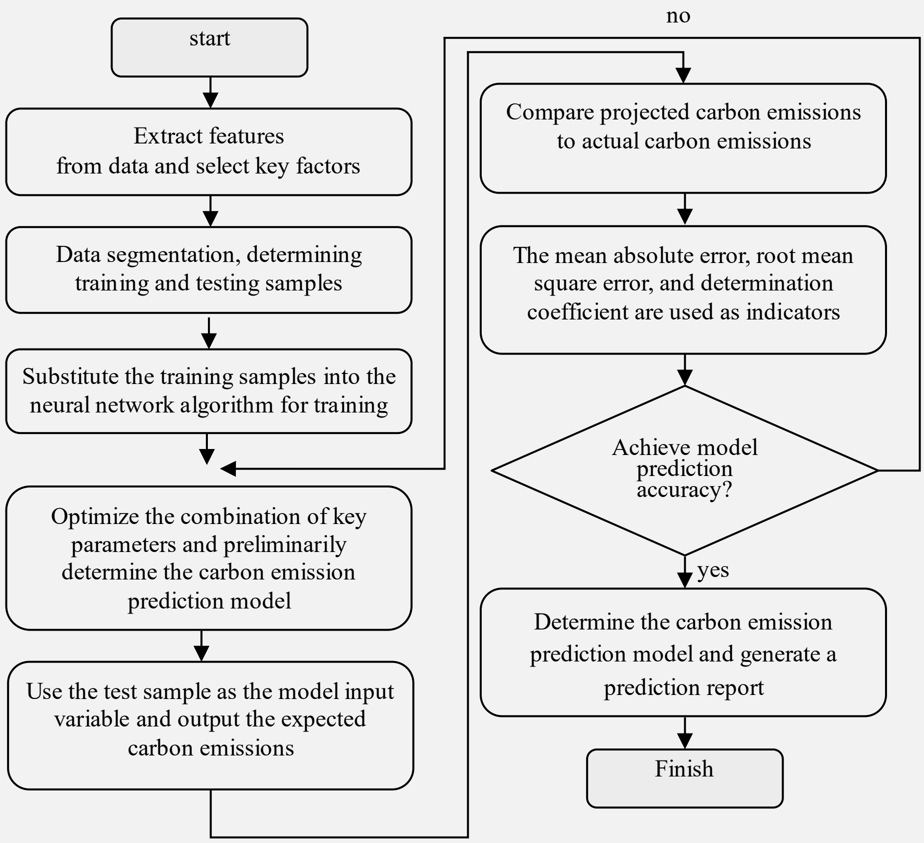

Figure 5: Schematic diagram of the working principle of the information system

Real-time weather data and weather forecast data for the next 15 days can be obtained from the Met website through the program. These data include indicators such as temperature, humidity, wind speed, and rainfall.

A company's carbon emissions can be calculated by monitoring energy consumption and CO_2 emissions from production processes. Methods such as direct monitoring of emissions from outlets, the use of fuel metering, or the use of carbon footprint tools can be employed.

Predictive models can be built based on existing historical data. In this process, the factors that affect carbon emissions need to be identified and used as input variables for the prediction model (Lou, et al, 2024). Machine learning algorithms such as BP neural networks can be used for modeling. The structure of the BP neural network is shown in Figure 6.

BP neural network is a powerful feedforward neural network model, which is efficient and accurate in achieving complex nonlinear mapping. The model trains the neural network by minimizing the error function, and uses the error backpropagation algorithm to continuously correct the weights, and solves complex problems by optimizing the network structure and model parameters.

The structure of the BP neural network includes an input layer, a hidden layer and an output layer, and the training is completed by minimizing the mean square deviation between the actual output and the desired output through gradient search technology. The BP algorithm includes forward propagation of signals and backpropagation of errors. When calculating the actual output, the signal is passed from the input layer through the hidden layer to the output layer; When correcting weights and thresholds, errors are backpropagated from the output layer to the input layer.

By combining weather forecast data and machine learning modeling, data analysis and cost prediction can be carried out to provide enterprises with reliable carbon cost prediction and management services. These information technology tools can help enterprises adjust production plans, improve production efficiency, and formulate more scientific and effective emission reduction strategies.

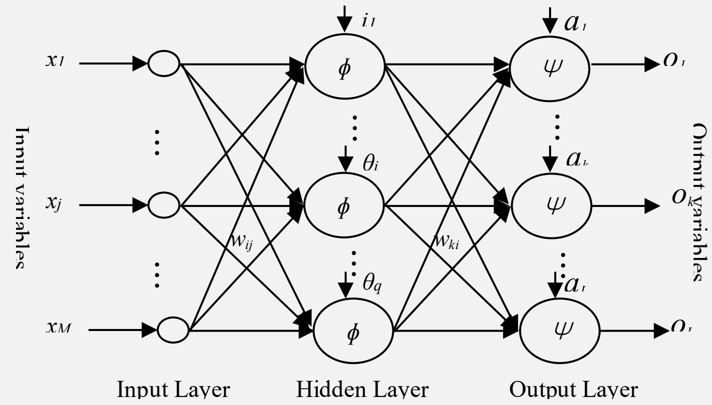

Figure 6: Schematic diagram of BP neural network structure

Where x_j represents the input of the jth node in the input layer, $j = 1, \ldots, M$; w_{ij} represents the weight between the i-th node in the hidden layer and the j-th node in the input layer; θ_i represents the threshold of the i-th node in the hidden layer; Φ represents the activation function of the hidden layer; w_{ki} represents the weight between the k-th node in the output layer and the i-th node in the hidden layer, $i=1,2,\ldots,q$; a_k represents the threshold of the k-th node in the output layer, $k=1,\ldots,L$; $\phi(x)$ represents the activation function of the output layer; O_k represents the output of the k-th node in the output layer.

Although the traditional BP neural network has good results in practical applications, there are still some limitations. The BP algorithm is easily disturbed by noise during the training process, resulting in the over-complexity of the parameters of the neural network and the over-fitting situation, which can only ensure the smallest error on the training set, and the actual error on the test set may be large, resulting in the reduction of prediction accuracy. Secondly, the BP algorithm is an optimization method based on gradient descent, which can only guarantee to find the optimal solution of the current point, and it is easy to fall into the local optimum, but cannot guarantee the global optimal solution. Figure 7 shows the BP algorithm program flow.

In order to improve the accuracy of the traditional BP neural network model, this work improves the traditional BP neural network model by increasing the adaptive adjustment learning step size and increasing the momentum term, so as to further improve the optimization ability of the neural network, so as to make more accurate predictions of power carbon emission factors in the future.

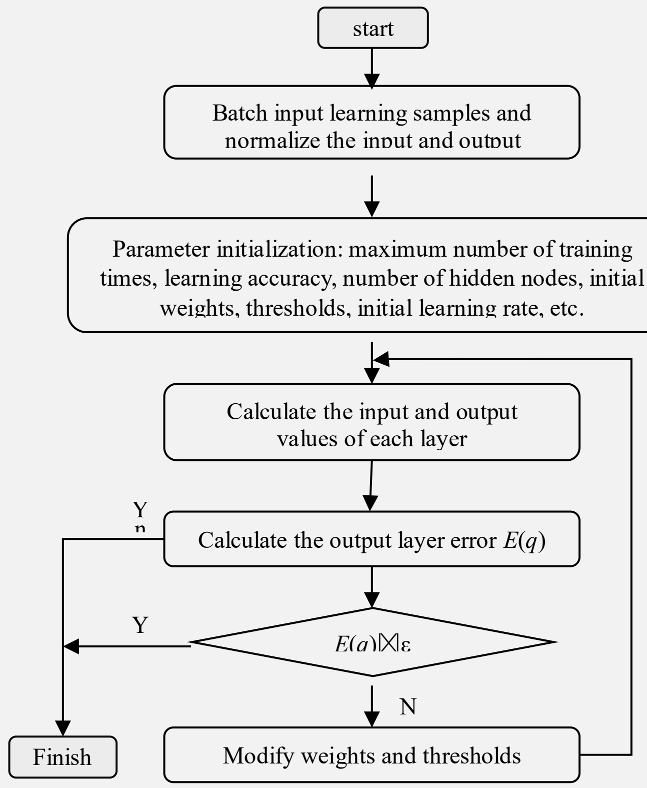

Figure 7: BP algorithm program flow chart

In order to solve the problems of low prediction accuracy and possible overfitting in the training of traditional BP neural network models, this paper proposes to increase the adaptive adjustment learning step size on the traditional model. The learning step size is a constant η, and if the value is too large or too small, it will affect the training effect of the model. When the η error surface is relatively flat, the learning step size is too small, which will cause the increase of learning times, and it should be increased η appropriately. When around the minimum, the learning step size is too large to cause oscillations, which should be reduced η. Based on this, the rules for the adaptive learning step size are set as follows. where is the $E(k)$ sum of squares of the error of the first step k.

$$\eta(k+1) = \begin{cases} 1.05\eta(k) & E(k+1) < E(k) \\ 0.7\eta(k) & E(k+1) > 1.04E(k) \\ \eta(k) & Other \end{cases} \quad (1)$$

The idea of overall adjustment is to increase the adaptive increase η when the learning converges to shorten the learning time. When it is too large to converge, η it should be reduced immediately η until it converges.

In order to solve the problem that the traditional BP neural network model is easy to fall into the local minimum value and cannot get the optimal value in the training, this paper proposes a method to increase the momentum term, and uses the momentum factor to transmit the last weight change. When the momentum factor is 0, the last weight is generated by the gradient descent method. When the momentum factor is 1, the new weight generated by the momentum factor method is the last weight change. Increasing the momentum method is essentially equivalent to adding a damping term in the training process, which reduces the sensitivity of the network to the local details of the error surface and slows down the oscillation trend of the learning process, so as to avoid the network falling into the local minima Improve its astringency. The modified formula for the momentum term is as follows:

$$\Delta w_{ij}(k+1) = (1-mc)\eta\delta_i p_j + mc\Delta w_{ij}(k)$$
$$\Delta b_i(k+1) = (1-mc)\eta\delta_i + mc\Delta b_i(k) \quad (2)$$

Among them, k is the number of training times, mc is the momentum factor, which is generally 0.95. By adding the momentum term, the network optimization can be helped to break away from the local minimum of the error surface, effectively preventing the situation of falling into the local optimum.

Therefore, in order to ensure the generalization ability and reliability of the model, the model is improved to a certain extent when selecting the model.

Based on the established machine learning model, combined with historical data and current weather forecasts, the future carbon cost can be predicted, and management measures can be formulated accordingly to reduce the carbon emissions and carbon costs of enterprises. With the help of real-time sensor monitoring and data analysis, the system can track the actual carbon emissions in real time, compare them with the predicted values, and identify potential problems in time and take countermeasures. Once the actual carbon emissions exceed the predicted value, the system will automatically alarm and remind the user to deal with it (Liu, et al, 2024).

The system displays data in various forms such as charts and maps to facilitate users to grasp data trends. At the same time, it supports custom reports and indicator cards to meet the needs of users to view data personally. Users can use the reporting feature to export data as a table or PDF file for in-depth analysis. The system can also provide targeted recommendations, such as optimizing production processes or equipment, to help companies reduce their carbon footprint.

In addition, the system has strict security measures, including user authentication, data encryption, etc., to ensure data security, prevent leakage and tampering, and strictly comply with relevant data protection regulations (Qiu, et al, 2024).

Results and discussion

Studies have shown that weather factors have a significant impact on carbon costs. Temperature, humidity, wind speed, etc. are closely related to carbon cost, and when the temperature increases, the humidity increases, and the wind speed increases, the carbon cost of enterprises often decreases, which is closely related to energy consumption. For example, the use of air conditioners by enterprises at high temperatures increases carbon emissions; The use of heating equipment increases at low temperatures, and carbon emissions are reduced; The increase in wind speed promotes natural ventilation of the atmosphere, reduces the accumulation of indoor pollutants, and lowers carbon costs. Different industries respond differently to weather factors, with manufacturing and construction industries responding significantly to temperature and humidity and less to wind speed, which is related to their energy consumption patterns and utilization efficiency. The impact of weather factors on carbon costs is not direct or linear, but through various approaches such as production efficiency, employee behavior, and energy efficiency, and subsequent studies need to consider these intermediate variables to more accurately simulate and predict their impacts (Shang, et al, 2024).

In this study, a neural network-based machine learning algorithm is used to predict the carbon cost of enterprises, which outperforms the traditional linear regression method and can predict more accurately and sensitively. With the help of deep learning algorithms, the neural network learns complex patterns and relationships in historical data through multi-layer neurons, uses backpropagation algorithms to optimize parameters during training, and uses cross-validation to evaluate prediction accuracy and generalization ability during testing. The results show that the model has high accuracy and sensitivity in predicting corporate carbon costs and can be effectively applied to corporate carbon management. At the same time, the model copes with data noise, missing or outliers through data cleaning and preprocessing, and has high stability and reliability.

In practical applications, the model has significant advantages. The deep learning algorithm enables it to better capture the nonlinear relationship of data and provide more accurate carbon cost prediction. The cross-validation method ensures the stability of the prediction results of the model on different datasets. Data cleaning and preprocessing ensure model stability and reliability. However, the model also has shortcomings. On the one hand, when a large amount of historical data is required to make the amount of data insufficient or inaccurate, it will affect the prediction results. Deep learning algorithms, on the other hand, involve a large number of matrix operations and backpropagation calculations, relying on high-performance computers or cloud computing support.

Conclusion. Based on weather forecasting and machine learning techniques, this paper proposes a new enterprise carbon cost prediction and management model and verifies its practical effect through a case study. The main contributions of this paper include providing a new way of thinking and methodology, identifying the main factors affecting corporate carbon emissions, and formulating carbon management strategies. In the future, the model can be further improved and optimized to better cope with practical application scenarios, including adding more feature variables and improving prediction algorithms. In addition, the relationship between carbon costs and corporate profits can be studied, and corresponding strategies can be developed to balance the relationship between carbon emissions and corporate profits. In short, the model has a wide range of application prospects in the prediction and management of corporate carbon costs, which can help enterprises effectively control carbon emissions, reduce carbon costs, and promote the process of sustainable development.

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