Check for updates

Carbon emission scenario prediction for highway construction projects

Qixian Wu[1], Yun Chen[2]*, Congying Li[2] and Xiaoya Shi[2]

[1]Country Management College, Wuzhou University, Wuzhou, China, [2]Traffic and Transportation Engineering College, Changsha University of Science and Technology, Changsha, China

In order to carry out the research on the measurement and prediction of carbon emissions from highway projects, the prediction index system is constructed by selecting seven influencing factors, namely, urbanization rate, industrial structure, energy intensity, energy structure, key low-carbon technologies, highway construction planning, and green financial support. The carbon emission coefficient method is used to measure the carbon emissions of highway projects from the perspective of energy consumption, and finally, a carbon emission scenario prediction model based on the scenario analysis method and the LSTM algorithm of the recurrent neural network is constructed to put forward a new way of predicting the carbon emissions of highway projects. Taking Hunan province as a case study object, the carbon emission trends in the next 15 years are predicted under three scenarios: low carbon, baseline, and high carbon. The results show that the highway project in Hunan province is expected to peak in 2031 under the low-carbon scenario, in 2037 under the baseline scenario, and around 2044 under the high-carbon scenario. It is also found that energy saving and emission reduction measures have a certain lag in the emission reduction effect of highway projects. Finally, based on this, suggestions and countermeasures for carbon emission reduction of highway development in Hunan province are proposed.

1 Introduction

Climate change is one of the most serious challenges faced by all countries and regions of the world. The Government of China is committed to peaking carbon dioxide emissions by 2030 and striving to achieve carbon neutrality by 2060. Achieving the goal of carbon peaking and carbon neutrality requires the joint efforts of the whole society and the full participation of all industries, among which the transportation industry is no exception.

The rapid development of China's highways is not only the focus of China's construction of a strong transportation country but also an important support for the development of the national economy. Highway engineering not only contributes to economic and social development but also is the main source of carbon emissions; therefore, highway engineering and construction of low-carbon development is imperative. This paper takes Hunan province as a case study, analyzes and combs the main influencing factors of carbon emission of highway projects, predicts the time of reaching the peak, and puts forward the emission reduction path, which is of important research significance for highway development planning.

The study of highway engineering carbon emission measurement is mainly carried out for the division project in the highway, through the analysis of the carbon emission source of the asphalt pavement construction link, to construct the carbon emission measurement model based on the carbon emission factor and global warming potential measurement of asphalt pavement construction machinery (Yun et al., 2019).

The whole life cycle of a highway project is divided into four stages: planning, design, construction, and operation, and the existing carbon emission measurement method is mainly applied to the construction stage. The construction period is divided into three phases: material materialization, mechanical construction, and material transportation, and the emission coefficient method is used to establish the calculation model (Ying and Shuangshuang, 2022). With the endogenous carbon emissions during the construction period as the object of research on construction machinery, personnel activities, and resource changes in the cluster analysis, through the IPCC recommended methods, similarity studies and engineering analogies are used to determine the different clustering coefficients and then carry out divisional carbon emission accounting (Guangyuan, 2013). Research results for the scale of CO_2 emissions associated with infrastructure construction activities on mountain highways show that CO_2 emissions from road segments are one order of magnitude lower than those from bridges and tunnels (Yuanyuan et al., 2019). The mainstream analytical method in the field of energy and carbon emission forecasting research at home and abroad is the scenario analysis method. From the point of view of the forecasting model used, domestic and foreign macro carbon emission forecasting methods can be categorized into three types: the macro energy-economic environment modeling method, the model fitting forecasting method based on the key influencing factors of carbon emissions, and the environmental Kuznets curve modeling method (Huaquan, 2015). For industry, studies have been conducted to predict the future values of the influencing factors of carbon emissions as well as the industrial carbon emissions under the target scenario (Xiaosong and Guohao, 2014; Zhenying and Jiangao, 2014). For the construction industry, neural networks and system dynamics are utilized to predict the carbon emission intensity of the construction industry (Donglei and Yisheng, 2019; Guangtai et al., 2021). For highway engineering, the BP neural network and random forest are used to learn the carbon emission data and then establish the prediction model of carbon emission during the highway construction period (Huiying, 2022).

Through the analysis of the existing literature, it is found that there are two major problems in the calculation and prediction of carbon emissions during the highway construction period; that is, there are few calculation models for carbon emissions of regional highway projects, and the carbon emission scenario prediction indexes are not closely related to highway projects. Therefore, this paper proposes to take the urbanization rate, industrial structure, energy intensity, energy structure, key low-carbon technologies, highway construction planning, and green financial support as the carbon emission prediction indicators of highway projects and use the carbon emission coefficient method to construct the carbon emission measurement model of highway projects from the perspective of energy consumption. Through the carbon emission scenario prediction model based on the scenario analysis method and the LSTM algorithm of recurrent neural network, the carbon emission trends in Hunan province under three scenarios of low carbon, baseline, and high carbon are analyzed to provide theoretical basis for the realization of the dual-carbon target.

2 Research methods and models

2.1 System of forecasting indicators

Based on the relevant literature at home and abroad, the actual situation in China, and the questionnaire survey on the front-line practitioners, using the Likert scale and Pearson correlation analysis, we finally determined seven important influencing factors, namely, urbanization rate, industrial structure, energy intensity, energy structure, key low-carbon technology, highway construction planning, and green financial support, to build the carbon emission prediction index system for highway construction projects. The process of calculating each indicator is shown in Table 1.

Urbanization rate: It is a measure of urbanization, calculated by the ratio of the urban population to the total population.

Industrial structure: The industry proposed in this paper refers to the secondary industry which is highly related to the construction of the highway and is calculated by the ratio of the value added of the secondary industry to the regional GDP.

Energy intensity: It refers to the energy consumption per unit of output value and is calculated by the ratio of energy consumption to GDP. The lower energy intensity represents the less energy consumed and the higher quality of GDP, and it also reflects the degree of economic dependence on energy.

Energy structure: It is calculated as the ratio of raw coal in transportation to the total energy consumption.

Key low-carbon technology: Green low-carbon technology patents, which refer to patents with green low-carbon technology as the subject of invention, should have the technical effect of reducing carbon emissions compared with existing technologies (Jianchun, 2023). In this paper, the annual number of green low-carbon technology patents is used as a value to measure the development of low-carbon technology in a region.

Highway construction planning: The degree of highway development in a region is measured by the density of the highway network, and this paper uses the density of the highway network to indicate the highway construction planning, calculated as the ratio of the number of miles to the total area of the region.

Green fiscal support: It is the value of a series of fiscal policies and measures enacted by the government to promote the development of green economy. The implementation of an effective green fiscal policy is an important means to realize the goal of "carbon peak and carbon neutral."

2.2 Carbon emission measurement

Based on the energy consumption characteristics of the highway project, seven energy types, namely, raw coal, gasoline, kerosene, diesel fuel, fuel oil, natural gas, and electricity, are selected and

TABLE 1 Table of the projected indicator system.

Influencing factor	Calculation method
Urbanization rate	Urban population/total population
Industrial structure	Value added of the secondary sector/GDP
Key low-carbon technology	Annual number of green patents granted
Energy intensity	Total energy consumption/GDP
Energy structure	Coal consumption/total energy consumption
Highway construction planning	Total regional highway mileage/total regional area
Green financial support	Annual fiscal environmental protection expenditure/fiscal general budget expenditure

discounted according to the carbon emission factor method. The calculation formula is as follows:

$$C = \sum_i C_i = \sum_i E_i \times F_i. \qquad (2-1)$$

In Eq. 2-1, C is the carbon dioxide emissions; E_i is the consumption of the ith energy source; and F_i is the carbon emission factor of the ith energy source.

2.3 Carbon emission scenario projections

Referring to the results of the Energy Research Institute of the National Development and Reform Commission and combining with the general background of highway construction, this paper sets three scenarios of high carbon, low carbon, and baseline based on the future development trend of the predicted indicators, and the specific meanings of the scenarios are shown in Table 2.

2.3.1 Carbon emission prediction model construction based on long short-term memory

The long short-term memory (LSTM) network is a temporal recurrent neural network, which is specially designed to solve the long-term dependency problem that exists in general recurrent neural networks (RNNs) (Bingxiao et al., 2022).

The carbon emission prediction of highway projects is uncertain, complex, and time-series and needs to consider the long-term trend and short-term fluctuations and other comprehensive factors at the same time. The LSTM network is more suitable for dealing with time-series data, as it can capture the long-time dependence and learn adaptively, consider long-term and short-term information at the same time, and record the historical information and apply it to the current prediction.

(1) Data processing

Since the seven influencing factors of urbanization rate, industrial structure, energy intensity, energy structure, key low-carbon technologies, highway construction planning, and green financial support have large differences in the order of magnitude, it is necessary to normalize the data used for model training and testing to be between [0,1], and this processing can be accomplished by relying on the function of MinMaxScaler in Scikit-Learn. The normalization mathematical expression is shown as follows:

$$X = 2 \times \frac{X_0 - X_{\min}}{X_{\max} - X_{\min}} - 1. \qquad (2-2)$$

In Eq. 2-2, X0 is the original data and X is the processed data.

After the prediction, the output value y should be inverse normalized, and the expression is shown as follows:

$$\frac{(y+1) \times (y_{\max} - y_{\min})}{2} + y_{\min} = y. \qquad (2-3)$$

(2) Projected evaluation indicators

TABLE 2 Definitions of low-carbon, baseline, and high-carbon scenarios.

Scene	Scenario definition
Low-carbon scenario	The low-carbon scenario refers to further emphasizing the role of science and technology in energy conservation and emission reduction in highway construction projects, increasing the development and research of key low-carbon technologies in construction, and promoting them on a large scale for use in projects under construction as well as projects to be commenced, and significantly increasing the proportion of cleaner production in the production of high-energy-consuming construction materials. Carbon emissions under a low-carbon development scenario are at a low level
Baseline scenario	The baseline scenario is based on the current path of social, economic, energy consumption, and highway development without further strengthening energy conservation and emission reduction measures. The significance of the baseline scenario is to simulate the maintenance of the existing development plan without further energy saving and emission reduction measures, to study the trend of carbon emissions on this basis, and to compare the carbon emissions and trend with the implementation of energy saving and emission reduction policy scenarios, so as to facilitate the search for the early realization of the policy path of carbon peaking (Xiaodie 2022)
High-carbon scenario	The high-carbon scenario is a projection of CO_2 emissions based on the current highway development scenario, in which the government is still aiming for economic improvement and exceeding the currently planned economic development and other targets, while the development of energy saving and emission reduction influencing factors has stagnated compared to the baseline development scenario

TABLE 3 LSTM model parameter setting table.

Parameter name	Parameter value
Data slice	0.8
Training step	3
Number of layers	1
Training wheels	200
Optimizer	Adam
Learning rate	0.001

After outputting the predicted values, the gap between the predicted and true values is evaluated using mean absolute percentage error (MSPE), mean absolute error (MAE), and root mean square error (RMSE), with a smaller gap representing a smaller error (Shipeng, 2021).

2.3.2 Parameterization of the LSTM prediction model

The data cutoff is set to 0.8, but considering the small number of test sets, the window value is set to 3 so that the test set can be taken forward for three more years; the training step size T is set to 3; layer_size, i.e., the number of hidden layers of the LSTM model, is set to 1; epoch, i.e., the number of training rounds, is set to 200; and Adam is chosen as the optimizer. MAE is chosen for the loss function; the learning rate is a constant affecting the independent variable used to reduce the loss value, set to 0.001; and the activation function is the tanh function.

The training parameter settings of the LSTM prediction model are organized as shown in Table 3.

3 Case study of Hunan province

3.1 Analysis of the current status of carbon emissions

3.1.1 Current situation of highway development in Hunan province

The construction of highways in Hunan province began in 1993. As the country and Hunan province strengthen the investment in highway transportation infrastructure, the scale of transportation infrastructure in Hunan province has seen unprecedented growth during the "13th Five-Year Plan" period. 5,700 km of highway mileage in 2015, as of the end of 2022, the highway mileage in Hunan province exceeded 7,300 km of highway, an increase of 28.07%. The total mileage of highway is 5,700 km in 2015. The highway network skeleton of "five vertical and seven horizontal" is basically formed (Figure 1).

3.1.2 Calculation of carbon emissions

Carbon emissions from highway construction projects in Hunan province from 2000 to 2021 are calculated (Figure 2). The consumption of raw coal, gasoline, kerosene, diesel fuel, fuel oil, natural gas, and electricity in the transportation industry of Hunan province is taken from the China Energy Statistical Yearbook, and the basic data and results of the accounting are shown in Table 4.

The following conclusions can be drawn from the analysis of the calculation results and change trends of carbon emissions from highway projects in Hunan province from 2000 to 2021.

If the influence of abnormal years is ignored, it can be found that the carbon emissions from highway projects in Hunan province from 2000 to 2021 show two stages of characteristics. The first stage is the rapid growth stage (2000–2015), from 613,200 tons in 2000 to
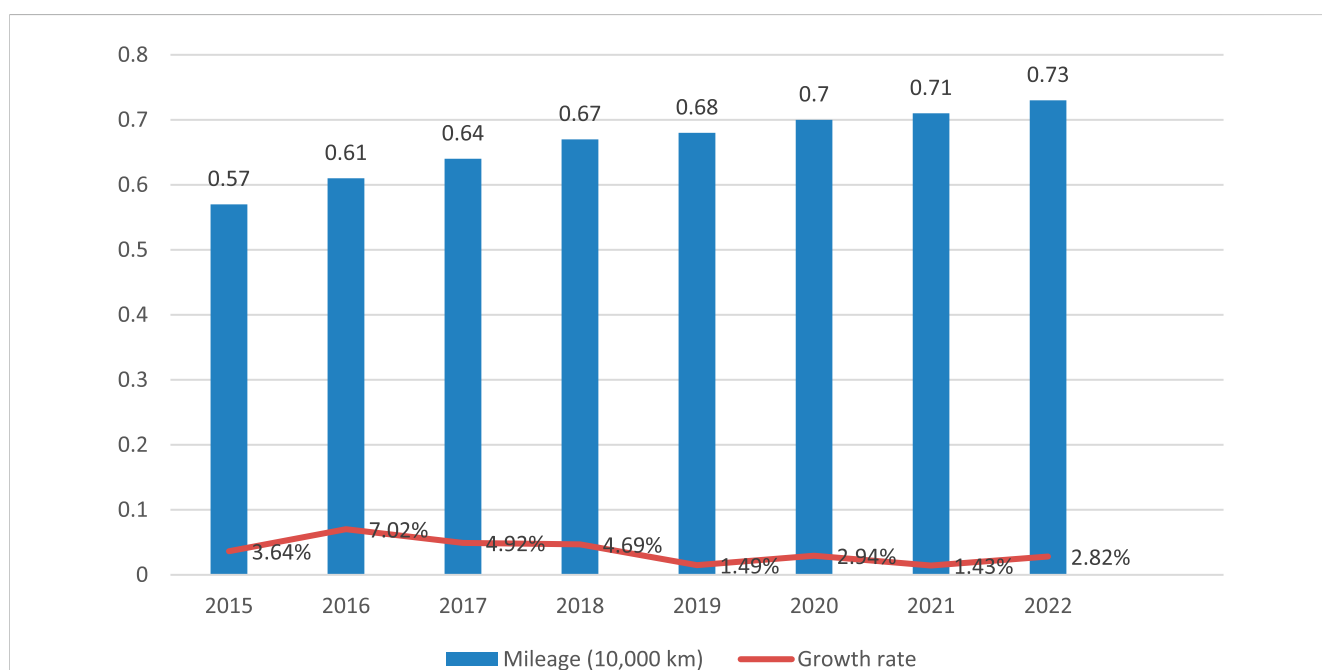

FIGURE 1
Changes in the total mileage of highways in Hunan province in the past 8 years.
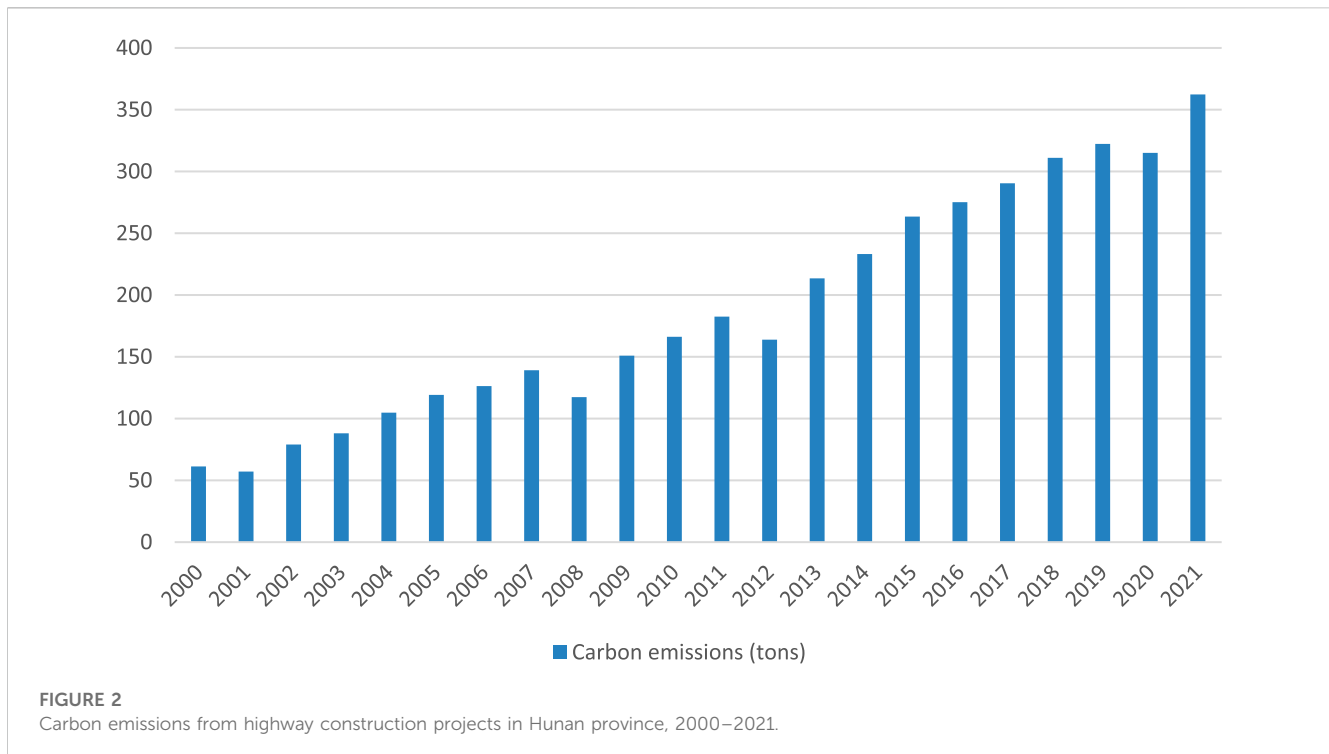
FIGURE 2
Carbon emissions from highway construction projects in Hunan province, 2000–2021.

2,634,900 tons in 2015, an increase of 329.30%, with an average annual growth rate of 21.95%. The second stage is the slow growth stage (2015–2021), from 2,634,900 tons in 2015 to 3,624,200 tons in 2021, with an average annual growth rate of 6.26%.

3.2 Scenario setting

The parameter values of the screened influencing factors were set based on the three scenarios of low carbon, baseline, and high carbon, and the LSTM model and scenario analysis were applied to forecast the CO_2 emissions of Hunan province from 2022 to 2036.

3.2.1 Data sources

The urbanization rate, the number of highway mileage in Hunan province, the value added of the secondary industry for calculating the industrial structure, and the GDP of Hunan province are from the Hunan Provincial Statistical Yearbook; the energy intensity is obtained by converting the measured total energy consumption; the number of green patents in Hunan province is from the China Research Data Service Platform (CNRDS); and the financial environmental protection expenditure and the financial general budget expenditure of Hunan province are from the National Bureau of Statistics (NBS). Specific forecast indicators are shown in Table 5.

Pearson correlation analysis of highway construction project carbon emissions and prediction index data: The results show that the carbon emissions and the seven influencing factors all show significance, and the correlation coefficient values are 0.98, 0.78, −0.92, −0.87, 0.98, 0.89, and 0.86. It means that the selected variables are basically reasonable.

3.2.2 Scenario parameterization

(1) Scenario setting for urbanization development

The "14th Five-Year Plan for New Urbanization in Hunan province" combines the development rate of urbanization in Hunan province over the past decade and draws on the urbanization development laws of first-tier cities to scientifically formulate that the urbanization rate of the resident population will reach 63% by 2025 and strive to reach 72% by 2035. Through calculation, it can be seen that in order to achieve this goal, the average annual growth rate of urbanization in Hunan province from 2022 to 2035 will be 1.35%. Setting this growth rate as the baseline development scenario, the corresponding urbanization growth rates of Hunan province in the high-carbon and low-carbon development scenarios increase and decrease by 0.1%, respectively.

(2) Scenario setting for industrial structure development

According to the statistics of Hunan province during the period of the "Tenth Five-Year Plan," "Eleventh Five-Year Plan", and "Twelfth Five-Year Plan," the secondary industry of Hunan province has shown an increasing and then decreasing trend. However, the tertiary industry has been growing continuously, and its proportion shows a trend of surpassing that of the secondary industry. Therefore, the study predicts that under the baseline development scenario, the proportion of the industrial output value in Hunan province will be reduced to 35% in 2050, with an average annual growth rate of −0.38%, while under the high-intensity emission reduction measures, the average annual growth rate under the low-carbon development scenario is −0.58%, and the

TABLE 4 Carbon emissions from highway construction projects (unit: thousand tons).

Particular year	Emission level	Carbon emissions per km	Raw coal	Fuel	Gasoline	Diesel fuel	Bunker fuel	Petroleum	Electrical power
2000	613.22	—	188.70	869.00	69.70	977.70	0.30	—	90.60
2001	571.59	—	191.50	879.50	40.90	858.70	0.40	—	114.60
2002	789.84	—	203.10	1066.60	72.00	1350.40	0.40	—	149.80
2003	880.99	0.65	215.00	1218.00	81.80	1485.00	0.60	—	170.70
2004	1048.26	0.72	189.00	1415.90	98.50	1723.20	113.20	—	200.30
2005	1191.78	0.85	281.00	1785.10	101.10	1756.70	135.00	—	190.50
2006	1263.59	0.90	81.00	1564.70	180.20	2177.00	201.30	—	206.30
2007	1391.38	0.79	99.90	1483.30	201.60	2636.00	200.00	0.30	242.20
2008	1174.22	0.59	227.40	970.40	204.10	2434.70	104.50	2.60	241.60
2009	1509.72	0.68	213.50	1109.20	257.20	2995.70	444.50	5.10	243.40
2010	1662.46	0.70	66.60	1204.40	278.40	3457.70	455.30	5.80	318.50
2011	1825.52	0.69	73.10	1293.70	291.70	3930.20	408.50	7.50	349.60
2012	1638.59	0.41	70.40	1332.40	328.80	3240.10	420.80	12.90	359.90
2013	2134.45	0.42	1271.20	1412.30	360.60	3969.60	446.00	18.20	370.20
2014	2332.30	0.42	1370.60	1522.70	388.80	4380.00	480.90	19.60	395.50
2015	2634.93	0.47	1404.60	1674.40	448.10	5006.30	608.80	19.60	425.30
2016	2751.19	0.45	1611.60	1884.70	475.70	5032.50	605.40	21.00	484.20
2017	2904.26	0.45	2753.90	2084.10	552.10	4572.00	601.30	17.30	563.70
2018	3110.76	0.46	2890.80	2487.70	579.60	4709.20	631.20	28.50	594.50
2019	3223.33	0.47	3003.60	2554.70	602.20	4892.90	655.80	29.70	650.50
2020	3151.36	0.45	2975.30	2449.40	586.90	4773.50	672.00	32.50	612.20
2021	3624.22	0.51	404.90	3151.50	921.70	5601.90	816.80	11.90	693.40

growth rate is set at −0.18% under the high-carbon development scenario.

(3) Energy intensity development scenario setting

The World and China Energy Outlook 2050 (2020 Edition) of the China Academy of Petroleum Economics and Technology forecasts an average annual decline in energy intensity of about 3.5% between 2020 and 2050 under the baseline scenario. This is used as a basis to set the average annual energy intensity growth rate for 2022–2036 at −3.50%, −4.00% for the low-carbon development scenario and −3.00% for the high-carbon development scenario.

(4) Scenario setting for energy mix development

Currently, the proportion of coal consumption in China has reached 57.64%, and the proportion of raw coal consumption in Hunan province's transportation sector in 2020 was 19.45%. However, the data show that there is a precipitous drop in raw coal consumption in 2021, which is very different from the trend in previous years, plus the fact that the statistics for 2022 have not yet been released, so it is not possible to know whether the change is consistent going forward. This paper, therefore, uses energy mix data for 2020 as the basis for calculating the development scenario.

(5) Prospects for the development of key low-carbon technologies are set

The country's average development rate for 2016–2021 is set as the baseline scenario at 6.5%. The annual growth rates for the low-carbon and high-carbon scenarios are set at 7.5% and 8.5%, respectively.

(6) Highway construction planning and development prospect setting

As of the end of 2021, the density of highway network in Hunan province was 334.42 km²·km⁻². According to the "14th Five-Year Plan for Transportation Development in Hunan province (Highway and Waterway)" released in 2021, the density should reach 613.79 km²·km⁻² by 2050. This is set as the baseline scenario for highway construction planning, with an average annual growth rate of 2.12%, and the low-carbon development scenario and high-carbon development prospect are set at 1.92% and 2.32%, respectively.

TABLE 5 Influence factor data of the carbon emission prediction model for highway projects.

Particular year	Urbanization rate (%)	Industrial structure (%)	Energy intensity (tce/ten thousand Yuan)	Energy structure (%)	Highway Planning (km km^{-2})	Key low-carbon technologies (pieces)	Green financial support (%)
2000	29.75	36.41	1.1462	6.18	20.77	124	1.16
2001	30.80	36.87	1.2062	6.64	27.62	153	0.98
2002	32.00	36.67	1.2143	5.11	47.78	138	0.98
2003	33.50	38.03	1.1936	4.84	57.51	186	1.27
2004	35.50	38.53	1.3710	3.58	57.51	188	1.03
2005	37.00	39.09	1.5242	4.71	66.24	243	1.17
2006	38.71	40.78	1.4238	1.28	66.24	273	1.18
2007	40.45	41.65	1.2524	1.43	83.29	364	1.37
2008	42.15	43.07	1.0927	3.86	94.48	545	1.58
2009	43.20	43.02	1.0437	2.86	105.10	666	1.85
2010	46.72	45.17	0.9554	0.80	112.65	1110	1.96
2011	45.10	46.97	0.8544	0.80	125.07	1396	1.47
2012	46.65	46.81	0.7895	0.85	187.35	1664	1.87
2013	47.96	46.35	0.6336	12.21	240.04	2367	2.00
2014	49.28	45.69	0.5918	12.06	259.35	2385	2.05
2015	50.89	44.38	0.5086	10.94	266.90	3088	1.59
2016	52.75	41.95	0.4811	11.99	287.06	3473	2.08
2017	54.62	39.79	0.4493	19.56	303.07	3856	1.66
2018	56.09	38.27	0.4279	19.14	317.52	4972	2.09
2019	57.45	38.61	0.4011	19.14	321.15	5269	2.17
2020	58.76	38.39	0.3949	19.45	328.19	8167	2.14
2021	59.71	39.05	0.3589	2.46	334.42	11,004	2.52

Taking the year 2000 as an example, the calculation process is shown below.

Urbanization rate (%) = urban population/total population = 1915.92/6440.07 ≈ 0.2975*100% ≈ 29.75%.

Industrial structure (%) = gross secondary product/GDP = 1293.18/3551.49 ≈ 0.3641.

Energy intensity = total energy consumption/GDP, 4070.71/3551.49 ≈ 1.1462.

Energy structure = coal consumption/total energy consumption = 18.87/305.19351 ≈ 6.18%.

Highway planning = 440/21.18 ≈ 20.77.

Green financial support = annual fiscal environmental protection expenditure/fiscal general budget expenditure = 4.02/347.83 ≈ 0.0116.

TABLE 6 Setting of growth rates for each of the projected indicators under different scenarios (in %).

Predictive indicator	Low-carbon scenario (%)	Baseline scenario (%)	High-carbon scenario (%)
Urbanization rate	1.25	1.35	1.45
Industrial structure	−0.58	−0.38	−0.18
Energy intensity	−4.50	−3.50	−2.50
Energy structure	−2.94	−2.64	−2.34
Construction plan	1.92	2.12	2.32
Key low-carbon technologies	7.5	6.5	5.5
Green financial support	4.43	3.93	3.43

TABLE 7 Table of model evaluation results.

Dataset	RMSE	MAE	MAPE
Training set	5.91	4.65	0.023
Test set	7.36	5.06	0.032

(7) Setting the scene for green financial development

The proportion of fiscal environmental protection expenditure in Hunan province increases from 2.08% in 2016 to 2.52% in 2021, with an average annual growth rate of 3.93%, which is set as the growth rate under the baseline scenario, and the low-carbon and high-carbon scenarios are set at 4.43% and 3.43%, respectively.

The parameters of the above seven projected indicators for the low-carbon, baseline, and high-carbon scenarios are summarized in Table 6.

3.3 Scenario forecasting and outcome analysis

3.3.1 Scenario prediction and model training

The model is first trained, and the final batch size and number of implied nodes are determined to be 4 and 7, respectively. At this point, the performance of the model is as shown in Table 7.

According to the table of model evaluation results, it can be found that no overfitting occurred in the model. In order to further verify the prediction effect, the LSTM model was trained and tested, and the comparison of its simulated and real values is shown in Figure 3 and Table 8.

A comparison of the simulated and real values of the LSTM model is shown in Figure 3.

The specific values are shown in Table 8.

As can be seen from the graph, the LSTM model has individual error values that are large, but the overall prediction error is low and has high accuracy.

3.3.2 Analysis of the results of carbon emission projections

With the three scenarios of low carbon, baseline, and high carbon and the different settings of their prediction indexes, the data are organized and then imported into the LSTM model for prediction, thus obtaining the prediction results of the carbon emissions from highway construction in Hunan province under the three development scenarios in the period of 2022–2036, and the specific results are shown in Figure 4 and Table 9.

Figure 4 shows the results of the LSTM model prediction of future carbon emissions from highway projects in Hunan province under different scenarios, from which the trend change of future carbon emissions can be seen.

(1) Comparison of the trends: The years in which carbon emissions peak under different scenarios are different. The results show that as of 2036, the low-carbon scenario will peak in 2031, the baseline scenario will peak in 2037, and the high-carbon scenario is expected to peak around 2044.

(2) Total carbon emissions are analyzed: Carbon emissions increase under the low-carbon scenario, the baseline scenario, and the high-carbon scenario, in that order. Under the three different scenarios, there is a large gap in carbon emissions, with the low
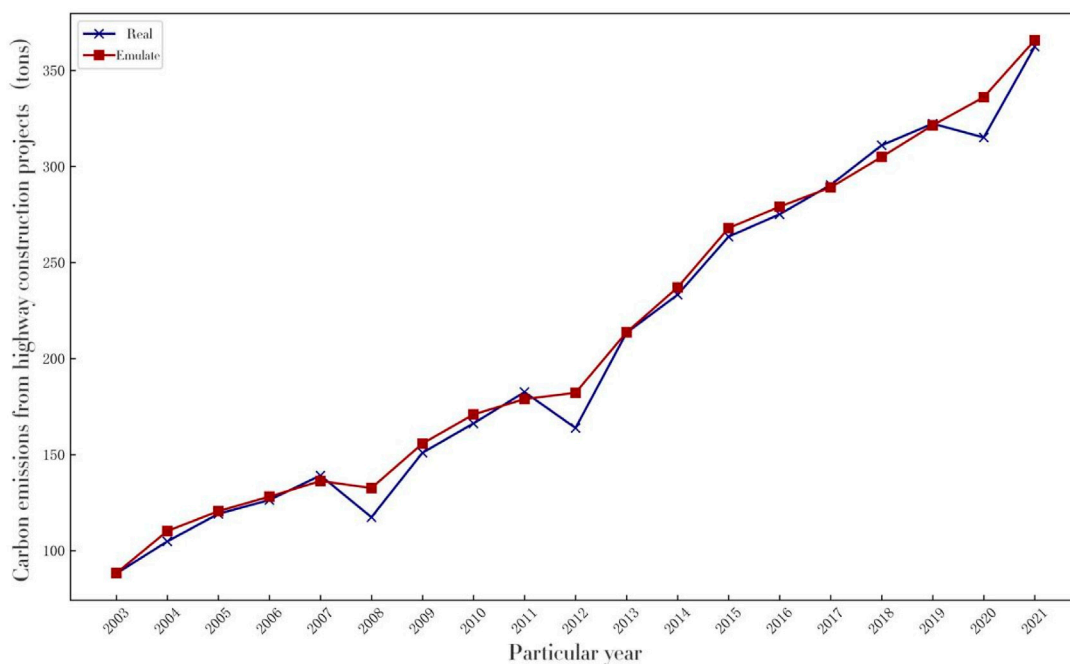

FIGURE 3
Comparison of predicted and real carbon emissions from highway construction projects in Hunan province.

TABLE 8 Specific data on the predicted and real values of carbon emissions from highway construction projects in Hunan province.

| Particular year	Real value	Projected value	Particular year	Real value	Projected value
2003	88.10	90.18	2013	213.44	214.85
2004	104.83	113.05	2014	233.23	230.13
2005	119.18	123.35	2015	263.49	266.95
2006	126.36	132.15	2016	275.12	273.36
2007	139.14	138.03	2017	290.43	290.10
2008	117.42	132.44	2018	311.08	302.25
2009	150.97	155.58	2019	322.33	319.92
2010	166.25	168.45	2020	315.14	331.77
2011	182.55	178.61	2021	362.42	360.39
2012	163.86	168.05	—	—	—
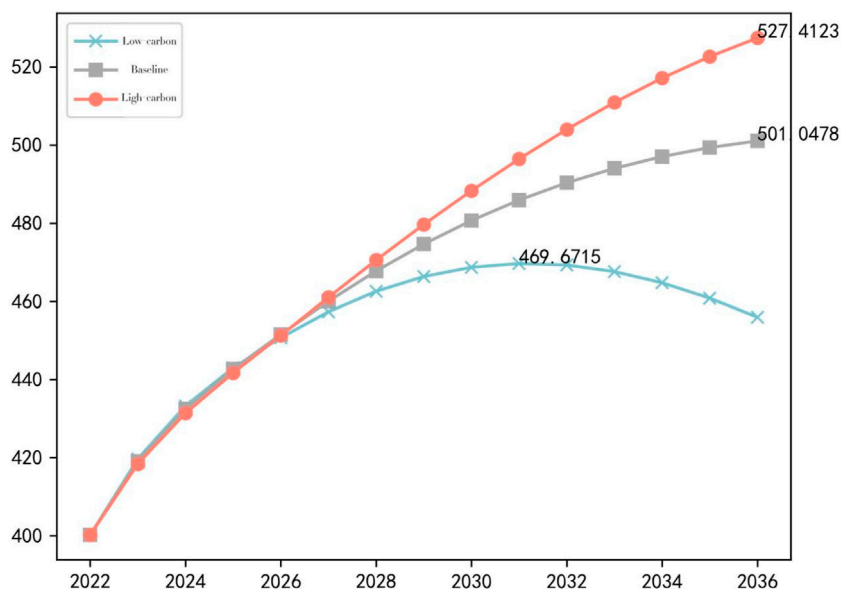
FIGURE 4
Carbon emission trends of highway construction projects in Hunan province under different scenarios.

carbon peaking at 469.6715 tons and the high carbon yet to peak will reach 527.4123 tons.

(3) Analyzing the growth rate of carbon emissions: The average growth rate of carbon emissions in Hunan province in the last 5 years is 6.26%, 2022–2036; the average growth rate of carbon emissions under the three scenarios increases in the order of low carbon, baseline, and high carbon, which is 0.94%, 1.62%, and 1.99%, respectively, and all of them are lower than the average growth rate in the last 5 years.

(4) All three scenarios for the first year of the forecast, 2022, show a substantial increase relative to 2021, due to the impact of the new crown epidemic. In 2021, the society was still under epidemic control, and after the initial liberalization of the new crown epidemic policy, projects began to return to normal construction. Therefore, the real data of carbon emissions in

2021 have a large rebound compared to 2020, with a growth rate of 15%, which appears clearly different from the anomalies of other years, due to which the forecast results may be overall large. However, with the new crown epidemic having been fully liberalized, this effect is no longer present in subsequent years.

In summary, under the baseline scenario, that is, under the existing economic and social development level and highway construction planning in Hunan province and the implementation conditions of relevant emission reduction policies, the highway construction project in Hunan province cannot realize the goal of carbon peak before 2035, and it is expected to lag behind by 2 years, whereas under the low-carbon scenario, it can realize the carbon peak 4 years ahead of time with 2035 as the baseline, and the high-carbon scenario can

TABLE 9 Results of LSTM projections of carbon emissions for 2022–2036 (in tons).

Particular year	Low-carbon	Baseline	High-carbon
2022	400.1858	400.1858	400.1858
2023	419.6641	419.073	418.4141
2024	433.2277	432.4377	431.3701
2025	442.9975	442.6581	441.6820
2026	450.7141	451.5494	451.2695
2027	457.3318	460.0307	461.0305
2028	462.5708	467.7685	470.5603
2029	466.3568	474.6562	479.6808
2030	468.7102	480.6982	488.3258
2031	469.6715	485.9246	496.4483
2032	469.286	490.3646	503.9920
2033	467.6170	494.0535	510.9041
2034	464.7542	497.0329	517.1383
2035	460.8161	499.3484	522.6537
2036	455.9473	501.0478	527.4123

realize the carbon peak with a delay of 9 years with 2035 as the baseline. This suggests that if Hunan province maintains the current level of carbon emissions, it will not be able to achieve the peak carbon target. This suggests that if Hunan province maintains its current highway construction and development plans, it will need to implement stronger energy conservation and emission reduction policies in order to effectively reduce the total amount and growth rate of carbon emissions.

4 Conclusion and recommendations

4.1 Conclusion

Based on the scenario analysis method and the LSTM algorithm of the recurrent neural network, this paper constructs a carbon emission prediction model and carries out the carbon emission scenario prediction of highway projects in Hunan province as an example and obtains the following main conclusions:

(1) The carbon emission prediction index system of highway projects is constructed, and the relationship between various indexes and carbon emission of highway projects is sorted out. The results show that the key low-carbon technologies have the greatest impact on carbon emissions, which is also in line with the current academic research focusing on engineering technology research and development.

(2) Construction of the highway engineering carbon emission prediction model: Since the highway engineering carbon emission has not been monitored in the field, there is no accurate historical data, so first of all, we constructed the highway engineering carbon emission measurement model and,

thus, completed the measurement of historical data in Hunan province. Then, using the advantage of deep learning, the prediction model with LSTM as the core algorithm was constructed, and a more excellent prediction model was obtained, and the relevant departments can draw on this model to predict, test, and refer to the regional highway carbon emissions.

(3) Scenario prediction of the carbon emission trend of highway projects in Hunan province from 2022 to 2036 was carried out. The results show that under the low-carbon scenario, highway construction in Hunan province can achieve carbon peak in 2031, under the baseline scenario, there is a two-year delay from the planned carbon peak in 2035, and the high-carbon scenario will have a serious lag and reach the peak in 2044; at the initial stage of the sub-scenario prediction, there is not much difference in the carbon emissions of the three scenarios, and the gap is gradually obvious with the time, which indicates emission reduction. This indicates that the implementation of the policy has a certain lag in the impact of carbon emissions from highway projects.

(4) Based on the results of scenario prediction in Hunan province, we propose countermeasures for carbon emission reduction in regional highway development from the perspectives of socio-economics, green technology, and development planning. Based on the results of the scenario prediction in Hunan province, the countermeasures for carbon emission reduction of regional highway development are proposed from the perspectives of socio-economy, green technology, and development planning, which are of certain reference value for the relevant departments of highway construction to formulate development planning.

4.2 Countermeasures and recommendations for carbon emission reduction

(1) Adjusting the structure of energy consumption and reducing the intensity of energy consumption

At present, China's electricity mainly relies on coal, further reducing the proportion of coal in energy consumption and using more natural gas, solar energy, nuclear energy, and other energy sources that replace coal. A reasonable energy structure will help promote the energy-intensive highway construction projects to achieve carbon peak.

(2) Appropriately slowing down the urbanization process and keeping highway construction in sync with urbanization development

The promotion of urbanization is the most fundamental reason for highway construction. Based on the current urbanization planning goal of Hunan province, in order to achieve peak carbon as soon as possible, planning adjustments can be made from the root, that is, to appropriately slow down the process of urbanization, and the simultaneous development of highway development speed will be slowed down.

(3) Actively cultivating outstanding scientific and technological talents to improve the research and development of low-carbon technology

In the process of highway construction, the application of low-carbon engineering technology plays a vital role in carbon emission reduction. The construction and development of the relevant disciplines and specialties in universities should be strongly supported and a series of favorable policies to ensure the high-quality development of the disciplines and specialties should be formulated, in order to lay the foundation for the training of talents. At the same time, the construction of highway technology research and development centers should be actively promoted, and there should be a wide range of absorption of talent to focus on energy saving and emission reduction in the research and development of the neck of the problem, for the future of more key low-carbon technology research and development to create a good environment.

(4) Increasing green financial support

At present, many highway construction enterprises are reluctant to use some of the advanced technologies, which is an important reason for the funds, leading to the decline of the project's benefits. In view of this situation, the relevant departments should increase the green financial support and give different degrees of financial subsidies to the enterprise projects that actively use low-carbon technologies to promote the application and promotion of green low-carbon technologies in the actual engineering and construction projects.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

QW: conceptualization, data curation, formal analysis, methodology, visualization, and writing–review and editing. YC: conceptualization, supervision, and writing–review and editing. CL: supervision and writing–original draft. XS: writing–review and editing.

Funding

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Bingxiao, L., Shiwei, Z., and Feihu, H. (2022). Power load forecasting based on LSTM and self attention mechanism. *China Meas. Test* 48 (S2), 38–43.

Donglei, Z., and Yisheng, L. (2019). Carbon emission prediction of China's construction industry based on system dynamics. *Henan Sci.* 37 (12), 2025–2033.

Guangtai, Z., Rui, P., Pingan, N., and Shuwen, D. (2021). Artificial neural networks for predicting the construction industry's carbon emission intensity: taking beijing-tianjin-hebei as an example. *Sci. Technol. Industry* 21 (9), 15–20.

Guangyuan, S. (2013). Comparative analysis of the endogenous carbon-emission in the expressway construction period. *Highw. Eng.* 38 (4), 203–206.

Huaquan, Y. (2015). *Scenario-based prediction of building carbon emissions and peak control strategies in hubei Province. [master's thesis]*. Huazhong University of Science and Technology.

Huiying, W. (2022). *Study on carbon emission calculation and prediction of guangxi expressway construction period*. Guangxi University. [master's thesis].

Jianchun, Y. (2023). China becomes an important force to pull global green low-carbon technology innovation. *China's Foreign Trad.* (3), 32–34.

Shipeng, D. (2021). Research on stock index forecast based on deep model. *Mod. Inf. Technol.* 5 (16), 100–101+104.

Xiaodie, L. (2022). *Research on provincial carbon emission scenario prediction and carbon peak path in China*. Anhui University of Science and Technology. [master's thesis].

Xiaosong, R., and Guohao, Z. (2014). Gray forecasting of China's industrial carbon emissions and its influencing factors —a study based on the STIRPAT model. *J. Beijing Jiaot. Univ. Soc. Sci. Ed.* 13 (4), 18–24.

Ying, Z., and Shuangshuang, S. (2022). Calculation and analysis of carbon emission from expressway construction. *Value Eng.* 41 (8), 156–158.

Yuanyuan, L., Wang, Y., Li, Di, and Yu, Q., (2019). Life cycle assessment for carbon dioxide emissions from freeway construction in mountainous area: primary source, cut-off determination of system boundary. *Resour. Conservation Recycl.*, 14036–14044.

Yun, C., Chan, L., and Jingjing, L. (2019). The carbon emission calculating model of the asphalt pavement construction machineries of highway. *Highw. Eng.* 44 (1), 140–144.

Zhenying, Y., and Jiangao, N. (2014). Forecast on the industrial carbon emissions and analysis on the energy saving potential in hebei Province. *Contemp. Econ. Manag.* 36 (4), 69–74.