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Study on the Contribution of Shale Gas Exploitation and Utilization to Carbon Emission Reduction Based on LEAP Modeling

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ABSTRACT
The development and utilization of shale gas is the main path to solve the current high carbon dioxide emissions, and this paper proposes to use the LEAP model to explore the role of shale gas development and utilization on carbon emission reduction in all aspects. Under the principle and definition of LEAP model framework, shale gas development and utilization scenarios and parameters are determined to facilitate the research and analysis work, and in order to realize the intelligent monitoring of carbon emission reduction work, the neural network two-layer carbon emission reduction prediction model is constructed. With the support of research data and LEAP model, the relationship between shale gas development and utilization and carbon emission reduction is studied and analyzed, and the carbon pulse analysis and prediction model validation model of LEAR simulation results are also supplemented. Although all three scenarios have different contributions to carbon emission reduction, the green scenario is the most obvious means of carbon dioxide emission reduction, with a total of 52.87 from 2010 to 2050, and the prediction model in this paper is able to satisfy the current demand for carbon dioxide emission reduction work, and provide a guiding reference for urban carbon emission reduction.

Keywords: shale gas, LEAP model, carbon emission reduction, plot setting

1. Introduction

Shale gas is an aggregation of natural gas located in dark mud shale or high carbon mud shale in an adsorbed or free state as the main mode of existence, which is a kind of unconventional natural gas [1]. As a new type of methane-rich energy resource, shale gas can be widely used in gas, power supply, chemical industry and other fields [2]. The United States and other European and American countries

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explored the utilization of shale gas earlier, and successfully realized the commercial exploitation and large-scale application of shale gas, and also have more advantages in horizontal drilling, hydraulic fracturing and other technologies [3-6]. However, with the continuous development of global shale gas extraction technology, experts hold different views on the pros and cons of shale gas development. On the one hand, shale gas development requires the use of high-pressure pumps to inject large quantities of water, chemical additives, and proppants into the ground, which may cause environmental problems such as large consumption of soil and water resources, water pollution, atmospheric pollution, solid waste pollution, radioactive pollution, and noise pollution, to the extent of generating more net economic costs than benefits [7-10]. In addition, cheap shale gas competes for the market with green energy sources such as wind, solar, and nuclear, which may hinder the development of renewable energy sources and lead to increased energy consumption and carbon emissions [11-12]. On the other hand, some studies have suggested that the adoption of shale gas to replace traditional fossil energy sources can effectively reduce carbon emissions and air pollution [13-14].

In recent years, focusing on the role relationship between economic development, energy consumption, environmental protection and carbon emissions has become an important research direction for a wide range of scholars. Long-term energy alternative planning model (LEAP) is an integrated energy-environment-economy model based on scenario analysis, which can simulate the activity level, energy intensity and corresponding emission factors of the end-use sectors under different scenarios through the “bottom-up” modeling idea, so as to comprehensively predict the environmental impacts of energy demand and carbon emissions [15]. Therefore, the LEAP model is introduced to analyze the carbon emission reduction measures and suggestions during shale gas development from the perspective of shale gas development and utilization, in order to provide reference for promoting the green development of shale gas industry in China [16-17].

Since energy consumption demand directly contributes to carbon emissions, there has been a proliferation of related studies surrounding the forecasting of energy demand and carbon emissions in China. Qin, Y. et al. compared the full life-cycle greenhouse gas (GHG) emissions of shale gas, which is used as an energy source for the electricity, residential, and industrial sectors, with that of coal, and found that shale gas development and utilization contributes to the net reduction of GHG emissions, and has the potential to bring air quality and climate benefits [18]. Li, X. et al. constructed a comprehensive model of upstream GHG emissions during the pre-production phase of shale gas using a hybrid life-cycle inventory approach, which can effectively reduce the uncertainty of pre-production GHG emission estimation, and then accurately assess the impacts of shale gas development and utilization on the atmospheric environment [19]. Wang, J. et al. further introduced energy ROI into the constructed hybrid life-cycle inventory model, which helps to understand the impacts of shale gas development in China on GHG emissions and net energy benefits [20]. Chen, Y. et al. developed an integrated evaluation framework of water and carbon footprint trade-offs to compare the full life cycle water consumption and greenhouse gas emissions of shale gas, oil and natural gas, and established the optimal production process for shale gas with minimal environmental impacts supported by scenario analysis and white noise techniques [21]. Xu, C. et al. designed a CO2-ESGR net CO2 emission evaluation system based on life cycle evaluation, which is capable of analyzing the net CO2 emission analysis under different injection source modes, and shows high application potential for producing carbon-negative shale gas [22]. Umeozor, E. C. et al. proposed a predictive modeling approach to describe the overall energy consumption and GHG emission contributions at each stage of the shale gas development process, which can help to understand the impact of shale gas development on the environment [23]. The LEAP model has significant advantages in predicting the trend of energy consumption and carbon emissions in the region, analyzing the regional low-carbon development path by setting up different scenarios, and comprehensively evaluating the impact of various energy-saving and carbon-reducing measures on the peak carbon emissions, which is conducive to promoting the implementation of carbon emission reduction strategies for shale gas development and utilization.

In this study, a research program on the role of shale gas development and utilization on carbon emission reduction under the framework of LEAP model is formulated to address the urban carbon emission reduction problem. The modules and principles of the LEAP model are outlined in detail from six aspects, three scenarios of shale gas development and utilization are assumed, four research parameters are set, and the corresponding research data sources are identified. Using the LEAP model, the interaction between shale gas development and carbon emission reduction is explored and analyzed, and in order to make the research results more convincing and rigorous, the carbon pulse analysis of LEAR simulation results and the performance analysis of the neural network two-layer carbon emission reduction prediction model are also supplemented, which jointly promote the development of carbon dioxide emission reduction in a green and sustainable direction.

2. Shale Gas and Low Carbon Issues

2.1. Shale gas

Shale gas is endowed in the shale with high organic matter in adsorption state or free state, and its main component is CH4. Due to the successful breakthrough of the horizontal well segmental fracturing technology, the development and utilization of shale gas has been developing rapidly, and shale gas, as a kind of low-carbon energy source, has gradually won the acceptance of the society and the public [24-25]. The United States is the earliest country to realize the commercial development of shale gas, and the proportion of its shale gas production in the total natural gas production is increasing day by day, and the production in 2019 is close to 100 billion m^3. Shale gas is rich in resources, and the distribution area is wide, and the basins and deformation zones include the Tarim Basin, the Sichuan Basin, the Ordos Basin, the Bohai Bay, and the edge of the Junggar Basin slope, which has a very good prospect of resource exploration. However, the exploration and development history of shale gas is relatively short, still in the experimental stage, and has not yet realized commercial development. The future work should focus on proving the recoverable resources, analyzing the enrichment and distribution law of shale gas, selecting advantageous areas for exploration and development, and at the same time, strengthening the cooperation with foreign institutions in the areas of development and technical cooperation and research, so as to learn and learn from the advanced foreign technology, and to get ready for the large-scale development and utilization of shale gas in the future.

2.2. Low-carbon issues

People will step into the low-carbon era, and the use of traditional fossil energy will be gradually reduced and replaced by green energy and renewable energy. The development of green energy is an important step towards realizing a low-carbon economy, and it is also the most direct and effective means to reduce CO2 emissions. Therefore, with conventional fossil energy gradually leaving the stage, shale gas has begun to emerge, providing a reliable guarantee for the world's energy supply. The development of unconventional oil and gas is precisely the consideration of “saving for a rainy day”. Promote the use of low-carbon energy and vigorously develop unconventional oil and gas. The energy structure should be gradually adjusted to reduce the use of coal and oil, and at the same time increase investment in the low-carbon energy industry. Part of the oil of other countries has to be imported from Arab countries and transported to other countries through the Strait of Malacca. Once there are special circumstances, such as a war in a localized area, especially in the Middle East, or the blockade of the Strait of Malacca, it will pose a threat to the national energy security, and the consequences are unimaginable. Therefore, solely from the aspect of reducing oil dependence on foreign considerations, shale gas is also imperative.

3. Low-carbon shale gas development based on LEAP modeling

3.1. LEAP Modeling Framework

The long-term energy alternative planning system model is mainly developed by the Stockholm Environment Institute, which is referred to as the LEAP model in this paper. The model adopts a bottom-up architecture, which can be integrated with scenario analysis and is commonly used in the system modeling simulation of energy-environmental research scenarios [26]. The framework of the LEAP model is shown in Fig. 1, and is based on the theory of the 3Es. Based on the "3E" theory, this paper carries out regional carbon emission prediction modeling through the LEAP model, and divides the LEAP model into three systems: economic-social, energy, and environmental, in which the economic-social system mainly incorporates the key parameter assumption module, the energy system includes the module of terminal energy demand, the module of energy conversion and transmission, and the environmental system mainly includes the module of non-energy activities (carbon sinks), the module of result analysis (environmental impact assessment). The environmental system mainly includes the module of non-energy activities (carbon sinks) and the module of results analysis (environmental impact assessment); in addition, the LEAP model also involves auxiliary modules such as scenarios.

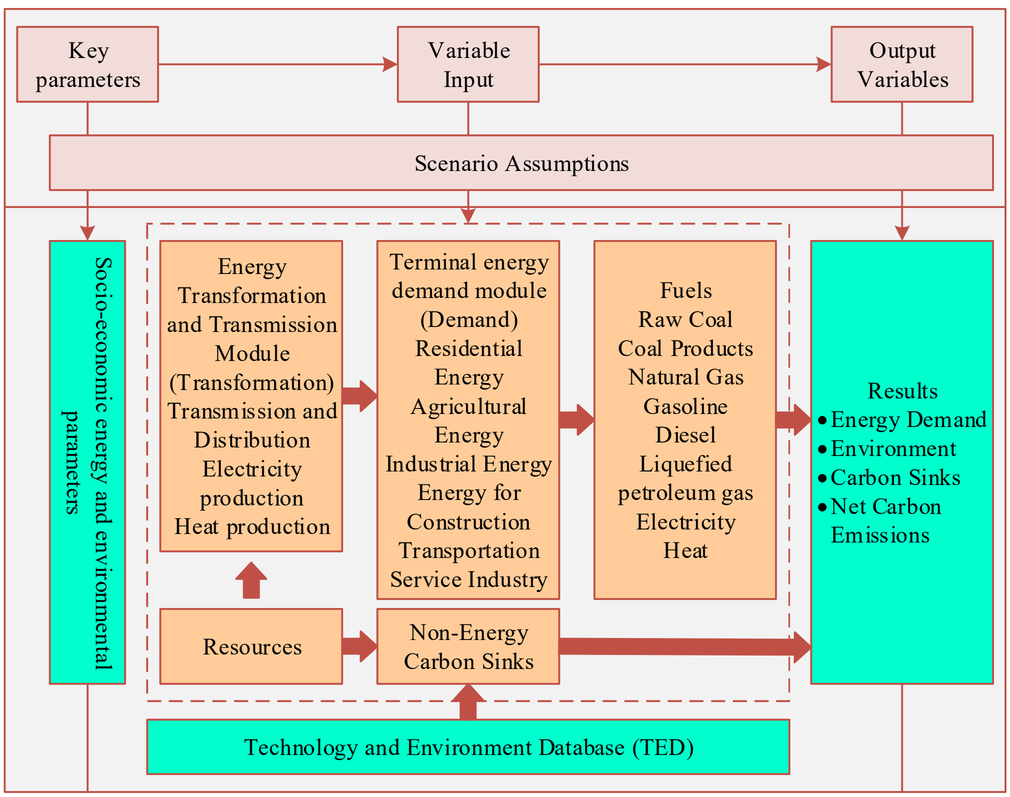

Fig. 1. LEAP model framework

3.1.1. Terminal energy demand module. The model in this paper divides the end-use energy demand module into two subsectors: urban and rural living sectors, and industrial sectors: agriculture, industry, construction, transportation, and services, so as to facilitate subsequent research on sectoral carbon emission forecasts, quantitative assessment of carbon reduction potential, and identification of key carbon reduction sectors.

3.1.2. Energy conversion and transmission module. Comprehensively consider the energy carbon emissions generated by energy processing and conversion and energy transportation. In the energy supply chain, the main consideration includes two energy production modules, namely, electricity production and heat production, while in the energy transportation chain, the main consideration is the energy loss and corresponding carbon emissions caused by the transmission process from the electricity production end to the electricity demand end.

3.1.3. Module on non-energy activities. Since this paper considers to increase the research and analysis of regional carbon absorption from the perspective of carbon sinks, the carbon sink module is included in the non-energy activity module of the LEAP model, and the prediction of carbon sinks is carried out with full consideration of parameter factors such as standing tree stock, arborvitae forests, and scattered four sparse stock, so as to provide support for the subsequent development of the regional carbon neutrality measurements.

3.1.4. Key Parameter Assumption Module. In this paper, four levels of socio-economic-energy-environmental parameters are created to drive the analytical calculations in the end-use energy demand module and the energy transmission and conversion module, which serve as model-driven intermediate variables that are called uniformly in the key parameter assumption module.

3.1.5. Resource module. The resource module is a functional setup module reflecting the production and import/export of primary and secondary resources in the region. The LEAP modeling process in this paper assumes that when the regional primary and secondary energy sources are insufficient, they are all able to be acquired by unlimited outward transfers from other regions.

3.1.6. Scenario modules. Researchers can carry out further research by designing scenarios that meet their own research objectives. In this paper, the scenario setting module mainly carries out scenario design from the perspective of quantitative analysis of the overall carbon emission reduction potential of the region, the carbon emission reduction potential of policies, and the carbon emission reduction potential of sectors.

3.2. Scenario setting

3.2.1. Baseline scenario. This scenario is only a simple trend extrapolation of the relevant industries, and does not make clear provisions for the development indicators, which are consistent with the current industrial activity level, energy intensity, and energy structure situation. At the activity level, based on the calculated elasticity coefficients of each sub-sector of the petrochemical industry, and combining with the GDP growth rate of a certain city as well as the trend extrapolation method to predict the growth rate of output value of each sub-sector of the petrochemical industry in a certain city from 2010-2040, the output value of each sub-sector of the petrochemical industry in a certain city as well as the total output value of the petrochemical industry in a certain city will be predicted. The petrochemical industry in a certain city should both restrict the high-energy-consuming industries and encourage the low-energy-consuming industries. Under the premise of this assumption, we have to continuously regulate the energy intensity: during the “14th Five-Year Plan” period, the total energy consumption will continue to decline, and under this assumption, the energy consumption of high-energy-consuming industries will continue to decline by 9.06%, while the energy consumption of low-consuming industries will decrease by 7.6%, and based on this, we will make a five-yearly time node to gradually reduce the rate of energy intensity. In terms of the energy structure of each sub-sector of a city's petrochemical industry, the fuel share of coal and petroleum products will be gradually reduced by 2040, and the share of clean energy will be increased, including electricity and shale gas. The baseline scenario is set to facilitate comparison and analysis with other scenarios.

3.2.2. Low-carbon scenarios. The Low Carbon Scenario has the potential for shale gas development and utilization in the Baseline Scenario. Compared with the baseline scenario, it adjusts upward the growth rate of output in low-energy-consuming industries and their share at the activity level, and reduces the growth rate of output in high-energy-consuming industries and their share. In 2010-2050, the reduction of energy intensity of high-energy-consuming and low-energy-consuming industries is maintained at 12.4% and 11.4%, respectively, and on this basis, the rate of energy intensity is gradually reduced by making a time point every five years. The energy structure is consistent with the baseline scenario.

3.2.3. Green scenarios. The energy saving and carbon reduction potential of the petrochemical industry is further explored based on ensuring policy implementation and tangible technological progress. The objective of the scenario is to realize the sustainable development of a city's petrochemical industry earlier, so that the peak of carbon emissions from a city's petrochemical industry will be further reduced.

3.3. Parameterization

3.3.1. Economic data. A city vigorously promotes the green development of the petrochemical industry, proposing that its internal layout should be further adjusted to further reduce the proportion of high-energy-consuming enterprises in the national economy and accelerate green transformation. Taking the shale gas extraction industry as an example, the output value growth rate of this industry in 2020 is -19.45%, while the GDP growth rate of a city in 2020 is 5.33%, so the elasticity coefficient is obtained from 5.33%/(-19.45%)=-0.2478. When the elasticity coefficient is 1, it means that the output growth rate of an industry is the same as the GDP growth rate, but when its growth rate is more than 1, its output growth rate will be higher than the current year's GDP growth rate, and when its growth rate is less than 1, its output growth rate will be lower than the current year's GDP growth rate. Considering the low energy-consuming industries in the petrochemical industry, the future rate of its sub-sectors will not be too high, so the elasticity coefficients of the sub-sectors should be estimated by choosing the maximum value in their respective intervals.

3.3.2. Fuel data. The energy share of crude oil in the shale gas extraction industry can then be obtained by dividing the end-use energy consumption of crude oil in that year by the total end-use energy consumption of the industry in that year, and the main energy varieties of fuels accounted for as shown in Table 1. It can be known that the high energy-consuming industry raw materials and products, chemical fiber, high-emission energy coal and various petroleum fuels accounted for 71.08% and 39.64%, respectively. The share of clean energy such as shale gas and electricity is 11.66% and 51.18% respectively. Low energy-consuming industries such as oil and shale gas extraction industry, petroleum processing and coking industry, rubber and plastic products of shale gas and electricity and other clean energy accounted for 62.57%, 43.01%, 71.27%, respectively. It can be seen that the energy structure of some sub-sectors of petrochemical industry in a certain city is not good, and the proportion of shale gas and electricity is not high, and a certain city should solve the problem of carbon emission by increasing the proportion of clean energy in petrochemical industry in a certain city in the future. The “Outline of the 14th Five-Year Plan for the National Economic and Social Development of Certain City and the Vision 2050” issued by Certain City puts forward the systematic requirements of promoting the efficient utilization of clean energy and controlling the total amount of coal consumption in enterprises. The “14th Five-Year Plan for Energy Development” of a certain city also points out that the energy structure of a certain city should be optimized, and the proportion of shale gas should rise by 1.27-4.18% in five years. The “Implementation Plan for High-Quality Development of Petrochemical and Chemical Industry in a City” also requires that the proportion of green energy such as cold energy, wind power and photovoltaic power generation in the petrochemical industry should strive to reach more than 12.41%. This paper combines the above information to set the trend of energy structure evolution of each sub-sector of petrochemical industry by analyzing the change rule of energy structure during 2010-2050, and combining the current situation of energy structure of each sub-sector in 2020.

Table 1. The proportion of main energy types and fuels

Energy type	Mining reserve	Coking	Raw materials and products	Chemical fiber	Rubber and plastic
Coal	0	0.27%	11.15%	39.13%	16.89%
Crude oil	17.85%	1.36%	0	0	0
Gasoline	0.73%	0.06%	0.04%	1.78%	11.16%
Diesel oil	14.05%	0.35%	0.06%	1.76%	11.87%
Shale gas	34.09%	25.57%	14.96%	15.82%	27.20%
Heat	2.33%	35.35%	16.53%	4.07%	14.42%
Fuel oil	0	0.36%	0	0	13.82%
Other petroleum products	0	17.92%	58.84%	0	0
Electricity	30.95%	19.02%	9.56%	76.56%	21.53%

3.3.3. Data from the processing and conversion sector. To calculate the energy consumption of a city's petrochemical industry, in addition to considering the parameters of each subsector of the petrochemical industry mentioned above, the parameters of the processing and conversion sectors, such as the efficiency of the power generation and heat supply sectors, should also be considered. Based on the energy consumption statistics of a city in 2020, the data of the processing and conversion sectors are shown in Table 2, which yields the efficiencies of the power generation and heating sectors to be 32.57% and 65.83%, respectively, with coal accounting for a proportion of the total energy in the range of 82-85%. Thermal power generation is the main source of electricity in a certain city, and at present, thermal power generation in a certain city still mainly relies on coal, but coal fuel can be replaced by cleaner shale gas energy, so there is a huge potential for shale gas power generation in a certain city in the future, and in the future, a certain city will vigorously push forward the "retreat from coal to gas", vigorously push forward the integrated gas comprehensive recycling and waste heat comprehensive utilization technology. In the future, a city will vigorously promote the "coal to gas conversion", vigorously promote the integrated gas cycle and comprehensive utilization of waste heat technology, and gradually phase out the old-fashioned and backward thermal power generation, so as to further improve the efficiency of production conversion. Based on the above, the scenario sets out to further reduce the share of coal in power and heat supply in the coming years, thus reducing the carbon emissions of the petrochemical industry in a city.

Table 2. Processing and transformation efficiency of industrial sector

Energy type	Thermal power generation Energy consumption	The unit is converted to tons of standard coal The proportion of all kinds of energy	Heat supplyEnergy type	Energy consumption	The proportion of all kinds of energy
run-of-coal	-2017.4	82.87%	Run-of-coal	-891.54	-84.71%
Coke oven gas	-45.2	1.86%	Gasoline	-0.018	0.00%
Blast furnace gas	-18.4	0.76%	Diesel oil	-0.1832	-0.02%
Converter gas	-9.2	0.38%	Fuel oil	-0.1924	-0.02%
Crude oil	-36.4	1.50%	Petroleum coke	-46.7521	-4.44%
Diesel oil	-0.8	0.03%	Other petroleum products	-1.886	-0.18%
Fuel oil	-0.7	0.03%	Shale gas	-95.569	-9.08%
Petroleum coke	-27.4	1.13%	Other energy sources	-16.34	-1.55%
Other petroleum products	-1.4	0.06%	Sum total	-1052.48	100.00%
Shale gas	-252.7	10.38%	Heat	692.8423	-65.83%
Heat	-9.6	0.39%			
Other energy sources	-15.2	0.62%			
Sum total	-2434.4	100.00%			
Electricity	793	-32.57%			

3.3.4. Emission factor data. The carbon emission factor of each fuel is shown in Fig. 2, by which all the parameters in the LEAP model of petrochemical industry in a city have been set up. The carbon emission factor of shale gas and blast furnace gas is in kg CO2/m^3, that of oil products is in kg CO2/liter, that of bituminous coal and coke is in kg CO2/kg, and that of shale gas is 1.554.

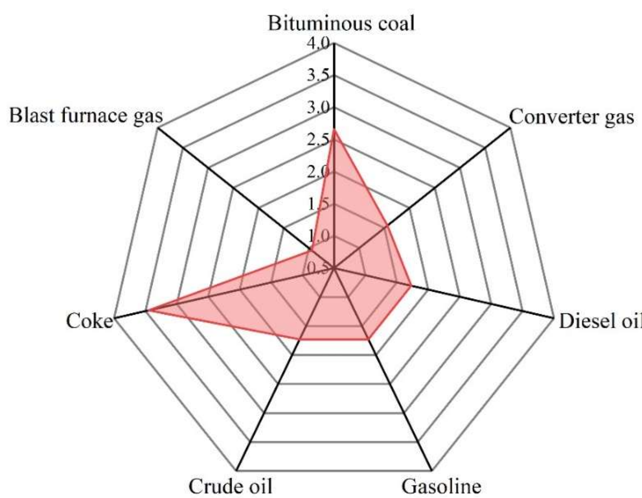

Fig. 2. Carbon emission factors of each fuel

3.4. Neural network-based two-layer prediction framework

For the purpose of long-term carbon emission measurement, this study proposes a two-layer prediction framework to predict the underlying data for carbon emission measurement.The basic structure of an RNN consists of one or more temporal layers, each of which has a self-recycling neuron. These neurons take the output of the previous moment as input and combine it with the input of the current moment to compute a new output and a new state. This new state is then used again as one of the inputs for the next moment, and so on. Specifically, at practice step t, the RNN receives an input

x_t and the previous state h_{t-1}, and then computes the hidden state h_t and the output at that moment y_t. Assuming that the current RNN layer has n neurons, the formula is as follows:

$$h_t = f_h\left(x_t, h_{t-1}\right) = \sigma_h\left(W_{xh} + W_{hh}h_{t-1} + b_h\right) \tag{1}$$

$$y_t = f_y\left(h_t\right) = \sigma_y\left(W_{hy}h_t + b_y\right) \tag{2}$$

where, W_{xh}, W_{hh} and W_{hy} are the input to hidden state, hidden state to hidden state and hidden state to output weight matrices respectively, b_h and b_y are the bias vectors, and σ_h and σ_y are the activation functions, which are usually tanh or ReLU.In practice, RNNs are usually stacked to form Deep Recurrent Neural Networks (Deep RNNs) or Long Short-Term Memory Networks (LSTMs). The first layer of the two-layer prediction framework will utilize parametric data combined with recurrent neural networks to form LSTMs to predict carbon emissions, and the second layer will use Deep RNN models to predict various types of energy consumption as well as the development of carbon emission factors for energy consumption.

4. The role of shale gas development and utilization on carbon emission reduction

4.1. Analysis of simulations in different contexts

4.1.1. Total primary energy consumption. The total primary energy consumption of a city from 2010 to 2050 is shown in Fig. 3. With the growth of population and end-use effective energy consumption intensity, China's total primary energy consumption will still be climbing from 2010 to 2030, and will peak around 2025 at about (59.31-61.62) × 10^8t standard coal. After 2025, with the decrease in population size, stabilization of the intensity of end-use effective energy consumption, and improvement of the efficiency of comprehensive energy utilization, the total primary energy consumption will decrease year by year, and be reduced to (54.07-56.64) × 10^8 t of standard coal by 2050. Of the three scenarios, the green scenario has the lowest total primary energy consumption, which is due to the fact that this scenario benefits from technological progress, increased end-use electrification, and improved efficiency in the comprehensive use of energy, which also provides conditions for the achievement of emission reduction targets.

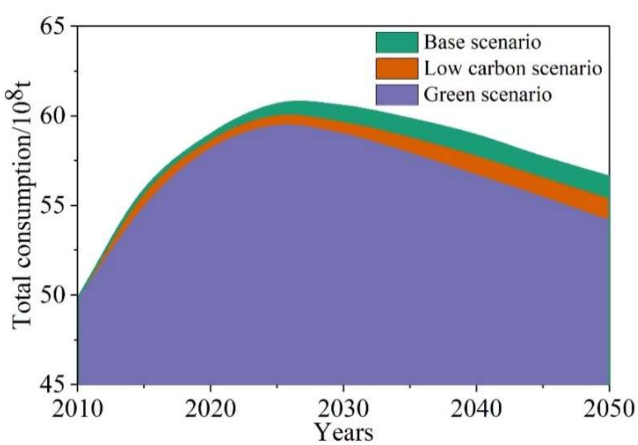

Fig. 3. Total primary energy consumption of a city from 2010 to 2050

4.1.2. Shale gas consumption. The total shale gas consumption in a city from 2010 to 2050 is shown in Figure 4. Shale gas consumption will peak around 2030, with a peak of about 6,952×10^8m^3 in the base scenario, accounting for about 14.61% of total energy consumption. Shale gas consumption in the Green Scenario is lower than in the previous two scenarios due to the presence of carbon constraints and relatively low total primary energy consumption. The 2010-2030 period under this scenario is a period of rapid growth in shale gas consumption, during which shale gas consumption grows rapidly due to the combined effects of the yearly growth in total energy consumption, a significant decline in the share of coal power, and the continuous increase in shale gas storage and production, which plays an important role in making up for the energy consumption gap left by coal reduction. In order to meet the emission reduction target, the LEAP model replaces gas-fired electricity with non-fossil energy electricity in the process of shale gas development and utilization, so that gas-fired power generation shale gas consumption decreases year by year from 2040 to 2050, with a drop of about 776×10^{8}m^3, and the total consumption of shale gas will drop to 4,291×10^{8}m^3 in 2050.

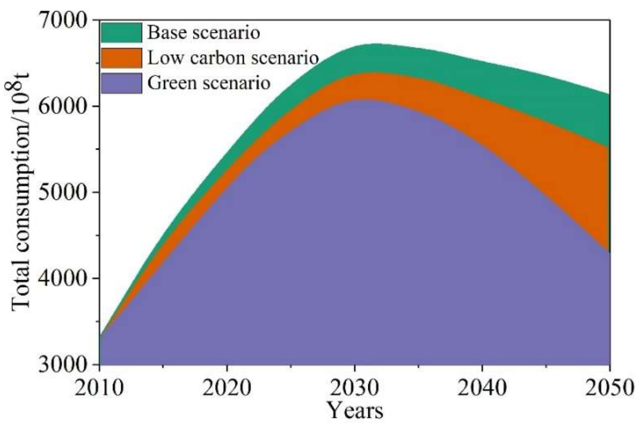

Fig. 4. Total consumption of shale gas in a city from 2010 to 2050

4.1.3. Shale gas production. Shale gas production in the baseline scenario is shown in Figure 5, shale gas production in the low carbon scenario is shown in Figure 6, and shale gas production in the green scenario is shown in Figure 7. The cumulative production will be (4.07-4.48) × 10^{12}m^3, and the cumulative production in the new areas will be (5.73-8.15) × 10^{12}m^3 over the forecast period. The baseline scenario, in which production is lower than the other scenarios due to the lower reserve proving rate, reserve utilization rate and the degree of recovery during the forecast period, peaks at about 2,794 × 10^8 m^3 in 2025, and gas production decreases to 1,542 × 10^8 m^3 in 2050 (see Figure 5). Under the low-carbon scenario, technological advances in exploration and development drive shale gas to continue to increase storage and production, with production peaking at 3,091×10^{8}m^3 in 2030 and remaining above 2,311×10^{8}m^3 in 2050 (see Figure 6). In the green scenario, technological breakthroughs in the exploration field grow new proven reserves to 43.66×10^{12}m^3, and technological breakthroughs in the development field grow new utilized reserves in the new area to 21.83×10^{12}m^3, and the average degree of extraction grows to 38.07%, with uptake to 3,400×10^{8}m^3 in 2035 (see Figure 7). The production of different types of gas reservoirs in the prediction period under different prediction scenarios also varies, with the peak production of conventional gas (including tight gas) at (2082-2314) × 10^{8}m^3, shale gas at (609-1039) × 10^{8}m^3, and coalbed methane at (141-225) × 10^{8}m^3. In the composition of shale gas production, conventional gas will always play the role of production cornerstone, with the production contribution rate always higher than 63.71%. Shale gas, on the other hand, is the key to upward production, and when production peaks, the proportion of new shale gas production to total new production will be more than 34.8%. Future breakthroughs in shale gas technology are expected to provide a new impetus for carbon emission reduction.

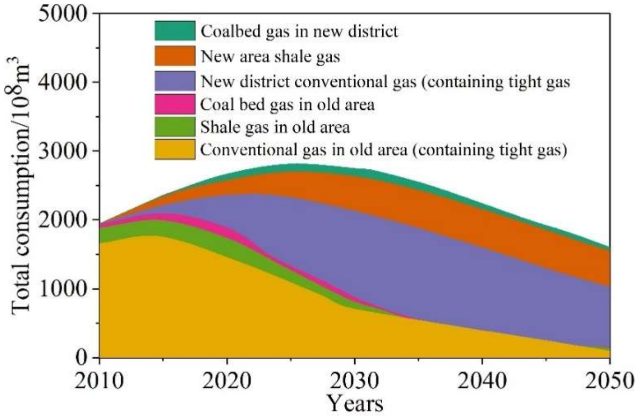

Fig. 5. Shale gas production under baseline heat conditions

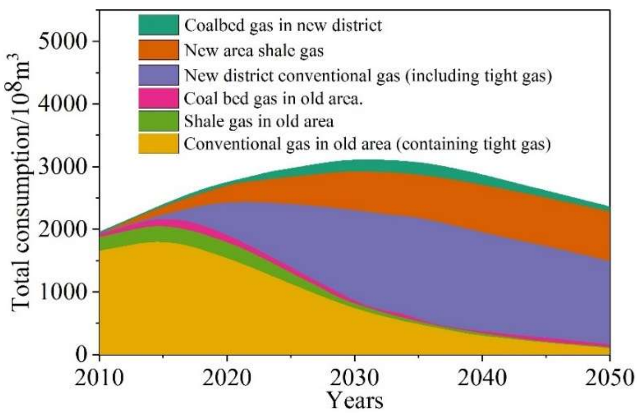

Fig. 6. Shale gas production under a low carbon scenario

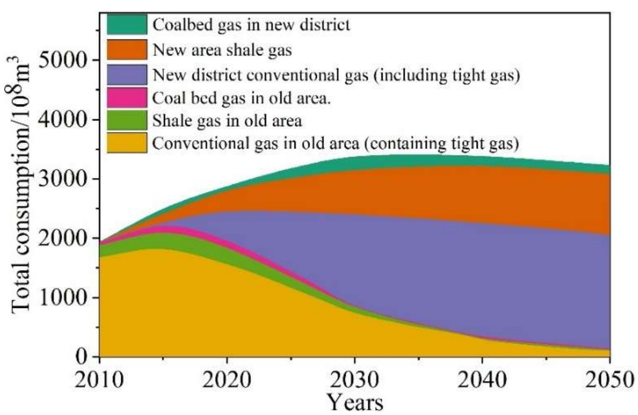

Fig. 7. Shale gas production under the green scenario

4.2. Analysis of scenario contribution levels

4.2.1. Analysis of the level of energy saving contribution. The LEAP model is used to simulate and analyze the energy saving contribution levels of three scenarios in a city from 2010 to 2050, and the results of the energy saving contribution level analysis are shown in Figure 8. It can be seen from the figure that the contribution level of green scenario to energy saving is always the highest, and the proportion has slightly increased, accounting for 34.86% of the total energy saving in 2010 and 36.79% of the total energy saving in 2050. Followed by the change of life style, reasonable consumption concept and saving life style gradually increase the contribution level of energy saving in the long term, and the proportion of energy saving increases from 17.92% in 2025 to 25.93% in 2050. Industrial structure optimization accounts for a larger share of energy saving contribution in the medium and long term, but as Shanghai's economic development enters the post-industrial era after 2035, the industrial structure tends to stabilize, and the level of contribution of industrial structure optimization measures to energy saving gradually decreases, with the share increasing to 14.69% in 2035, and then dropping back to 9.89% in 2050. The improvement of terminal energy utilization efficiency will play an increasingly important role, with the share growing to 20.94% by 2050. The level of contribution of industry structure optimization measures to energy efficiency gradually increases and its share increases, from 6% in 2015 to 9.92% in 2050. The contribution of industry structure optimization, energy processing and conversion efficiency improvement, and population size control to total energy saving is still relatively limited in the medium and long term in terms of the level of contribution to energy saving, accounting for 5.82%, 1.06%, and 0.74% respectively in 2050. In addition, shale gas substitution measures do not reduce total energy demand, but are significant for carbon emission reduction, as described in more detail below.

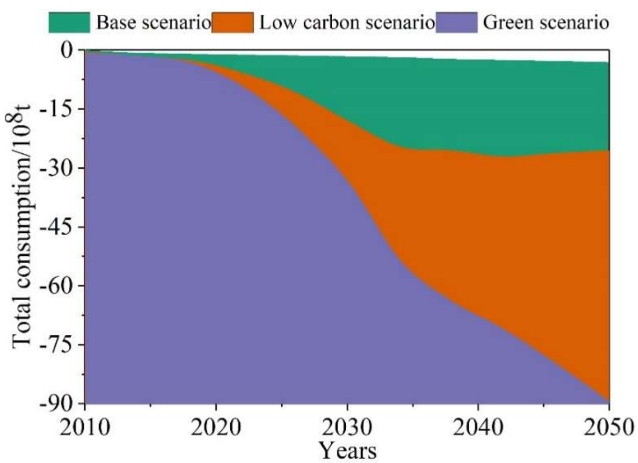

Fig. 8. Analysis results of energy saving contribution level

4.2.2. Level of carbon emission reduction contribution. Also with the help of LEAP model, the carbon emission reduction contribution levels of three scenarios in a city from 2010 to 2050 are simulated and analyzed, and the results of the carbon emission reduction contribution level analysis are shown in Fig. 9. It can be seen that the ratio of emission reduction contribution level of the three scenarios is basically consistent with the ratio of their corresponding energy saving contribution level. Among them, the green scenario is still the most powerful means of emission reduction, accounting for 52.87% of the total emission reduction by 2050. It is followed by lifestyle change, which accounts for 18.96% of the total emission reduction in 2050. Terminal energy efficiency improvement accounts for 14.86%, and industrial structure optimization accounts for 6.97%. Industry structure optimization accounts for 2.88%. Population control accounts for 0.18%. Although the shale gas alternative measures do not account for a large proportion of the total emission reduction, they are still an important supplemental measure for carbon emission reduction, and the emission reduction can reach 13.82 million tons of carbon dioxide/year by 2050, accounting for 2.94% of the total emission reduction. It should be noted that although the contribution level and share of carbon emission reduction of the three scenarios are consistent with the trend of their energy saving level and share, the specific values are not the same. This is mainly caused by the different sub-species energy consumption structures of the three scenarios and the carbon emission factors of different energy species.

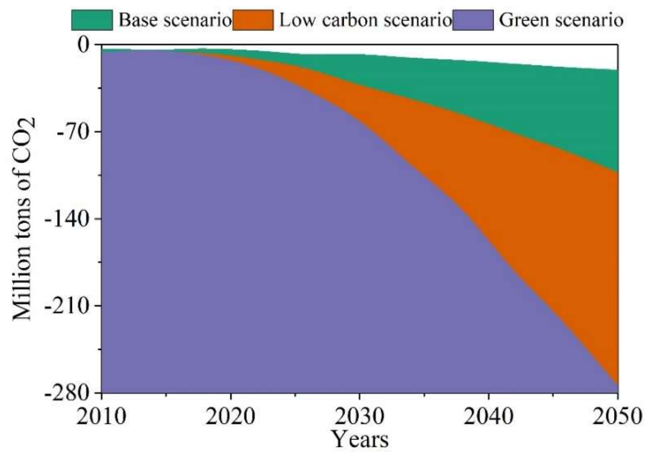

Fig. 9. Results of analysis of contribution levels of carbon reduction

4.3. Carbon pulse analysis of LEAR simulation results

In this study, the energy balance of a city under the 2010-2050 green scenario obtained by LEAP model simulation is utilized to carry out carbon pulse analysis, and Table 3 shows the energy balance of LEAR simulation results. Existing LEAP studies at the provincial and municipal levels have either focused on energy supply (e.g., renewable energy) or on the analysis of energy demand and consumption, neglecting the holistic grasp of the energy system as a dynamic system and limiting their attention to a certain part of the energy system (supply or consumption). Considering this, this study tries to analyze the flow of energy and carbon in the natural environment and socio-economic system through the perspective and framework of energy flow and carbon pulse. Under the perspective and framework constructed in this study, we examine the energy flow and carbon pulse under different scenarios through the LEAP model, and decompose the time-series results obtained from the analysis of scenarios into the cross-sectional results of a number of years, so that the energy flow from supply to consumption in the major years under the scenarios is analyzed in detail. The time series results obtained from the scenario analysis are decomposed into cross-sectional results of several years to analyze in detail the energy flow from supply, conversion to final consumption, and the carbon pulse from crustal input, processing and utilization by the economic system to environmental carbon output of the major years under different scenarios. In the total energy supply, the production of shale gas is 51,366 kilotons of standard coal, which is much more than that of other kinds of energy, and has an excellent effect of supplying energy with low carbon emission, and the same is true for the other items. All in all, the research in this paper can provide a basis for relevant energy saving and emission reduction policy making.

Table 3. Energy balance for LEAR simulation results

Thousand tons of standard coal	Electricity	Shale gas	Oil products	Crude oil	Coal and its products	Renewable energy	Heat	Total
Give birth to	0	7845	0	121	0	139	0	8105
Entrance	4908	3816	63553	54269	55049	408	39	182042
Exit	-217	0	-48319	-88	-12419	0	0	-61043
Inventory change	0	0	0	0	0	0	0	0
Total energy supply	4641	51366	15183	14294	42131	547	39	128201
Oil refining	0	0	53203	-54248	0	0	0	-1045
Coking	0	0	0	0	-411	0	0	-411
Air production	0	189	-24	0	-254	0	-11	-100
Heat supply	0	-549	-138	0	-1456	-16	2022	-137
Generate electricity	14265	-5252	-817	0	-25170	-529	0	-17503
Distributive loss	-627	-416	0	0	0	0	0	-1043
Total amount of processing and conversion	13439	-6156	52193	-54249	-27253	-542	2017	-20551
Balance the balance	0	0	0	0	0	0	0	0
Agriculture	42	0	238	0	8	0	0	288
Industry	6322	1339	13107	87	11208	18	1945	34026
Building industry	226	4	1049	0	216	0	8	1503
Traffic	534	316	44212	0	24	0	11	45097
Commerce	1149	441	1744	0	433	0	22	3789
Other tertiary industries	2051	823	3617	0	311	0	19	6821
Inhabitant	3038	2044	0	0	575	0	9	5666
Total end energy demand	13439	5208	64233	87	13021	16	2022	98026

4.4. Analysis of carbon emission projections

4.4.1. Forecast evaluation criteria. In order to better realize the intelligent management and monitoring of urban carbon emissions, a two-layer prediction framework based on neural network is proposed. Next, in order to prove the accuracy of the prediction model in this paper, four evaluation indexes, namely, the average absolute error (MAE), the average absolute percentage error $(MAPE)$, the root-mean-square error $(RMSE)$, and the coefficient of determination (R^2), are used as the comprehensive evaluation criteria, and the specific formulas are shown as follows:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\hat{y} - y_i\right| \tag{3}$$

$$MAPE = \frac{100\%}{n}\sum_{i=1}^{n}\left|\frac{\hat{y} - y_i}{y_i}\right| \tag{4}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\hat{y} - y_i\right)^2} \tag{5}$$

$$R^2 = 1 - \frac{\sum_i\left(\hat{y} - y_i\right)^2}{\sum_i\left(y_i - \bar{y}\right)^2} \tag{6}$$

where: $\hat{y}$ is the predicted value, $\hat{y}$ is the true value and $\bar{y}$ is the average value.

4.4.2. Analysis of results. In order to show the priority of this paper's model more intuitively, two groups of control models are set up, respectively CNN, RNN, LSTM, SVM, and the comparison of carbon emission prediction effect is shown in Table 4.The indexes of this paper's method are 0.013, 0.022, 0.034, and 0.983, and compared to the other models, this paper's model has a higher superiority in the urban emission reduction management, and it can better provide intelligent monitoring and management of emission reduction.

Table 4. Comparison of carbon emission prediction effect

Name	CNN	RNN	LSTM	SVM	Ours
MAE	0.098	0.085	0.067	0.056	0.013
RMSE	0.121	0.092	0.071	0.069	0.022
MAPE	0.161	0.121	0.094	0.077	0.034
R^2	0.882	0.897	0.914	0.924	0.983

5. Conclusion

Under the framework of LEAP model, this paper sets three scenarios and related parameters to explore the effectiveness of shale gas development and utilization on carbon emission reduction with the help of research data.

1) Compared with the baseline scenario and the low carbon scenario, the green scenario, along with technological breakthroughs in the exploration field, performs more prominently when the production of shale gas increases to $43.66\times10^{12}m^3$, which is expected to provide a new impetus for carbon emission reduction.

2) Both in terms of energy saving contribution and carbon emission reduction contribution, the green scenario is much better than the other two scenarios, with the total energy saving share and total emission reduction share of 36.79% and 52.87% respectively in 2050.

3) Among the different total energy supplies, especially the shale gas energy supply effect is especially obvious, with a value of 51,366 kilotons of standard coal and less carbon dioxide content, which well practices the principle of green sustainable development.

4) The two-layer prediction framework of the neural network in this paper has excellent prediction efficiency in the management of urban emission reduction, and better promotes the digital management of urban carbon emission reduction.

About the Author

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