Team Control Number
22052302
Problem Chosen
B
2022
IMMC
Summary Sheet

Global warming, which mainly results from fossil fuel burning and CO_2 release into the atmosphere, has become a major environmental concern after industrialisation. Over the years, people have been searching for ways to deal with the issue, among which came out the idea of filtering CO_2 from the atmosphere and storing it underground, which seems very potential according to previous articles. However, it might become a problem as space is limited and it's impact on the surroundings should be considered. We want to estimate the maximum quantity of underground storage in China and, thus, find out whether it can be an effective solution.

We have built three models to achieve the goal.

In Model A, we investigate into storage in deep saline aquifers, where underground water abundant in minerals takes up much of the space. After consideration, we decide that forming a combination of CO_2-water solution and supercritical CO_2 fluid would be the most efficient method.And then we take into account the properties of supercritical carbon dioxide and the solubility of carbon dioxide at this particular pressure, which we know.We assume that the volume of water doesn't change very much after it absorbs carbon dioxide, combined with other known quantities and we get the theoretical mass of carbon dioxide that can be stored

With the Model A, however, only a rough estimation can be made and some deviation is unavoidable. So, in Model B, we modified the model by adapting the method to a broader environment, where one of the former assumptions are no longer suitable.In the process of calculation, we found that the assumptions we had made in order to simplify the problem would cause great errors, so we had to delete some of the original assumptions and bring them into our own consideration. We take the crevice water into consideration while adjusting a few other factors,such as the density, and the optimised model obtained more accuracy.For instance, the gap of porosity and crevice rate between pore water and fracture water is too large to be considered together. However, in order to prevent further complexity of the model, we determined the area weight between them according to the ratio of porosity and fracture rate between them, which not only did not change the original formula, but also solved the previous problem.We also take the effective storage coefficient into consideration to make the result more accurate.

Finally, we calculated that the theoretical storage in the deep saline aquifer is 3.24×10^{15} kg.And its actual value is related to how long it exists.

In Model C, we look into CO_2 storage in other manmade structures, such as oil wells and abandoned coal mines. The reason we think of these two together is because they are very similar in nature, and they both exist in a relatively confined space. By fitting the curve of the density and pressure of carbon dioxide at a certain temperature and solving the differential equation, we solve these two problems with the same model, and provide a general idea and idea for solving such problems later.

How much CO_2 can we store within the subsurface in China?

Team#22052302

November 22, 2021

Contents

1 Introduction

1.1 Background

In recent years, there are a large amount of global greenhouse gas emissions.Technologies such as carbon emission reduction and carbon sequestration techniques can effectively reduce carbon emissions.These techniques can reduce its negative impact on the environment, and they have gained more and more attention at home and abroad.

As the world's energy consumption and carbon dioxide emissions are increasing, China's energy conservation and emission reduction task is difficult.Energy conservation and emission reduction has become a basic national policy of China. To tackle climate change, the Chinese government in 2009 set a greenhouse gas action target of reducing carbon dioxide emissions per unit of GDP by 40-45 percent from 2005 levels by 2020. At present, China is rich in coal, less oil, lack of gas energy resources.And it determines that in China in the future for a long period of time coal is still the main energy, its combustion will emit a lot of carbon dioxide. Therefore, it is necessary and urgent to seek effective ways and technologies for carbon dioxide emission reduction.

In recent years, CNPC has made important progress and achievements in the "utilization of carbon dioxide for enhanced oil recovery and underground storage", and listed "carbon dioxide sequestration in salt water layer" as the key content of the major science and technology special project of "CNPC Low-carbon Key Technology Research".[1] Relying on the low-carbon special project of CNPC and under the leadership of CNPC Safety and Environmental Protection Institute, the joint Project team of carbon dioxide Geological Sequestration was formed by bringing together the research forces in the field of carbon dioxide sequestration in China and oil field enterprises.

CO_2 uptake by terrestrial ecosystems is a natural carbon sequestration process. Carbon sequestration through reforestation and limiting deforestation is considered to be the most cost-effective way. The conservation and optimization of terrestrial ecosystems are beneficial to the maintenance and expansion of carbon sequestration.

In terms of the main types of CO_2 sequestration capacity around the world, geological sequestration has a greater potential to capture CO_2 than forests and land, which require scarce resources.

The geological mechanism of CO2 is divided into four parts.

The first is structural trap burial. Structural trap is the basic geological body of CO2 sequestration in saltwater layer. After CO2 injection into saltwater layer, it accumulates at the top of structural trap under the action of reservoir heterogeneity and buoyancy, forming structural trap burial.

The second is residual gas storage. Because the buoyancy of CO2 is not enough to overcome the capillary breakthrough pressure in the pore throat, it is separated from the continuous phase during the migration process of injection and is isolated in the pore space. This trapping mechanism is called residual gas trapping.

The third is dissolved storage. Some of the CO2 injected into the salt water will dissolve in the salt water, depending on the temperature, pressure, and salinity of the storage medium.

The fourth is mineral storage. As the amount of co2 dissolved and stored increases, it will react with refractory ions and rocks to form new minerals, which is considered the most durable and stable method of storage. Sequestering carbon dioxide in the saline aquifer is a very common and effective method.According to the International Energy Organization, the contribution of CCS to carbon dioxide reduction is about 19%, which is the largest contribution of a single technology among various emission reduction technologies.The national research data shows that the storage potential of brine layer is larger than that of oil and gas fields and deep coalbed methane fields, and the storage potential of the saline aquifer accounts for more than 90% of the geological storage potential in China.Meanwhile, the saline aquifers are widely distributed and have a good match with high-concentration CO2 emission sources to reduce transportation costs.However, the research in this area has just started in China, and its feasibility, storage capacity and risk have not been systematically studied, and many scientific and technical problems have not been solved.

The Global Carbon Capture and Storage Institute's annual report on global carbon capture and Storage deployment shows that projects under development in the United States and Canada are focused on using captured carbon to restore oil extraction.The report also shows that while developing countries' greenhouse gas emissions are expected to rise as a result of population growth and industrialization, some progress has been made in the early stages of carbon capture and storage.

This summer, The UN's climate change institution decided that carbon capture and storage projects would qualify as carbon offsets under the Clean Development Mechanism, prompting developing countries to adopt the technology to earn carbon credits.[3]China's five-year plan lists carbon capture and storage as a policy priority.

1.2 Problem Restatement

1. Build a model to estimate the storage capacity .The model should contain the the capacity in the deep saline aquifers, the oil and gas field, the coal bed of no commercial value and the plants.And estimate the storage capacity in China through this model.Estimate the total CO2 storage capacity within all deep saline aquifers in China.

2. Based on the storage capacity model, calculate the density of CO_2 and then test the sensitivity of it.

3. Write a popular science essay to introduce the CO_2 storage model we built and show the significance and contribution to carbon emissions peaking and carbon neutrality.It also should give corresponding suggestions and measures according to the model.

1.3 Our work

- We measured the storage of different forms of CO_2 in different media and built model for them separately.Then, we added the storage capacity up to get the total amount of CO_2 storage capacity in China.

- Then, We figured out the density of CO_2 and we did the sensitivity analysis on it.

- Finally, we wrote a popular science essay to introduce the model and the result of it.

2 General Assumptions

1. We only consider that CO2 is stored underground.
Naturally, CO_2 can be stored in the plants.China need to contain the area of cultivation, so it is impossible to maasively increase the amount of plants planted

2. We didn't consider the condition that CO_2 is stored in the shallow water area.
Firstly, the reason we are doing this is to avoid CO_2 to escape into the atmosphere. if the water is shallow, when it comes to violent crustal movement, such as earthquakes, CO_2 will be released.
Secondly, the pressure is high in the deep area.And CO_2 is more easily to concentrate at high pressure in the saline aquifer.
Then, the shallow water resources are very precious.Hence, they should be left in case of need.
Finally, CO2 can form carbonic acid by dissolving in water.But carbonic acid is unstable, so the solubility of CO_2 in the shallow water is very low.

3 Model A

3.1 Model Overview

In this model, we calculate the CO_2 storage capacity in the deep saline aquifer.We only consider the supercritical CO_2 and the gaseous CO_2 that can be dissolved in water.For the capacity that these two kinds can store mainly show the whole storage capacity in this area.

3.2 Model Assumptions

1. We didn't consider the CO_2 in the mineral substance.
   There is very little mineral substance in the deep saline aquifer.Meanwhile, it need a lot of time for the CO_2 to be stored in the mineral substance and this process always happens on the basis of the process of dissolving the CO_2 in the water

2. We didn't consider the volume change of water after CO_2 is took in.
   When the CO_2 inject the water, the volume of water is bound to change.But the solubility of CO_2 in the salty water is very high,especially when the pressure is very high.

3. We only consider the pore water.
   There are three kinds of water underground: pore water, crevice water and karst water(in China).The distribution of crevice water is not uniform and there is often no unified hydraulic connection.And the karst water only occurs in China for the karst landform is unique for China.When we pull the CO_2 into the karst water, it will corrode the landform and make disruption to it.So we choose the pore water to represent the general case.

3.3 Variables and Constants

Table 1: variables and constants of Model A

Symbol	Definition
ω_w	the solubility of CO_2 in salty water
ρ_e	the average density of the earth's crust
ρ_{sc}	the density of supercritical CO_2 at temperature T and pressure P
P_{max}	the maximum pressure that can be sustained underground
m_w	the weight of water underground
m_{wc}	the weight of CO_2 dissolved in the water
m_{sc}	the weight of supercritical CO_2 above the water
V_{wc}	the volume of the water and CO_2 that dissolves in it
V_{sc}	the volume of the supercritical CO_2 that stored underground
V	the total volume of the deep saline aquifer
S	the area of the deep saline aquifer that can store CO_2
g	the acceleration of gravity
h	the average thickness of the rock above the deep water
h_d	the depth of this layer
p_w	the proportion of water in the pore in the total space
p_s	The proportion of the volume of a pore other than water in total space

3.4 The mechanism of the CO_2 input

CO_2 has different forms at different pressure and temperatures, and the density and the volume it occupied of each form is quite different.The figure below can clearly show this:[5]

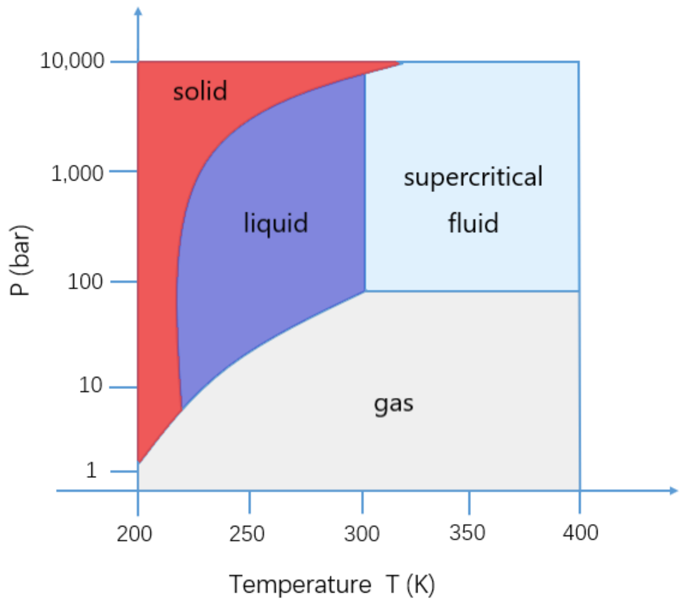


Figure 1: **The form of CO_2 at different temperatures and pressure**

Then, the CO_2 can be pulled in the deep saline aquifer by a pipe from above-ground to underground.This process can be shown in the figure below:

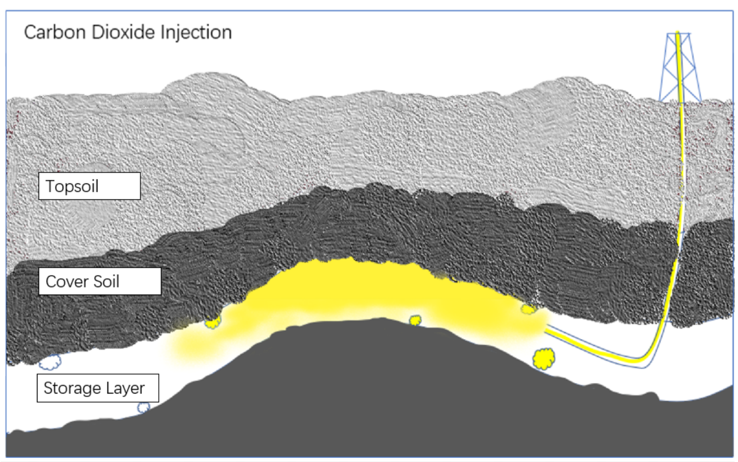


Figure 2: **The transmission process of CO_2**

And here is the flow chart of the CO_2 input mechanism:

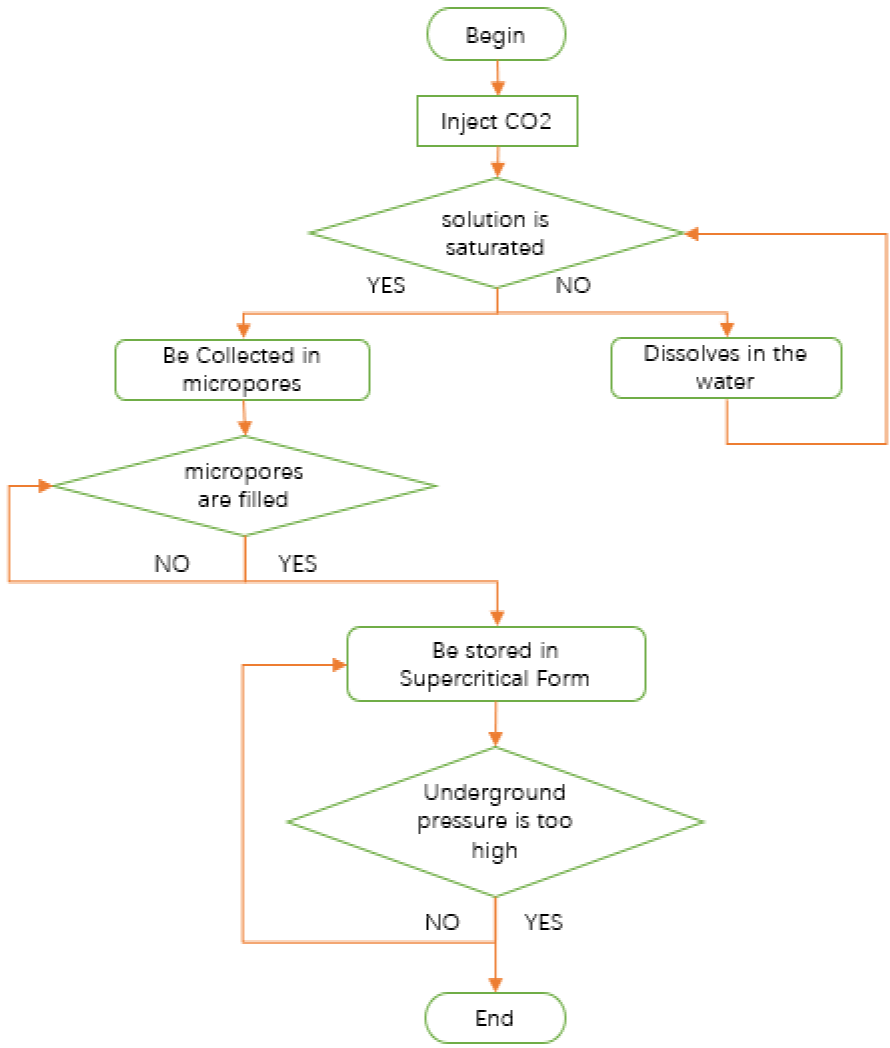


Figure 3: **The flow chart of this process**

3.5 The basic model

We built the model based on these two formulas.When CO_2 is led in the water, the volume of the whole saline aquifer will not change.Hence, the first equation should always be established.While P_{max} is the largest pressure that can be sustained, the pressure underground should always be less than P_{max}, or the water and the CO_2 in it will be released in the atmosphere.Hence, it will destroy the environment as well, which goes against the purpose for which we store CO_2.These two formulas are both used in the calculation and they can also be used to verify our result.

$$\begin{cases} V_{wc} + V_{sc} = V \\ \frac{(m_w + m_{wc} + m_{sc})g}{S} \le P_{max} \end{cases}$$

3.6 The storage capacity calculating model

First, we calculate the P_{max}.We use the density, the acceleration of gravity, and the thickness to describe the pressure according to the pressure calculation formula.Then, we multiply the formula by a coefficient.

On top of this layer, there are layers of water, layers of rock.And their density is different from the mean density of the crust, and only a small fraction can be represented by the mean density of the crust. The density of rock is about 1.2 g/cm^3, the density of water is 1 g/cm^3 and the density of the upper crust is 2.65 g/cm^3.At the same time, P_{max} refers to the maximum pressure that the deep salt water layer can withstand inside, and this value is not exactly equal to the pressure exerted by the crust or water layer above it, but is less than the actual pressure exerted by the layer above it. In the end, we get a coefficient of 0.4, which satisfies the previous equilibrium between the rock and the crust, but also reduces the pressure exerted by the upper layer.

$$P_{max} = 0.4\rho_e \times g \times h_d \tag{3.1}$$

Then, we calculate V and m_w by the basic definition.V is constant, since the position of the surrounding rocks is fixed, the total volume is not going to change very much.At the same time, ρ_w can be determined.Hence, we can determine m_w.It will also help us verify our model.

$$V = S \times h \times p_w \tag{3.2}$$

$$m_w = V \times \rho_w \tag{3.3}$$

Next, we need to calculate the amount of carbon dioxide that can be stored in the water at P_{max} and the current temperature.We have known the temperature in the deep saline aquifer is 45°C.Meanwhile, the mass fraction of saline solution is 10%.According to the temperature and the mass fraction, we can get ω_w equals to 3.75g/100g salty water.Hence, we can get the equation below:[6][7]

$$m_{wc} = \omega_w \times m_w \tag{3.4}$$

$$m_{wc} = 0.0375m_w \tag{3.5}$$

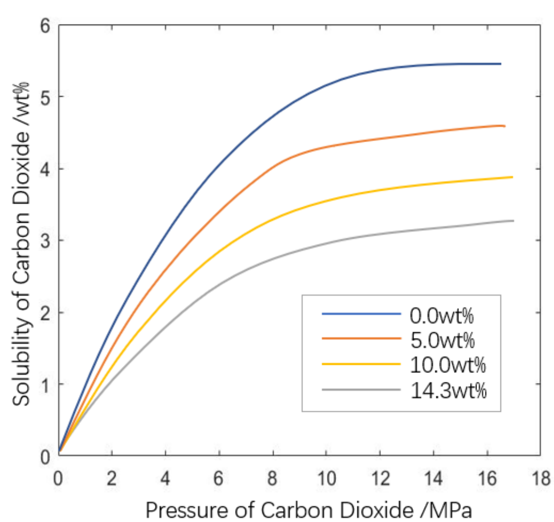


Figure 4: **The relationship between the solubility and pressure of CO_2**

Then, we are going to calculate the V_{sc}.When the water can no longer dissolve CO_2, at these pressures and temperatures, gaseous carbon dioxide turns into supercritical carbon dioxide, occupying the volume of pores. But because supercritical carbon dioxide is nearly as dense as liquid, nearly as viscous as gas, and has 100 times the diffusion coefficient of liquid, it is a very special substance. Since the density of supercritical carbon dioxide is lower than that of water underground, the difference in density between the two produces buoyancy, which makes it float upward.It results in the situation that the supercritical carbon dioxide is on the top and the carbon dioxide aqueous solution is at the bottom.

$$V_{sc} = S \times h \times p_s \tag{3.6}$$

Hence, we can get the weight of supercritical CO_2 by multiplying the volume by the density.And we calculate the density by a program.When you input the mass, status and temperature of it, you can get the density.

$$m_{sc} = V_{sc} \times \rho_{s(P,T)} \tag{3.7}$$

Finally, we can add m_{sc} and m_{wc} up.And we can get the storage capacity m.

$$\text{Storage Capacity} = m_{sc} + m_{wc} \tag{3.8}$$

4 Model B:The optimization of Model A

4.1 Model Overview

In Model A, we treat all water as pore water, and in this optimized model, we want to improve on that. However, by considering this change, some incorrect or rough formulas in the original model will be improved in this model.So this model, in the end, is going to be as accurate as possible.

Therefore, in this model, we optimize the original estimation of the area. We assign the weight of the area of pore water and the area of fracture water respectively by the difference in the capacity of pore water and fracture water to store carbon dioxide. Accordingly, we also optimize the average density of the crust.At the same time, we also consider the effective storage coefficient.

4.2 Taking crevice water into consideration

In the previous model, we only consider the pore water.[8]There were three reasons that we didn't consider it before.

- The crevice rate is very low: in the whole rock mass, the proportion of the space occupied by the crevice channel is very low, generally a few parts per thousand.

- The crevice water only flows in each crevice channel: the flow field of fracture water is actually discontinuous, and the potential of seepage field is virtual except some points in the crevice water.

- The local and global flow directions are different: water flows are confined to a network, and local flow directions are often inconsistent with and sometimes even opposite to the overall flow direction.

But the amount of CO_2 that can be stored between crevice water and pore water is different in one to two orders of magnitude, so crevice water cannot be regarded as pore water approximately.And we can get the data of crevice water and pore water distribution area and the ratio relationship between the porosity and crevice rate, thus determining the weight between them.

Table 2: variables and constants of this optimized model

Symbol	Definition
S	the area covered by pore water
S'	the area covered by crevice water
m	the number of regions covered by pore water
n	the number of regions covered by crevice water
r	the ratio of porosity to crevice rate

Hence, we can get the equation:

$$S = \sum_{i=1}^{m} S + \sum_{i=1}^{n} S' \tag{4.1}$$

And we can take the r into the calculation of S.Because we only want to change the amount of area in the original formula to reflect the changes brought to it by pore water and crevice water, but do not want to change the porosity in the original formula, we can take this ratio and put it in the area calculation.And then we get the same result and calculate it more easily as well.

$$S = \sum_{i=1}^{m} S + \frac{1}{r} \times \sum_{i=1}^{n} S' \tag{4.2}$$

So we replace the S in our original model with this formula.

4.3 The average density above

In Model A, We multiply the average density of the crust by a coefficient of 0.4 to show the uneven density. However, this value of 0.4 is too rough, so we need to recalculate it to determine the final coefficient. And the thickness of the crust above it varies from place to place, so it's not a generalization.

In areas of plain or basin interior where there is pore water, as a result of sand and gravel layer and clay layer interbedded, it usually forms confined pore water aquifer. If the terrain is mountainous or hill, there are large, thick pore aquifers made up of gravel. If it is an area with crevice water, the deep saline layer is dominated by denser rock.

And here is the table of the density of the rock.

Table 3: The density of each rock

Serial number	Area	Material	Density
D_1	S_1	sand	$1.2 \times 10^3 \mathrm{kg/m^3}$
D_2	S_2	gravel	$2.2 \times 10^3 \mathrm{kg/m^3}$
D_3	S_3	granite	$2.6 \times 10^3 \mathrm{kg/m^3}$
D_4	S_4	clay	$1.3 \times 10^3 \mathrm{kg/m^3}$

We can calculate the average density above by calculating the ratio of the area occupied by each type of rock to determine the weight of each density.[9][10]

$$D' = \sum_{i=1}^{4} n_i \times D_i \tag{4.3}$$

And n_i should satisfy:

$$\begin{cases} 1 = \sum_{i=1}^{4} n_i \\ \frac{S_p}{S_q} = \frac{n_p}{n_q} \end{cases}$$

Therefore, we can work out that :

$$D' = 1.92 \times 10^3 \text{kg/m}^3 \tag{4.4}$$

4.4 Effective storage coefficient

What we calculate in Model A is the theoretical storage capacity, which is to assume that every pore is filled with an aqueous solution of carbon dioxide or supercritical carbon dioxide, but in fact, that's not going to happen. In other words, our theoretical value should be multiplied by a coefficient between 0 and 1.

In fact, this value is related to the time it takes for CO_2 to enter the salt water layer, which cannot be completely sequestered for a short time, but if sequestered for too long, the supercritical CO_2 will also be lost. This value is also determined by the pressure and injection rate of injected carbon dioxide. Since this value requires field surveys to obtain accurate values, we used data from other surveys here.

However, the tools used in other people's studies and their measurements of the area and location of the saltwater layer cannot be estimated or predicted. Therefore, the results must have a certain deviation from the actual situation.

4.5 The result of optimized model A

First, we have known that h=1487m, ρ_e=2.7 × 10^3, so:

$$P_{max} = D' \times g \times h_d \tag{4.5}$$

$$P_{max} = 1.92 \times 10^3 \times 9.8 \times 1487\text{Pa} \tag{4.6}$$

$$P_{max} = 2.80 \times 10^7\text{Pa} \tag{4.7}$$

It is used to calculate the amount of CO_2 and to modify the final result. These are two figures that show the distribution of deep saline layer in China and the distribution of pore water and crevice water.[11]

Hence, we can calculate S.

$$S = 34 \times 10^{10}\text{km}^2 \tag{4.8}$$

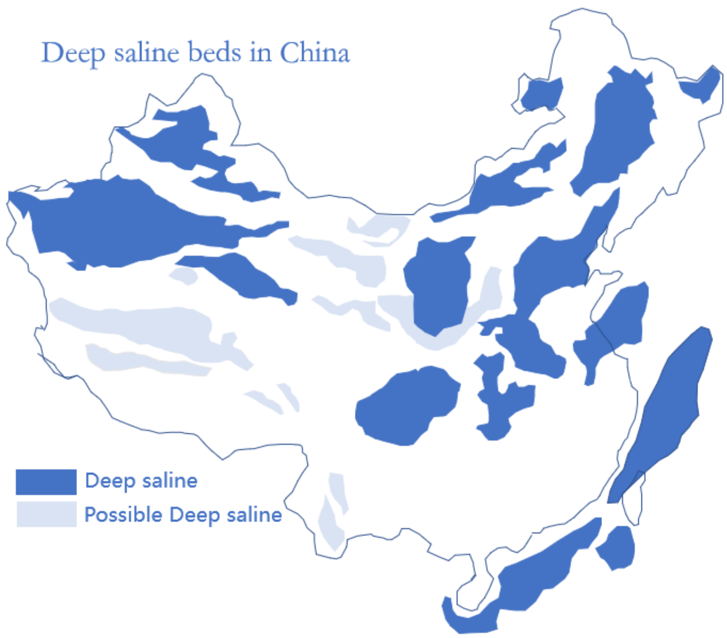


Figure 5: **the distribution of deep saline bed in China**

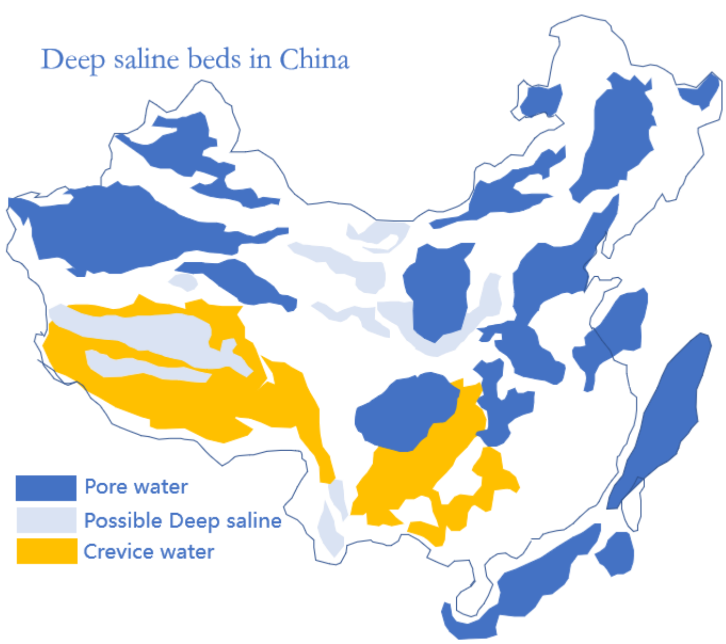


Figure 6: **the distribution of pore water and crevice water**

The area ratio between the areas covered by pore water and crevice water can be approximately be regarded as 2:1. The area occupied by crevice water is multiplied by its coefficient, which is the ratio of crevice rate to porosity.Therefore, we can calculate S'.

$$S = \sum_{i=1}^{14} S + \frac{1}{r} \times \sum_{i=1}^{2} S' \tag{4.9}$$

$$S = \frac{2}{3} \times 34 \times 10^{10} + \frac{1}{3} \times 34 \times 10^{10} \times \frac{1}{200} \mathrm{km}^2 \tag{4.10}$$

$$S = 22.7 \times 10^{10} \mathrm{km}^2 \tag{4.11}$$

Hence, we can calculate V:

$$V = S \times h \times p_w \tag{4.12}$$

$$V = 22.7 \times 10^{10} \times 110 \times 0.15 \mathrm{km}^3 \tag{4.13}$$

$$V = 3.74 \times 10^{12} \mathrm{km}^3 \tag{4.14}$$

And then, we can calculate m_w

$$m_w = V \times \rho_w \tag{4.15}$$

$$m_w = 3.74 \times 10^{12} \times 2.5 \times 10^3 \mathrm{kg} \tag{4.16}$$

$$m_w = 9.35 \times 10^{15} \mathrm{kg} \tag{4.17}$$

Hence, we can get m_{wc}

$$m_{wc} = 0.0375 \times m_w \tag{4.18}$$

$$m_{wc} = 0.0375 \times 9.35 \times 10^{15} \mathrm{kg} \tag{4.19}$$

$$m_{wc} = 3.5 \times 10^{14} \mathrm{kg} \tag{4.20}$$

Then, we start to calculate V_{sc}:

$$V_{sc} = S \times h \times p_s \tag{4.21}$$

$$V_{sc} = 22.7 \times 10^{10} \times 110 \times 0.1 \mathrm{km}^3 \tag{4.22}$$

$$V_{sc} = 2.5 \times 10^{12} \mathrm{km}^3 \tag{4.23}$$

Hence, we can calculate m_{sc}:

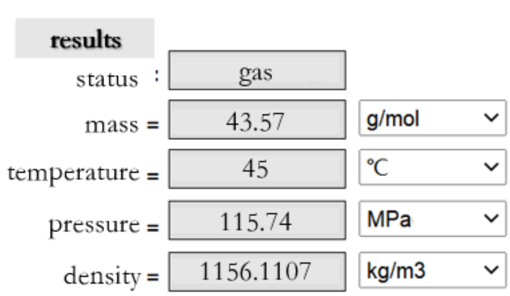


Figure 7: **the operating interface of the density of supercritical CO_2**

$$m_{sc} = V_{sc} \times \rho_s \tag{4.24}$$
$$m_{sc} = 2.5 \times 10^{12} \times 1156.1107 \tag{4.25}$$
$$m_{sc} = 2.89 \times 10^{15}\text{kg} \tag{4.26}$$

Thus, you can calculate the whole storage capacity:

$$\text{Storage Capacity} = m_{sc} + m_{wc} \tag{4.27}$$
$$\text{Storage Capacity} = 2.89 \times 10^{15} + 3.5 \times 10^{14}\text{kg} \tag{4.28}$$
$$\text{Storage Capacity} = 3.24 \times 10^{15}\text{kg} \tag{4.29}$$

Hence, we should estimate the efficient storage capacity of the CO_2.

Table 4: the effective storage capacity in different conditions

Primary Operation Conditions	Effective storage Capacity($10^{15}kg$)	C_c
60 MMscf/day(H)	2.69(457years)	0.83
60 MMscf/day(L)	2.85(484years)	0.88
120 MMscf/day(H)	2.66(225years)	0.82
120 MMscf/day(L)	2.20(184years)	0.67
$\Delta p = 500psi$(H)	2.50(160years)	0.77
$\Delta p = 500psi$(L)	2.85(452years)	0.88
$\Delta p = 650psi$(H)	2.13(97years)	0.66
$\Delta p = 650psi$(L)	2.82(315years)	0.87

Hence, we can get the The change of Effective storage Capacity as time changes.

5 Model C:the storage capacity in oil and gas field and coal seam

5.1 Model Overview

In this model, we consider the storage capacity in oil and gas field and coal stream.In addition to being stored in water, CO_2 can also be stored in crevices or spaces in the ground.Oil fields and coal seams are typical examples. Although they do not allow full access to all the space that can store CO_2 in the earth's crust, they are still useful. So we're going to focus on oil fields and coal seam.And Oil fields and coal seams have similar morphological structures, so we can use a model to solve these two kinds of problems. It's doable to use different data for different problems.

5.2 Model Assumptions

1. We don't consider the change of weight when CO_2 is injected to the Saturated salt solution. *The volume fraction of CO_2 in saturated salt solution is less than 80%, so the influence of its mass is not considered.*

5.3 Variables and Constants

Table 5: variables and constants of Model C

Symbol	Definition
h	the average depth of the oil and gas field
h_s	the depth of the supercritical CO_2
p_0	one atmosphere
p_s	the pressure at the top of supercritical CO_2
ρ	the density of the Saturated salt solution
p_{min}	The minimum pressure at which CO_2 reaches supercritical CO_2
m	the storage capacity of CO_2

5.4 The mechanism of the model

This is a figure that clearly shows the final state of the coal seam.

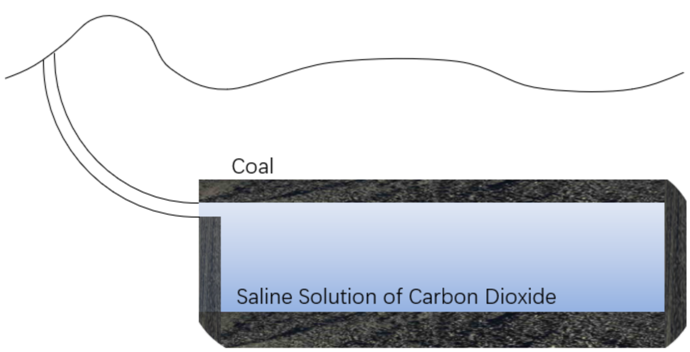


Figure 8: **a figure that shows the final state of the coal seam**

This is a figure that clearly shows the final state of the oil and gas field.

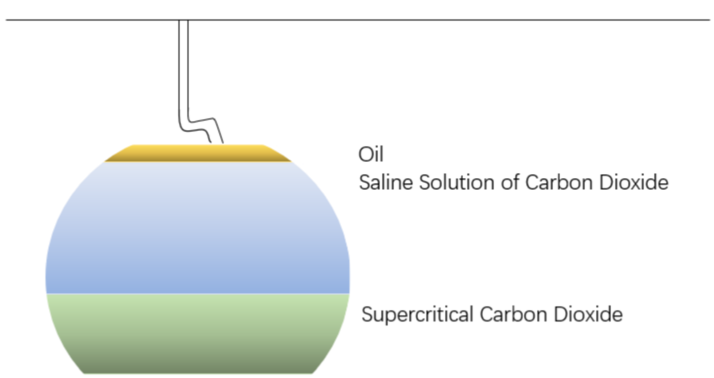


Figure 9: **a figure that shows the final state of the oil and gas field**

It is mainly divided into three levels.

- The top layer is oil, but its volume and mass are small, just to prevent the CO_2 below it from spilling out, so the volume of this layer can be ignored in the calculation.

- The middle layer is a saline solution of carbon dioxide. The purpose of dissolving carbon dioxide in saline solution is to dissolve as much carbon dioxide as possible in the same volume.

- The bottom layer is supercritical carbon dioxide because when you reach a certain depth and the pressure and temperature reach a certain value, you're in a supercritical state.Although supercritical carbon dioxide is the most efficient form of storage, its existence is limited to a small fraction of the bottom.

5.5 A model for the oil and gas fields and coal seams

Under these two circumstances, the CO_2 is sealed in a relatively closed space, and the transmission of CO_2 is quite the same.So, we can use the same model to calculate the capacity.
Firstly, we have an equation that:

$$p_{min} = p_0 + \rho g h_s \tag{5.1}$$

Hence,

$$h_s = \frac{p_{min} - p_0}{\rho g} \tag{5.2}$$

h_s is used for judging whether there is supercritical CO_2.If the depth of the field is higher than h_s, there will be supercritical CO_2 and vice versa.

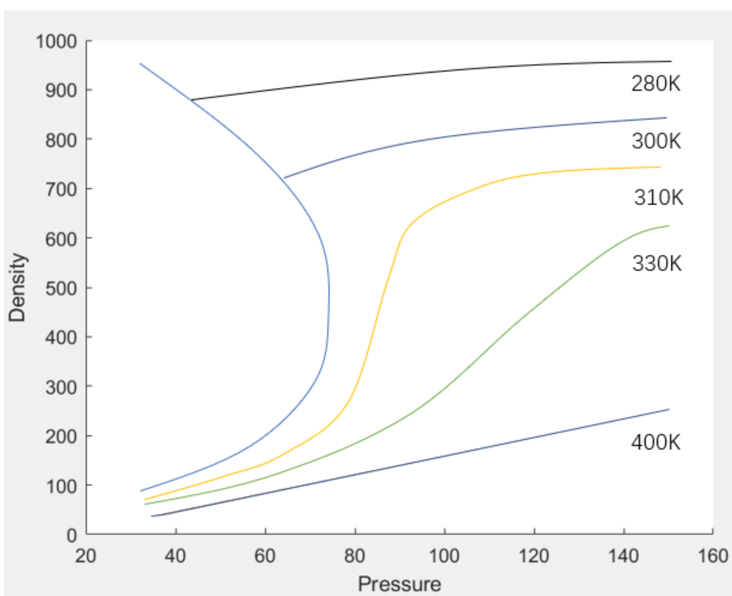


Figure 10: **the relationship between pressure, temperature and density**

According to Model A, 310K is the closest to the temperature below the field. So we took this curve and fitted it.

We found that this curve could not be accurately fitted, so we chose to fit its inverse function and got a cubic function.

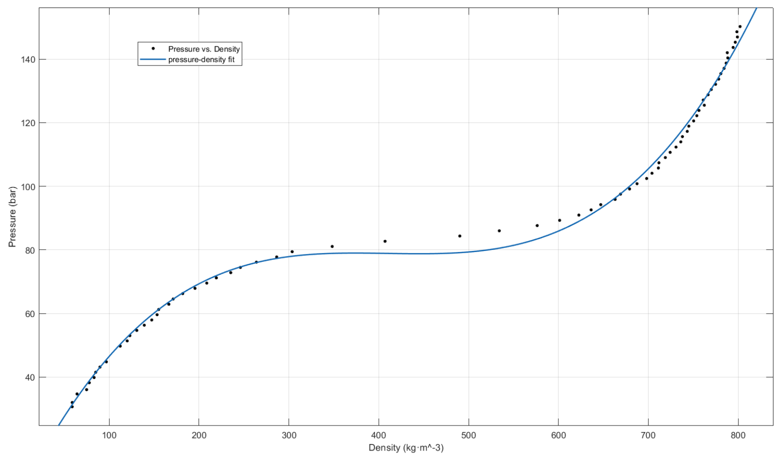


Figure 11: **Fitting curves for these discrete points**

Hence:

$$\rho = f^{-1}(p) \tag{5.3}$$

Therefore, we can get a table of the change of depth, density, pressure, mass of CO_2.

Table 6: a table of the change of depth, density, pressure, mass of CO_2.

Depth	Density	Pressure	Mass of CO_2
h_0	ρ_0	p_0	m_0
$h_0 + \Delta h$	ρ_0	$p_0 + \Delta h \times \rho_0 \times g$	$m_0 + \rho_0 S h$

According to the first three columns of the table, we make a differential equation that:

$$\mathrm{d}p = \mathrm{d}h \times \rho_0 \times g \tag{5.4}$$

$$\mathrm{d}p = \mathrm{d}h \times f^{-1}(p) \times g \tag{5.5}$$

Hence, we can get a formula $h(p)$ that explains the relationship between h and p
Then, according to the forth column of the table,we can get another differential equation:

$$\mathrm{d}m = \rho S \times \mathrm{d}hm \tag{5.6}$$

$$m = \int_{f^{-1}(p_{min})}^{h(p)} \tag{5.7}$$

6 Sensitivity Analysis

6.1 Determine the analytic object

Basic factors involve model changes and calculations that have an effect on a certain result. Sensitivity analysis does not analyze all factors, but only those influential and important uncertainties. From the point of view, the quantities that affect the change of carbon dioxide storage include pressure, density and mass of salt water, solubility of carbon dioxide in salt water, etc. However, these variables have a small and indirect impact on carbon dioxide storage and are not suitable for sensitivity analysis. Some factors that have little influence on carbon dioxide storage are the volume of deep saline aquifers, the porosity of core in deep saline aquifers, and the density and mass of brine. However, some of these factors are determined by the congenital geological environment and cannot be changed; Some of the changes in this book are determined by changes in other quantities, for example the solubility of carbon dioxide is determined by a combination of pressure, temperature, etc. In this case, the variable that allows sensitivity analysis happens to be the density of carbon dioxide.

6.2 Analysis on the density of carbon dioxide

In this formula, because part of the carbon dioxide is dissolved in water, the mass of this part remains the same. By changing the density of carbon dioxide injected, the mass of supercritical carbon dioxide is changed proportionally. The volume of supercritical carbon dioxide is determined by the total volume and porosity, so we can infer that the relationship between the final carbon dioxide storage in saline layer and the density of carbon dioxide injected into the stratum may be a fixed value plus a direct proportional function, that is, the storage and density is a one-time function.

- Then we multiply the density of carbon dioxide in the formula by a coefficient, for example, +-10. In this sensitivity analysis, since only one aspect of carbon dioxide density is analyzed for the time being, we can multiply several different isometric coefficients for further observation. So we can figure out how carbon dioxide stocks change based on their concentration.
  This isometric coefficient of arithmetic is generally not very large, as you take into account the fact that this factor generally varies over a very small range. However, considering that it is in a very deep underground confined space, the value of pressure, temperature and variation are not small, so in order to observe the rule of change, the maximum volume is five times the original value, which is convenient to observe the rule of change from a large scale.The figure is shown below:

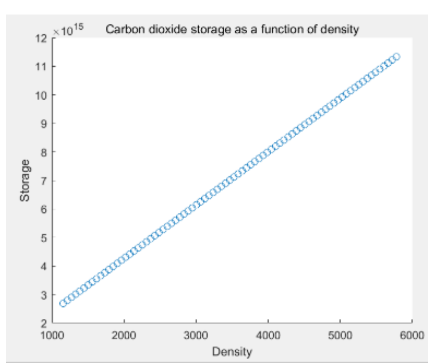


Figure 12: **Carbon dioxide storage as a function of density**

- Of course, when we find out that the change rule seems to be a simple first-order function, we can also make a small-range change prediction to support the view and observe whether there is a non-first-order function type change behavior on a small scale.The figure is shown below:

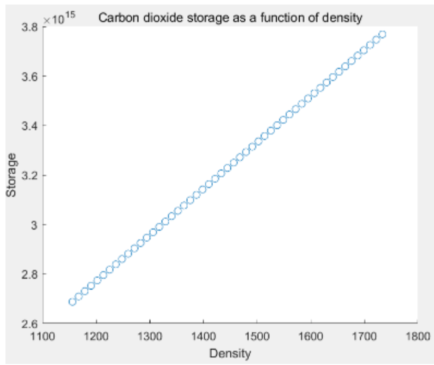


Figure 13: **Carbon dioxide storage as a function of density**

- We can also get the change rule of carbon dioxide reserves based on the change of its concentration, which is the influence of the expansion of its concentration on its reserves. This pattern is shown below:

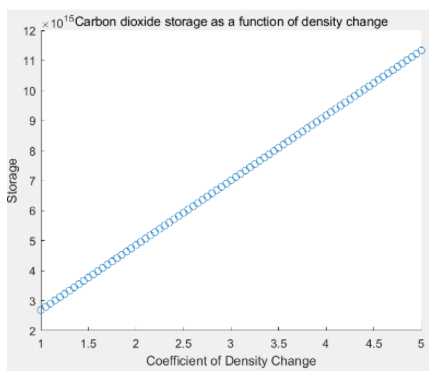


Figure 14: **Carbon dioxide storage as a function of density change**

- In addition, we can also explore the impact of equal scale reduction of carbon dioxide density on storage. As can be seen from the previous conclusion, the result will be equally scaled down.

7 Strengths and weaknesses

7.1 Strengths

1. **Universality**
In our model, the variables we set are accessible. These numbers are not unique to China, which means that the model can be used around the world to estimate how much carbon dioxide they can store. Therefore, we believe that our model is universal and can be applied to all regions.

2. **Simpleness**
The calculations we did in Model A and Model B weren't complicated, they were very basic, so there weren't a lot of errors, which ensured that our models were very stable and could be used for a long time.

3. **Improvability**
In the process of building our model, we do not directly represent all known quantities with numbers. Instead, we take a variable and then substitute in the value. This provides a basis for further optimization and improvement of the model.

7.2 Weaknesses

1. **Inaccuracy**
The problem of saltwater distribution is very complicated, and it is very different from place to place. It is impossible to collect all the specific data, so we generally use an average to reflect a more average level. Although it generally reflects the overall level, there are inevitable errors. So in that sense, our calculations are not accurate enough.

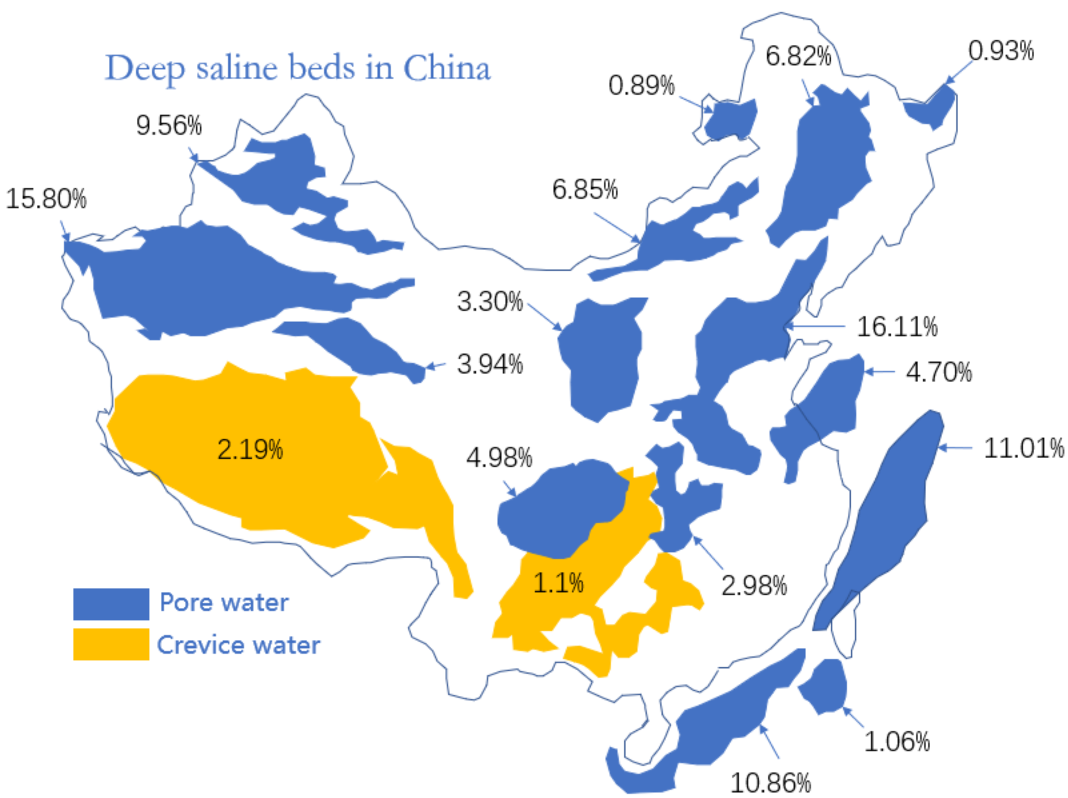
2. **The lack of data**
We need a lot of data when we are doing some calculations, but some data cannot be obtained directly.The absence of operational data is a weakness of our model.

8 A popular science essay

Carbon emissions peaking means the annual carbon dioxide emissions of a region or industry reach a record high and then plateau into a process of continuous decline, which is the historical inflection point of carbon dioxide emissions from increase to decline .Carbon neutrality means capturing and storing CO_2 safely instead of releasing CO_2 directly into the atmosphere.Realizing carbon emissions peaking and carbon neutrality is the main goal for the government and citizens.

The harm of global warming is unimaginable.It will lead to some cities drowning, the outbreak of the virus that used to be in the glacier, etc.Therefore, we must pay attention to protect the environment. When increasingly harsh atmosphere today is increasingly harsh, sequestration of carbon dioxide to alleviate environmental pollution can be regarded as an efficient and useful strategy. The figure below shows the amount of CO2 that can be stored in different deep saline layers as a percentage of the total storage volume.

The geological mechanism of CO2 can be divided into many different parts.



It's easy to see where the storage capacity is larger. But this kind of sealing can also have a certain impact on the lives of those around them.If there is a very violent crustal movement in this part of the earth, carbon dioxide stored underground can be released, causing sudden and huge damage to the environment, so we should try not to put too many residential areas in these dense sequestration areas. The amount of noise emitted during co2 sequestration can also affect the lives of residents. The government should take certain measures to protect and regulate these.

At the same time, the government's efforts and work on carbon sequestration and carbon emission reduction are displayed on TV or radio to emphasize the importance of low-carbon environmental protection to residents and advocate a low-carbon life.

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