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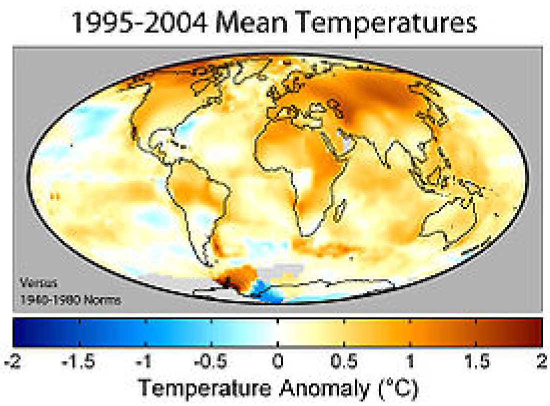
1. Introduction

Due to human activities such as the combustion of fossil fuels and deforestation, and the increased release of CO_2 from the oceans due to the increase in the Earth's temperature, the concentration of atmospheric carbon dioxide has increased by about 35% since the beginning of the age of industrialization. According to the fact given by EIA, total CO_2 emissions worldwide has been growing to 29,000 Million Metric Tons of Carbon Dioxide in recent years.



Mean surface temperature anomalies during the period 1995 to 2004 with respect to the average

The high concentration of atmospheric carbon dioxide leads to the severe global warming, which has been a threat to all human beings. A series of changes as the melting of polar ice and rise of levels takes place due to the temperature increase. Country like Tuvalu has been forced to move onto New Zealand for its own land has already been drowned under seawater. Other Pacific islands like Fiji and Nauru also have to face the crisis of losing their own lands.

Nations have been paying attention to the global warming issue long ago. On 11 December 1997 in Kyoto, Japan, Kyoto Protocol was established legally binding commitments for the reduction of six greenhouse gases including carbon dioxide at the United Nations Conference on Environment and Development. The treaty is intended to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." As of 2008, 183 parties have ratified the protocol.

Currently, USA ranks first in the total emission of CO_2 worldwide.

Table 4. U.S. Carbon Dioxide Emissions from Energy and Industry, 1990, 1995, and 1999-2006
(Million Metric Tons Carbon Dioxide)

Fuel Type or Process	1990	1995	1999	2000	2001	2002	2003	2004	2005	P2006
Energy Consumption										
Petroleum	2,172.0	2,199.6	2,407.3	2,452.0	2,464.0	2,461.5	2,506.9	2,597.1	2,614.8	2,581.2
Coal	1,799.7	1,897.5	2,051.2	2,144.9	2,083.6	2,092.7	2,130.1	2,154.6	2,162.4	2,134.1
Natural Gas	1,033.6	1,193.0	1,199.2	1,239.8	1,190.3	1,245.7	1,216.7	1,194.1	1,192.8	1,163.1
Renewables[a]	6.3	10.5	10.9	10.6	11.2	13.1	11.8	11.5	11.6	11.9
Energy Subtotal	**5,011.6**	**5,300.6**	**5,668.6**	**5,847.2**	**5,749.1**	**5,813.0**	**5,865.5**	**5,957.4**	**5,981.6**	**5,890.3**
Nonfuel Use Emissions[b]	*98.8*	*105.5*	*125.0*	*110.8*	*105.8*	*106.2*	*104.2*	*112.1*	*107.3*	*111.5*
Nonfuel Use Sequestration[c]	*251.2*	*286.5*	*325.9*	*308.2*	*293.8*	*293.9*	*289.6*	*311.9*	*302.3*	*302.0*
Adjustments to Energy	-82.4	-62.4	-66.5	-59.0	-44.0	-36.4	-27.3	-42.8	-43.8	-64.8
Adjusted Energy Subtotal	**4,929.3**	**5,238.1**	**5,602.1**	**5,788.3**	**5,705.1**	**5,776.6**	**5,838.2**	**5,914.6**	**5,937.8**	**5,825.5**
Other Sources	88.2	105.2	101.1	102.2	101.2	99.3	102.2	105.3	107.1	108.8
Total	**5,017.5**	**5,343.4**	**5,703.1**	**5,890.5**	**5,806.3**	**5,875.9**	**5,940.4**	**6,019.9**	**6,045.0**	**5,934.4**

[a]Includes emissions from electricity generation using nonbiogenic municipal solid waste and geothermal energy.
[b]Emissions from nonfuel uses are included in the energy subtotal.
[c]Carbon sequestered by nonfuel uses is subtracted from the energy emissions subtotal.
P = preliminary data.
Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0573(2005) (Washington, DC, November 2006). Totals may not equal sum of components due to independent rounding. Adjusted energy subtotal includes U.S. Territories but excludes international bunker fuels.
Source: EIA estimates.

The total amount of emissions is as much as, or even more than 60 Trillion Tons. The situation is not optimistic and the task of CO2 consumption is arduous. If there were significantly less CO2 in the atmosphere, global temperatures would drop below levels to which ecosystems and human societies have adapted.

2. Analyze

2.1 Neutrality

We noticed that in the problem Neutrality appeared more than once and basically take this most vital factor Neutrality into consideration in our model. In other words, we run the program to work out the most optimal plan of distribution as long as the neutrality is fulfilled.

When we say neutrality, that is to say the total amount of emissions equals to the total amount of consumption. Nowadays, CO2 emissions in the US is far more than the consumption, leading to the annually increase of CO2 concentration in the atmosphere and causing quite a few problems as global warming. To reach neutrality, more consumption is needed base on the amount of original consumption.

Since the problem defines the total U.S. carbon dioxide emissions are capped indefinitely, the only approach to achieve neutrality is to augment the amount of consumption.

The equation of neutrality can be expressed like this:

Total Emissions=Total Consumption

=Original consumption+ Newly-Added consumption

That is:

The Newly-Added consumption=Total Consumption- Original consumption

In conclusion, the newly-added consumption would be the main factor our model aims at. We would look for the most optimal, the most economic and the least cultural cost plan to fulfill the requirement of newly-added consumption.

2.2 Methods of CO2 consumption (sequestration)

In order to obtain quite precise newly-added amount of CO2 consumption, calculation of the original consumption amount is needed. The several main methods of carbon dioxide sequestrations are: trees absorption, factory carbon dioxide sequestration facility, and geo-sequestration. Geo-sequestration is divided into two parts: sea sequestration and oil field storage.

i) Consulting the data, we figure out the US forest coverage and then obtain the original consumption amount of carbon dioxide absorbed by trees.

ii) Learning the efficiency of sequestration facility, we obtain the total amount of carbon dioxide sequestrated by factories.

iii) Consulting the <Science> Magazine, we learned that sea sequestration is estimated to absorb 1/4 of the total human CO2 emissions.

The original carbon dioxide consumption is the sum of the three methods above.

As long as the total amount of original carbon dioxide consumption is subtracted, the result turns to be the required newly-added amount of CO2 consumption.

Since planting trees is the most efficient way of absorbing carbon dioxide and meantime does the least damage to the environment and cultural tradition compared to the other methods, the newly-added consumption is all assigned to be processed by newly-planted trees in our model.

Therefore, by dividing the newly-added consumption with trees absorption efficiency, we obtain the total amount of area to satisfy the need of newly-planted trees.

2.3 CO_2 sequestration in the industrial sector

2.3.1 Introduction

The acceleration of global industrialization has brought about exceeding CO_2 emission along with severe environmental problems. But CO_2 is not at all a kind of 'waste gas', it is actually an easily obtainable carbon-rich resource. CO_2 can be widely utilized in multiple fields, such as the chemical synthesize of urea, methanol and carbohydrates. CO_2 also serves as filler gas in fire extinguishers and protective gas during the welding process of metal. The healthy recycle and reuse of CO_2 can promote the sustainable development of various industries as well as retard the global warming efficiently.

As the industry-produced CO_2 is always released with high concentration, it's inappropriate and inefficient to utilize bio-absorption. Instead, the sequestration, recycle and reuse procedure should first be conducted manually with certain facilities and then absorbed biologically.

However, because the amount of CO_2 consumed by US industry is somewhat limited to approx. 10 million tons per year, the bulk of the sequestrated CO_2 needs to be absorbed geologically, which means the gas should be filled into the crust to re-enter the natural carbon recycle.

2.3.2 CO_2 sequestration in power plants

Currently, global power plants count for 40% of the total CO_2 emission. As fossil fuels serves as the bulk of global energy sources, the utilization of CO_2 capture and storage technology (CCS) in power plants will play a vital role in global sequestration. Special facilities can be installed to capture CO_2 before, during and after the combustion procedure.

The US Istank co. ltd. has developed a comprehensive CO_2 recycle and reuse system for power plants. The system requires 30 million dollars of initial investment and owns the capability to produce 1000 tons of industry pure CO_2 (98~99%) a day.

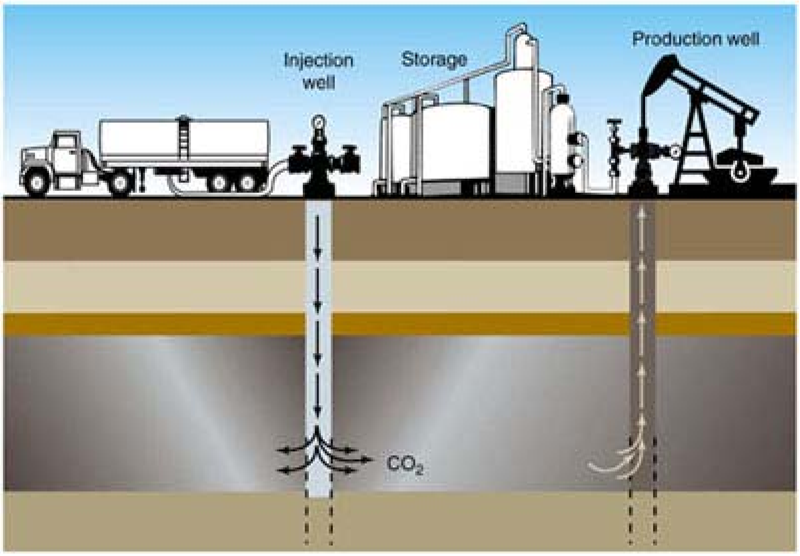
2.3.3 CO_2 sequestration in oil refineries

China's Dalian University of Technology invented a kind of solid compound absorbent efficient for removing impurities such as SO_2, NO_X and H_2O from the gas emitted by oil refineries. After distillation and pressurization, fine purity(99.99%) CO_2 can be produced in large amount. The entire facility installed in oil refineries cost approx. 2.9 million dollars and has an output of 30000 tons of food pure CO_2 (99.99%) per year.

2.3.4 The EOR technology

One major method of geological CO_2 absorption is to adopt the Enhanced Oil Recovery technology, which is being developed by the US petroleum industry. This technology involves injecting high-pressure CO_2 gas into nearly depleted oil fields to pressurize the production well, driving the rest crude oil to the surface and thus recovering a considerable amount of yield.

Figure 2.3.1 A Demonstration of EOR



The instilled CO_2 will undergo the following chemical reaction:

$$CO_2\,(g) + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^{-} + H^{+} \leftrightarrow CO_3^{2-} + 2H^{+}$$

The derived CO_3^{2-} will combine with metallic ions such as Ca^{2+}, form carbonates and ultimately settle down, placing the carbon element into the natural recycling process.

2.4 Trees planting

We mainly take two factors into consideration when making out the actual trees planting plan, where to plant the trees and when to plant them.

2.4.1 Where to plant

To mark out where to plant the trees, we take 'state' as unit and analyze the certain forest area each state should possess. In order to get a relatively exact outcome, we use AHP method while calculation, introducing population, economy, and state area the 4 elements. The newly-added area of forest equals to the certain subtracts the original forest area.

That is:

The newly-added area=The area each should possess- the original forest area

2.4.2. When to plant

Rome was not built in a day. Because of greatness of newly-added forest area, we adopt simulation to make the total area of forest increase with years so as to minimize the economic and biological impact caused by planting trees.

3. Assumptions

1. The main method of CO2 consumption is through geo-storage & the absorption of trees at present in the US. The sea absorbs 1/4 of the total carbon dioxide emissions.

2. In the Model, only factory CO2 sequestration facility and trees influence the consumption of CO2, other methods, such as sea-dissolving, are not included.

3. Since every population has a characteristic biotic potential, the maximum rate at which a population could increase under ideal conditions, in the model the mount of CO2 consumption by trees is idealized as only affected by area, but not intensity or other factors.

4. While calculating the forest area in each state, Hawaii and Alaska, with the extreme little forest area, are neglected. Washington DC does not count.

4. Industrial Sequestration

4.1 CO_2 sequestration in power plants

Table 4.1 Annual Power Plant CO_2 Emission from 1949 to 2008

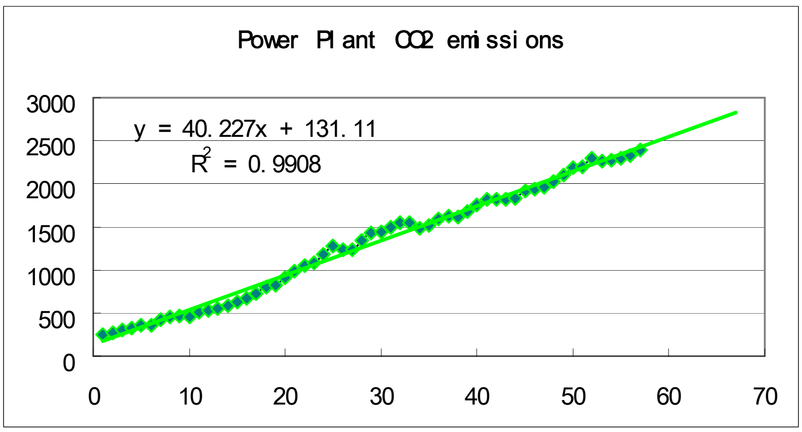
Year	Year counting from 1949	Power Plant CO2 Emission (Million Metric Tons)
1949	1	247.8110337
1950	2	275.284224
1951	3	306.0336327
1952	4	320.1537272
1953	5	354.4582768
1954	6	360.4234244
1955	7	420.8636776
1956	8	454.7209758
1957	9	470.3932913
1958	10	458.7191006
1959	11	506.4432344
1960	12	529.9428998
1961	13	547.6753106
1962	14	580.3319187
1963	15	631.7144346
1964	16	676.1621867
1965	17	723.9603551
1966	18	797.1463868
1967	19	827.7186817
1968	20	913.5785962
1969	21	982.9512127
1970	22	1049.685427
1971	23	1087.705151
1972	24	1184.008804
1973	25	1274.275798
1974	26	1239.295648
1975	27	1232.325732
1976	28	1339.73415
1977	29	1428.359332
1978	30	1435.415869
1979	31	1491.819804
1980	32	1543.442934
1981	33	1551.256219
1982	34	1481.058686
1983	35	1520.944397
1984	36	1588.490131
1985	37	1619.989248

1986	38	1613.573413
1987	39	1680.570794
1988	40	1757.552076
1989	41	1823.178285
1990	42	1820.205287
1991	43	1817.307037
1992	44	1831.191761
1993	45	1912.323078
1994	46	1939.162103
1995	47	1954.97081
1996	48	2026.134598
1997	49	2095.955166
1998	50	2185.316481
1999	51	2196.256221
2000	52	2300.679573
2001	53	2261.100924
2002	54	2270.939291
2003	55	2298.806226
2004	56	2330.977786
2005	57	2397.141748
2006	58	2464.276
2007	59	2504.503
2008	60	2544.73

The table above was downloaded from EIA (Energy Information Administration). However, the data provided was only updated to year 2005. So we performed a linear regression and estimation to achieve the data of year 2006, 2a007 and 2008 (yellow-shaded in the table above). Here's the result.

$$Y = 40.227X + 131.11$$

Figure 4 Linear Regression of Annual Power Plant CO_2 Emission



Y represents the estimated amount of power plant CO_2 emission (Unit: Million Metric Tons), and X represents the number of years counting from 1949. As for the year 2008,

$$Y = 40.227 * (2008 - 1949 + 1) + 131.11 = 2544.73(MMT)$$

As a result, US power plants are estimated to release 2544.73 MMT of CO_2 into the atmosphere in 2008. As mentioned before, the most efficient way to sequestrate this part of CO_2 is to utilize the CCS technology.

According to the EIA official website, there are a total of 2776 power plants in US. Suppose every power plant is equipped with a set of Istank comprehensive CO_2 sequestration system, then we have

$$Y_{ps} = 365(days) * 1000(tons/day) * 2776 = 1013.24(MMT)$$

Y_{ps} represents the annual sequestrated amount of power plant generated CO_2, which is 1013.24 MMT as shown above.

$$\frac{Y_{ps}}{Y} = \frac{1013.24}{2544.73} = 39.81\%$$

The calculation above indicates that we will reduce approx. 39.81% of CO_2 emitted by US power plants if we widely install CO_2 sequestration facilities.

4.2 CO_2 sequestration in oil refineries

According to Wikipedia, there are a total of 151 oil refineries in US. Suppose every oil refinery is equipped with a set of Dalian University of Technology CO_2 recycling facility, then we have

$$Y_{rs} = 151 * 30000(tons/year) = 4.53(MMT)$$

Y_{rs} represents the annual sequestrated amount of oil refinery generated CO_2, which is 4.53 MMT as shown above.

$$1013.24 + 4.53 = 1017.77(MMT)$$

So the CCS technology, if broadly adopted, will hopefully retract 1017.77 million tons from US power plants and oil refineries.

4.3 A calculation on the potential capacity of CO_2 in EOR

As mentioned in 2.3.1, the CO_2 consumed by US industry is limited to approx. 10 million tons per year, so the bulk of the gas should be engaged in the EOR process. And here is a calculation performed to evaluate the capacity of CO_2 in EOR.

We imported the van der Waals Formula to perform the calculation.

$$(p + a\frac{n^2}{V^2})(V - nb) = nRT$$

p(Pa) is the pressure of gas.

n(mol) is the amount of gas.

V(m^3)is the volume of gas.

T(K) is the thermodynamic temperature of gas.

R is gas constant, R=8.314472J·K-1·mol-1.

a is the van der Waals pressure correction constant.

For CO_2, a=0.364Pa·m^6·mol^{-2}

b is the van der Waals volume correction constant.

For CO_2, b=0.4267*$10^{-4}$$m^3$·$mol^{-1}$

The data above were all referenced from Inorganic Chemistry (written by Dalian University of Technology).

Then we consulted EIA and downloaded a table demonstrating the US oil resources.

Table 4.3 U.S Oil Resources

Original, Developed and Undeveloped Domestic Oil Resources (Billion Barrels)*						
				Future Recovery**		
	Original Oil In- Place	Developed to Date	Remaining Oil In-Place****	Conventional Technology	EOR*** Technology	Total
I. Crude Oil						
1. Discovered	**582**	**(208)**	**374**	**-**	**110**	**110**
• Light Oil	482	(189)	293	-	90	90
• Heavy Oil	100	(19)	81	-	20	20
2. Undiscovered	**360**	**-**	**360**	**119**	**60**	**179**
3. Reserve Growth	**210**	**-**	**210**	**71**	**40**	**111**
4. Residual Oil Zone	**100**	**-**	**100**	**-**	**20**	**20**
II. Tar Sands	**80**	**-**	**80**	**-**	**10**	**10**
TOTAL	**1,332**	**(208)**	**1,124**	**190**	**240**	**430**

Note that the developed oil resources measure 208 billion barrels. According to international oil trade convention

$$1barrel = 158.98l = 158.98*10^{-3}m^3$$

$$208*10^9 barrels = 3.30*10^{10}m^3$$

Because this volume of oil has been developed, the space where they used to be in-place will be vacant and available for CO_2 injection

EOR requires the injection of considerably high pressure CO_2. Take the Canadian Weyburn EOR Oilrig as example. The instilled CO_2 is pressurized up to 152 bars.

$$152\,bars = 152*100000\ pa = 1.52*10^7\ pa$$

The temperature deep down oil fields varies, but it's generally much higher than the surface one. We took 50ºC for calculation.

$$50^\circ C = (273+50)K = 323K$$

So we have

$$(p + a\frac{n^2}{V^2})(V - nb) = nRT$$

$$-\frac{ab}{V^2}n^3 + \frac{a}{V}n^2 - (pb + RT)n + pV = 0$$

$$-\frac{0.364*0.4267*10^{-4}}{(3.30*10^{10})^2}n^3 + \frac{0.364}{3.30*10^{10}}n^2 - (1.52*10^7*0.4267*10^{-4} + 8.314*323)n + 1.52*10^7*3.30*10^{10} = 0$$

Since it's a cubic equation, there is no direct algebraic solution method for it. So we used MATLAB to find the root.

Figure 4.3 Finding the Root using MATLAB

```
>> solve('-1.426*(10^(-26))*x^3+1.103*(10^(-11))*x^2-3334*x+5.016*10^17=0','x')

ans =

 179758665427625.80675729188719384-229470025847595.02367934772097775*i
 179758665427625.80675729188719384+229470025847595.02367934772097775*i
                                   413974955259755.39910813712322802
```

Note that the first two roots contain imaginary numbers and should be abandoned.

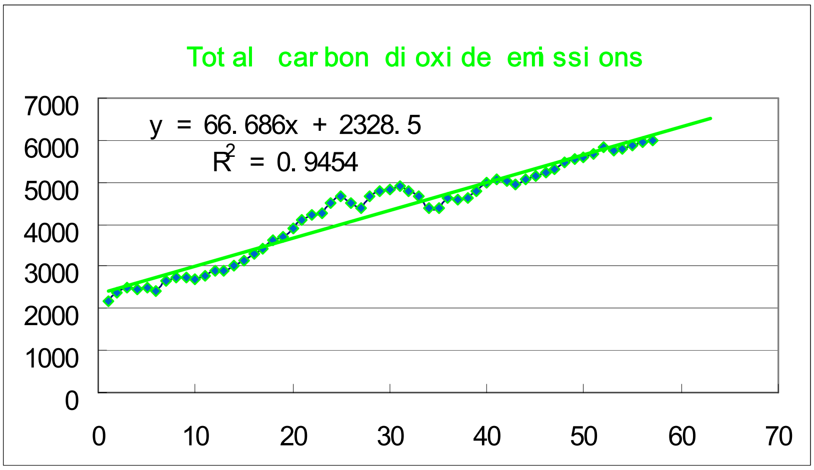
The real root reads approx. $4.140*10^{14}$ mol. 1 mol CO_2 weighs 44g (M_{co2}=44g/mol), so the weight of CO_2 capable to be injected is

$$m_{co_2} = M_{CO_2}n = 44*10^{-6}*4.140*10^{14} = 1.822*10^{10}(tons)$$

The value actually triples the total CO_2 emission of USA in 2008, demonstrating the almost infinitely large potential CO_2 capacity. So we reached the conclusion that the EOR technology can dispose of as much CO_2 as is captured. Therefore, the state-wide utilization of Carbon Capture and Storage technology to manually sequestrate CO_2 is proved feasible and effective.

5. Trees planting

5.1 Total forest land area in need



According to the data listed by EIA, we processed data through simulation and got the formula to calculate the total carbon dioxide emissions since the year 1949. Figures on the horizontal axis demonstrate every 10 years since 1949; Figures on the vertical axis demonstrate total carbon dioxide emissions (million metric tons) each year.

The data was calculated as follow:

2006	6196.288
2007	6262.974
2008	6329.66
2009	6396.346
2010	6463.032

So this year, in 2008, the total carbon dioxide emissions are approximately 6329.66 million metric tons

Additionally, according to the information, the sea absorbs 1/4 of the total carbon dioxide emissions. The rest amount of carbon dioxide should be:

6366.26-6266.26*1/4=4747.245 million metric tons.

According to the model 4.1(CO2 sequestration in power plants and oil refineries), the consumption of CO2 has already reached **1013.24 +4.53 =1017.77** million metric tons.

So all the trees should absorb carbon dioxide with total amount of **4747.245-1017.77=3729.475 million metric tons.**

Since a hectare trees could have 7.2tons carbon dioxide consumption, only when the US forest area reaches to at least 517,982,639 hectares, emission and consumption neutrality could be achieved.

5.2 Where to plant the trees

5.2.1 AHP

Analytic Hierarchy Process (AHP) is an approach to decision making that involves structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives.

By organizing and assessing alternatives against a hierarchy of multifaceted objectives, AHP provides a proven, effective means to deal with complex decision making. In this model, we use AHP to allow a better, easier, and more efficient identification of factor criteria, their weighing and analysis.

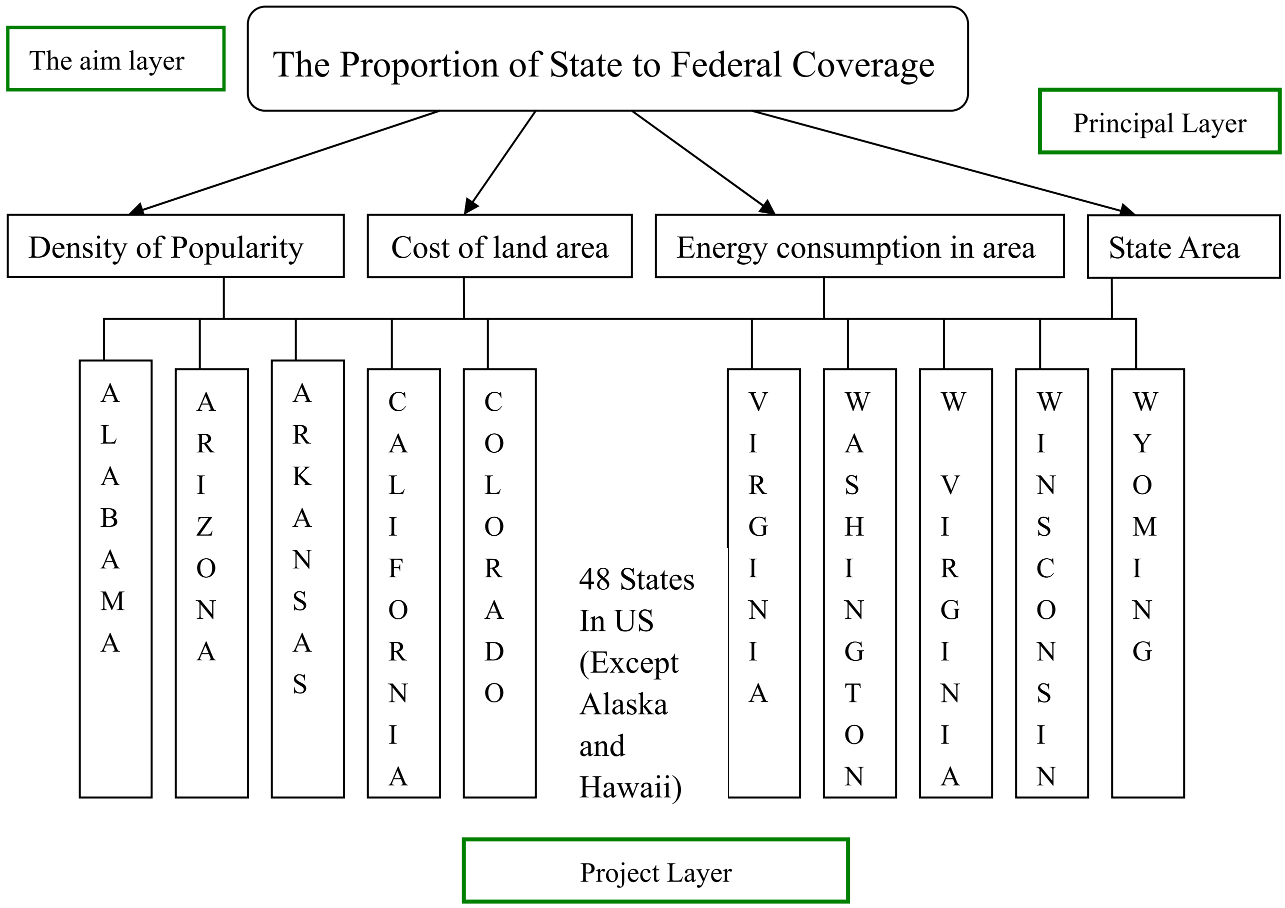
Variables	
A，B1，B2，B3，B4	The Comparison Matrix
n，m	The Exponent Number of A，B

Aw	The Vector of Weighing
Bw1	Weighting of Density of Popularity in Each State
Bw2	Weighting of Cost of Land Area
Bw3	Weighting of Energy Consumption In Area
Bw4	State Area
CR	Coherent Ratio
Importance	The Proportion of State to Federal Coverage

Procedure I: Draw the Hiberarchy Image

This is the partial application of AHP, where we aim at determining the weighing of each factor.

The Hiberarchy Image



Procedure II: Construct a Comparison Matrix

Principal:

Relative importance	Grade
Equally Important	1
Generally more Important	3
Far more Important	5
More Important at the second highest degree	7
More Important at the highest degree	9

Note:

1) 2 , 4 , 6 , 8 represents the importance level is in between according to the chart.

2) The reciprocal value is used to express 'Less important'

A . Principle layer

Explanation for importance grade:

Factors include: Density of popularity, Value of land area, Energy consumption in area, State area, as are defined.

1) State land area is essential to the growing of new trees. No land, no more trees. Therefore state land area is vital to trees planting and holds the most importance.

2) The cost of land is strongly related with the national economic development. Large area trees planting costs quite a large sum and needs to be aware of. The efficient way of planting trees is to plant them in the low-cost areas. Since the US government is facing the severe economic crisis, each step of governmental disbursal should be considered scrupulously. Therefore, economic weighs much in determining the importance of factors. Compared to the rest three factors, the cost of land holds the most importance at second degree.

3) The ultimate purpose of planting trees is to increase the consumption of CO_2. Where there is more energy consumption, trees are in greater need. So the energy consumption has generally more importance compared to the dense of population but less importance to cost of land area. Thus, we render it the generally important factor.

4) People's perception of environmental satisfaction is subjective and will grow with the increase in green coverage. But it is not so important when calculated into the whole model. Therefore, the dense of population holds the least importance.

The result is as follow:

	Density of Popularity	Cost of land area	Energy consumption in area	State Area
Density of Popularity	1	1/5	1/2	1/9
Cost of Land Area	5	1	2	1/7
Energy Consumption in Area	2	1/2	1	1/8
State Area	9	7	8	1

B．Project layer

Due to the large number of factors in this layer, we basically calculate the value in the matrixes as: log2 (the result of division between each of the two factors), the result is listed as follow:

Factors	Dense of Population	Value of Land	Energy Consumption	State Area
Units	population/square km	$thousand/ha	Trillion Btu	Hectare
Alabama	35.21259872	12.61515986	2,119	13142600
Arizona	21.537535	8.393405638	1,480	29431200
Arkansas	21.02091861	7.072062051	1,135	13485600
California	90.4932625	44.88288899	8,360	40393300
Colorado	18.09764097	8.797477543	1,426	26862700
Connecticut	279.1129264	172.3509723	900	1254800
Delaware	170.9019763	118.8102767	313	506000

Florida	130.6740388	52.58960407	4,563	13967000
Georgia	63.64184936	26.43783005	3,173	14997600
Idaho	6.996285824	2.386638297	503	21431400
Illinois	89.27798501	42.34271782	4,122	14396100
Indiana	68.30603369	26.52876904	2,905	9289500
Iowa	20.64979509	8.916731743	1,228	14470100
Kansas	13.10050496	5.535865975	1,032	21190000
Kentucky	41.22098041	14.98445032	1,970	10289600
Louisiana	38.05188566	19.1576335	3,613	11282500
Maine	16.4793009	6.018691121	482	7993100
Maryland	221.9461168	106.1408707	1,555	2531400
Massachusetts	317.628041	173.1084409	1,562	2030600
Michigan	68.45944495	25.96250705	3,167	14712100
Minnesota	25.20804214	12.36583911	1,852	20618900
Mississippi	24.02529468	7.288456473	1,182	12148800
Missouri	32.94817111	12.86165884	1,915	17841400
Montana	2.540886893	0.908618252	419	37697900
Nebraska	8.913008101	4.022772591	655	19909900
Nevada	9.018808359	4.472276128	728	28444800
New Hampshire	56.65079433	24.68721746	335	2322700
New Jersey	452.1326323	242.3007652	2,729	1921100
New Mexico	6.267447003	2.423665883	675	31430900
New York	157.8120344	90.20256291	4,180	12228300
North Carolina	71.82118087	31.66160699	2,732	12616100
North Dakota	3.580888568	1.551943218	412	17864700
Ohio	108.1213416	43.96818662	4,082	10605600
Oklahoma	20.33948281	7.833868437	1,551	17784700
Oregon	15.07235622	6.363767994	1,096	24863100
Pennsylvania	107.110912	45.75615556	4,050	11607400
Rhode Island	390.9209165	173.3185514	228	270600
South Carolina	56.52140851	19.59786107	1,694	7798300
South Dakota	4.051154981	1.726569655	274	19654000
Tennessee	57.67310214	22.8444432	2,339	10675200
Texas	35.25454575	16.84187473	11,558	67805100
Utah	12.4339251	4.966275129	757	21275100
Vermont	25.9331274	10.24503256	167	2395600
Virginia	75.20469439	37.34485314	2,610	10254800
Washington	37.5311811	18.06055191	2,059	17234800
West Virginia	29.05718318	9.254341656	794	6236100
Wisconsin	39.82312335	16.51415084	1,862	14066300
Wyoming	2.078937846	1.253096557	462	25148900

*Note:

1) The value of land area is weighed by calculating the influence on GSP brought by trees planting per hectare.

2) The comparison matrixes formed by principal layer among B1, B2, B3, B4 are three

48*48matrixes and is hardly possible to be fully listed here.

Procedure III: Calculation of The Vector of Weighing and Coherent Check

A．Calculation of The Vector of Weighing

A=

$$\begin{pmatrix} 1 & 1/5 & 1/2 & 1/9 \\ 5 & 1 & 2 & 1/7 \\ 2 & 1/2 & 1 & 1/8 \\ 9 & 7 & 8 & 1 \end{pmatrix}$$

n=4

After the standardization of eigenvector,

The Vector of Weighing is:

(0.051466 0.17164 0.088181 0.68871)

B．Coherence Check

$$CL = \frac{A_{w\max} - n}{n-1}$$

Calculated by Matlab, $A_{w\max} = 4.1634$

$$CR = \frac{CI}{RI}$$

Table of the RI Value

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.901	1.12	1.24	1.32	1.41	1.45

CR= 0.060439 < 0.1

So the coherence of the matrix is qualified.

Procedure IV: Hierarchy total taxis and coherence check

A．Hierarchy total taxis

After the standardization of eigenvector, Apply the algorithm to generate Bw1, Bw2, Bw3, in each of the state; the proportion of state trees planting to all trees:

$$\text{Bws}=\left\{\begin{matrix}\text{Bw1}\\ \text{Bw2}\\ \text{Bw3}\\ \text{Bw4}\end{matrix}\right\}$$

Importance=Aw*Bws

B．Coherence Check

Hierarchy	$A_1 \quad A_2 \ldots A_m$ $a_1 \quad a_2 \ldots a_m$				Hierarchy total taxis
B_1	$b^{(1)}{}_1$	$b^{(2)}{}_1$		$b^{(n)}{}_1$	$\sum_{i=1}^{m} a_i b_1^{(i)}$
B_2	$b^{(1)}{}_2$	$b^{(2)}{}_2$		$b^{(n)}{}_2$	$\sum_{i=1}^{m} a_i b_1^{(i)}$
⋮	⋮	⋮	⋮	⋮	⋮
B_n	$b^{(1)}{}_n$	$b^{(2)}{}_n$		$b^{(n)}{}_n$	$\sum_{i=1}^{m} a_1 b_n^{(i)}$

$$CR=\frac{a_1CI_1+a_2CI_2+\cdots+a_mCI_m}{a_1RI_1+a_2RI_2+\cdots+a_mRI_m}$$

CR= 0.020884<0.1

So the coherence of the matrix is qualified.

5.2.2 Mathematical equation of the model for the distribution of tree planting

The mathematical equation of the distribution of tree planting is generated through the following procedures. In terms of practicability, after the distribution of tree planting areas according to the weight in each state finishes, a certain circumstance would appear. Such is the case that the original tree in the state is more than the total amount of tree it is distributed to possess, or the sum of the original with the distributed amount is larger than its land area. In order to be practical, we add two limit conditions to the distribution.

1. Delete “0”

As a state in which its original amount of trees is larger than the amount it is distributed, we delete its weight (decreasing to 0) ,indicating that trees in this state has already reached the balance. The state is in no need to be counted into distribution.

2. Definition of limit

As for the condition that the sum of the original with the distributed amount is larger than the state’s land area, we define the highest forest coverage state-the forest coverage in West Virginia as our limit (**Limit=0.973525119866583),** representing the highest forest coverage in a state. As far as we are concerned, when the forest coverage is larger than the limit in a state, the forest area is so huge that it circumscribed activities and social development of human beings. As a state in which the sum of the original with the distributed amount is larger than the state’s land area, we delete its value of weighting (decreasing to 0). The newly-planted area should be Limit-the amount of original trees, indicating that no more trees can grow in the area, and quit the distribution.

Repeat the distribution procedure till all the states taking part in distribution have no conditions like 1 or 2.

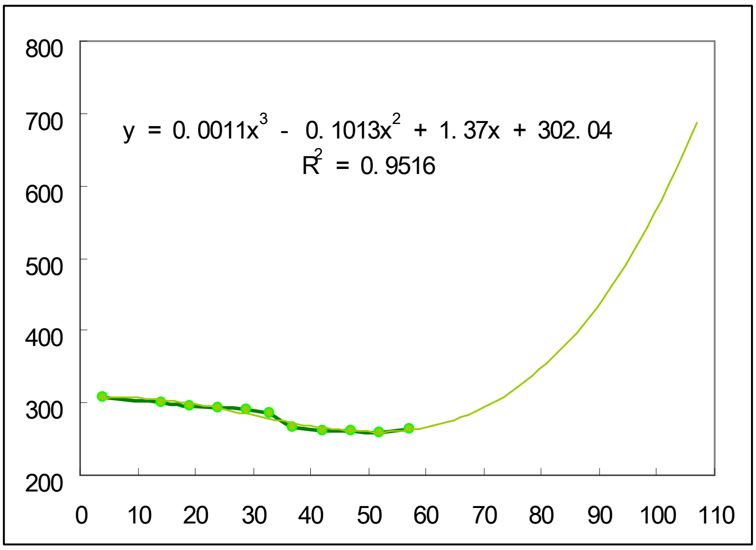
3．Result of distribution

State	newly-added (unit: hectare)	State	newly-added (unit: hectare)	State	newly-added (unit: hectare)
Alabama	601678	Maine	2181149	Ohio	5199544
Arizona	10543096	Maryland	903381	Oklahoma	12805421
Arkansas	3276171	Massachussetts	763840	Oregon	2465399
California	9917473	Michigan	1315576	Pennsylvania	1038544
Colorado	3883096	Minnisota	4100096	Rhode Island	145436
Connecticut	304579	Missisippi	1487171	South Carolina	4201763
Delaware	249604	Missouri	4345096	South Dakota	16061939
Florida	5232630	Montana	14929734	Tennessee	1551249
Georgia	3028249	Nebraska	13899843	Texas	16607614
Idaho	5285332	Nevada	13810843	Utah	10044843
Illinois	7135544	New Hampshire	526207	Vermont	210177
Indiana	6041562	New Jersey	1223239	Virginia	1309813
Iowa	6103846	New Mexico	10806332	Washington	3519488
Kansas	14155399	New York	961407	West Virginia	0
Kentucky	1787678	North Carolina	3694576	Wisconsin	4790488
Louisana	3386981	North Dakota	16957255	Wyoming	12365255

Note: The sum of distribution (265155639 hectare) is the total area of newly-added forests.

5.3 How many trees to plant and when to plant them

In order to reduce the instant impact brought by large area trees planting, we think of planting step by step. To make sure of the annual amount of tree planting, we process data through simulation and get the predicted data as follow:



Through the observation of the US forest coverage data from 1949 to 2002, we are not hard to find that the data shown to have a trend first goes up and then goes down. And from what we learn about the US history, we get the conclusion: the US industry had been in a rapid growing period, large amount of forest had been industrialized and urbanized, the area of forest decreased as years passed. In the recent years, environmental care has received wide attention and US has been taking up methods to plant more vegetations to protect environment.

With this characteristic, we adopted the 3rd function during the simulation.

The ultimate result is as follows:

Note: In order to make calculation easier, X represents the Xth year since 1945.

year	Total Land Area (million ha)	year	Total Land Area (million ha)
2007	259.7436	2029	354.3216
2008	261.342	2030	362.135
2009	263.1536	2031	370.3068
2010	265.185	2032	378.8436
2011	267.4428	2033	387.752
2012	269.9336	2034	397.0386
2013	272.664	2035	406.71
2014	275.6406	2036	416.7728
2015	278.87	2037	427.2336
2016	282.3588	2038	438.099
2017	286.1136	2039	449.3756
2018	290.141	2040	461.07

2019	294.4476	2041	473.1888
2020	299.04	2042	485.7386
2021	303.9248	2043	498.726
2022	309.1086	2044	512.1576
2023	314.598	2045	526.04
2024	320.3996	2046	540.3798
2025	326.52	2047	555.1836
2026	332.9658	2048	570.458
2027	339.7436	2049	586.2096
2028	346.86	2050	602.445

In conclusion, US should have the total forest area for about 517.982639 hectares, so will be finishing the tree planting plan till 2045, the annual total forest area is demonstrated in the graph above.

6.COST

1. Industrial:

As CO_2 is a valuable resource in industry, it possesses relatively high price. For instance, the price of industry pure CO_2 used for welding is \$90~105/ton, CO_2 used in EOR is about \$120/ton, and food pure CO_2 filled in beer bottles is even more expensive, reaching \$140~170/ton.

Also, the oil fields utilizing EOR can gain a 25-year yield recovery on average, and more oil means greater economic profit. As a result, the cost of the sequestration process (eg. energy price, transportation fee, etc.) is apparently low in comparison with the considerable economic benefit of CO_2. So we will omit the production cost and count the initial investment only.

If all the US power plants and oil refineries commence the aforementioned industrial CO_2 sequestration, the initial investment 'I' will be

$$I = 2776*30+151*2.9 = 83717.9\ (million\$) = 83.7179 (billion\$)$$

2. Trees

As is estimated, suppose to plant 1000 trees in each hectare. The average cost of seedling is 1$/tree. Thus, the total cost of trees in a hectare should be:

1000*3=3000 $

$$I=265155639*3000=79546.6917\ (million\$)=79.5466917(billion\$)$$

Total cost of both industrial and planting trees is:

83.7179+79.5466917=163.2645917 (billion $)

7 . EVALUATION

Strength

1. Uses of scientifically methods as simulation, AHP that enables the outcome to be relatively objective and reasonable.
2. Factors such as feasibility, effectiveness, and impacts to economy are taken into consideration to make the problem fully discussed and are ensure the result to be reasonable.
3. Different methods of carbon dioxide consumption are adopted to deal with carbon dioxide from different sources. The methods are variable.

Weakness

1. The precision of AHP is relatively low
2. The completion of model takes a couple of years and is hard to predict with too many variables.

8 . APPENDIX

8.1 Reference

1. US CO_2 emission data

http://www.eia.doe.gov/environment.html

2. The total number of US power plants

http://www.eia.doe.gov/cneaf/electricity/ipp/html1/ippv1te1p1.html

3. List of US oil refineries

http://en.wikipedia.org/wiki/List_of_oil_refineries#United_States

4. An introduction to CCS

http://en.wikipedia.org/wiki/Carbon_capture_and_storage#cite_note-12

5. An introduction to EOR

http://en.wikipedia.org/wiki/Enhanced_oil_recovery

6. Geological absorption of CO_2

http://www.ipcc.ch/pdf/special-reports/srccs/srccs_chapter5.pdf

7. Istank's cooperation with China's Dagang power plant on CO_2 sequestration

http://www.022net.com/2008/8-19/472055292963673.html

8. CO_2 recycling facility developed by Dalian University of Technology

http://scidep.dlut.edu.cn/kfk/chengguo/showdetail.asp?id=1539

9. US oil resources update

http://fossil.energy.gov/programs/oilgas/publications/eor_co2/G_-_Updated_U_S__
Oil_Resources_Table_2-1.pdf

10. An example of EOR utilization – the Weyburn oil field

http://www.seed.slb.com/zh/scictr/watch/climate_change/weyburn.htm

11. Prices of CO2

http://chemic.dlut.edu.cn/html/20080823101010121612.htmla

12. <Science>: Ocean absorbs approx. 1/4 of the human CO2 emission

http://news.bbc.co.uk/chinese/simp/hi/newsid_6660000/newsid_6668100/6668159.st
m

13. http://www.lvhua.com/chinese/biz/seed_pd_list.asp?id=195

14 The van der Waals Equation

http://en.wikipedia.org/wiki/Van_der_Waals_equation

8.2 CO2 Total Emission Data

Year	CO2 total emission (million tons)	Year	CO2 total emission (million tons)	Year	CO2 total emission (million tons)
1949	2183.881195	1970	4212.865349	1991	4964.529922
1950	2354.823133	1971	4262.34483	1992	5062.965029
1951	2498.811297	1972	4486.955602	1993	5168.182623
1952	2446.835325	1973	4685.651308	1994	5245.998488
1953	2511.20394	1974	4521.339635	1995	5300.582947
1954	2403.744125	1975	4389.066044	1996	5487.640515
1955	2663.263777	1976	4654.797281	1997	5569.12076
1956	2748.845185	1977	4793.839348	1998	5606.131296
1957	2737.425611	1978	4843.482111	1999	5668.624225
1958	2681.838135	1979	4904.730102	2000	5847.241308
1959	2787.87754	1980	4769.549622	2001	5749.121248
1960	2889.008571	1981	4648.941969	2002	5812.97734
1961	2910.073593	1982	4404.945877	2003	5865.501171
1962	3030.890296	1983	4369.554501	2004	5957.366723
1963	3148.167046	1984	4615.222912	2005	5981.57019
1964	3282.451174	1985	4603.204269	2006	6196.288
1965	3426.585677	1986	4613.599738	2007	6262.974
1966	3614.297626	1987	4773.437771	2008	6329.66

1967	3708.81688	1988	4992.322788	2009	6396.346
1968	3920.51969	1989	5070.997645	2010	6463.032
1969	4090.379691	1990	5011.62262		

8.3 Program

Programme for distribution of newly-added forest

```
n=4;
A=[1,1/5,1/2,1/9;5,1,2,1/7;2,1/2,1,1/8;9,7,8,1];
[x,y]=eig(A);
p=max(y);
Amax=max(p);
CI=(Amax-n)/(n-1);
RI=0.901;
CRA=CI/RI;
if CRA>=0.1
    disp('wrong')
    return
end
disp('right')
wa1=sum(A);
for i=1:n
    for j=1:n
        wa2(i,j)=A(i,j)/wa1(j);
    end
end
wa3=wa2';
wa4=sum(wa3);
Aw=wa4./n;

m=48;

b1=[5,4,4,6,4,8,7,7,5,2,6,6,4,3,5,5,4,7,8,6,4,4,4,1,3,3,5,9,2,7,6,1,6,4,3,6,9,5,2,5,5,3,4,6,5,4,5,1;];
for i=1:m;
    for j=1:m;
        if b1(i)>=b1(j);
            B1(i,j)=b1(i)-b1(j)+1;
            B1(j,i)=1/B1(i,j);
        end
    end
end
```

```
[x,y]=eig(B1);
p=max(y);
q=max(p);
BCI1=(q-m)/(m-1);
wb1=sum(B1);
for i=1:m
    for j=1:m
        wb2(i,j)=B1(i,j)/wb1(j);
    end
end
wb3=wb2';
wb4=sum(wb3);
Bw1=wb4./m;

b2=[5,5,6,3,5,1,2,3,4,7,3,4,5,6,5,4,6,2,1,4,5,6,5,9,6,6,4,1,7,2,4,8,3,6,6,3,1,4,8,4,4,6,5,3,4,5,4,8;];
for i=1:m;
    for j=1:m;
        if b2(i)>=b2(j);
            B2(i,j)=b2(i)-b2(j)+1;
            B2(j,i)=1/B2(i,j);
        end
    end
end
[x,y]=eig(B2);
p=max(y);
q=max(p);
BCI2=(q-m)/(m-1);
wb1=sum(B2);
for i=1:m
    for j=1:m
        wb2(i,j)=B2(i,j)/wb1(j);
    end
end
wb3=wb2';
wb4=sum(wb3);
Bw2=wb4./m;

b3=[5,5,4,8,5,4,2,7,6,3,7,6,4,4,5,7,3,5,5,6,5,4,5,3,3,3,2,6,3,7,6,3,7,5,4,7,1,5,2,6,9,3,1,6,5,3,5,3;];
for i=1:m;
    for j=1:m;
        if b3(i)>=b3(j);
            B3(i,j)=b3(i)-b3(j)+1;
            B3(j,i)=1/B3(i,j);
        end
```

```
        end
end
[x,y]=eig(B3);
p=max(y);
q=max(p);
BCI3=(q-m)/(m-1);
wb1=sum(B3);
for i=1:m
        for j=1:m
                wb2(i,j)=B3(i,j)/wb1(j);
        end
end
wb3=wb2';
wb4=sum(wb3);
Bw3=wb4./m;

b4=[7,8,7,9,8,1,0.5,7,7,8,7,7,7,8,7,7,6,1,1,7,8,7,8,9,8,8,1,1,8,7,7,8,7,8,8,7,0.2,6,8,7,9,8,2,7,8,7,8,8;
];
for i=1:m;
        for j=1:m;
                if b4(i)>=b4(j);
                        B4(i,j)=b4(i)-b4(j)+1;
                        B4(j,i)=1/B4(i,j);
                end
        end
end
[x,y]=eig(B4);
p=max(y);
q=max(p);
BCI4=(q-m)/(m-1);
wb1=sum(B4);
for i=1:m
        for j=1:m
                wb2(i,j)=B4(i,j)/wb1(j);
        end
end
wb3=wb2';
wb4=sum(wb3);
Bw4=wb4./m;

Bws=[Bw1;Bw2;Bw3;Bw4];
BCI=[BCI1;BCI2;BCI3;BCI4];
importance=Aw*Bws;
CRB=Aw*BCI;
```

```
if CRB>=0.1
    disp('wrong')
    return
end
disp('right')
save importance;

load forest;
load land;
sumup=517982639;
flag=1;
limit=0.973525119866583;
while flag==1;
    flag=0;
    for i=1:m
        if importance(i)~=0;
            new(i)=sumup*importance(i)/(sum(importance))-forest(i);
        end
    end
    for i=1:m;
        if importance(i)~=0;
            if new(i)<0;
                sumup=sumup-forest(i);
                importance(i)=0;
                flag=1;
            end
            if new(i)+forest(i)>land(i)*limit;
                new(i)=land(i)*limit-forest(i);
                sumup=sumup-land( i)*limit;
                importance(i)=0;
                flag=1;
            end;
        end
    end
end
new
save new;
```

note: data loaded

State	forest	land	State	forest	land
Alabama	8770000	13142600	Nebraska	357000	19909900
Arizona	3350000	29431200	Nevada	446000	28444800

Arkansas	6581000	13485600	New Hampshire	1735000	2322700
California	12501000	40393300	New Jersey	647000	1921100
Colorado	10010000	26862700	New Mexico	4707000	31430900
Connecticut	917000	1254800	New York	8992000	12228300
Delaware	243000	506000	North Carolina	5802000	12616100
Florida	4939000	13967000	North Dakota	58000	17864700
Georgia	6194000	14997600	Ohio	4603000	10605600
Idaho	10228000	21431400	Oklahoma	2076000	17784700
Illinois	2667000	14396100	Oregon	11990000	24863100
Indiana	3002000	9289500	Pennsylvania	8764000	11607400
Iowa	2765000	14470100	Rhode Island	118000	270600
Kansas	300000	21190000	South Carolina	2312000	7798300
Kentucky	7584000	10289600	South Dakota	876000	19654000
Louisana	6530000	11282500	Tennessee	7671000	10675200
Maine	5276000	7993100	Texas	6844000	67805100
Maryland	1561000	2531400	Utah	4212000	21275100
Massachussetts	1213000	2030600	Vermont	2122000	2395600
Michigan	8181000	14712100	Virginia	7798000	10254800
Minnisota	9793000	20618900	Washington	9898000	17234800
Missisippi	8370000	12148800	West Virginia	6071000	6236100
Missouri	9548000	17841400	Wisconsin	8627000	14066300
Montana	10928000	37697900	Wyoming	4650000	25148900

A Letter to US Congress

To whom it may concern:

It is sympathetic to see that only when some countries like Tuvalu have become the victims of global warming do nations begin to realize the increasing atmospheric carbon dioxide concentration and grow panic.

Ranking the first in the world carbon dioxide emissions, US has the responsibility to make efforts to realize neutrality as much as possible. Realizing the adverse economic situation US is currently engaged in, aware of the urgent need of carbon dioxide consumption, we are pretty sure that you are willing to adopt a complete model that is highly practical, effective and economic. Consists of exact data and analysis, specific predictions and plans that could help US to increase its carbon dioxide consumption, our model is your ideal option to adopt and could even make the national carbon neutrality a possibility.

Why choose our model?

First of all, if you take time to view our paper, then there's no need to spend extra time to get the understanding of current US conditions. The clearly illustrated date will enable you find the information you need while calculation

Second, our model is practical and is based completely on the real world situation. What makes US rank the 'first' in carbon dioxide emissions? Excessive emphasis on urbanization and industrialization but deficient awareness of environment, especially the forest protection. Indispensable species on this planet, trees absorb carbon dioxide and release back to us the oxygen, a common understanding known to all. It is no need to exaggerate, but with the actual movement, if the government is able to afford to plant the additional 51million hectares trees according to the setting of our models, the day to achieve neutrality is within sight.

Third, factors such as land area in each state, population and impacts to economy are taken into consideration to make the problem fully discussed in our model. Therefore, the total cost and cultural impact have been minimized.

At last but not least, although we tried our best to achieve neutrality, it is an ideal, even impossible to reach the balance. The best method other than the increase of consumption should be the reduction of carbon dioxide emissions.

To continue wondering about the carbon dioxide emission or just have some patience finishing reading our paper and doing a little calculation? The future of US lies in your hand. You won’t regret.

Yours sincerely,

Qiqin Xie, Yuting Chen, Mo Zhou, Limin Zhu