Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal Resources Development Forecast Under Policy Incentives in China: A System Dynamics Analysis

LI Qun, LEI Yalin, GE Jianping, WEI Jingxue, LI Dongrui, ZHANG Zhicong

School of Economics and Management, China University of Geosciences, Beijing, 100083, China;

Key Lab. of Carrying Capacity Assessment for Resources and Environment, Ministry of Natural Resources, Beijing, 100083, China

liquncugb@gmail.com

Keywords: policy incentives, system dynamics, development forecast

ABSTRACT

Driven by climate change and fossil fuel depletion, renewable energy will undoubtedly become the developing trend worldwide especially in those countries which depend heavily on foreign fossil fuels. Faced with the pressing need to reduce coal-fired and environmental improvements the geothermal resource industry in China has achieved rapid development in recent years. China has brought out several incentive policies to stimulate investment in geothermal resource industry. Under this favorable policy environment, geothermal resource is undoubtedly facing enormous development opportunities. This study combined with the theory of system dynamics and the theory of resource demand forecasting, analyzing current policy environment and interactions between involved variables, a simulation model of China's geothermal resources development was built using system dynamics methodology considering both economic and technical factors. Five Scenario are established in the model, then the model using the historical data to simulate the process of simulation and forecast the demand and supply in 2019-2050. The model allows an understanding of geothermal resources long-term development pattern under China's latest incentive policies, thus helping to provide reference for policy-making institutions.

1. INTRODUCTION

Energy is of extraordinary significance to the sustainable development of any country's society, economy and environment. Energy is closely linked to industrial production, agricultural production, health care, water supply, population, education, quality of life and so on. Over the past decade, the energy consumption index has been on a worldwide upward trend (Yi, 2017). The overall economic growth of every country highly depends on its usage of renewable and nonrenewable energies; Energy is the lifeblood of modern industrial economies. For the last century, world economic growth has been largely affected by the supply of fossil fuel resources production and vice versa (Behdad, 2017) . A sustainable supply of energy is key to future economic prosperity and environmental security.

However, with the rapid development of industrialization and economy, the world is being faced with imbalances and challenges of resource depletion and the deterioration of the ecological environment because of unreasonable development of mankind and the use of natural resources, as well as any emissions of pollutants (Abosedra, 2017 and Alam, 2012) .Historical experience shows that energy, the environment, and the economy form an interrelated complex entity. The coordinated development of energy, economical, and environmental subsystems is not only an essential requirement of the sustainable development theory but also an effective way to achieve sustained, steady and high-speed development of the national economy. How to coordinate the relationship among the economy, energy, and the environment and how to explore their sustainable development have become important problems for the government and academia to solve urgently (Zuo, 2017) .

Driven by climate change and fossil fuel depletion, renewable energy will undoubtedly become the developing trend worldwide especially in those countries which depend heavily on foreign fossil fuels (Liu, 2014). With the rapid development of China’s economy, fossil fuel-based energy consumption continues to increase. As a result, air pollution, greenhouse effects and other environmental problems have become increasingly prominent, seriously restricting the sustainable development of China’s economy (Fan and Lei, 2015) . The State Council put forward their target for the reduction of emissions intensity from economic growth by 40–45% below 2005 levels by 2020 (The State Council, 2009) . Faced with the pressing need to reduce coal-fired and environmental improvements the geothermal resource industry in China has achieved rapid development in recent years. Geothermal energy is a clean energy source that can potentially mitigate greenhouse gas emissions, as its use can lead to a lower mitigation cost (Jiang, 2019). The geothermal technologies should be advanced as a solution to global warming, air pollution, and energy security (Mark, 2009) . However, research on the economic impacts of the geothermal industry is scarce (Jiang, 2019). The diffusion of geothermal resources development has been limited due to high costs (Lund, 2005). National incentive policy seems to be the only way to promote geothermal resources development. Thus, the Chinese government has taken the development of geothermal resources as an important policy measure to reduce emission. Further, these policy measures are accompanied by policy incentives, including price subsidies, technology supporting and cost reduction. Nonetheless incentive policy will continue to bring new developing opportunities to China's geothermal resources development. So it is of great significance to investigate China's geothermal resources long-term developing pattern under policy driving.

System dynamics (SD) method can not only model system's real behavior but also explain the relationship between main variables within the system (Sheikhi Fini, 2014). It enables us to stimulate the cost decline, investment fulmination and scale expansion, and optimize development patterns of China's geothermal resources development in the new policy situation (Guo, 2015) .This study combined with the theory of system dynamics and the theory of resource demand forecasting, analyzing current policy environment and interactions between involved variables, a simulation model of Chinese geothermal resources development was built using system dynamics methodology considering both economic and technical factors. Five Scenario are established in the model, then the model

using the historical data to simulate the process of simulation and forecast the demand and supply in 2019-2050. The model allows an understanding of geothermal resources long-term development pattern under China's latest incentive policies, thus helping to provide reference for policy-making institutions.

2. METHODOLOGY

2.1 System dynamics

As one of the first responses to the shortcomings of Operation Research and other management science techniques for complex problems such as those having large number of variables and nonlinearities, an idea, which now is known as system dynamics, was introduced by J.W Forrester in the 1960s at the Massachusetts Institute of Technology (Forrester, 1961). SD is a systems modeling and dynamic simulation methodology for the analysis of dynamic complexities in socio-economic and biophysical systems with long-term, cyclical, and low-precision requirements (Kamarzamana, 2014). Through the complex relationship between the various elements of the system, SD establishes a relatively effective model, which can achieve the predetermined goal and meet the predetermined requirements. Based on the principle of system thinking and feedback control theory, SD helps understand the time-varying behavior of complex systems (Ming, 2013). Although other types of quantitative modeling can be used for the impact analysis, the SD model, which has the advantage of solving dynamic problems, can better simulate the process of sustainable development of systems (Guo, 2015). There are almost some system dynamics models in each group. Meanwhile, authors hold this view that the energy-related system dynamics models should be taken more into consideration because of the characteristics of energy systems especially in policy making. Because of existing characteristics such as considerable delays in industry and new energy development, advanced and fast growing technology, resource limitations and depletions, price fluctuations, increasing costs, growing demand, pollution and environmental concerns, political issues, etc , energy sector has one of the most complicated systems in the world and should be seen holistically (McIntyre and Pradhan, 2003).

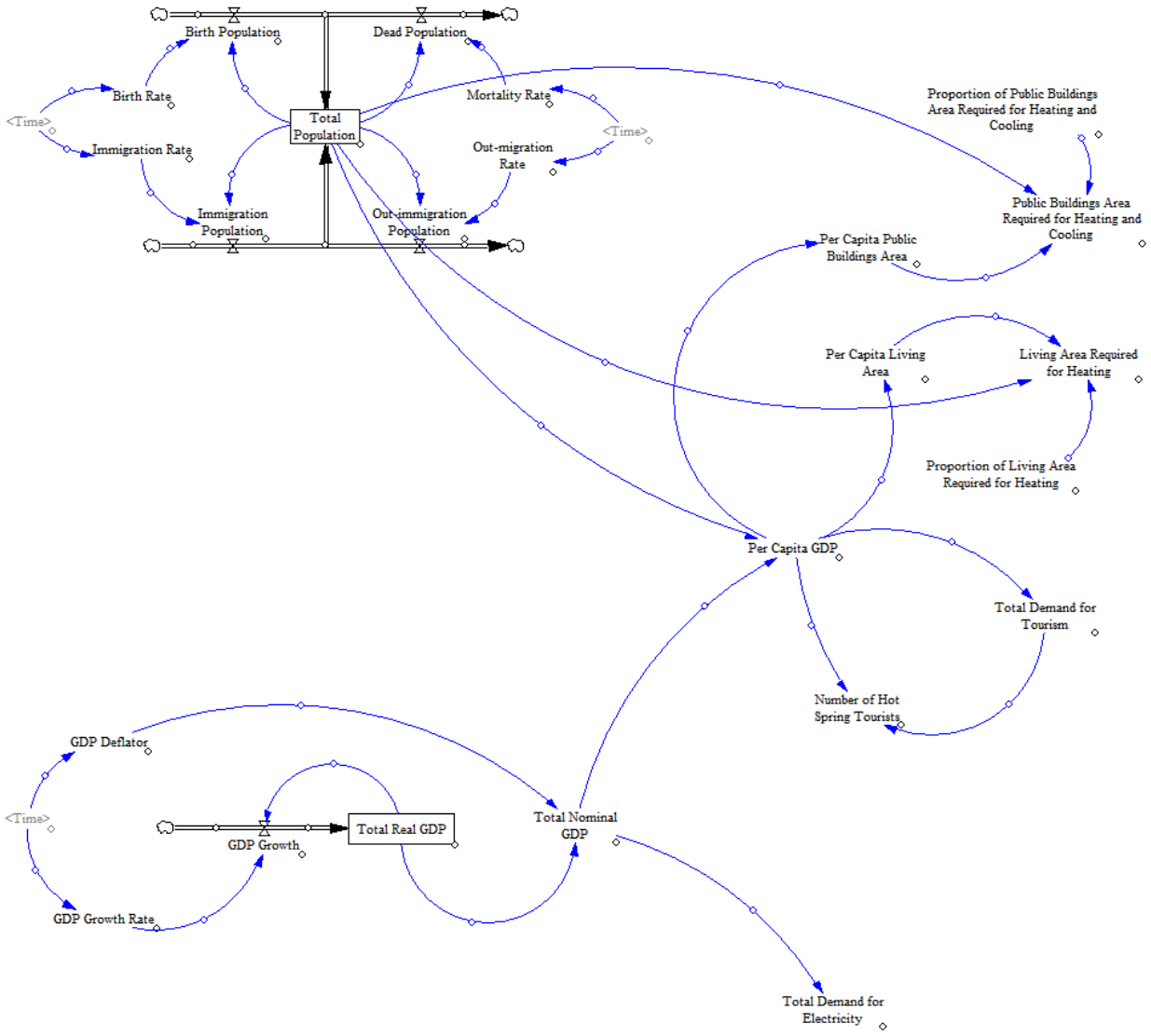

Figure 1: Stock and flow diagrams of the social and economic subsystem

2.2 Model Structure Analysis

2.2.1 The Social and Economic Subsystem

This subsystem mainly reflects the changing situation of population, capital and energy demand under certain economic conditions. The system model assumes that GDP keeps a reasonable growth level, population keeps a certain scale, and the economic subsystem

influences the development of science and technology through the proportion of R&D investment. At same time, with the increasing per capita GDP and total population, the per capita living area and public buildings area are increasing, the total demand for electricity and tourism are increasing, and the increasing use of energy products and the total emission of carbon dioxide in production and life has a certain impact on the carbon emission constraint subsystem. Furthermore, the demand for energy and tourism driven the development and investment of geothermal resources industry.

2.2.2 The Science and Technology Subsystem

The subsystem of science and technology is an important support to improve the efficiency of exploration and development and reduce the cost of development. Considering the low technical difficulty of heating/cooling of ground source heat pump, the rate of technological progress is different from that of hydrothermal geothermal resources and exploration of medium and high temperature geothermal resources. For the sake of acquirement and operability, this paper characterizes the technical level of the year with geothermal resources development invested in R&D of 10,000 yuan and ground source heat pump patents invested in R&D of 10,000 yuan. In this paper, the ratio of technology level in T year to that in T-1 year is used as the rate of technological progress to characterize the rate of increase in exploration and development efficiency and the rate of decrease in cost, so as to influence the subsystem of geothermal resources development.

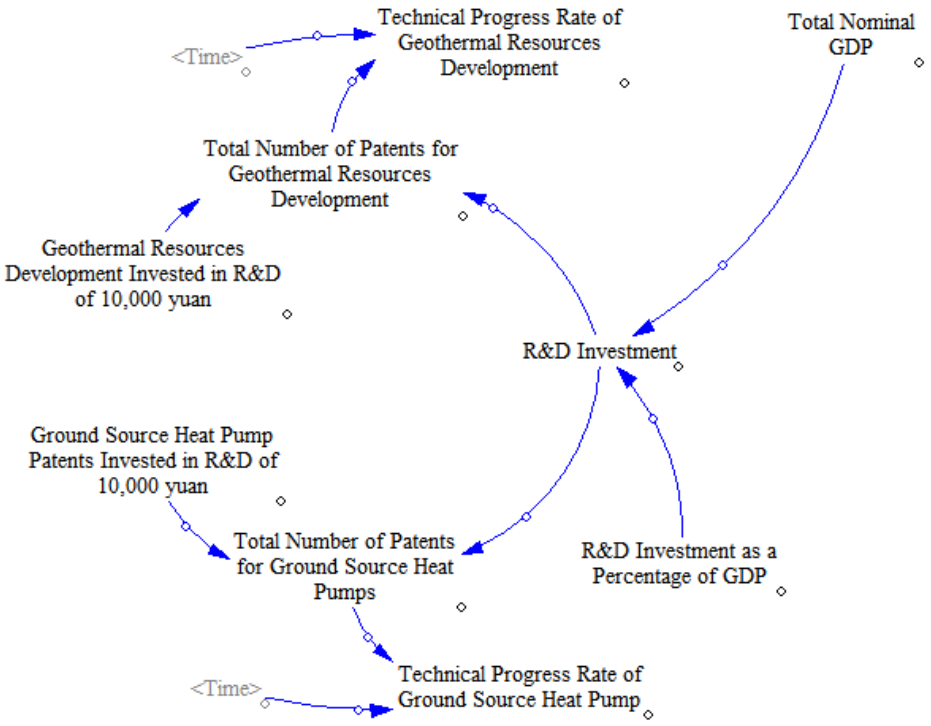

Figure 2: Stock and flow diagrams of the science and technology subsystem

2.2.3 The Geothermal Resource Development Subsystem

This subsystem is the core system of the model. This paper mainly studies the change of the total demand for geothermal resources development upon the condition of certain economic development level and population growth, influenced by the endowment of geothermal resources, with the continuous investment of development funds.

The development of ground source heat pump is limited by resource endowment because of the wide distribution of suitable areas. Therefore, without considering the constraints of resource endowment, the development of ground source heat pump can be carried out by investing a small amount of exploration funds for basic evaluation. The expected investment ratio of ground source heat pump is the average value of historical investment data in the total GDP of that year. The investment inertia of ground source heat pump is characterized, and the total investment of the year is revised by adding the total CO2 emission constraint factor.

The development of hydrothermal geothermal resources is constrained by resource endowment, and the initial investment is high. Moreover, the exploration investment may not necessarily lead to the exploration of economically recoverable reserves, and it is also related to the success rate of exploration affected by technological level.

The development of hydrothermal geothermal heating is affected by the current development investment. It is also limited by the annual economic recoverable reserves of undeveloped hydrothermal geothermal resources. For example, the development of hydrothermal geothermal resources will be hampered by inadequate investment in geological exploration and lack of new economic recoverable reserves. The investment in hot spring development is related to the registered capital of newly established hot spring enterprises in China. The average investment of each hot spring project is 60 million yuan. At the same time, the quantity of hot spring development is affected by both total investment and resource endowment. When the existing resources of hot springs have

been exploited and no new exploration funds have been invested in resource exploration, the growth of investment in hot springs will not bring about the growth of the total amount of hot springs tourism projects.

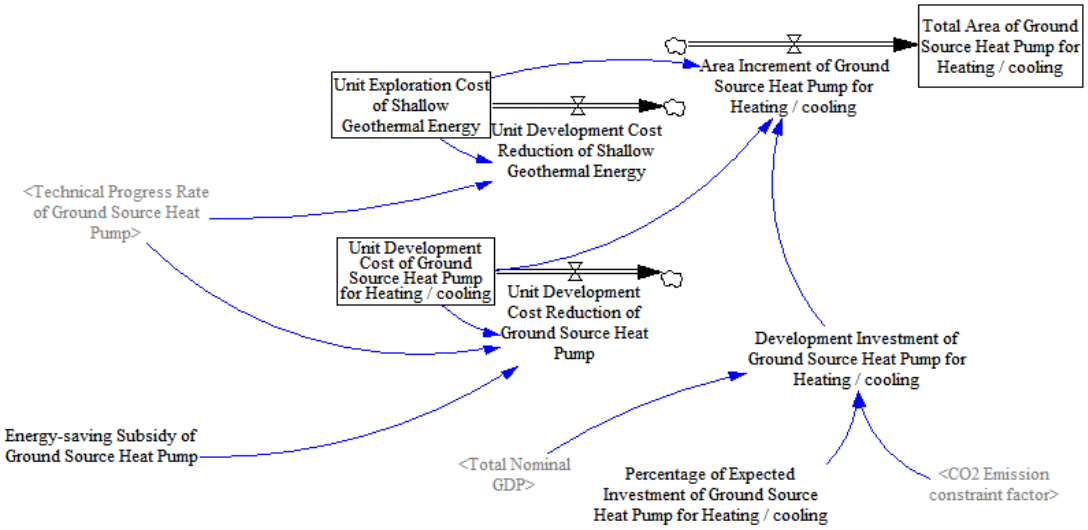

Figure 3: Stock and flow diagrams of the development of ground source heat pump

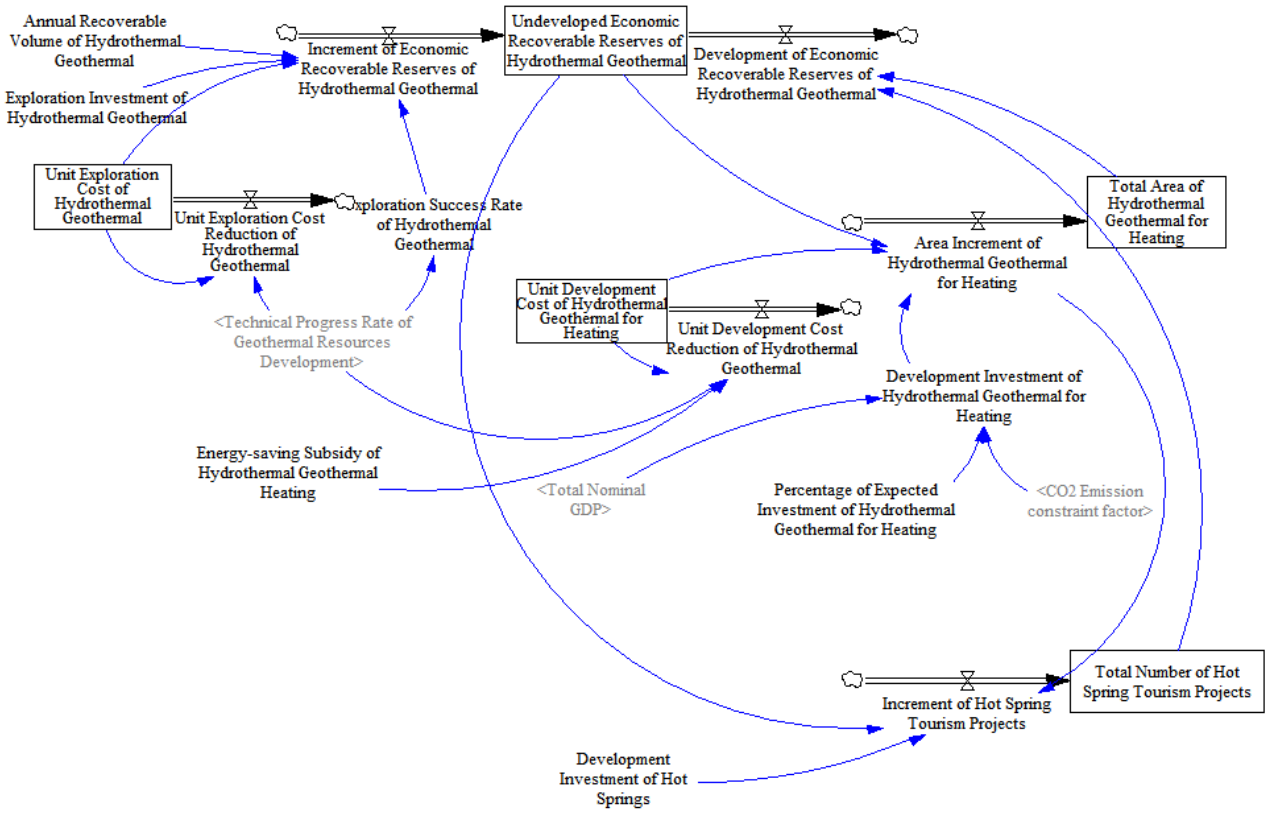

Figure 4: Stock and flow diagrams of the development of hydrothermal geothermal resources

The development of medium and high temperature geothermal resources is also affected by the total investment and resource endowment. Moreover, the total investment of geothermal power generation is affected by the ratio of geothermal power generation cost to coal power generation cost. Due to the high investment of geothermal power generation in the early stage, the risk of resource exploration is relatively high. Without the support of the geothermal power tariff policy, the investment of geothermal power generation increases gradually with the decrease of the cost of geothermal power generation. Furthermore, the installed capacity of geothermal power generation increases with the increase of investment in geothermal power generation.

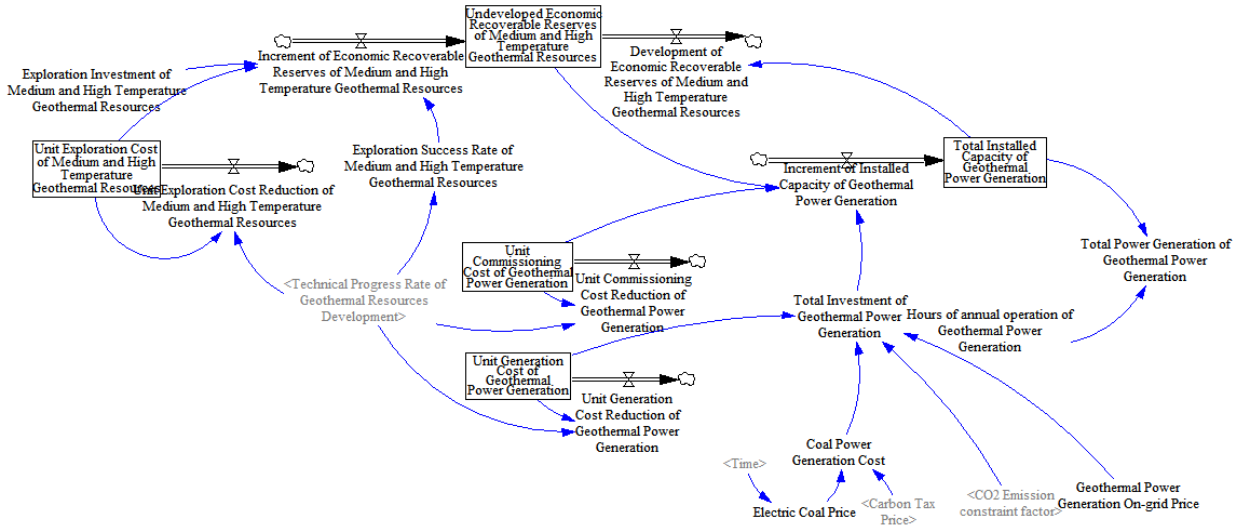

Figure 5: Stock and flow diagrams of the development of medium and high temperature geothermal resources

2.2.4 The Carbon Emission Control Subsystem.

This system mainly studies the influence of the increase of CO_2 emission caused by the increase of gross leasable area over time under the condition of certain economic development level and population growth on the subsystem of geothermal resources development. The system only considers the substitution relationship between heating/ cooling by GSHP, water-heat geothermal resource heating and coal-fired heating. It is assumed that, of all the Gross leasable area that require heating, an increase in geothermal heating will result in a decrease in the area heated by coal. The change of CO_2 emission from building heating/cooling System is studied under the condition of continuous increase of building total area. The constraint factor of CO_2 emission is the ratio of the total CO_2 emission from building heating/cooling in the current year to the total CO_2 emission from building heating/cooling in the previous year. When the ratio is greater than 1, the total CO_2 emission constraint factor will promote the development investment of GSHP heating/cooling and hydrothermal geothermal heating, thus reducing the area of coal-fired heating. When the ratio is less than or equal to 1, the development investment of geothermal resources remains unchanged at the current level.

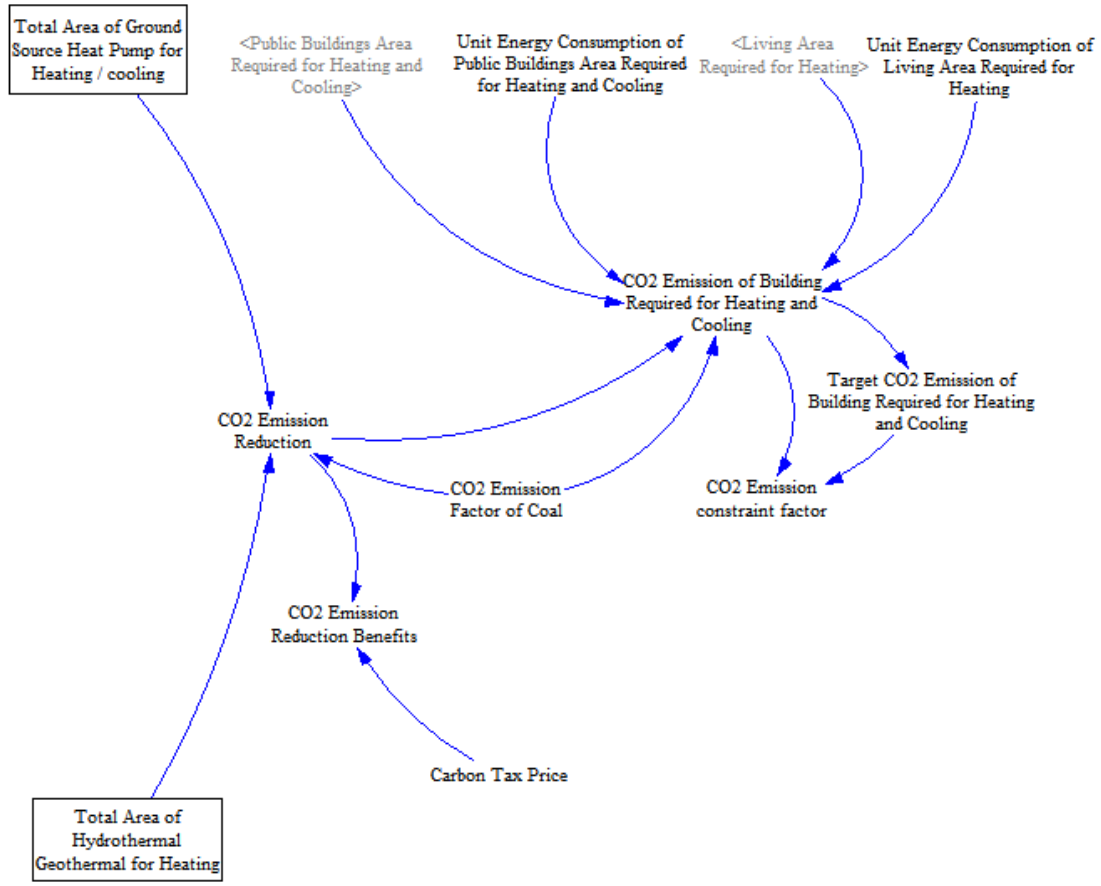

Figure 6: Stock and flow diagrams of the carbon emission control subsystem

2.2.5 The Policy Subsystem.

The policy regulation subsystem includes several policy tools such as carbon tax, subsidy, exploration investment and geothermal power price. Because it acts as a factor to promote development investment in each subsystem, it does not show the subsystem flow graph separately.

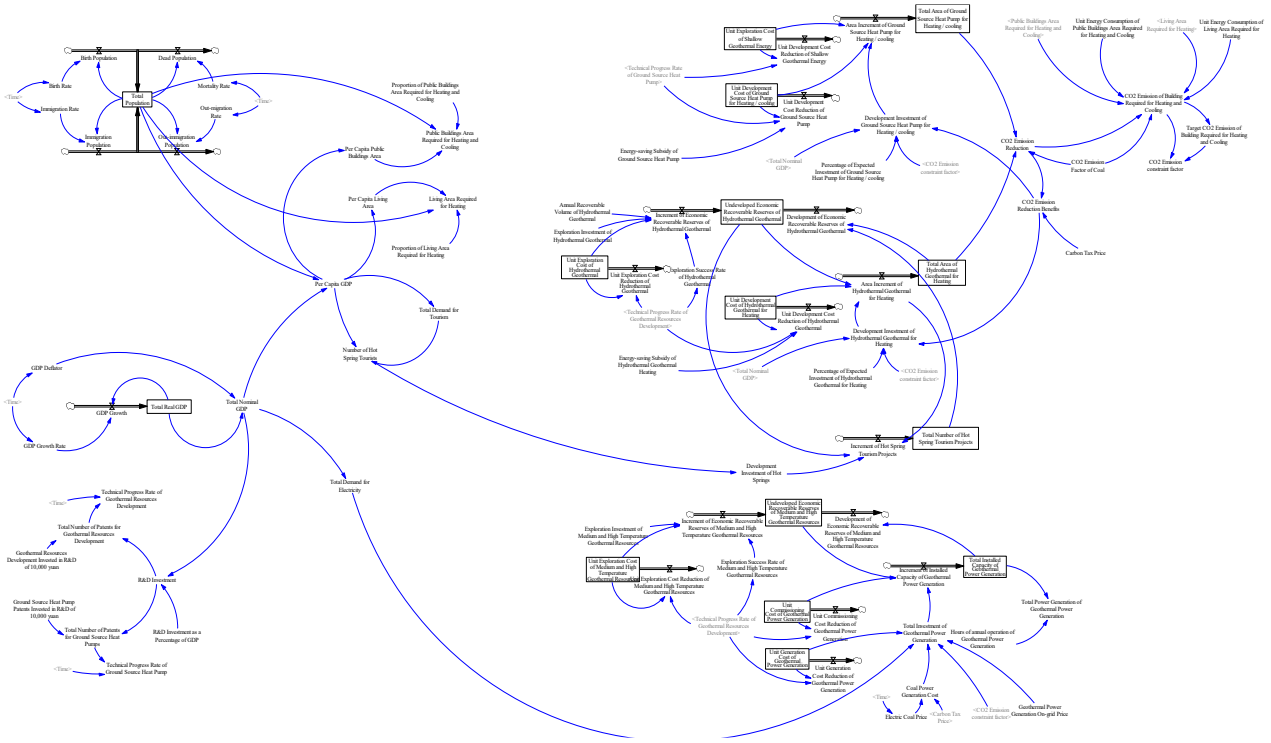

Figure 7: Stock and flow diagrams of geothermal resources development forecast under policy incentives in China

3. SIMULATION PREDICTION OF THE DEVELOPMENT OF GEOTHERMAL RESOURCES IN CHINA

This section uses the socio-economic driving model of China's geothermal resource development demand constructed above to simulate the development state of geothermal resource development demand under different policies by changing the system parameters of policy variables. By comparing the simulation results under different scenarios, we can judge the effect and efficiency of policy effects and the completion of policy objectives.

3.1 Scenario Setting

This paper sets five scenarios of geothermal resource development pattern according to the policy. Scenario 1: no baseline scenario to promote policy; Scenario 2: subsidy of 50 yuan per square meter for hydro-geothermal heating and ground source heat pump heating/cooling, hydro-geothermal resource exploration investment and high-temperature geothermal resources exploration investment is set at 150% of the benchmark value; Scenario 3: hydro-geothermal heating and ground source heat pump heating/cooling new development amount subsidies 100 yuan per square meter, geothermal power grid-on electricity price is 1 yuan; Scenario 4: a carbon tax of 5 yuan per kilogram of CO2 emissions, a new development of hydro-geothermal heating and ground source heat pump heating/cooling subsidies of 50 yuan per square meter, and a hydro-geothermal resource exploration investment set to a reference value of 150%, high-temperature geothermal resources exploration investment is set to 200% of the benchmark value, geothermal power on-grid price is 0.5 yuan. Scenario 5: A tax of 10 yuan per kilogram of CO2 emissions, a subsidy of 100 yuan per square meter for increasing of hydro-geothermal heating and geothermal heat pump heating / cooling, and a subsidy of 200% of the benchmark for investment in exploration of high temperature geothermal resources, the grid price for geothermal power generation is 1 yuan. In this paper, the specific policy measures and policy objectives in different scenarios are sorted out, as shown in Table 1.

The following policy measures and objectives can be used to simulate the control behavior of policy to the development of geothermal resources development demand under different scenarios. What needs to be explained is that the measures and targets are set according to the actual content of the development plan or the current policy to ensure the authenticity of the system dynamics model. Therefore, the impact of combined policies can be evaluated by comparing the predicted values of variables in different situations. It should be noted that the objectives set by the policy and the external economic factors faced by geothermal resource development are changing over time, so the effect of the policy is ideal.

Table 2: Policy scenarios setting.

Policy impact content	Policy tool	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5
Heating + GSHP + Power Generation	Carbon Tax	0	0	5	5	10
Heating + GSHP	Hydro-geothermal Subsidy	0	50	100	50	100
Heating + GSHP	GHP Subsidy	0	50	100	50	100
Heating + GSHP	Investment in Exploration of Hydro-geothermal Resources	not changed	150%	not changed	150%	200%
Power Generation	Investment in Exploration of Middle and High Temperature Geothermal Resources	not changed	150%	not changed	200%	200%
Power Generation	Geothermal Power Generation On-grid Price	0	0	1	0.5	1

3.2 Policy Simulation

3.2.1 The simulation of ground source heat pump heating/cooling requirements

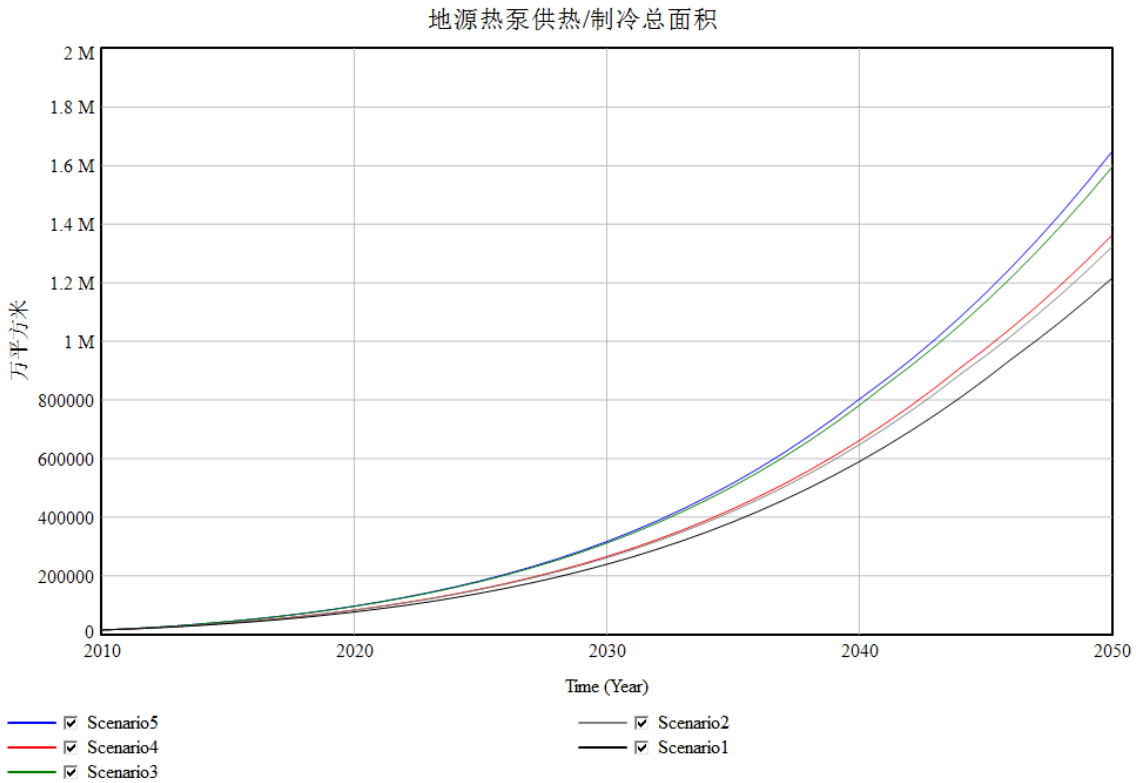

Figure 8: Demand for ground source heat pump heating / cooling development.

The total demand area of ground source heat pump heating/cooling showed a rapid growth in all five scenarios, which is also consistent with the current development of geothermal heat pumps. Among them, under the Scenario5 exploration investment high subsidy scenario, the average annual compound growth rate reached 12.47%. The area of ground source heat pump heating/cooling occupied the total area of heating/cooling buildings from 1.01% in 2015 to 1.63% in 2019, and in the first time in 2040, it accounted for more than 10%, reaching 10.33%. In Scenario1 it takes more than 10% by 2044, more than 10% in Scenario2 in 2043, more than 10% in Scenario3 in 2041, and more than 10% in Scenario4 in 2043, which also indicates that in the highly subsidized Scenario3 and the high subsidy of the Scenario5 ground source heat pump for exploration and investment has increased rapidly. The main reason is

that the construction of ground source heat pump heating/cooling is directly subsidized according to the area, greatly reducing the investment cost of ground source heat pump and stimulating the source. Investment in heat pump development.

Table 2: Ground source heat pump heating/cooling area under different policy scenarios.

Ground source heat pump heating / cooling area(unit:1000m2)					
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5
2010	15000	15000	15000	15000	15000
2011	17760.1	18036.1	18605.5	18050.8	18622.9
2012	21370.8	22007.9	23324.3	22043.1	23366.7
2013	25811.3	26892.4	29132.7	26956.4	29211.2
2014	30916.5	32508.1	35817.8	32610.3	35944.9
2015	36648.6	38813.4	43332.3	38964.6	43523
2016	42954.6	45750	51609.4	45962.6	51880.7
2017	49917	53408.7	60758.4	53696.6	61129.4
2018	57810.6	62091.7	71139.4	62470.9	71632.2
2019	66635	71798.5	82757	72288.9	83399.2
2020	76347.3	82482	95558.2	83105.6	96380.2
2021	86993.3	94192.6	109606	94973.7	110642
2022	98647.3	107012	125001	107978	126289
2023	111408	121048	141875	122230	143460
2024	125363	136399	160350	137831	162279
2025	140575	153133	180511	154855	182840
2026	157154	171369	202506	173424	205297
2027	175182	191200	226449	193635	229770
2028	194759	212735	252478	215604	256406
2029	215988	236087	280735	239449	285356
2030	238977	261374	311367	265294	316775
2031	263818	288700	344504	293245	350803
2032	290638	318202	380321	323448	387628
2033	319536	349990	418954	356018	427397
2034	350627	384190	460563	391087	470282
2035	384028	420931	505311	428791	516456
2036	419859	460345	553362	469269	566095
2037	458240	502564	604883	512660	619378
2038	499291	547720	660044	559106	676487
2039	543136	595949	719014	608750	737605
2040	589896	647385	781966	661734	802919
2041	639692	702162	849072	718203	866729
2042	692633	760396	914225	778283	934688
2043	748852	822238	983473	842134	1.01E+06
2044	808455	887801	1.06E+06	909880	1.08E+06
2045	871558	950904	1.13E+06	975352	1.17E+06
2046	938262	1.02E+06	1.22E+06	1.04E+06	1.25E+06
2047	1.00E+06	1.09E+06	1.30E+06	1.12E+06	1.34E+06
2048	1.07E+06	1.16E+06	1.40E+06	1.19E+06	1.44E+06
2049	1.14E+06	1.24E+06	1.49E+06	1.28E+06	1.54E+06
2050	1.22E+06	1.32E+06	1.59E+06	1.36E+06	1.65E+06

The heating demand area of hydro-geothermal resources shows a rapid growth in all five scenarios, which is also consistent with the current development of hydro-geothermal resources, but the development speed is slow. The heating area of hydro-geothermal resources accounts for heating/

The proportion of total area of refrigerated buildings increased from 0.41% in 2019 to 4.1% in 2050, and from the comparison between Scenario2 and Scenario4, the carbon tax only played a small role in promoting the comparison between Scenario5 and other scenarios.

It can be found that the hydrothermal heating area has developed to the middle and late stages, and the annual increase in area is only the area explored each year. It has not developed rapidly with the increase of investment, which also indicates that the exploration investment of hydro-geothermal resources is far away.

The demand cannot be met, and the exploration cost has not decreased much. The economically recoverable reserves of hydro-geothermal resources have limited the demand for heating of hydro-geothermal resources.

The total number of hot spring tourism projects showed rapid growth in the early development period under the five scenarios, and stopped growth in the later period, which is also consistent with the scarcity of hydro-geothermal resources suitable for the development of hot springs. From the comparison between scenario 5 and other scenarios, it can be found that the total number of hot spring tourism projects has not developed rapidly with the growth of investment, which also indicates that the exploration investment of hydro-geothermal resources is far from meeting the demand.

The economically recoverable reserves of hydro-geothermal resources limit the hot spring tourism projects. When the hydrothermal geothermal resources explored in the year did not reach the minimum resource occupancy of the hot springs, the hot spring tourism project could not be added.

3.2.2 Simulation of heating demand for hydro-geothermal resources

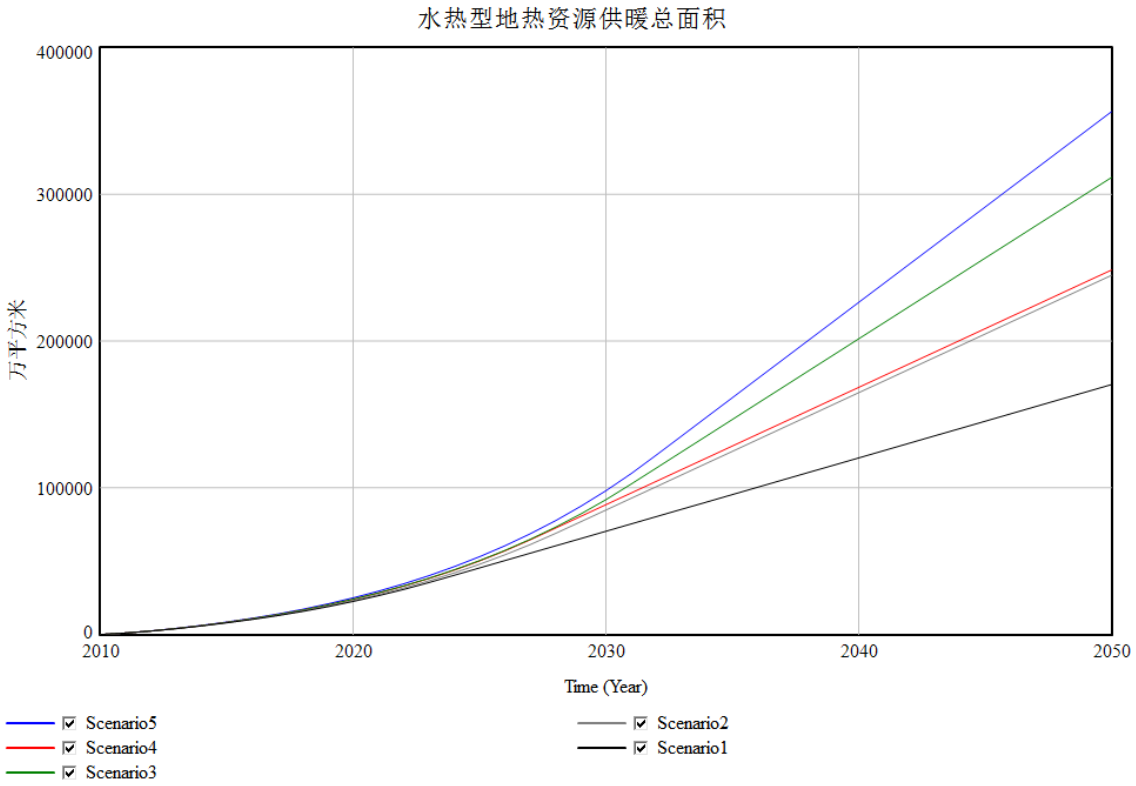

Figure 9: Demand for hydro-geothermal resource heating development.

Table 3: Total area of hydro-geothermal resource heating under different policy scenarios.

Ground source heat pump heating / cooling area(unit:1000m2)					
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5
2010	35	35	35	35	35
2011	1048.56	1048.56	1067.3	1067.3	1086.04
2012	2374.49	2387.09	2432.91	2432.15	2478.84
2013	4000.17	4043.74	4128.72	4126.01	4214.07
2014	5873.35	5961.38	6099.47	6093.28	6238.45
2015	7974.41	8119.34	8326.78	8315.27	8535.99
2016	10290.5	10504.5	10799.9	10780.9	11098.5
2017	12845.4	13141.2	13545.4	13516.5	13954.7
2018	15743.5	16139	16676	16634.5	17220.8
2019	18983.4	19502.5	20202.7	20145	20914.6
2020	22550.8	23214.8	24111.3	24033.5	25024.7
2021	26457.5	27288.6	28418.5	28316.3	29572
2022	30737.5	31760.7	33165.8	33034.2	34603.3

2023	35422	36665.6	38393.2	38226.6	40164.3
2024	40422	42034.9	44138	43930.1	46298.6
2025	45422	47905.7	50444	50187.8	53057.3
2026	50422	54312.4	57352.4	57040	60488.9
2027	55422	61294.7	64910.9	64533.2	68649.8
2028	60422	68889.3	73164.3	72533.2	77593.8
2029	65422	76889.3	82164.1	80533.2	87382.6
2030	70422	84889.3	91963.7	88533.2	98080.7
2031	75422	92889.3	102614	96533.2	109750
2032	80422	100889	113614	104533	122461
2033	85422	108889	124614	112533	135461
2034	90422	116889	135614	120533	148461
2035	95422	124889	146614	128533	161461
2036	100422	132889	157614	136533	174461
2037	105422	140889	168614	144533	187461
2038	110422	148889	179614	152533	200461
2039	115422	156889	190614	160533	213461
2040	120422	164889	201614	168533	226461
2041	125422	172889	212614	176533	239461
2042	130422	180889	223614	184533	252461
2043	135422	188889	234614	192533	265461
2044	140422	196889	245614	200533	278461
2045	145422	204889	256614	208533	291461
2046	150422	212889	267614	216533	304461
2047	155422	220889	278614	224533	317461
2048	160422	228889	289614	232533	330461
2049	165422	236889	300614	240533	343461
2050	170422	244889	311614	248533	356461

3.2.3 Simulation of Hot spring tourism project development

Table 4: Total number of hot spring tourism projects under different policy scenarios.

Total number of hot spring tourism projects					
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5
2010	561	561	561	561	561
2011	837	837	837	837	837
2012	1113	1113	1113	1113	1113
2013	1428	1428	1428	1428	1428

2014	1805	1805	1805	1805	1805
2015	2260	2260	2260	2260	2260
2016	2805	2805	2805	2805	2805
2017	3447	3447	3447	3447	3447
2018	4198	4198	4198	4198	4198
2019	5082	5082	5082	5082	5082
2020	6110	6110	6110	6110	6110
2021	7203	7294	7294	7294	7294
2022	7923	8645	8645	8645	8645
2023	8238	10176	10176	10176	10176
2024	8238	11903	11903	11903	11903
2025	8238	13842	13842	13645	13842
2026	8238	15435	16010	14792	16010
2027	8238	16452	18427	15298	18427
2028	8238	16857	21112	15298	21112
2029	8238	16857	23112	15298	24088
2030	8238	16857	24312	15298	26389
2031	8238	16857	24661	15298	27719
2032	8238	16857	24661	15298	28007
2033	8238	16857	24661	15298	28007
2034	8238	16857	24661	15298	28007
2035	8238	16857	24661	15298	28007
2036	8238	16857	24661	15298	28007
2037	8238	16857	24661	15298	28007
2038	8238	16857	24661	15298	28007
2039	8238	16857	24661	15298	28007
2040	8238	16857	24661	15298	28007
2041	8238	16857	24661	15298	28007
2042	8238	16857	24661	15298	28007
2043	8238	16857	24661	15298	28007
2044	8238	16857	24661	15298	28007
2045	8238	16857	24661	15298	28007
2046	8238	16857	24661	15298	28007
2047	8238	16857	24661	15298	28007
2048	8238	16857	24661	15298	28007
2049	8238	16857	24661	15298	28007
2050	8238	16857	24661	15298	28007

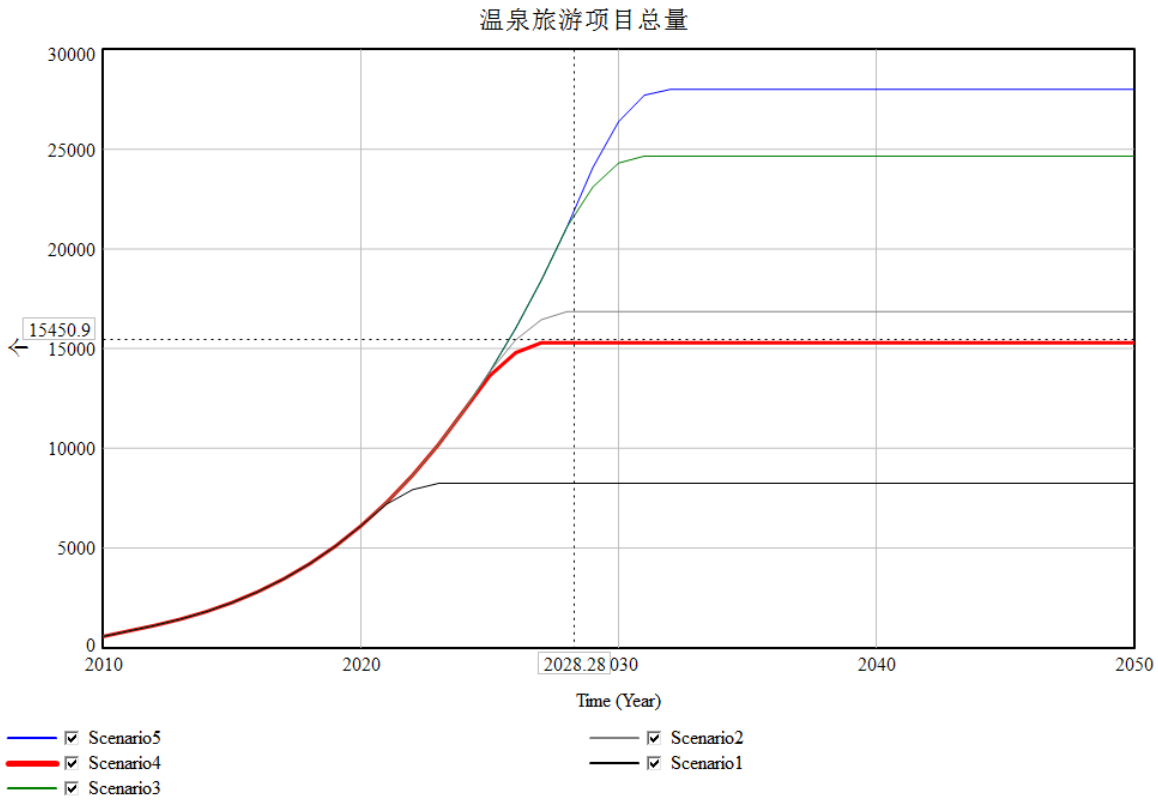

Figure 10: Demand for hot spring tourism project.

3.2.4 Simulation of geothermal power development

The total installed capacity of geothermal power generation is relatively slow in the early stage of development under five scenarios, mainly due to the high cost of geothermal power generation, and high investment in exploration. With the continuous advancement of technology, the cost of geothermal power generation has gradually decreased, and it has dropped to 0.64 yuan per kWh in 2021. The cost of electricity for coal-fired power generation increased to 0.43 yuan in 2021 as the price of coal increased, and the ratio of geothermal power generation price to coal-fired power generation price fell below 1.5.

According to the experience of foreign geothermal power generation, the key cost nodes that attract social investment in geothermal power generation, social investment increased, and the installed capacity of geothermal power generation continued to rise.

With the geothermal power grid price of Scenario3 and Scenario5 set to 1, the geothermal power generation profit level rises, attracting a large amount of investment into the geothermal power industry. In Scenario3, although the on-grid price is 1, it is attractive for investment. However, due to insufficient investment in exploration and development of geothermal resources and enhanced geothermal system suitable for geothermal power generation, economically recoverable reserves are growing slowly, severely restricting the installed geothermal power generation.

Under the premise that the per capita GDP is increasing and the total amount of residential building area and public building area to be heated is increasing, the area of geothermal heat pump heating/cooling demand and the heating area of hydro-geothermal resources are rapidly increasing, so that the coal-fired heating area obtained effective pressure reduction. In Scenario5, total national CO_2 emissions of building heating/cooling peaked in 2036 year.

In Scenario, the total CO_2 emission of national building heating/cooling peaked in 2037 year, while in Scenario 1, the total CO_2 emission of national building heating/cooling peaked in 2046 year.

Under the dual effect of carbon tax and subsidy clean heating policy, the energy saving and emission reduction effect of building heating/cooling is prominent. It can be foreseen that if the exploration investment for hydro-geothermal resources continues to increase and the hydro-geothermal heating area is increased, the total CO_2 emissions from building heating/cooling in the country can reach the peak earlier. Energy saving and emission reduction effects using geothermal resource heating/cooling will be more significant.

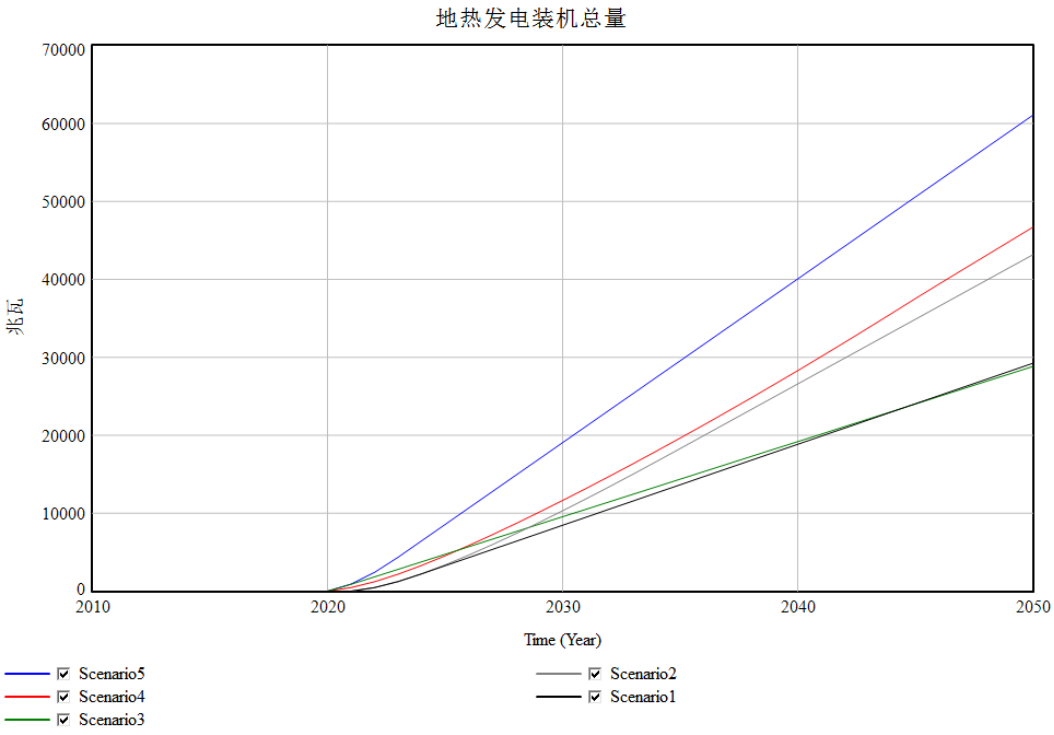

Figure 11: Demand for Geothermal power.

Table 5: Total number of installed capacities of geothermal power generation under different policy scenarios.

Total number of installed capacities of geothermal power generation(unit:MW)					
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5
2010	24.78	24.78	24.78	24.78	24.78
2011	24.78	24.78	24.78	24.78	24.78
2012	24.78	24.78	24.78	24.78	24.78
2013	24.78	24.78	24.78	24.78	24.78
2014	24.78	24.78	24.78	24.78	24.78
2015	24.78	24.78	24.78	24.78	24.78
2016	24.78	24.78	24.78	24.78	24.78
2017	24.78	24.78	24.78	24.78	24.78
2018	24.78	24.78	24.78	24.78	24.78
2019	24.78	24.78	24.78	24.78	24.78
2020	24.78	24.78	24.78	24.78	24.78
2021	24.78	24.78	894.934	473.394	922.007
2022	481.703	481.703	1858.38	1229.39	2434
2023	1252.44	1252.44	2821.84	2199.51	4374.24
2024	2241.34	2241.34	3785.29	3321.34	6473.73
2025	3279.89	3384.5	4748.74	4553.11	8573.21
2026	4318.44	4639.48	5712.19	5867.17	10672.7
2027	5356.99	5977.78	6675.64	7244.85	12772.2
2028	6395.53	7380.49	7639.09	8673.82	14871.7

2029	7434.08	8834.76	8602.54	10145.6	16971.1
2030	8472.63	10332.1	9565.99	11654.6	19070.6
2031	9511.18	11866.7	10529.4	13197	21170.1
2032	10549.7	13434.6	11492.9	14770	23269.6
2033	11588.3	15033	12456.3	16371.9	25369.1
2034	12626.8	16660	13419.8	18001.2	27468.5
2035	13665.4	18314.2	14383.2	19657	29568
2036	14703.9	19970.7	15346.7	21338.5	31667.5
2037	15742.5	21627.2	16310.1	23045.1	33767
2038	16781	23283.7	17273.6	24776.2	35866.5
2039	17819.6	24940.2	18237.1	26531.2	37966
2040	18858.1	26596.7	19200.5	28309.8	40065.4
2041	19896.7	28253.2	20164	30111.4	42164.9
2042	20935.2	29909.7	21127.4	31935.5	44264.4
2043	21973.8	31566.2	22090.9	33781.9	46363.9
2044	23012.3	33222.7	23054.3	35650	48463.4
2045	24050.9	34879.2	24017.8	37539.3	50562.8
2046	25089.4	36535.7	24981.2	39390.1	52662.3
2047	26128	38192.2	25944.7	41221.2	54761.8
2048	27166.5	39848.7	26908.1	43044.8	56861.3
2049	28205.1	41505.3	27871.6	44868.9	58960.8
2050	29243.6	43161.8	28835	46698.8	61060.2

4. CONCLUSION

This paper sorts out the policy content that affects the development needs of geothermal resources, evaluates the effects of various portfolio policies, and judges the degree of achievement of policy objectives. According to the simulation result, the policy recommendations for the development of geothermal resources in China are proposed.

(1) Increase investment in exploration and development of hydrothermal geothermal resources. The basis for the development of geothermal resources is to clearly understand the distribution and reserves of geothermal resources. China has not yet officially unified data on the total amount of geothermal resources in the country and in various regions. The premise of hydro-geothermal heating development is to have a clear exploration of resources.

(2) Increase the subsidy for the new development of hydro-geothermal heating and ground source heat pump heating/cooling. The upfront investment in geothermal resource heating is relatively high. By increasing subsidies, we will curb the high upfront investment costs of geothermal resource heating and attract more social investment.

(3) Conduct carbon price research and collection implementation work. Through the policy simulation of low-cost levy on carbon tax, it is found that it can obviously promote the development and utilization of geothermal resources. Moreover, the carbon emission reduction of geothermal resource heating is high, and the timely introduction of carbon tax can effectively guide social investment and promote the development of geothermal heating and geothermal power generation.

(4) Develop on-grid electricity prices for geothermal power generation. The risk of geothermal power generation is relatively high, and the cost of geothermal power generation is high, so there is no cost advantage in renewable energy generation. Stimulated by the on-grid tariff policy, the installed capacity of geothermal power has been significantly improved. According to the simulation results of this paper, when the on-grid price of geothermal power generation is set at 1 yuan/kWh or more in the early stage, the development effect is obvious.

3.2.5 Simulation of CO2 emission reduction for geothermal resource heating/cooling

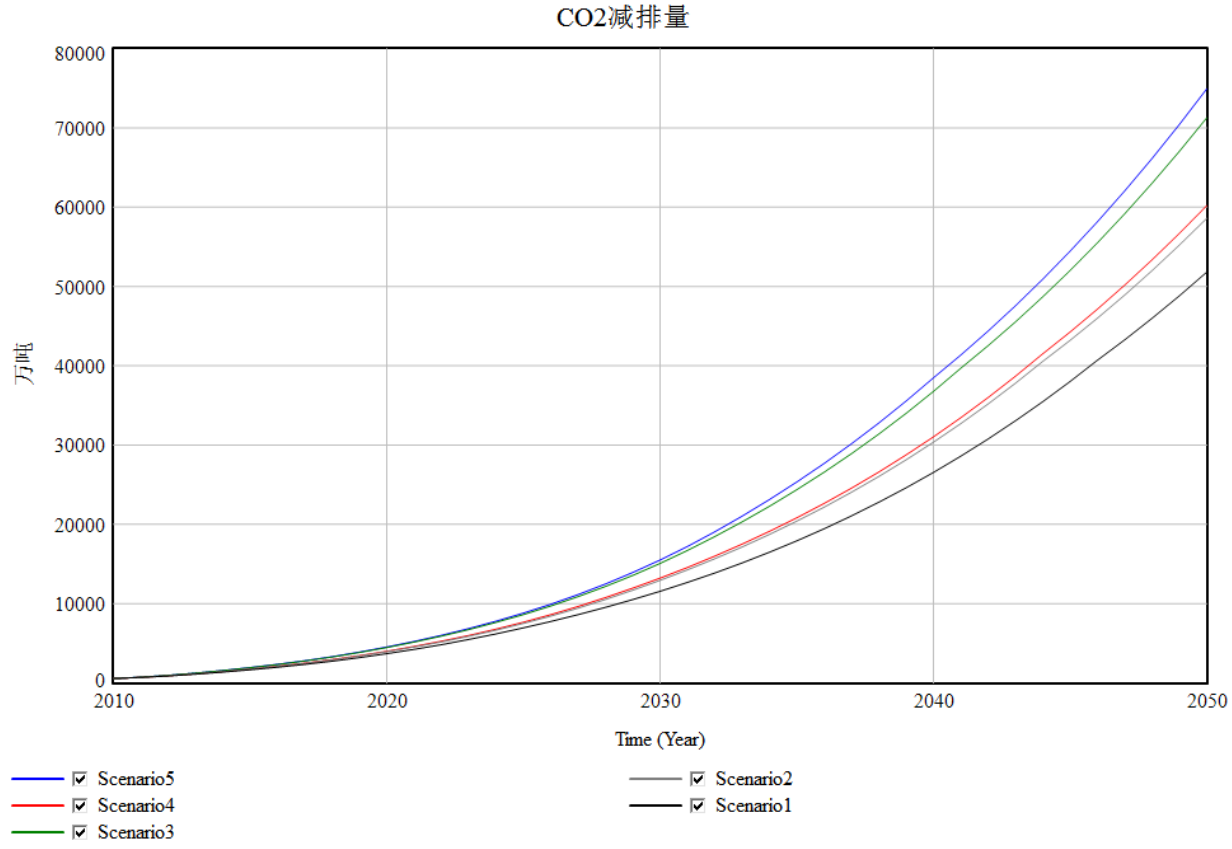

Figure 12: CO_2 emission reduction.

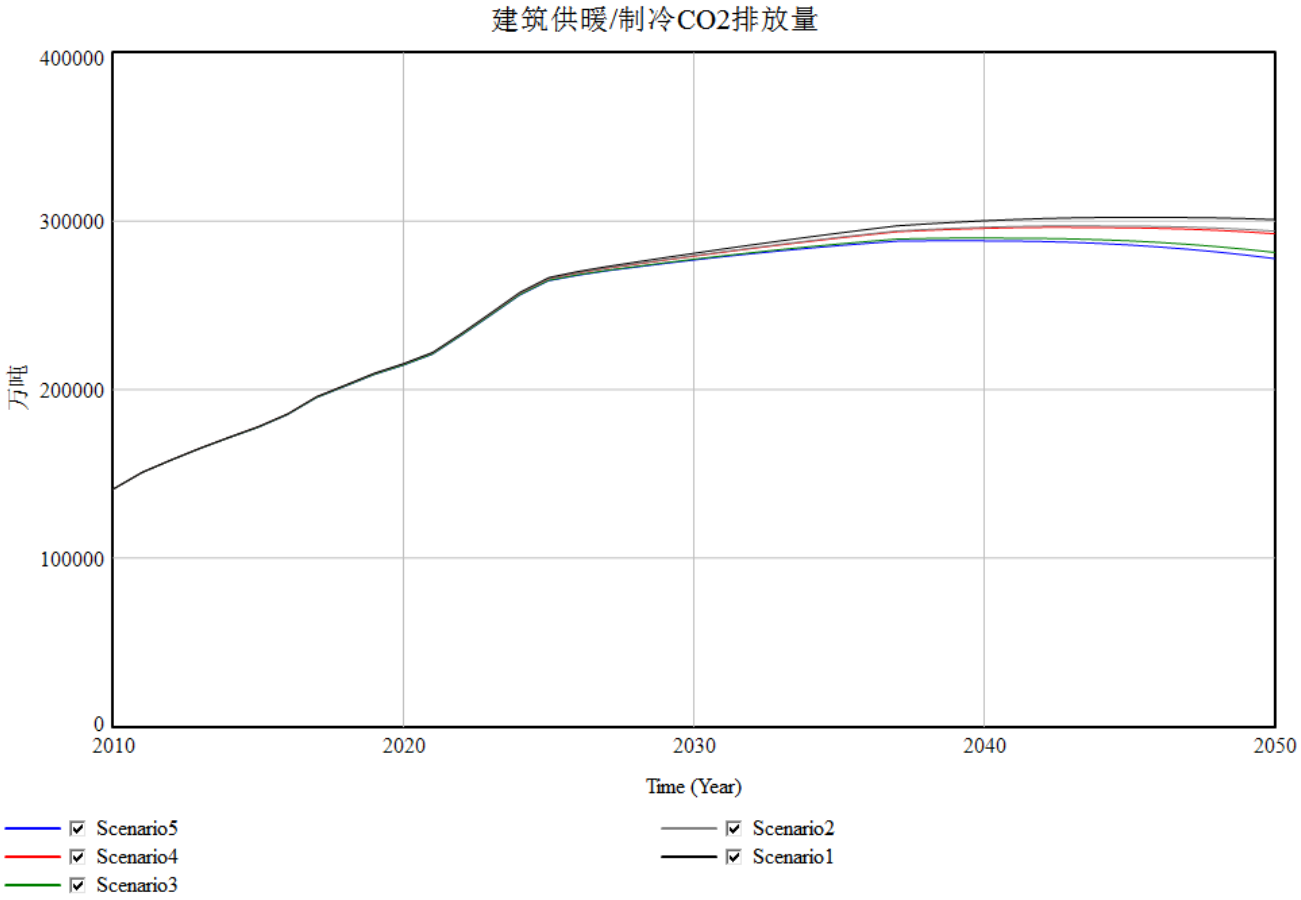

Figure 13: CO_2 emission reduction for geothermal resource heating/cooling.

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