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Study on Energy Strategy of Chinese Capital Region under the New National Policy of Reducing Carbon Dioxide Emissions

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Abstract: Chinese government committed to reducing carbon dioxide emissions per unit of GDP by 40% to 45% by 2020. As the capital and one of the biggest cities, Beijing expected to both keep higher GDP growth than average and cut unit GDP carbon emission, and has to adjust the relevant energy strategy in near future. The paper analysis the characteristics of energy supply and energy consumption in Beijing, and setups the economic-energy-environment-oriented reference energy system (RES), selects MARKAL as the optimal model and constructs districted multi-period linear programming matrix, which including 15 energy carriers, 4 energy processes, 17 energy conversions, and 18 energy end-use sets. Furthermore, the paper designs 11 scenarios in various pollute emission restrictions, and establishes the total economic cost as the optimize target, the low-carbon emission as main restriction, to obtain the suitable energy supply structure and end-use technology structure. At last, we have the conclusion that Beijing can attach the demands of cutting carbon emissions per unit of GDP by 45% under the scheduled GDP growth.

Keywords: Capital regional energy strategy, Economic-energy-environment (3E), Low-carbon emission, MARKAL model.

1. INTRODUCTION

In the end of 2009, Chinese government committed to reducing carbon dioxide emissions per unit of GDP by 40% to 45% by 2020. On the contrary, Chinese government must expect that the GDP growth rate will not be hurt badly by the positive commit, which shown by Mike, et al [2008]. As the capital and one of the biggest cities, Beijing is now in the process of rapidly civilization and has the higher GDP growth expect than the national average. However, more and more conflictions among economic development, energy supply restrict, and environment protection requires the local government make more strictly policy to control and reduce carbon dioxide emissions per the unit of GDP, and drive the continual development for the system of economic, energy, environment and the city safety, which shown by Dolf, et al [2001].

Beijing has an excessive speed growth in population. According to the government statistic data, Beijing has 11.075 million residents in 2000, 15.38 million residents in 2005, 17.55 million residents in 2009, and predictable 18 million residents in 2010. However, the limit of 18 million residents was the previous urban planning target for 2020. Nowadays, we had to adjust the target of 2020 into 22 million residents in the urban planning. So, we had to also face the continuously increase in population, upgrade consumption structure, and the stricter demands for the energy supply structure, energy consumption structure and pollution emission limitation.

Accompany with the rapid urban development, the energy consumption also increase rapidly. In 2008, the total energy consumption is 63.347 million tons of coal equivalents (mtce) in Beijing and growth rate is 0.93%, but per unit GDP was 0.6619 mtce, and less

than 7.36% in 2005. Inside, the primary industry is 0.93 mtce, growth rate is 1.97%, and account for 1.6%; the secondary industry is 25.191 mtce, down rate is 9.83%, and account for 39.7%; the tertiary industry is 26.075 mtce, growth rate is 9.12%, and account for 41.1%; Residential routine is 11.188 mtce, growth rate is 11.29%, and account for 17.6%.

In the contrary, Beijing is a scarce resource city, especially highly depends on other regions in energy supply. At the moment, 79% coal, 100% oil and 100% natural gas are all import from other regions, and 66% electric power from other provinces.

Beijing is not only the political, economic and cultural center of China, but also plans to be liveable city in the city plan. The environment is the base and core of the liveable city establishing. In spite of the emission of SO₂ and NO₂ are both attaching the National air quality specification level II, and there were 285 days of air quality in downtown attached inhabitable standard, account for 78.1% and the growth rate is 7.5% in 2009, but we should recognize that parts of the achievement owe to the temporary enforcement action after Olympic. In the near future, Beijing has to face the pressure of energy supply and environmental protection, and has to adjust the relevant energy strategy.

2. MARKAL Model of 3E System in Beijing (B3ES)

2.1 Design for the MARKAL model of B3ES

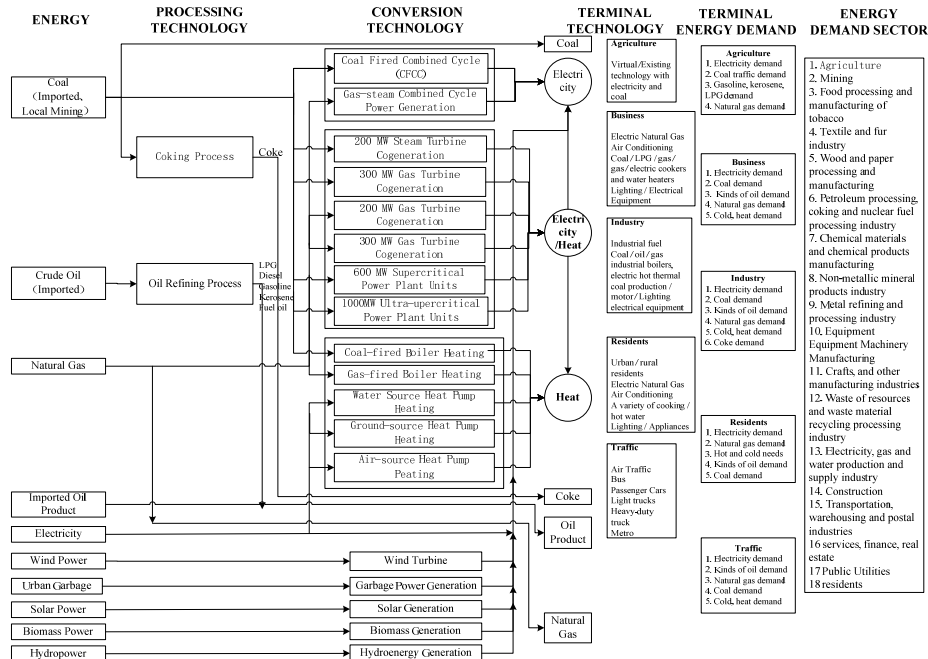


Figure 1 RES network diagram of B3ES

As an energy system optimization model which developed and recommended by IEA, MARKAL (MARKet ALlocation) is a mathematical model of entire energy system of one several regions that provides a technology-rich basis for estimating energy dynamics over multi-period horizon, which is shown by Richard, et al [2009] and Sondes, et al [2008]. On the condition that meets the energy demands and pollution emission limitation, the MARKAL model can estimates end-use energy service demand on the basis of economic and demographic projections, analysis various primary energy supply, energy processing, energy conversion and energy uses distribution, so as to balances all level of an energy system, optimizes the structures of energy supply and energy uses technology for the total cost minimization, which shown by Nick, et al [2006].

In the MARKAL, a Reference Energy System (RES), in which a node represents a source, sink, technology, or demand, and a link (arc) represents a commodity (energy carrier, material, and energy service), is a network diagram to summarize the relationships among these various entities. The RES of B3ES use 2000 as the benchmark year period, 2005 as the check year period, 2002 as the end year period. So there are 4 time-periods,

which is regular 5 years, in the model time horizon. Figure 1 shows the network diagram of RES, contains sets of energy primary supply, source and sinks, process technologies, conversion technologies, end-use technologies, and demands for energy service.

The MARKAL model of B3ES defines 15 energy carriers, including crude oil, natural gas, coal, coke, wind energy, geothermic energy, solar energy, gasoline, diesel, kerosene, fuel oil, liquefied petroleum gas (LPG), thermal energy, electricity, and municipal refuse (urban garbage), and hereinto, the crude oil, natural gas, refined oil, electric power, wind energy, municipal refuse, geothermic energy and solar energy are all the input variable of the model.

Furthermore, the RES define 4 process techniques, such as coking, oil refining, and 17 conversion technologies, including conventional thermal power, supercritical power, ultra-supercritical pressure unit, integrated gasification combined cycle, pressurized circulating fluidized bed power generation, waterpower, wind power generation, garbage burning power, solar power, combined heat and power (CHP), and solar heating system.

Moreover, the RES select 18 energy service demand categories in 5 groups of economic sectors for Beijing. In detail, the agricultural segment can be divided into electricity demand, coal demand, and availability demand, the commercial segment can be divided into the demands of air-conditional, cooking, hot water heating, and lighting/electric equipment; the industrial segment can be divided into petroleum chemical industry, steel industry, metal-processing industry, manufacturing industry; residents segment can be divided into urban residents and rural residents; and the transportation segment can be divided into demands of aviation, autos, and rail transportation energy consumption.

2.2 Energy technologies & their parameters selection in MARKAL model of B3ES

1.1 Steam turbine power generation (Coal-Fired)	2.1 Heating
<ul style="list-style-type: none"> ● 600MW Supercritical Power ● 1000MW ultra-supercritical power 	<ul style="list-style-type: none"> ● coal-fired boiler houses ● gas boiler room ● Water Source Heat Pump(WSHP) ● ground source heat pump (GSHP) ● Air Source Heat Pump(ASHP)
1.2 gas turbine generator (GTG) (Natural Gas)	
1.3 Gas and steam Combined Cycle (GTCC)	2.2 New Energy Generation Technology
<ul style="list-style-type: none"> ● Gas-based combined-cycle ● Coal-based combined cycle 	<ul style="list-style-type: none"> ● Wind power generation ● Solar power generation ● Waterpower generation ● Garbage power generation ● Biomass power generation
1.4 combined heat and power generation(CHP)	
<ul style="list-style-type: none"> ● 200MW Steam Turbine CHP ● 300MW Steam Turbine CHP ● 200MW Gas Turbine CHP ● 300MW Gas turbine CHP 	
Centralized energy supply	Distributed Energy Supply

Figure 2 Categorization of technologies in MARKAL model of B3ES

Energy processing technology refer to a technology that transfer one energy form into another energy form, except for power generation technology and combined heat and power generation (CHP). According to actual situation of energy generation and consumption in Beijing, we define the technology of coking, oil refining, and gas production in the part of processing technology, to produce storable secondary energy such as coking, oil, gas and liquefied petroleum gas (LPG). Besides, another processing technology is the desulfurization technology for the coal-fired generating unit.

Energy conversion technology refers to power generation technology and CHP, which shown by Jan, et al [2008]. In the light of the existing generator set, cogeneration unit, and land-based wind turbine generator, we divide the conversion technology into various category of energy conversion according to various capacity and generator type. Besides, we use other energy conversion technology, such as ultra-supercritical coal-fired power unit, advanced natural gas combined-cycle generating units, IGCC, BPGG, and fuel cell power generating, to produce unstorable electric power and heat energy.

The descriptive parameters of end-use technology include investment cost, fixed & variable operation and maintenance cost in various time slices, and also include equipment depreciation factor and emission factor, initial year of use and tenure of use for the technology, which shown by Peter, et al [2007].

Beijing has a longer heating period and more heating consumption than other regions, the energy supply of small capacity unit should live on the CHP instead of condensing turbo-generator. So, there are not 100MW and 300MW Sub-critical power plant in the MARKAL model. Besides, we leave out the electric boiler room for its illogical energy utilization of transferring the high-quality electric energy into low-quality thermal energy. And we leave out regional CHP and regional combined cold and heat and power generation (CCHP) for their difficulty of pollution treatment. From the above, a technologies categorization of MARKAL model of B3ES was shown in Figure 2.

2.3 The mathematical framework in the MARKAL of B3ES

There is one objective function, total cost function, and 6 constraints, including satisfaction of energy service demands, capacity transfer, and balance for commodities, process capacity growth balance, technological level, energy carrier transfer balance, total pollution emission, and primary energy supply, for the MARKAL of B3ES.

Total cost function aims to the minimize of the B3ES total system cost,

$$NPV = \sum_{r=1}^R \sum_{t=1}^{NPER} (1+h)^{NYRS \cdot (t-1)} \cdot COST_{ann}(r,t) \cdot (1+(1+h)^{-1} + (1+h)^{-2} + \dots + (1+h)^{1-NYRS}) \quad (1)$$

Where, NPV is the net present value of the total cost for all regions; r , R is number of regions (here is 1); h is the general discount rate; t , $NPRE$ is number of periods (here is 4) in the planning horizon; $NYRS$ is the number of years in each period t ; $COST_{ann}$ is the annual cost in region r for period t .

In fact, there are 6 constraints for the equation 1, especially the total pollution emission. We can also change the optimization objective from total cost to the total pollution emission. On the contrary, a constraint variant of the emission is acted as the pseudo-optimizing objective in the paper.

3. MARKAL Model Scenarios Set

According to the various forecast of Beijing 3E system development, we designed 11 scenarios which including a fiducial scene, a set of controlling pollution emission scenarios, and a set of adjusting energy supply structure scenarios. The paper focuses on the fiducial scene and forced low-carbon emission scene for the limitation of paper space.

3.1 Fiducial scene (Scene A0)

Like shown by Thorsten, et al [2008], in Scene A0, there are not constraints for pollution emission and adjustment of energy structure. And, the MARKAL model can choose automatically the energy resources and technologies which meet both the energy service demands and the minimization of 3E system cost.

Table 1. Energy Carrier Production in A0 Scene (unit: 10,000 tons of coal equivalents)

No	Indigenous Carrier	Period 1	Period 2	Period 3	Period4
1	Coal	2289.96	2289.3352	2293.2603	2293.26
2	Wind energy	0	247.44099	321.67401	418.176
3	Solar energy	0	0	0	418.176
4	Biomass power	0	0	321.67401	321.674
5	Hydro power	0.086	0.086	0.086	0.086

* Other indigenous carrier productions are all zero in Beijing

At first, as table 1 shows, both coal mining and hydropower are in a stable condition in the whole time horizon, and keep the level of below 2.3 mtce for coal mining and the electricity capacity of 860 tons of coal equivalents for hydropower.

Secondly, new energy carriers come to join in the indigenous energy supply structure in scene A0. Wind energy collection and wind power start at 2nd period, and grow up at 3rd and 4th periods; moreover, biomass power technology starts to be brought to production at 2nd period, and keep the capacity of 3.2167 mtce power generation; Furthermore, solar power is put into use broadly, and the capacity attaches 4.1876 mtce.

Table 2. Import Energy Carrier Capacity in Scene A0 (unit: 10,000 tons of coal equivalents)

No	Import energy carrier	1 st period	2 nd period	3 rd period	4 th period
1	Coal	3560	4695	7048.83	9133.314
2	Crude oil	1085.75	1085.75	1085.75	1085.75
3	LGP	201.3847	270.5948	360.5677	477.5327
4	Diesel	587.783	1254.018	1200.124	1650.061
5	Gasoline	1390.8	1582.204	2124.616	2829.752
6	Kerosene	1061.811	1412.601	1868.628	2568.95
7	Fuel oil	213.1062	285.1813	378.8783	500.6852
8	Natural gas	1894.05	4254.195	5524.825	9850
9	Electricity	1998.375	3969.29	3304.879	2970.235
10	Coke	1409.952	2020.913	2612.692	3584.474

* Other import energy carrier capacities are all zero in Beijing

Table 3. Process technologies input in scene A0 (unit: 10,000 tons of coal equivalents)

No	item	Energy Carrier	1 st period	2 nd period	3 rd period	4 th period
1	Coke technology	Coal	925.41	680.88	925.41	680.88
2	Oil refining technology	Crude oil	1085.75	1085.75	1085.75	1085.75
3	CFCC	Coal	0	0	0	0
4	GTCC	Natural gas	0	0	0	2771.153
5	200MW Steam Turbine CHP	Coal	331.62	331.62	331.62	331.62
6	300MW Steam Turbine CHP	Coal	0	0	0	0
7	200MW Gas Turbine CHP	Natural gas	315.36	420.48	525.6	683.28
8	300MW Gas Turbine CHP	Natural gas	384.8	461.76	615.68	696.9595
9	600 MW Supercritical Power	Coal	0	0	0	0
10	1000 MW ultra-supercritical power	Coal	0	0	321.674	321.674
11	Coal-fired boiler heating	Coal	786.93	1023.01	1329.913	1728.887
12	Gas boiler room heating	Natural gas	702.025	912.63	1186.422	1542.349
13	WSHP heating	Electricity	157.4227	204.6499	266.0442	345.8574
14	GSHP heating	Electricity	0	0	0	0
15	ASHP heating	Electricity	0	0	0	0
16	Wind power	Wind energy	0	247.441	321.674	418.176
17	Urban garbage power	Urban garbage	0	0	0	0
18	Solar power	Solar energy	0	0	0	418.176
19	Biomass generator	Straw	0	0	321.674	321.674
20	Hydro power generator	Water energy	0.086	0.086	0.086	0.086

As shows in table 2, for the energy shortage limitation of Beijing, both the import coal and import electricity are hold in the main positions. Especially, for the application of wind generator, biomass power, and solar power, the import electricity amount reaches its peak of 39.69 mtce in the 2nd period, and turn to decline 9 mtce in 4th period; besides, the import natural gas is 19.98375 mtce in 1st period, and ascend gradually, and the import natural gas grow up by large scale to 121.21 mtce for the use of IGCC.

As shown in table 3, the capacities of coking process and oil refining process are stable in the whole time horizon, and the capacities of 200MW steam turbine CHP, 200MW & 300MW gas turbine CHP are in the state of steady climbing in the whole time horizon. Besides, we discovered that the new energy processing technologies join gradually in the energy process structure. Such as the wind power starts in the 2nd period and grows up in 3rd period and 4th period; biomass energy is used in 3rd period and keeps the stable electricity capacity at 3.2167 mtce; solar power is widely applied, and the 1000MW ultra-supercritical power and IGCC are separately in serviced in 3rd period and 4th period.

In the no-gas-limit MARKAL model, (, which rely on the national energy relationship between Russia and China in the future,) the emission of CO₂ is 231 million tons in 1st period, 299 million tons in 4th period, and is 1.29 times for that of 1st period.

Table 4. Total emissions of pollutants in Scene A0 (unit: ton)

no	item	1 st period	2 nd period	3 rd period	4 th period
1	SO ₂	59571.84	43693.37	50213.05	62209.42
2	NOx	250810.5	175129.9	203865	257317.7
3	Dust & fume	24616.83	17542.69	20421.14	23320.08
4	CO ₂	2.31E+08	1.57E+08	1.89E+08	2.58E+08

3.2 Scenes of various controlling for the emission of air pollution (Scene B1, SceneB2)

In the B3ES MARKAL model, we design two scenes of dynamic handling the emission speeds of 3 pollutants, CO₂, SO₂, and NOx as below. The two scenes are appropriate emission limit scene B1 and enhanced emission limit scene B2.

3.3 Scene of restraint of natural gas (Scene C1)

Not all scenarios can meet the requirement low-carbon emission in Beijing. There is existing fact that Beijing, as the capital region of China, input the natural gas from five pathways which including west China, imported LNG , imported natural gas from Central Asia, Russia, and Myanmar, which shown by Wenying, et al [2004]. However, the domestic natural gas input will not be permanent expend in future for the input depends on the mandatory national policy instead of market adjustment machine. Moreover, all imported natural gas from other countries depends on the international political circumstance and have enormous risks. So, we present a new scene of limitation of natural gas, the cleaner and greener energy, to compare with the scene A0 and search for the impact of the emission difference.

Table 5. Import Energy Carrier Capacity in Scene C1 (unit: 10,000 tons of coal equivalents)

No	Import energy carrier	1 st period	2 nd period	3 rd period	4 th period
1	Coal	6234.76	8874.739	11176.85	17570.81
2	Crude oil	1085.75	1085.75	1085.75	1085.75
3	LGP	201.3847	270.5948	360.5677	477.5327
4	Diesel	587.783	1254.018	1200.124	1650.061
5	Gasoline	1390.8	1582.204	2124.616	2829.752

6	Kerosene	1061.811	1412.601	1868.628	2568.95
7	Fuel oil	213.1062	285.1813	378.8783	500.6852
8	Natural gas	491.865	491.865	491.865	491.865
9	Electricity	2245.852	2333.587	2333.587	2333.587
10	Coke	1409.952	2020.913	2612.692	3584.474

* Other import energy carrier capacities are all zero in Beijing

Table 5 shows that natural gas capacity of Beijing region is no more than 491.865 tons of coal equivalents according to acceptable nowadays market ability. Besides, the import electricity upper limit is 2333.587 tons of coal equivalents for demand of the power line supply safety. On the contrary, the import coal will increase rapidly.

Table 6. Process technologies input in scene C1 (unit: 10,000 tons of coal equivalents)

No	item	Energy Carrier	1 st period	2 nd period	3 rd period	4 th period
1	Coke technology	Coal	925.41	680.88	925.41	680.88
2	Oil refining technology	Crude oil	1085.75	1085.75	1085.75	1085.75
3	CFCC	Coal	0	0	0	1556.808
4	GTCC	Natural gas	0	0	0	0
5	200MW Steam Turbine CHP	Coal	331.62	331.62	331.62	1890.376
6	300MW Steam Turbine CHP	Coal	384.8	461.76	1393.919	2587.838
7	200MW Gas Turbine CHP	Natural gas	0	0	0	0
8	300MW Gas Turbine CHP	Natural gas	0	0	0	0
9	600 MW Supercritical Power	Coal	0	0	1366.56	1366.56
10	1000 MW ultra-supercritical power	Coal	0	1428.643	1689.213	1689.213
11	Coal-fired boiler heating	Coal	786.93	1023.01	1329.913	1728.887
12	Gas boiler room heating	Natural gas	0	148.8595	0	0
13	WSHP heating	Electricity	332.4427	395.0636	561.828	730.3765
14	GSHP heating	Electricity	0	0	0	0
15	ASHP heating	Electricity	0	0	0	0
16	Wind power	Wind energy	0	0	0	0
17	Urban garbage power	Urban garbage	0	0	0	0
18	Solar power	Solar energy	0	0	0	0
19	Biomass generator	Straw	0	0	0	0
20	Hydro power generator	Water energy	0.086	0.086	0.086	0.086

Table 6 shows that coal firing technology including CFCC, 300 MW stream turbine CHP, 600 MW supercritical power and 1000MW ultra-supercritical power are all put into operation. Naturally, many gas generating technologies reduce output, close down or stop launch.

Table 7. Total emissions of pollutants in Scene C1 (unit: ton)

no	item	1 st period	2 nd period	3 rd period	4 th period
1	SO ₂	56342.92	44842.52	56837.08	75510.17
2	NO _x	239259.3	191046.5	256964.5	360628.3
3	Dust & fume	25392.59	21353.74	28743.22	40330.08

4	CO ₂	2.35E+08	2.11E+08	3.17E+08	1.1E+09
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Table 7 shows that the CO₂ emission at the 4th period reaches 1.1 billion tons and exceeded immensely the CO₂ reduced policy of China in 2020. In subsequent paper, we will present the new energy process technologies for cutting down the CO₂ emission, such as farther promoting the IGCC and ultra-supercritical power, and other new energy carriers.

4. CONCLUSION

Using the optimization of the MARKAL model and simulations of various scenarios, we can boost the economic development low-carbon emission in Beijing by adjusting energy supply structure, selecting process technologies, and changing the consumption mode. As an optimization result, Beijing can attach the demands of cutting carbon emissions per unit of GDP by 45% by 2020 under the scheduled GDP growth. By the way, we also found that there exist many difficulties such as the limitations of natural gas and import electricity. We need consider other new coal process technologies, new energy resources and new energy supplies.

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