Feasibility Study of CCS-Readiness in Guangdong Province, China (GDCCSR)

Final Report: Part 3

CO_2 Mitigation Potential and Cost Analysis of CCS in Power Sector in Guangdong Province, China

GDCCSR-ERI Team

March, 2013

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Disclaimer

This is the third part of the final report of the project "Feasibility Study of CCS-Readiness in Guangdong Province, China (GDCCSR)", which is funded by the Strategic Programme Fund of the UK Foreign & Commonwealth Office joint with the Global CCS Institute, nor of the funding organizations.

The report is written based on published data mainly. The views in this report are the opinions of the authors and do not necessarily reflect those of Energy Research Institute, nor of the funding organizations.

The full list of the GDCCSR project reports are as follows:

- Part 1 Analysis of CO_2 emission in Guangdong Province, China.
- Part 2 Assessment of CO_2 Storage Potential for Guangdong Province, China.
- Part 3 CO_2 Mitigation Potential and Cost Analysis of CCS in Power Sector in Guangdong Province, China.
- Part 4 Techno-economic and Commercial Opportunities for CCS-Ready Plants in Guangdong Province, China.
- Part 5 CCUS Capacity Building and Public Awareness in Guangdong Province, China
- Part 6 CCUS Development Roadmap Study for Guangdong Province, China.

Contents

Chapter 1 Background

Guangdong Province, China (hereinafter referred to as Guangdong) is one of the most economically developed province in China and its GDP is ranking fist ahead of other provinces, which is 5.321 trillion RMB in 2011. The per capita GDP in Guangdong is 50,800 RMB, ranking 7th among all provinces in China (including autonomous regions and municipalities directly under the central government). Meanwhile, the final energy consumption of Guangdong in 2010 is 263.44 MTCE (TCE), ranking 3rd in the China. Guangdong plays an important pioneer role in the economy development, and it’s relatively highly urbanized and industrialized. In 2011, the structures of primary, secondary and tertiary industries is 5:49.7:45.3 and urbanization rate reached 66.5%, higher than other provinces and regions except Beijing, Shanghai and Tianjin. Because of this, there are better basic conditions and advantages for Guangdong to do energy conservation and emission reduction than other regions, who has made some achievements in recent years. During "11th five-year plan" period, energy consumption per unit of GDP of Guangdong (in 2005 constant price calculation) has decreased from 7.94 TCE per thousand RMB to 6.64 TCE per thousand RMB, decreasing by 16.42%. In 2010, its energy consumption per unit of GDP is lower than other than other provinces and regions except Beijing.

There are big challenges for energy conservation and emission reduction in Guangdong. First of all, as there is good basis of economic development, energy conservation and emission reduction, Guangdong is facing higher requirement for energy conservation and emission reduction. According to “Work Plan for Greenhouse Gas Emission Control during the 12th Five-Year Period”, the energy consumption per unit GDP and carbon emission per unit GDP of Guangdong should decrease by 18% and 19.5% respectively during the 12th Five-Year period. These targets are higher than that of the national average level and most other provinces. Secondly, as the economic growth and people's living standards improve, the demand of energy use in Guangdong will further increase. Especially for end use sector such as construction and transport sector, their energy consumptions and carbon emissions will further go up. How to fundamentally change the economic growth mode, effectively adjust and optimize the industrial structure and reasonably control the consumption will be a key point for Guangdong to control the energy consumption growth and greenhouse gas emissions during the 12th-Five-Year and in a longer term. Thirdly, by comparison, the current energy consumption per unit of GDP of Guangdong has been on the lowest level in the whole country and the cost to further increase energy efficiency of main energy-intensive industries in Guangdong is relatively high. At the same time, the renewable energy development potential in Guangdong is relatively low because of the resource restriction. Therefore, there are more challenges for Guangdong to further reduce energy intensity and carbon emission intensity than other region. As a result, to vigorously develop and use all kinds of advanced low-carbon technologies and build their matching infrastructure systems are quite essential.

How to promote the energy saving of power industry in the future would be one of the important tasks for Guangdong since the power sector is the main energy consumer and carbon emitter. In Guangdong’s carbon emission trading pilot program, power sector has also been selected as one of main target industries. According to this situation, combining the present situation and development characteristics of energy and power sector of Guangdong, this study will concentrate on the analysis of application potential and emission reduction potential of carbon capture sequestration (CCS) technologies in the power sector, and give the policy suggestions to develop CCS in Guangdong, on the basis of the different scenarios setting and analysis. The petrochemical sector is also an early opportunity for CCS in Guangdong and the CCS application in it will be discussed separately and reported in the final report of project.

This study is the third part of the project “Feasibility Study of CCS-Readiness in Guangdong (GDCCSR)”, which is funded by the Strategic Programme Fund of the UK Foreign & Commonwealth Office joint with the Global CCS Institute.

Chapter 2 The current situation of energy and power sector in Guangdong

2.1 The current situation of energy consumption

With rapid economic development, the speed of energy consumption growth is becoming faster. Between 1990 and 2010, the total final energy consumption of Guangdong has increased from 39.36 Mtce to 263.44 Mtce, with an annual growth of 9.97%, about 4.5% higher than the average growth rate of the country in the same period. In recent years, as Guangdong is experiencing a rapid industrialization and urbanization process, the growing pattern has been extensive, leading to actual energy consumption exceeding planned energy demand. According to “the 10th five-year plan and the long-range objectives for the Year 2015 of Guangdong energy development”, in 2005 the energy consumption of the whole province has been planned to be 116.41 Mtce, but the actual consumption is 172.56 Mtce, which is much more than expected. During the 10th five-year, the elasticity of energy has been rising and has begun to come down during the 11five-year plan period, through strengthening the economic structure adjustment and energy conservation and emission reduction. (See Table 1).

Table 1: Energy Elasticity and Power Elasticity in Guangdong

Year	Energy consumption growth over the previous year（%）	Power consumption growth over the previous year（%）	GDP growth in Guangdong over the previous year（%）	Energy elasticity	Power Elasticity
1995	9.2	7.6	15.6	0.59	0.49
1996	5.5	8.9	11.3	0.48	0.79
1997	2.7	7.1	11.2	0.24	0.64
1998	5.3	7.5	10.8	0.49	0.70
1999	4.3	10.0	10.1	0.42	0.99
2000	8.2	22.9	11.5	0.71	1.99
2001	7.7	9.3	10.5	0.74	0.88
2002	11.6	15.7	12.4	0.93	1.27
2003	15.4	20.3	14.8	1.04	1.37
2004	16.1	17.5	14.8	1.09	1.18
2005	16.8	12.0	13.8	1.22	0.87
2006	11.2	12.4	14.6	0.77	0.85
2007	10.9	13.0	14.7	0.74	0.88
2008	5.3	16.8	10.1	0.52	1.66
2009	6.9	9.8	9.7	0.71	1.01
2010	8.9	12.5	12.4	0.72	1.00
2011	5.8	8.3	10.0	0.58	0.83

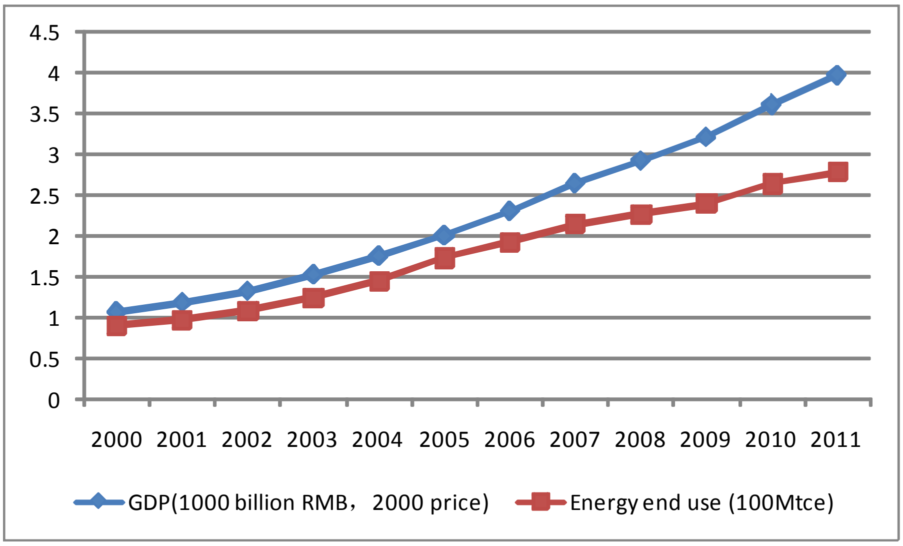

Figure 1: GDP and Energy Consumption Growth Trend in Guangdong

The energy consumption of Guangdong is large and same as other regions. Coal is the main energy, accounting for about half of the primary energy consumption in Guangdong. In 2005, the primary energy consumption reached 130.87Mtce, among which 53% is the coal consumption. In 2008 this share slightly reduces to 51%, which are mainly due to the increase of natural gas usage. In 2005, the natural gas consumption is only 39.26 thousand tce in Guangdong, which accounts for almost zero percentage in the primary energy consumption, while in 2011 this figure has grown to 39.09 Mtce, accounting for 6.2% of the primary energy consumption (See Figure 2).

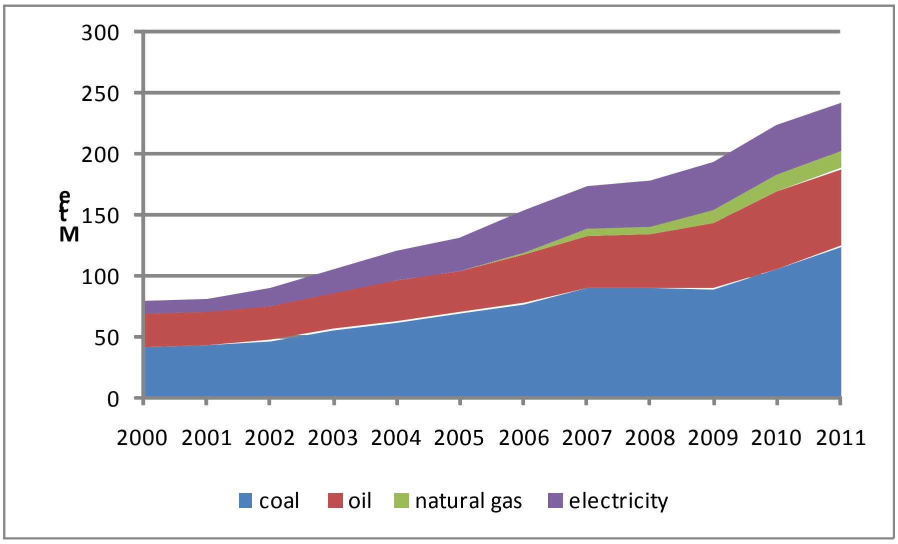

Figure 2: Guangdong's Primary Energy Consumption and its Composition Change

On the aspect of sectoral direction of energy consumption, industry accounts for more than 60% of total energy end use, followed by residential sector and transportation sector,, accounting for more than 12% and 10% respectively. During the 11th five-year plan period, the proportion of industry sector in energy consumption saw a falling after a slight rise, reflecting the effect of energy conservation. Till 2011, the industry ratio has declined to 63.9%, about 1% lower than that in 2005. Within the industry sector, the manufacturing industries contribute the major part of energy consumption, which is still increasing from 83% in 2005 to about 87% in 2011. Ores manufacturing industry, oil processing and coking industry and ferrous industry are of highest energy consumption among manufacturing industries.

Figure 3: The Energy Consumption by Industry sector in 2005, 2008 and 2011

2.2 Present situation of Guangdong power sector

Power consumption in Guangdong has stayed at a high level, with total power consumption increasing from 133.4 TWh in 2000 to 439.9 TWh in 2011, with an average annual growth of 11.5% and lower than GDP growth rate over the same period (12.6%). Even so, for around half number of years during the period from 2000 to 2011, the energy elasticity is greater than 1, reflecting generally the high level of power consumption in some year, leading to the shortage of power supply in some areas and periods. As the living standards of residents in Guangdong improve, the proportion of power consumption in energy end use is higher. In 1990, the proportion is only 33%, but risen up to 48.6% in 2011. In addition, to judge from industry structure of power consumption, the industry sector consumes about 2/3 of total power use, of which manufacturing industries accounting for 80%. Besides, the power consumption in residential sector accounts for 14.2% of total. Considering the economic increase will maintain at a high level in the future and the power demand in resident sector will keep increasing, the power consumption would increase further at a relatively fast speed, and the proportion of power consumption in energy end use would further increase.

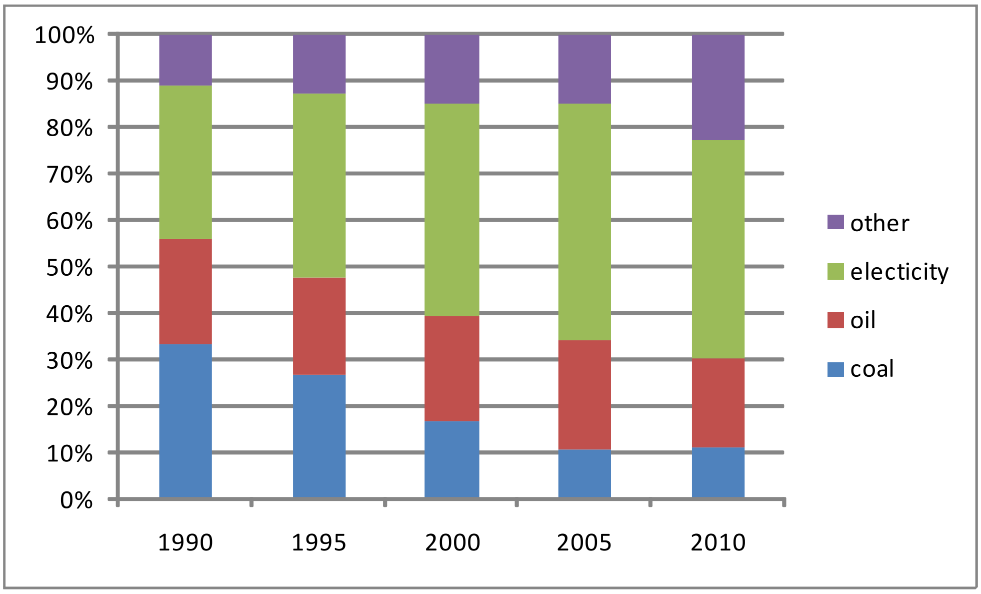

Figure 4: Energy End use Structure in Guangdong

From point view of installed capacity of power units in Guangdong, the coal fired units take a dominant share with some from oil-fired and gas-fired units. At the same time, the nuclear power and hydro power are very important. Especially for the nuclear power, Guangdong is not only the province having first commercial nuclear power plant, but also the province with most operating nuclear power plants in China. In 2008, the total installed capacity of Guangdong (including pumped-storage power) is 58.86 GW, accounting for 8.2% of the total in China and ranking the first in China. Among the total installed capacity in Guangdong, coal-fired power accounts for 56%, oil-fired power 12%, gas-fired power 8%, hydropower 17%, nuclear power 6% and wind power 1% respectively (See Figure 5). According to the current development trend, the share of coal-fired power units will decrease significantly, and oil-fired power units will be gradually eliminated. As a supplementary option, the nuclear power units will be well and rapidly developed, the gas power units will be steadily developed, and the hydro power units will be developed within a certain limitation on resource.

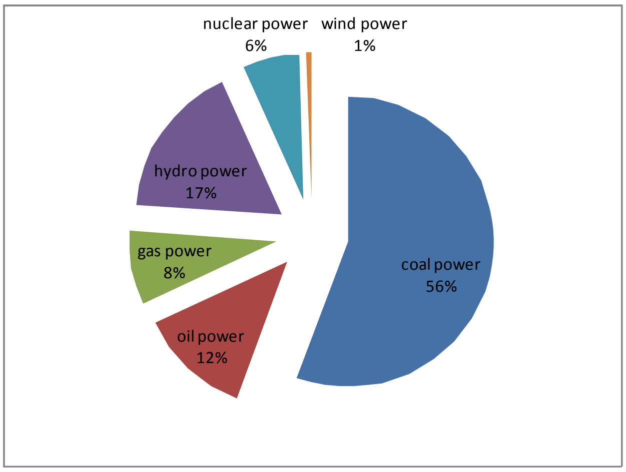

Figure 5: Installed Capacity in 2008 in Guangdong

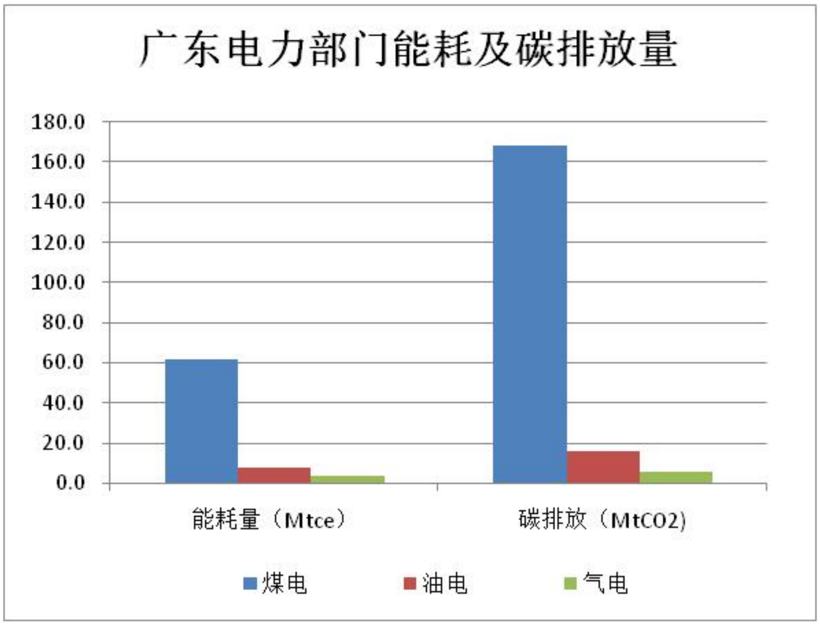

Figure 6: Energy Consumption and Carbon Emission of Power Sector in 2008 in Guangdong

As to the energy consumption, the power sector is the main energy consumption sector in Guangdong and mainly uses coal as fuel. The amount of coal, oil and gas used in power sector is 60Mtce, 8Mtce and 3Mtce in 2008 (See Figure 6). In 2005, the CO_2 emission from coal, oil and gas use in power sector is respectively 122Mt, 30 Mt and 0Mt and the total carbon emission of power sector is 152Mt CO_2. In 2008, the CO_2 emission from coal, oil and gas use of power sector is respectively 153Mt, 14Mt and 4Mt and the total emission of power sector is 172Mt CO_2. Based on the annual emission change caused by all kinds of energy consumption in power sector in Guangdong, the CO_2 emission from coal and gas use has increased, while the those from oil use has decreased from 30Mt in 2005 to 14Mt in 2008 (Figure 7).

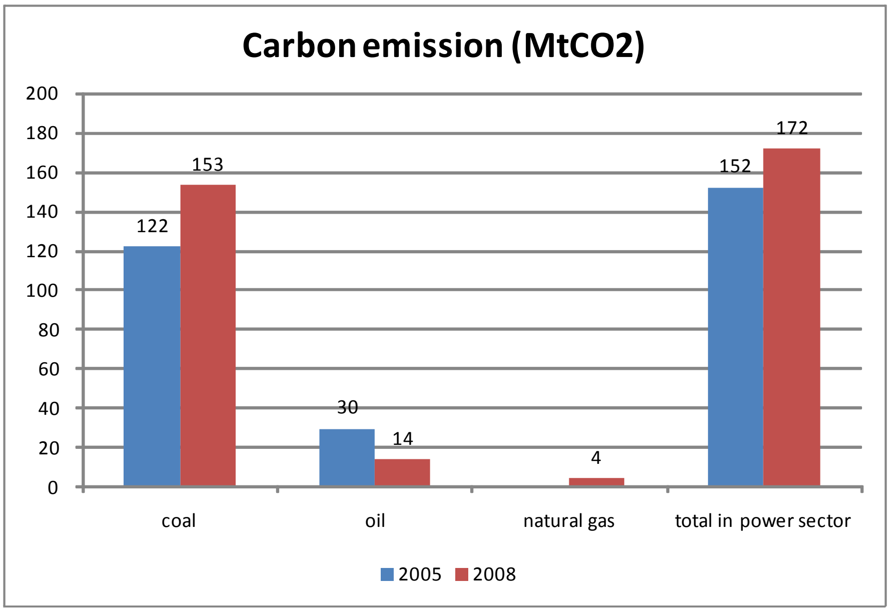

Figure 7: Carbon Emission of Guangdong Power Sector in 2005 and 2008

2.3 The energy and power consumption characteristics in Guangdong

There are three main types of characteristics of energy consumption in Guangdong. Firstly, the conventional energy and renewable energy are relatively scarce in Guangdong, the province depends heavily on the imported energy from other provinces, and there are a lot of constraints faced in the optimization of energy structure. The total energy resources of coal, oil, natural gas, hydro and other primary energy is 2.95 billion tce, which only accounts for 4% of the total in China. Guangdong is one of provinces with lowest conventional energy resources, and majority of its energy consumption relies on importing, which levy a big pressure on safe energy supply. In addition, the available resource of wind energy, biomass energy and other renewable energy is relatively low, and the solar energy is difficult to achieve the large-scale application in short time because of high cost. Therefore, in the future, the adjustment of energy consumption structure will face much restriction. Secondly, the energy consumption is still dominated by coal, oil and other fossil fuel, which leads to large amount of greenhouse gas emission and pollutant emission in Guangdong. In 2011, of the primary energy consumption structure, the coal, oil, natural gas, and other primary power (including imported power) account for 51.5%, 26.1%, 6.2% and 16.2% seperatively. Compared with figure in 2000, the share of coal in the primary energy use decreases by about 1%, the oil decreases around 9%, and the natural gas and other primary power increased about 6% and 4%. In recent years, there have been already an improvement in the optimization of energy consumption structure, but coal and oil are still main energy for Guangdong and have caused serious environmental pollution and high greenhouse gas emission. In this regard, we must fundamentally change energy consumption structure and reduce the share of fossil energy, especially coal, in order to solve the environmental problems and let people have blue sky, pure land and clean water. This would be an urgent need but also a huge challenge for Guangdong. Thirdly, the energy consumption of industry sector is still high, while the energy efficiency in industry sector is still lower than that of developed countries in general. How to improve the energy efficiency is still a big challenge for Guangdong. As stated above, the industrial energy consumption accounted for about 2/3 of the total energy consumption in Guangdong, which will be higher if the electric power sector is taken into account. During “the 11th-five-year plan” period, the energy conservation of industry sector had gained significant improvements, but the energy consumption per unit of product is yet 10% higher than the international advanced level. In 2010, the energy consumption per thousand US dollar of GDP is about 4tce, which is on the advanced level in China but still 2-4 times as that of the developed country, and about 50% higher than the world average level. We should pay full attention to improve the energy efficiency in building, transportation and other sectors, in addition to developing the industrial energy saving potential. The overall mission is quite hard for Guangdong.

Based on the above analysis, it can be realized that greater efforts must be taken on energy conservation and carbon reduction in Guangdong than other provinces in future, including cutting down energy intensity and carbon emissions intensity further, controlling GHG emission, or even reducing GHG emission in the long run. Therefore, Guangdong must give a full consideration to strengthen the low-carbon and energy conserving measures and their effects in major energy-intensive industries and areas, and power sector, as the largest energy-consuming industries, should be considered primarily.

Meanwhile, it should be noted that in the future the potential for traditional energy-saving and carbon reduction measures is getting smaller and smaller, such as the elimination of backward capacity and energy conservation improvement of existing facilities. As a result, innovative mechanisms and measures need to be considered and introduced in the future. Firstly, we need to actively take all kinds of measures as much as possible to strengthen the transformation of industrial structure and at the same time control the rapid growth of end-use demand, with a purpose to control the energy end use under certain level. Secondly, we should reduce the dependence on coal through the development of nuclear energy and natural gas, on the condition of limited potential of renewable energy utilization. Thirdly, we should fully explore the possibility of using other low carbon technologies, such as carbon capture, utilization and storage (CCUS), large-scale distributed renewable energy utilization, etc., bearing in mind that the potential of energy conservation for existing technologies is becoming less.

Chapter 3 Analysis of emission scenarios for power sector in Guangdong

3.1 The overall research framework

In order to analyze the possibilities of CCS application under different CO_2 mitigation targets, and to specify the optimal approach for CCS development in Guangdong, we developed a technology optimization model for Guangdong power sector using cost minimization as the objective function, built on the AIM/Technology model developed by National Institute of Environment Science (NIES), Japan. This model is then used to analyze the potential and cost of applying CCS in Guangdong's power sector by 2030 under different scenarios.

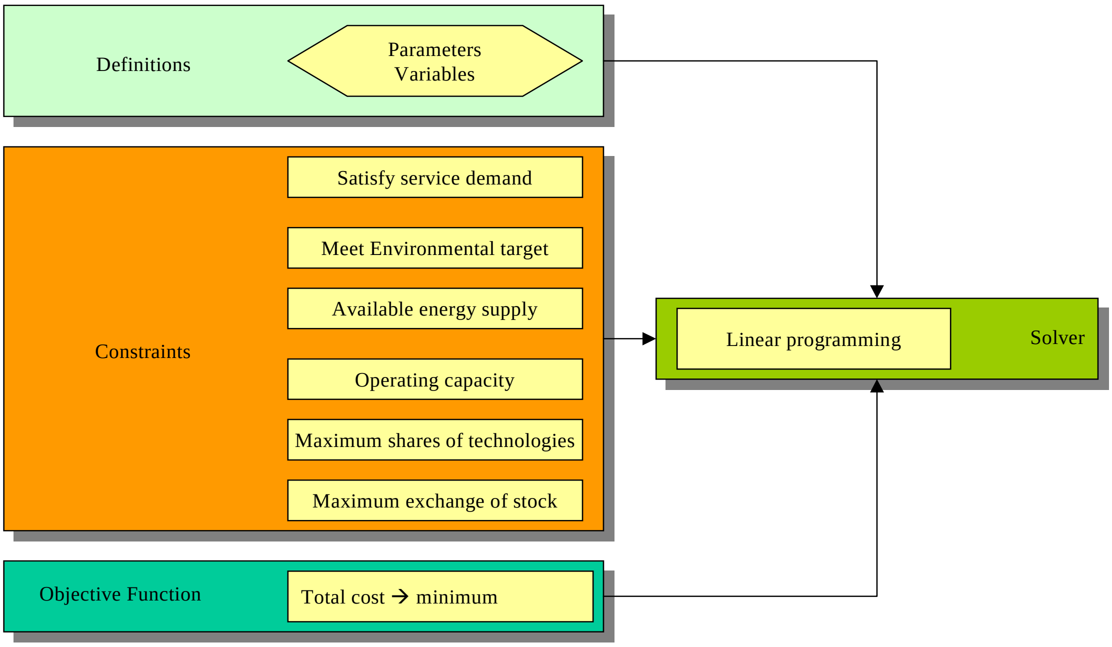

Figure 8: Framework of AIM/Technology Model

AIM/Technology model is an energy technology optimization model. This model can be used to represent the whole energy system or some parts of energy system and implement an analysis on the technology application during the projection period, by setting detailed parameters for each technology such as production capacity, output, energy efficiency, cost, emission factor, etc. The model takes technology cost minimization as the objective function, and obtains the best optimized technology structure under the least-cost condition by comparing the cost of different technology combination. The corresponding energy consumption and structure, the carbon emissions and structure, and the change of system cost will be then obtained. Many constraint factors such as subsidies, energy tax, carbon tax and carbon emission cap can be also added to the model. Meanwhile, the upper limit and speed of technology penetration can be also set in the model to reflect the practical application status of technologies.

One of advantages of AIM/Technology model is that it can reflect technical details by large degree and provide the prediction and assessment of technology development under different conditions, especially the application cost of technology. Nonetheless, AIM/Technology model has its disadvantages. For example, it cannot reflect the mutual effect between economic sectors and the mutual feedback between technology cost, technology capacity and technology efficiency. Thus, it is more suitable to analyze the technology change within the energy sector.

The target of this project is to study the potential of applying CCS technology in power sector for the carbon emission reduction. At present and for some time in the future, the application is affected by two factors. One is that whether the carbon emissions of power sector need to be controlled and if yes, what the control level should be. The other is that how the cost effectiveness of CCS technology is compared with other power generation technologies. After all, whether the CCS technology can be widely used depends on the relevant policies for carbon emissions control, such as carbon emission ceiling, subsidy for low-carbon technology R&D, carbon trading implementation, carbon tax, etc. If these policies could come into effect, carbon emission cost will be internalized, the cost competitiveness of CCS technology will be enhanced and further development and large-scale application of CCS could be expected.

CCS technologies can be applied in many sectors such as power sector, chemical sector, iron and steel sector, cement sector and so on, among which, the power sector is one of the most promising area for CCS application. Considering the effect of CCS application on other sector and versa visa is relatively low and the use of CCS is still at quite early stage, the application potential for CCS are mostly decided by the cost comparison with other power generating technologies, which can be well analyzed and simulated through the AIM/Technology model .

3.2 Technical setting of model

Based on the AIM/Technology model framework and in order to fully reflect the characteristics of Guangdong power sector, this study makes a detailed classification of power generation technologies. The carbon capture readiness (CCR) technologies and the CCS technologies are also classified. In total, there are 6 types and 17 subtypes of power generation technologies being set, as shown in Table 2. Since this study is target to give the application potential of CCS technologies in Guangdong, a detailed classification of CCS technologies is made in the model and the application of CCR is considered. In this study, the CCS technologies matching with coal power and gas power are mainly discussed. The additional incremental investment, operation cost, carbon transport and storage cost and the efficiency change of every kind of CCS technology are defined in detail. The comparison of energy efficiency of each technology can be seen in Figure 9.

In addition, the investment cost, operation cost, energy efficiency, operation hours and the maximum penetration rate of each type of power generation technology (except for CCS) are defined. The emission factor and price of each energy type are also defined. This study divides power facilities as area sources and point sources according to the actual situation of Guangdong power sector. The area sources are classified according to different types of power generation technologies. Totally 31 large point sources are defined, each of which represents a power plant with installed capacity larger than 300 MW.

Table 2: Classification and Description of technologies in AIM/Technology Model

No.	Type of generating	Types of technologies c	Index of technologies	Description of technologies
1	Coal-fired generation	Low-parameter coal power technology	LPCP	Refers to coal-fired power generation units with unit capacity below 100 MW. With low generating efficiency, this kind of generator will be eliminated after 2020.
		Conventional subcritical coal power technology	HPCP	Refers to subcritical coal-fired power generation unit with unit capacity between 100MW and 300MW. With a 37% conversion efficiency, the market share of this kind of generator will be gradually reduced.
		Supercritical coal power technology	SCCP	Refers to supercritical coal-fired power generation units with unit capacity larger than 300MW. With a 42% conversion efficiency, this kind of generator will be the main kind of the newly-installed coal power.
		IGCC coal power technology	IGCC	Refers to integrated gasification combined cycle coal-fired power generation unit. At present, this technology is at the research and demonstration stage. The energy efficiency of it is close to that of ultra-supercritical coal power generation unit. It is expected to be demonstrated in 2020 in Guangdong.
2	Gas-fired generation	Ordinary gas power technology	NGP	Refers to ordinary gas-fired generation unit, which is the main kind of gas-fired unit currently. The conversion efficiency is above 45%. In the future, there will still be newly installed capacity of such units, which is mainly used for peak load.
		Combined cycle gas power technology	NGCC	Refers to gas-fired combined cycle generation units. The conversion efficiency of it is about 50%, higher than that of the ordinary gas-fired unit. It will be the main kind of newly installed gas-fired unit, and mainly used for base load.
3	Oil-fired generation	Oil power technology	OLP	Refers to oil-fired generation units which is still of high proportion in Guangdong's power structure. It will be weeded out before 2020.
4	Nuclear electricity generation	Nuclear power technology	NUCP	According to Guangdong plan, the nuclear power units will be developed rapidly and the its proportion in total power capacity will rise rapidly. It should be one of main alternatives for coal power in Guangdong in the future.
5	Renewable energy electricity generation	Hydro power technology	HDRP	At present, the proportion of hydropower in installed capacity is below 20%. In the future, the space of additional installed capacity of it is limited and the proportion of it will decrease.
		Wind power technology	WINP	There are a few capacities now. Subjected to the resource constraints, the total installed capacity of it is limited though the growth can be expected.
		solar photovoltaic power technology	SOLP	There is no capacity now for this technology. Its potential mainly depends on the cost.
		biomass energy power technology	BIOP	There are few capacities now. Its potential depends on cost and fuel supply.
6	CCS	Existing supercritical coal power + CCS retrofit	ESC+CCS	Refers to the direct retrofit of existing coal power generation units to install CCS facility. The retrofit cost is relatively higher and the carbon capture rate is above 85%.
		Existing	ESC+CCR	Refers to the supercritical coal power generation unit

No.	Type of generating	Types of technologies c	Index of technologies	Description of technologies
		supercritical coal power + CCR		equipped with carbon capture ready. The carbon capture facility can be installed and operated as needed. The retrofit cost of it is lower than the direct retrofit without CCR. The carbon capture rate is above 85%.
		Newly-installed supercritical coal power + CCS	NSC+CCS	Refers to the new supercritical coal power generation unit equipped with CCS facility and the carbon can be captured along with the operation of generation unit. The carbon capture rate is above 85%.
		IGCC + CCS	IGCC+CCS	Refers to the new IGCC power generation unit equipped with CCS facility and the carbon can be captured along with the operation of generation unit. The carbon capture rate is above 85%.
		Gas-fired power + CCS	NGCC+CCS	Refers to the new NGCC power generation unit equipped with CCS facility and the carbon can be captured along with the operation of generation unit. The carbon capture rate is above 85%.

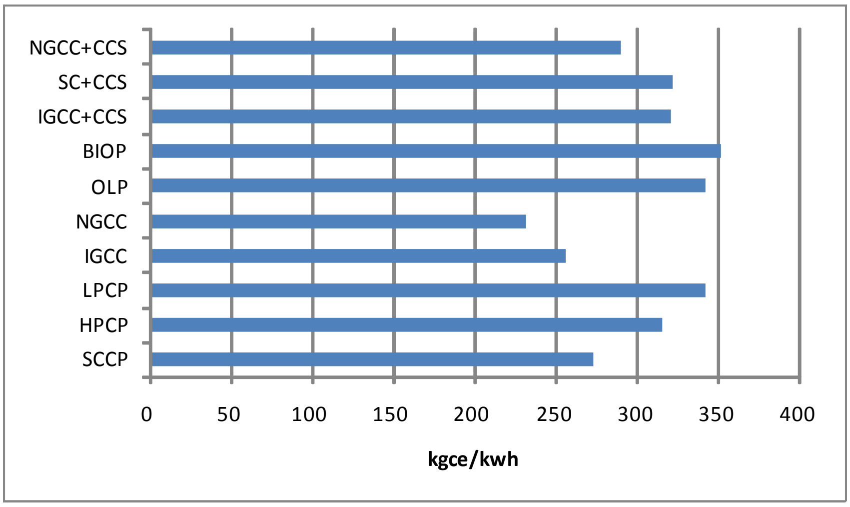

Figure 9: Comparison of Generating Efficiency of Different Power Generation Technologies

For an individual power generation technology, when it gradually changes from a new technology to a mature technology, its investment cost will decrease along with the increase of its total accumulated installed capacity, which is called “learning effect” and one of important driving forces for the technology penetration. Figure 10 indicates the relationship of the investment cost with the accumulated installed capacity of main power generation technologies, from which we can find each technology’s learning effect curve usually follows the “exponential function”. In other words, during the process of technology maturity, the investment cost of the technology will decrease rapidly at the early stage of technology development, decrease mildly at the middle stage and become stable and approach to some bottom price at the later stage.

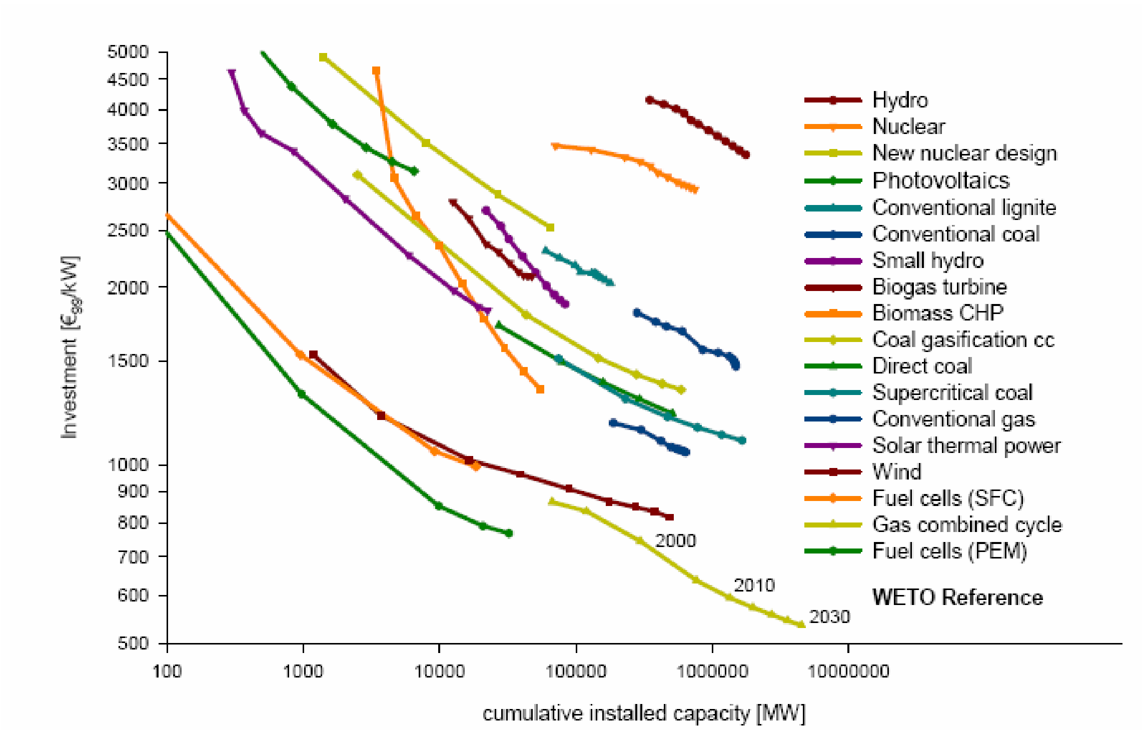

Figure 10: Learning Curve of Investment Cost of Some Power Generation Technologies

In China, the cost of power generation technologies also follows the above learning curve. However, due to different national conditions and technology maturity, the investment costs of technologies in China is obviously lower than that in developed countries. By summarizing related researches on learning effects of power generation technologies and the current average investment costs of different power generation technologies in China, we undertakes an analysis of the trend of investment cost of different power generation technologies in Guangdong, as shown in Figure 11. It can be found that although the unit investment cost of the solar photovoltaic could foresee a sharp fall in next 20 years, it is still the highest among all power generation technologies. The costs of IGCC+CCS, nuclear power, hydropower and biomass power are also high, around 10000 RMB/kW or higher in 2030. The cost of wind power will experience a rapid decrease from now to 2030, but is still higher than conventional fossil fuel power generation technologies. The cost of ordinary thermal power is always the lowest from now to 2030 (between 3000 and 3500 RMB/kW).

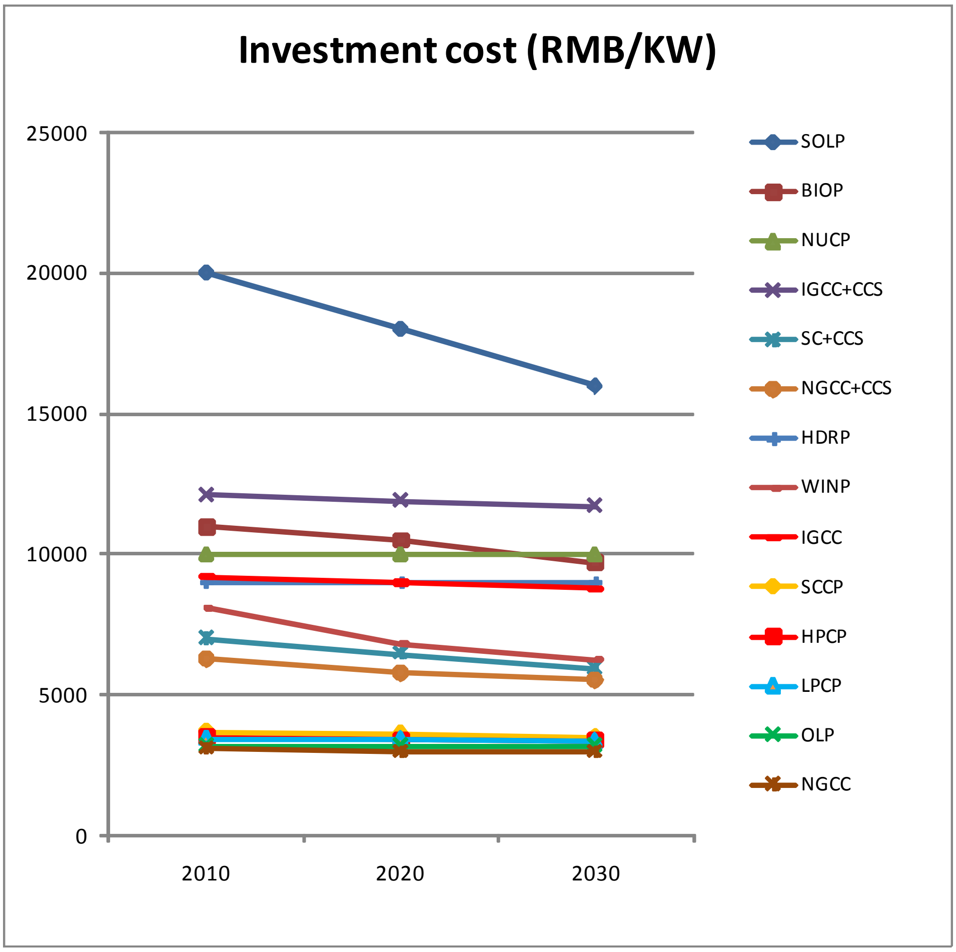

Figure 11: Changing of investment costs of different PG technologies in Guangdong

3.3 Emission scenario of power sector in Guangdong

Considering the development tendency of power sector in Guangdong, the power demand of Guangdong will maintain a growing trend in the future. However, in order to achieve the energy intensity reduction target and carbon intensity reduction target, it is needed to control the demand growth, optimize the power generation structure and improve the energy efficiency of thermal power units. Only through these actions, the rapid growth of energy consumption and carbon emission from power sector in Guangdong can be controlled effectively. In the meanwhile, it should be realized that the power generation efficiency of Guangdong is higher than other provinces, while the potential to expand the use of some renewable energy sources, such as wind power, hydropower and solar Power, is limited due to the resource constraint. The development of nuclear power and natural gas power will be fast, according to the planning target set by Guangdong government.

To control the carbon emission in Guangdong, there are generally four approaches. First one is to expand the use of nuclear, natural gas and other clean energy to replace the coal and oil use in the power generation, through which the energy structure of power sector in Guangdong will be largely optimized. Second one is to improve the generating efficiency of thermal power, through the replacement of existing low-efficiency coal-fired units by newly-built supercritical and ultra-supercritical units and closing down the backward low-scale coal-fired units. Third one is to strengthen the demand side management to effectively control the growth of power demand. This is actually most critical factor for Guangdong to achieve its energy saving and carbon emission reduction target. Fourth one is to develop the advanced low-carbon technology by large degree. This is also critical for Guangdong to get enhanced energy saving and carbon mitigation, of which a special effort should be given to strengthen the pilot demonstration of carbon capture and use.

Considering all these four approaches Guangdong can adopt in the future, and also with reference to other studies on the low carbon development of Guangdong, we set up three scenarios for power sector in Guangdong.

1. **BAU (baseline scenario)**: In this scenario, we suppose that Guangdong keep developing under the current development trend and no additional policies will be adopted in the future. Under this scenario, carbon emission per unit of GDP in 2020 will be reduced by 45% compared to 2005, and in 2030 reduced by 64% compared to 2005. There is not much constraint put on the future power demand of Guangdong, which means the power demand will sustain a fast growing trend as current pattern and the energy structure will be optimized to some extent. In particular, the nuclear power will develop quickly in accordance with the current planning of Guangdong. As a result of enhanced requirement on the low carbon development, the proportion of coal-fired and oil-fired power generation will be decreased significantly. Especially, the oil-fired power generation will be basically eliminated by 2020. The inefficient and low-capacity sets of the coal-fired units will be phased out with a faster speed, and replaced by various high-efficiency coal-fired generating units such as supercritical and ultra-supercritical units. The gas-fired units will be encouraged to achieve a quick development, but constrained by high price of natural gas, the development scale will be still restrained. The hydropower and wind power can reach the economic resource potential basically, while solar PV power generation cannot be applied due to the high investment cost. CCS will not play its role in the carbon mitigation, but CCR matched coal power units have been applied in the power sector from 2020 on.
2. **ES (energy saving scenario)**: Given that Guangdong is the pilot province on low carbon development and has initiated its carbon market since 2013, it might be required to take further steps on the carbon emission control and achieve more intensive target on energy demand management. Therefore, it is assumed that more intense energy-saving technologies and policies and measures will be adopted in this scenario and the power demand in Guangdong will be controlled effectively to a lower level. Under this scenario, carbon emission per unit of GDP in 2020 will reduce by 55% compared to 2005, surpassing the carbon emission intensity target for Guangdong, and in 2030 by 73% compared to 2005. The biggest difference between this scenario and BAU is the enhanced control of total electricity demand, which will be achieved mainly through the changing of consumption pattern, controlling of service demand in building sector and transportation sector, and optimization of industry structure. The total power generation will be significantly lowered with a 17% drop in 2030 compared with BAU. The development of nuclear power, gas-fired generation, hydropower and wind power are consistent with BAU basically, while the total capacity of newly-installed coal power will be reduced and the proportion of them in total generation will be much less than

3. **CS (CCS application scenario)**: In this scenario, the power demand is the same with ES. However, guided by the related policy, especially the incentives produced by the carbon market, CCS will be able to be applied in this scenario. Actually, in order to expand the use of high-cost low-carbon technologies, various market-based measures can be implemented in practical, such as financial instruments, pricing mechanism, carbon taxes, subsidies, carbon emission trading, etc. Though they are different in form, the nature of them is same, i.e. internalizing the external cost of carbon emission. Therefore, we can use carbon tax to represent the effects of such market-based measures and check the effect of them with different strength (different carbon tax rate). By comparison, it is found that when the carbon tax rate is in the range from 200 to 350 RMB/ton CO_2, the cost per ton carbon emission reduction will be lowest[1]. As a consequence, we set a carbon tax, which has a rate of 200 RMB/tCO_2 in 2020 and then increase linearly to 350 RMB/tCO_2 in 2030. The application of CCS in power sector can then be evaluated in this scneario.

[1] The detailed analysis can be seen below

Chapter 4 The development of power sector in Guangdong under different scenarios

Under these three scenarios, the trend of total electricity demand will all keep growing. Under BAU scenario, the power demand of Guangdong will reach 1050TWh, which will be supplied by Guangdong itself by 75% and the other 25% will be met through the imported power form other provinces, mainly hydro power from west China. Under ES and CS scenario, the total electricity demand is controlled to a lower level of about 870TWh, a decrease of approximately 17% compared with BAU. Accordingly, the power generation by Guangdong itself will be 640TWh, about 22% lower than that in BAU scenario (see figure 12).

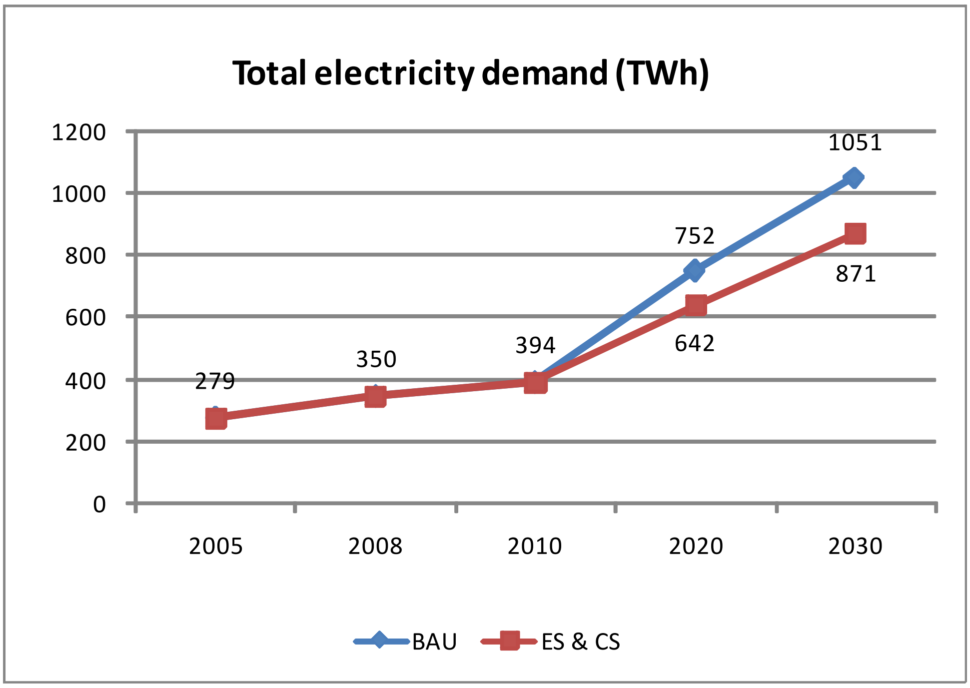

Figure12: The Power Demand of Guangdong under Different Scenarios

（1）comparison of installed capacity and power generation in 3 scenarios

In BAU scenario, the total installed capacity will rise from about 60GW in 2008 to about 145GW in 2030, increasing by 1.4 times. The new installed capacity mainly comes from coal, nuclear power and gas power. The newly-added capacity of nuclear power will be the largest, which is 34GW from 2008 to 2030, accounting for 40% of the total newly-added capacity during the same period. In the meanwhile, the newly-added coal power capacity will be 27.4GW, accompanying by an improvement of fuel structure, in which the share of supercritical and ultra-supercritical capacity will increase from about 34% in 2008 to 72% in 2020 and 84% in 2030; the new installed capacity of gas power will be close to that of coal power, which is 27.1GW, accounting for 32% of total newly-added installed capacity during the same period; oil power and small thermal power units will be completely phased out after 2020. IGCC power will gain a slight development, with a demonstration project completed by 2020 and the total installed capacity rising to 1GW in 2030. The carbon capture ready technology will be gradually deployed from around 2020 and an 'ultra-supercritical + carbon capture ready' demonstration project will be built in 2020. From 2020 to 2030, most all of newly-constructed supercritical and ultra-supercritical units will be equipped with carbon capture ready facility basically.

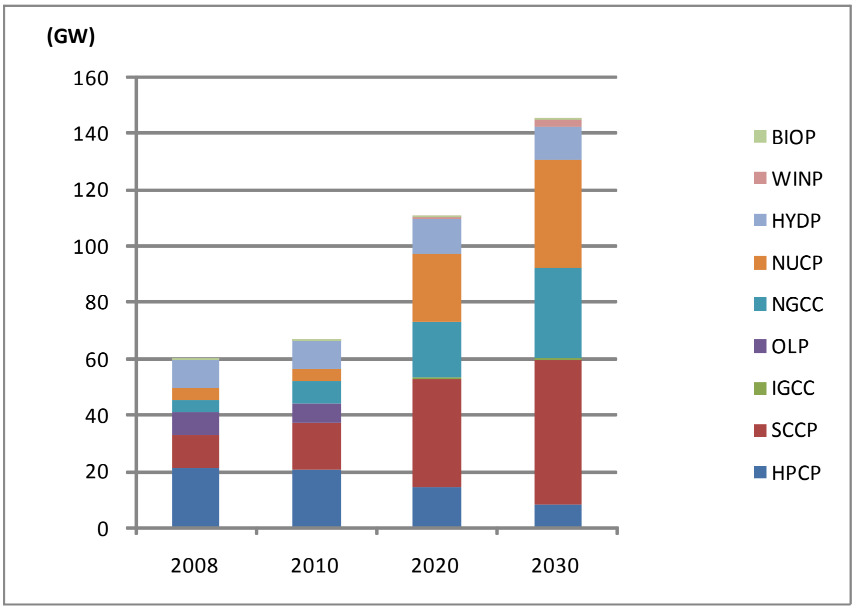

Figure 13: Installed capacity mixture in Guangdong under BAU scenario

Under ES scenario, the total installed capacity will increase from about 60GW in 2008 to 115GW in 2030, about 21% (30GW) lower than that in BAU. Compared with BAU, the decline of installed capacity under ES scenario primarily comes from the decline of newly-added coal power units. From 2008 to 2030, the newly-added installed capacity of coal power will be only 3GW, while that of nuclear power and gas power will be separately 31.2GW and 23.7GW, accounting for around 36% and 27% of the total newly-added installed capacity during this period. The development of IGCC and carbon capture ready technology is similar with those in BAU scenario basically.

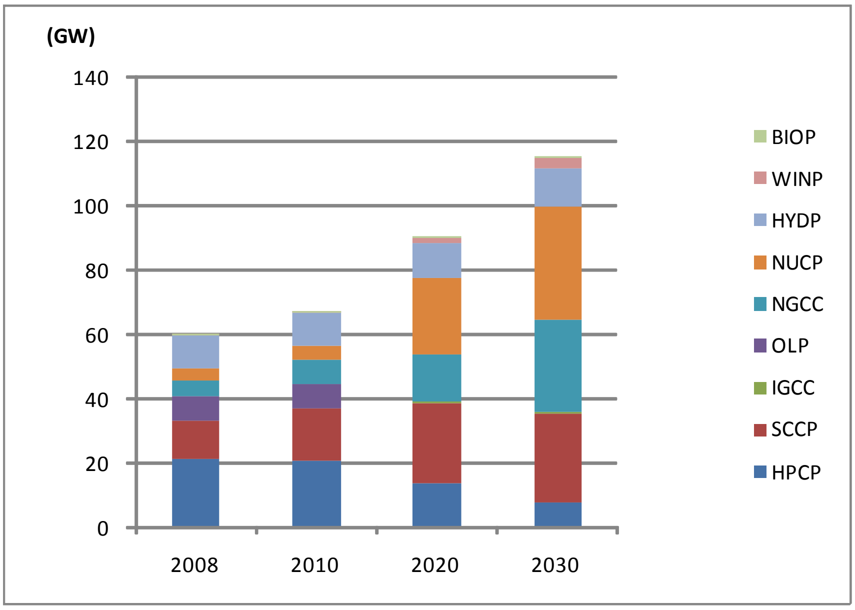

Figure 14: Installed capacity mixture in Guangdong under ES scenario

Under CS scenario, the share of installed capacity is similar to that of ES scenario essentially, but a significant change is that carbon capture technology starts to play a role in the power sector. By 2020, a "supercritical coal power + CCS" demonstration project with the capacity scale of 100MW-1000MW will be completed and start to capture carbon emission. By 2030, "existing supercritical + CCR" and "existing supercritical + CCS" projects could be built up respectively and start to capture carbon emission. As the projects with carbon capture ready are more cost-effective, the total installed capacity and the amount of carbon captured are bother higher than those without CCR. Meanwhile, it is expected that by 2030, the total capacity of supercritical coal power equipped with CCR facilities (only small part of them start to capture carbon emission) will be 3.5GW, accounting for about 4.5% of the total installed capacity then.

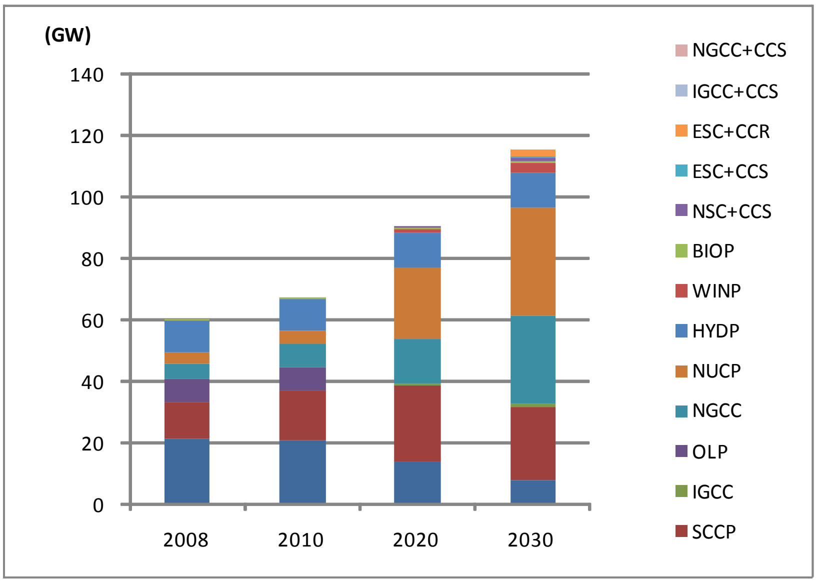

Figure 15: Installed capacity mixture in Guangdong under CS scenario

As for the power generating structure, there are significant differences among these three scenarios. Under BAU scenario, 34% of the total power generation in 2030 will come from coal power, 28% from nuclear power, 12% from gas power and only 4% from hydro power. Under ES and CS scenarios (the power generation structures of these two scenario are similar), nuclear power accounts for 32% of the total power generation, coal for 24%, gas for 13% and hydro power for 4% respectively.

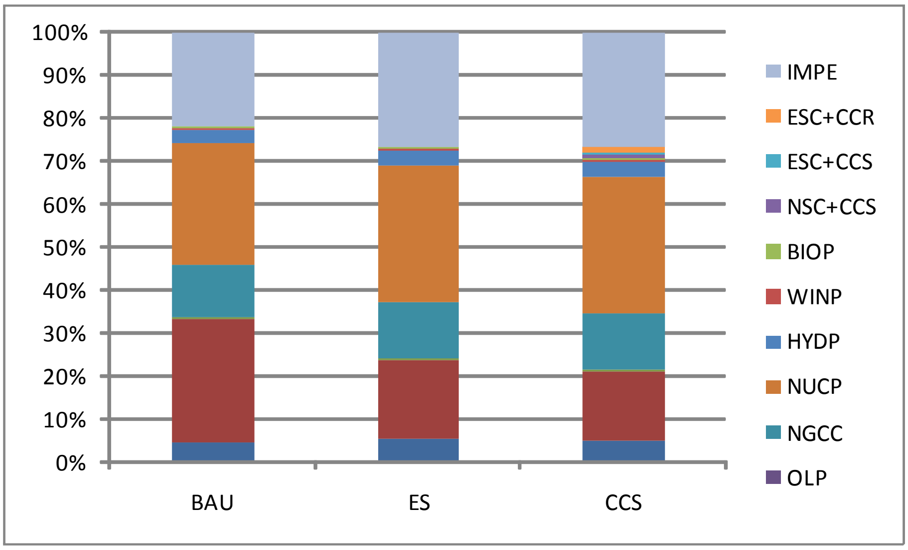

Figure 16: Power generating mixture in 2030 in Guangdong under 3 Scenarios

(Note: IMPE means imported electricity)

（2）Fossil fuel consumption and carbon emissions under 3 scenarios

Under all of these 3 scenarios, the fossil fuel consumption of power sector in Guangdong shows an increasing trend. However, the energy consumption in 2020 and 2030 will reach 144Mtce and 186Mtce respectively under BAU, which is significantly higher than 104Mtce and 124Mtce under ES scenario. The fossil energy consumption of CS will be 125Mtce in 2030, which is a bit higher than that in ES scenario since the application of carbon capture facility will need additional energy consumption.

With regard to the carbon emission from power generation from 2008 to 2030, it will increase from 169 MtCO_2 to 329MtCO_2 under BAU scenario, increased by 95. Under ES scenario, the carbon emission will increase by only 25%, from 169MtCO_2 to 212 MtCO_2 during the same period, which is a significant decline compared with BAU. Under CS scenario, the carbon emission will increase by 16%, from 169MtCO_2 to 197 MtCO_2, which is a further decline of emission compared with ES scenario.

In comparison, it can be found that in 2020 the carbon emission will be 74 MtCO_2 lower in ES scenario than in BAU scenario, while an additional emission reduction of 6 MtCO_2 can be achieved in CS scenario, since there is only one demonstration CCS project will operate in 2020 in CS scenario. In 2030, the carbon emission reduction in ES scenario compared with BAU scenario can reach to 117 $MtCO_2$, while a further 15$MtCO_2$ of carbon emission reduction can be achieved in CS scenario, as a result o f broader use of CCS technologies in 2030.

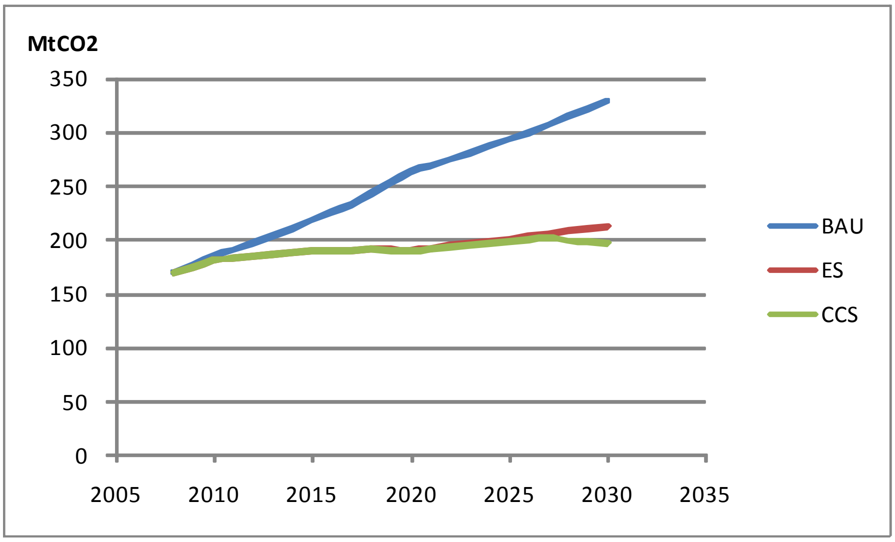

Figure 17: CO_2 emission from Power Sector under 3 Scenarios

Chapter 5　Application potential of CCS in Power Sector in Guangdong

5.1 Application of CCS in Power Sector under Different Carbon Taxes

As discussed above, the carbon tax will be used as a representative policy instrument in this study to observe the change of technology structure of power sector and its effect with the different pricing of carbon emission. In this study, we assume that the carbon tax will be levied from 2020 and then linearly increase to some value as set. Under this assumption, the cases with different carbon tax rates from 200RMB/tCO2 to 1200RMB/tCO2 (this tax rate refers to the value in year 2030) will then be analyzed. The CS scenario discussed earlier is set up as an optimized selection after comparing the effects under different carbon tax rates.

When carbon tax is levied on the power sector, due to the different carbon emission intensity of various power generation technologies, the additional costs for their application will differ from each other. For some low-carbon power technologies, such as nuclear power, hydropower, wind power, gas power, IGCC and carbon capture technology, as their carbon intensities are lower, their competitiveness will increase, which can help them to take bigger share in the market.

Considering the actual situation of Guangdong, even without carbon tax, the market share of some technologies, such as hydropower, wind power, nuclear power, will become close to the maximum application potential, by considering the current policies adopted by Guangdong. Therefore, the levy of carbon tax will not be able bring additional market share for these technologies. On the contrary, for other technologies such as gas power and carbon capture technology, the introduction of carbon tax will be able to increase their cost-effectiveness and application scales in the market. For the gas-fired power unit, it is mainly because its higher generation efficiency and lower carbon emission per unit of energy consumption that it can obtain higher cost-competitiveness than coal-fired unit after the introduction of carbon tax. Even though, due to the relatively high price of gas and the restriction of gas supply, the share of gas-fired power could not rise substantially unless a very high carbon tax is levied. For the CCS technology, it becomes cost effective after the introduction of carbon tax because the additional cost caused by high carbon tax could be avoided when the carbon is captured. In this sense, the introduction of higher carbon tax will mainly affect the CCS application and then lead to a change of carbon emission in power sector.

Considering the practical way for carbon tax levying, we use a progressive tax rate approach in this study. For example, when the carbon tax rate is 200 RMB/tCO_2, it means the carbon tax is levied from 2015 and then increases linearly to 200 RMB/tCO_2 by 2030. In the meanwhile, it is found that only when the carbon tax rate is higher than 200 RMB/tCO_2, there is an impact on the application of CCS in power sector. Therefore, we only analyze the cases with tax rate higher than 200RMB/tCO_2 in this study.

Figure 18 shows the changes of installed capacity of various power generation technologies equipped with CCS under different carbon tax scenarios. As shown by the figure, "new supercritical + CCS" is most cost-effective in all CCS technologies, which will become competitive with other traditional generation technologies and come into force when the carbon tax rat reaches as low as 200 RMB/tCO_2. Following it, the sequence of competitiveness of other CCS technologies, from higher to lower, will be respectively “Existing supercritical coal power + CCR”, “Existing supercritical coal power + CCS”, “IGCC + CCS”, “Gas-fired power + CCS”.

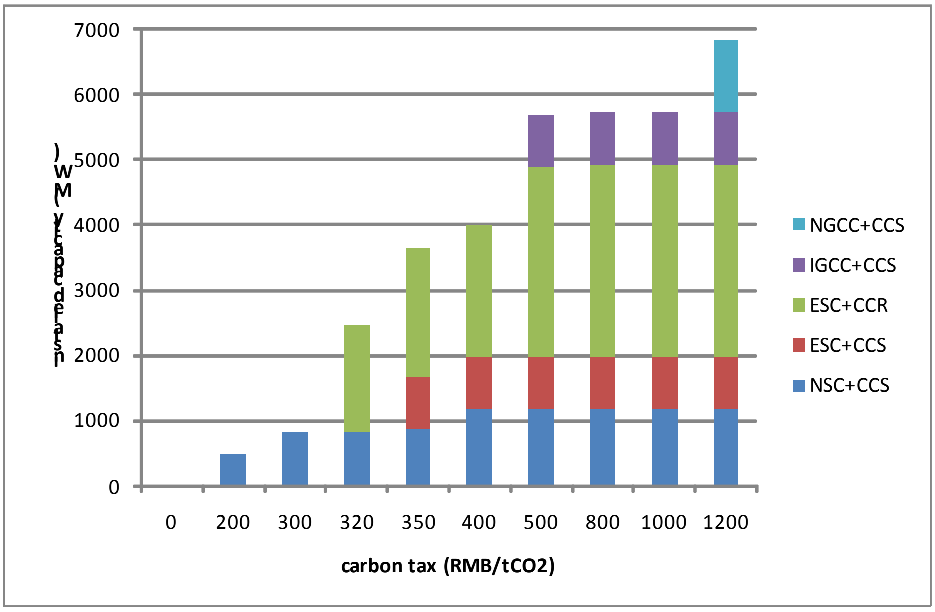

Figure 18： Installed Capacity of different CCS Technologies in 2030under Different Carbon Tax Rates

It is also found that the coal-fired unit with CCS facility is more cost-competitive than gas-fired unit with CCS facility. The supercritical coal-fired unit is the priority selection to implement carbon capture technology. For the CCS application with supercritical coal-fired unit, the most reasonable and cost-effective way is to build new supercritical power plant equipped with carbon capture facilities, though large amount of initial investment is needed to build such supercritical power plants. From a practical point of view, the appropriate development mode for CCS application with supercritical coal-fired unit in Guangdong is to install carbon capture ready facility together with the construction of new supercritical power unit, and retrofit power plant with carbon capture facilities afterward when condition and time become proper. For the carbon capture ready, the added investment cost when constructing the supercritical power unit will be very low and not more than 3% of total, but the cost saving in the later stage when carbon capture facility is needed to be equipped will be significant, compared with those without carbon capture ready. It is also shown in this study that “Existing supercritical coal power + CCR” is the option with largest application potential in all CCS technologies.

By comparison, the initial investment cost and power generation cost per unit of IGCC are both higher than supercritical coal power. Although combining IGCC with carbon capture facility has advantages from technical point of view, its cost-effectiveness is still lower than “supercritical coal power + CCS”. Based on the modeling analysis result, “IGCC+CCS” will only start to penetrate into the market when carbon tax rate reaches around 500 RMB/tCO_2. For “gas-fired power unit + CCS”, due to high gas price, it is very costly and will be only chosen by the market when tax rate reaches as much as about 1200 RMB/tCO_2. Therefore, “gas-fired power unit +

CCS" is not a preferred option for now. However, if coal price rises and total amount of coal consumption is controlled in the future, "gas-fired power unit + CCS" might become an important option of CCS application then.

As to the overall application potential, when carbon tax rate rises, the generating capacity with carbon capture technology will gradually rise. It will account for 1% of total installed capacity when carbon tax reaches 350 RMB/tCO_2 and 5% of total when carbon tax reaches 500 RMB/tCO_2. After that, when carbon tax continues to rise to higher level, the proportion of CCS technology will remain at a relative steady level and increase to 6% at highest (see figure 19).

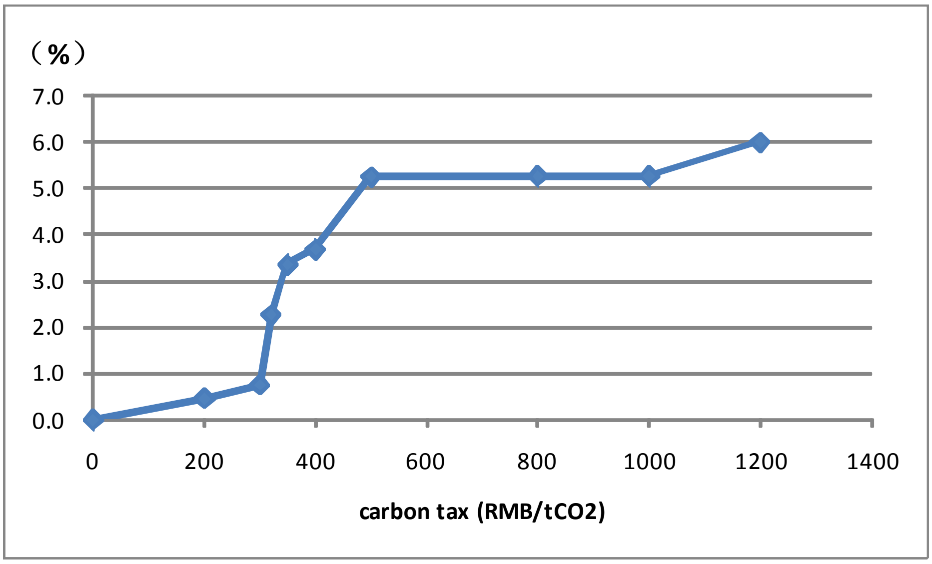

Figure 19: CCS technologies' share in total installed capacity under Different Carbon Taxes

5.2 Analysis of Emission Reduction Potential of CCS in Guangdong

Along with the increase of carbon tax rate, carbon capture technology will be able to be use in a wider range, and the carbon emission reduction will also increase correspondingly. It is found that when carbon tax rate reaches 300, 500 and 1000 RMB/tCO_2, annual carbon emission from CCS application will be 3.7, 22 and 31 MtonCO2, accounting for 1.8%, 11.7% and 17.6% of annual total emission. (As shown in Figure 20)

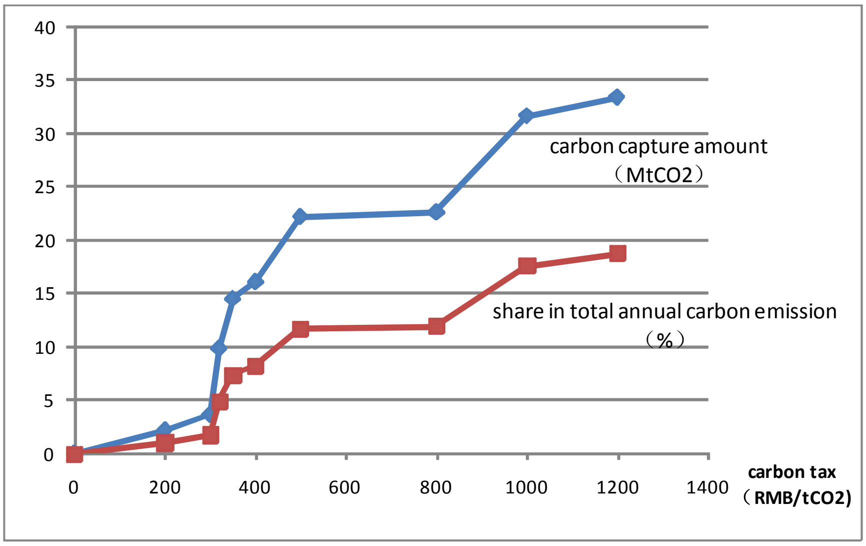

Figure 20: Carbon Emission Reduction Potential by CCS application under Different Carbon Taxes

In the meanwhile, the incremental costs of power sector will increase along with the increase of carbon tax. When carbon tax rate is below 350 RMB/tCO_2 level (the carbon emission reduction is less than 15 MtCO_2), the growth speed of carbon emission reduction is faster than the growth speed of incremental cost, which means the expansion of carbon capture capacity will help decrease the unit cost of carbon reduction during this period. However, when carbon tax rate is higher than 350 RMB/tCO_2, the further reduction of carbon emission will lead to higher incremental cost, especially when carbon emission reduction in 2030 exceeds 25 MtCO_2. This indicated that, for the CCS application in power sector in Guangdong, the annual amount of carbon emission reduction in 2030 should maintain in the range from 15 to 20MtCO_2, otherwise the mitigation cost will be too high, which will bring harm to the deployment and application of CCS technologies.

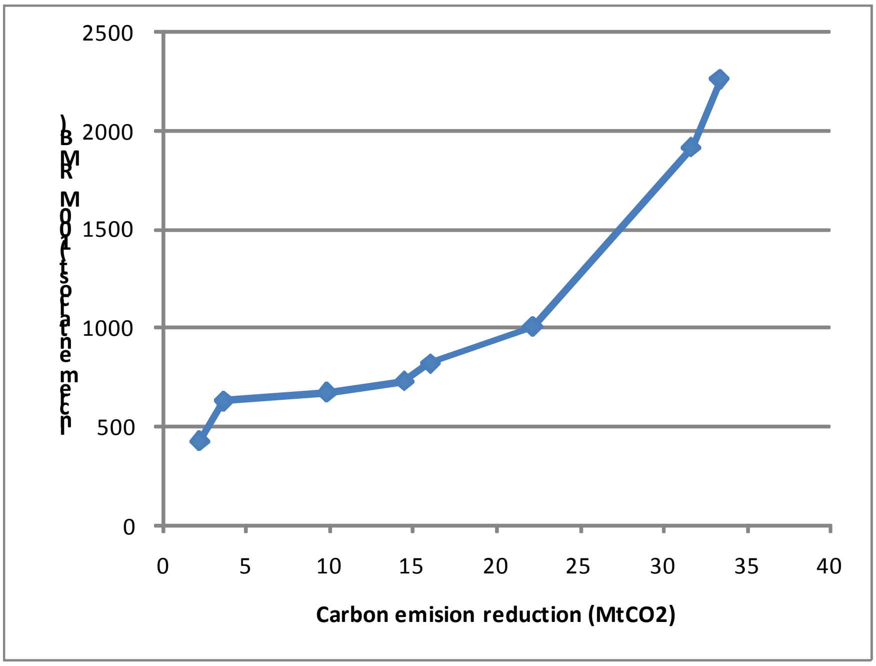

Figure 21: Incremental Cost of CCS application in 2030

In the analysis above, the potential for CCS application in Guangdong is analyzed from technological and economic viewpoint, but in reality a high carbon tax will lead to an apparent increase of power generation cost and a big overburden on power sector, will conversely affect the use of CCS. In addition, considering the current situation of domestic and international carbon market, it should not be proper to set a high carbon tax rate from the beginning.

Taking all these factors into consideration, the acceptable and reasonable carbon tax rate for Guangdong power sector should be around 200-350 RMB/tCO_2. Under this tax rate, the supercritical coal-fired unit with carbon capture technology will be able to capture carbon emission in a cost-effective way. A supercritical coal-fire unit with installed capacity more than 500 MW could by demonstrated to be equipped with CCS by 2020 and the annual highest potential of carbon captured would exceed 2 MtCO_2, and the annual actual carbon captured would reach to around 1 million ton CO_2. By 2030, the supercritical coal-fire units with CCS could operate commercially and their installed capacity would go up to over 4,000MW, with annual highest carbon captured can reach up to 15 million tons and actual carbon captured can be around 7 million tons.

If the central or local government provide sufficient policy supports and make a substantial reformation on power pricing scheme, and companies can also put more efforts on the technology demonstration of IGCC, it can be expected to complete an IGCC demonstration project by 2020. Then, build on the enhanced demonstration and deployment of “IGCC+CCS” afterward, the total capacity of 5000MW of CCS units, including “IGCC + CCS” and “ultra-supercritical + CCS”, could be installed by 2030, through which about 20MtCO_2 can be captured per year at maximum and 10MtCO2 can be captured in actual operation.

5.3 Mitigation costs of CCS in power sector of Guangdong

There are several factors that can affect the CCS costs, including carbon capture cost, carbon transportation cost and carbon storage and monitoring cost. Based on some case studies previously on the structure of CCS cost, capture costs is the highest cost followed by storage costs and transportation cost, which means capture costs is still the key direction and driving force for the reduction of CCS expenditure in the future. Carbon capture cost in different project varied significantly. It heavily depends on adopted technologies, CO_2 concentration in transportation, CO_2 capture rate, impurities and size of emission sources. Usually, the higher the CO_2 concentration in the emission source, the lower the capture cost. The higher the capture efficiency, the lower the capture cost. The CCS costs from related researches are displayed in table 3.

Table 3：Capture Costs of CCS Technology

Index	Coal-fire	NGCC	IGCC
Power generating costs without CCS（$/MW•h）	43~52	31~50	41~61
Capture scenario			
Fuel consumption increase ration（%）	24~40	11~22	14~25
CO 2 Capture amount（kg/MW•h）	820~970	360~410	670~940
CO_2 reduction amount（kg/MW•h）	620~700	300~320	590~730
CO_2 reduction rate（%）	81~88	83~88	81~91

Data source：Greengen report, 2009

Based on this research, we could see the impact of carbon tax (or carbon price) on the application of carbon capture technology. When the carbon tax rate exceeds 200 RMB/tCO_2, the application of carbon capture technology increases rapidly. However, due to the captured amount is still low, the unit cost for carbon emission reduction is very high. When carbon tax keeps increasing to around 350RMB/tCO2, the CCS technologies have been broadly applied in coal-fired power generation units. The unit cost of carbon emission reduction will be reduced to the lowest level of 50 RMB/tCO2 (see Figure 22). When carbon tax rate further increases, as the carbon capture technology application cost become higher, the unit cost of carbon emission reduction will increase. Therefore, it can be found that when carbon tax rate is in the range of 200 - 350 RMB/tCO2, the CCS technologies can be applied most cost-effectively in power sector in Guangdong, which is also the reason why this range of carbon tax is chosen in CS scenario mentioned above.

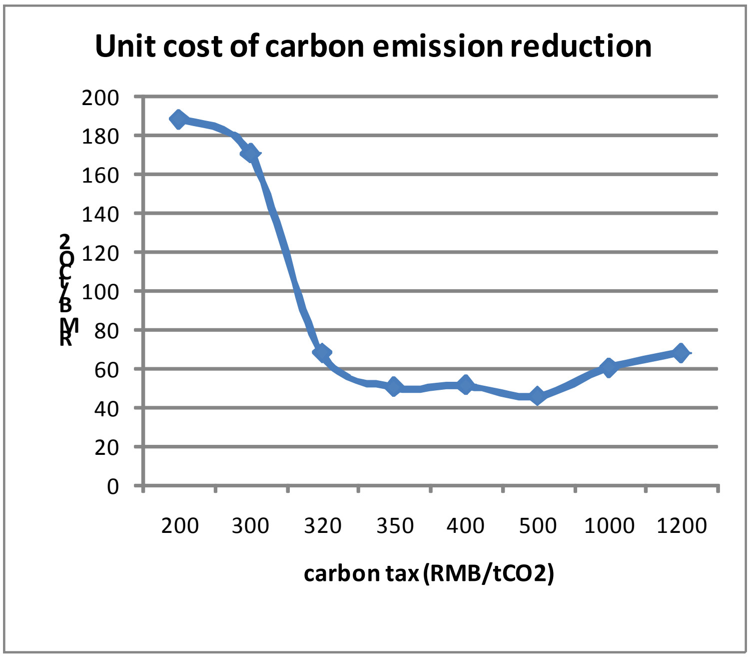

Figure 22: Unit cost of Carbon Emission Reduction under Different Carbon Taxes

As to the effect of CCS application on electricity price, it is found that the power price will increase along with the increase of carbon tax. By 2020, the electricity price will increase by about 30% in CS scenario compared that in ES scenario, and by 2030, this increase of electricity price will grow to 40%.

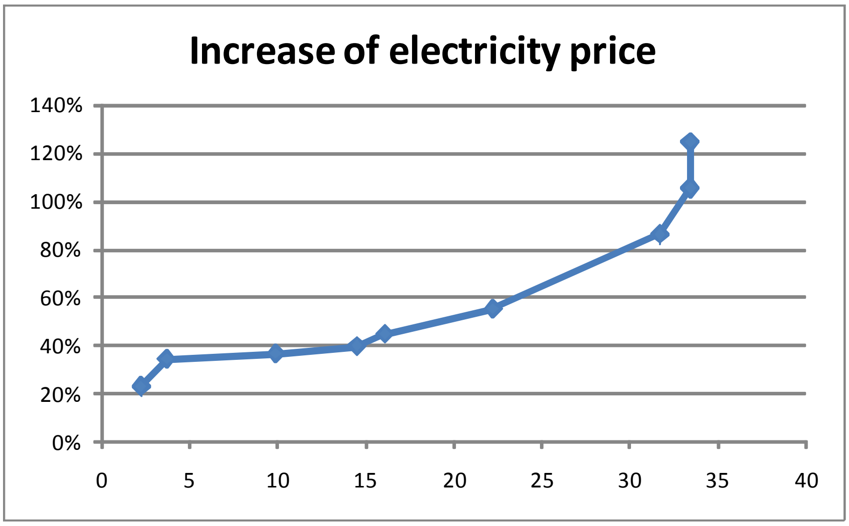

Figure 23: Influence of CCS Application on Electricity Price

The above cost analysis is only the technological analysis, while in practice the implementation of CCS also involves many other extra economic and social costs. Especially, under the conditions that the initial investment of CCS is large, the market prospect of CCS is unclear, and the technology stability and safety of CCS is still improving, there might be a high extra cost for CCS application other than the technology cost. Therefore, to lower the operation costs and the barriers to entry into the market of CCS technologies, and facilitate deployment and application of CCS technologies, it is required to provide more support and effective policy guidance for CCS application and fully use the market strength to improve the technology maturity of CCS, with a purpose to increase the efforts and acceptance of the whole society on the CCS development.

5.4 Comprehensive analysis of CCS application in power sectors in Guangdong

Currently, the application of CCS technologies still encountered many barriers, of which the key one is the high installation and operation costs. In order to successfully implement CCS at large scale, it is crucial to internalize the external cost of carbon emission reduction through market based or economic incentive approaches. As previously discussed, when carbon price exceeds threshold value (200 RMB/tCO_2), CCS technologies can become economically feasible. Though a further increase of carbon price will increase the possibility of CCS technology application, there is an optimal carbon price (350 RMB/tCO_2) for CCS application on carbon emission reduction. When carbon price is higher than this optimal price, the increase of carbon price will lead to a sharp growth of unit cost of carbon emission reduction. In a word, in order to utilize the CCS efficiently and effectively, a certain carbon price with relatively high value should be set for the power sector, but in the mean time, the carbon price should increase gradually from low value so as to alleviate the mitigation costs especially from the beginning of CCS application.

According to our analysis, the power generating structure of Guangdong will still be dominated by coal in a relatively long period from now on, and costs of different types of power generation technologies differ largely with each other. Considering the power structure status and implementation conditions, the most feasible CCS technology used in Guangdong power sector will be “coal power + CCS”. “Gas power + CCS” is very difficult to be selected as its implementation cost is much higher than coal power, although natural gas power can obtain a fast growth in next 20 years. In summary, the development priority order, from high to low, for CCS application in Guangdong power sector should be: “newly-installed supercritical coal power+ CCS”, “existing supercritical coal power+ CCR, “existing supercritical coal power+ CCS, “IGCC + CCS”, “NGCC + CCS”. We do not consider “Biomass power + CCS” in this study, which contains a high cost and will be hardly applied in next 20 years. For carbon capture used for coal-fired power generation, there are also several choices such as pre-combustion technology, post-combustion technology and oxy-fuel combustion technology. The pre-combustion technology is not yet fully mature and can only be applied in newly-built power plant. The oxy-fuel combustion technology is only in the small-scale demonstration stage and its performance on carbon emission reduction need to be further verified. Therefore, only post-combustion is considered and discussed in this study. The use of other two coal-based CCS technologies needs to be further analyzed based on the actual situation of Guangdong.

Based on the analysis on technology development potential and mitigation cost of CCS in power sector of Guangdong, carbon capture pilot demonstration should be set as a priority and further developed. By 2020, the coal-fired carbon capture projects at single-unit scale should be built and get into operation. It is better if two demonstration projects, one for “supercritical + CCS” and another for “IGCC+CCS”, could be built and at the same time the pilot integrated system covering carbon capture, transportation and storage could be finalized. On this condition, annual amount of CO_2 captured might reach around 1 MtCO2 by 2020. By 2030, it should be ensured that all newly-built supercritical coal-fired units should equipped with CCR, and there are several integrated CCS project on the basis of supercritical or ultra-supercritical coal-fired units, with the install capacity of 4GW and annual captured carbon of over 7 million tons CO_2.

Chapter 6 Policy suggestions for CCS application in Guangdong power sector

Firstly, CCS technology, as an emerging technology, has attracted extensive attention for its potential to realize great carbon emission reduction and the low-carbon usage of fossil fuel. However, it is difficult to step into the industrialization stage due to the high cost and technology uncertainty. In order to promote the development and application of CCS in Guangdong and avoid the possible economic and technical risk correspondingly, assessment of CCS in terms of long-term development potential, barriers and risks of its application should be fully carried out. The significance and effect of CCS on GHG emissions control and energy optimization in the long-term strategy should be fully analyzed in Guangdong.

Secondly, currently in Guangdong there is only the feasibility study but not pilot demonstration project of CCS application. Guangdong should cooperate with different countries, national organization and enterprises to speed up the CCS research and develop and demonstration project construction under the proper condition, including the designing of the full-process, large-scale and long-term project. For these demonstration projects, besides the government should provide the support, the investments from enterprises and research institutes should be also encourage for projects in coal, power generation, chemical, oil and gas mining industries and so on, in order to speed up the CCS development broadly. By 2020, the economic feasible demonstration project without governmental support should be built up in Guangdong. By 2030, a good and complete system of policy incentives for CCS application should be generally established, where such policies such as carbon tax, carbon market, emission standard, CCS certification system, electricity pricing, etc can be broadly used to support the scale development of CCS.

Thirdly, Guangdong, as a big economic province and with high strength of economy development, should also increase its investment on R&D of CCS key technologies. Especially this investment should be enhanced for carbon capture technologies and used for the promotion of cost-effectiveness of post-combustion and the research on key technologies of pre-combustion and oxygen fuel combustion capture.

Fourthly, from the aspect of policy and laws construction, it is necessary for Guangdong government to study and establish the local guiding and incentive policies to create an enabling policy environment for the development CCS technologies. At the same time, the legal and regulatory system construction should be intensified to reduce the long-term environmental risk and enhance the safe development of CCS technology application.

Fifthly, from the public participation aspect, it is important to reinforce the information spread and knowledge popularization of CCS technologies and raise the public knowledge and awareness on CCS. At the same time, a mechanism which all stakeholders can participate in should be established to provide the incentives and guidance for enterprises and research institutions to involve in this work actively.

Finally, with the further economic development and energy demand growth of Guangdong, building new IGCC, supercritical and ultra-supercritical power plant will be an inevitable trend. Therefore, the government should enhance the support on the research and project development for carbon capture ready, in order to install the carbon capture facilities with lower cost when the policy and market environment are mature.

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