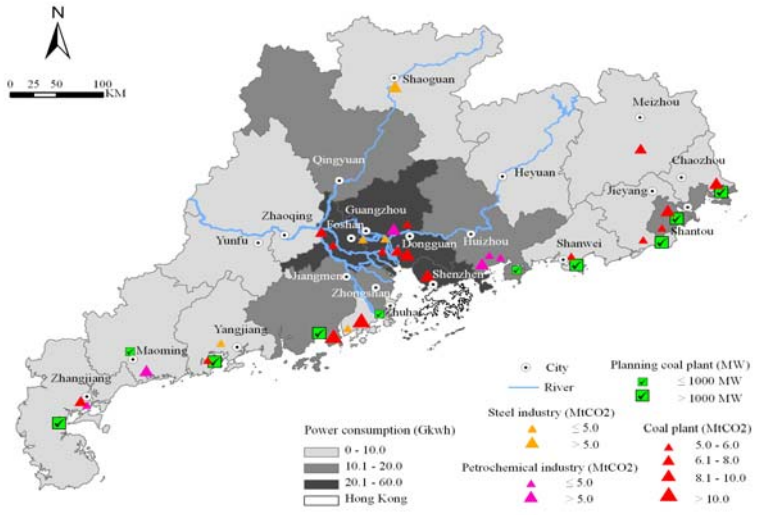
# Feasibility Study of CCUS-Readiness in Guangdong Province, China (GDCCSR) Final Report: Part 1

# Analysis of $CO_2$ Emission in Guangdong Province, China

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## Announcement

This is the first part of the final report 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.

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 the Guangzhou Institute of Energy Conversion, nor of the funding organizations.

The complete list of the 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

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# Background for the Report

Compared with energy efficiency improvement and renewable energy development, carbon capture and storage (CCS) is one of the most efficient technological options for greenhouse gas mitigation that allows continued use of fossil fuels. According to the forecast of IEA (2008), in the foreseeable future (up to 2050), most countries around the world will still use fossil energy as their primary energy supply source. In order to achieve the goal of keeping the increase of global average temperature below 2℃, great attentions have been paid to CCS all around the world.

As one of the biggest $CO_2$ emitters in world, China is inevitably experienced more pressure on global warming issues from other countries. In the long term, CCS can be one of the promising technologies that can decarbonize the energy sector while satisfying its fast-growing energy demand at the same time. Nowadays, China is undertaking a range of technical research and development projects on CCS. However, to date, all of the demonstration and R&D projects of CCS in China have been focused on the north of the Yangtze River, without substantial research on China's wealthy manufacturing provinces in the south (Zhou Di, et al., 2011). Considering the differences in geographical and climatic conditions, as well as energy structure and economic level, it is unreasonable to simply apply the results to the south. Therefore, it is urgent for carrying out the CCS-related research in this area.

Guangdong is a pioneer in the reform of the Chinese economy and one of the most developed provinces in the south of China. In late 2010 Guangdong was designated as one of the 13 pilot low-carbon zones in China by the National Development and Reform Commission (NDRC) to explore the pathway of low-carbon development. By considering the energy intensity per GDP of Guangdong is much lower than the average level of China, it will be difficult and costly to further improve the energy efficiency. And in the long term, the fossil energy will remain the mainstay energy for the economic. Therefore, it is necessary for Guangdong to study the feasibility of the development of CCS. The analysis of the provincial energy usage and $CO_2$ emission characteristics becomes an urgent task. This study addresses the energy consumption and $CO_2$ emission status of the Guangdong Province, analysis the emission characteristics and trends of major point sources, and also discusses the opportunity of CCS in the Province.

# Executive Summary

In recent decades, global warming issues aroused extensive concerns worldwide and the international community widely believed that the $CO_2$ generated from using fossil fuels is the leading reason to cause global warming. In order to avoid the irreversible and adverse effects on climate system, it is necessary to take actions to reduce GHG emissions. The reduction of GHG emissions, especially $CO_2$ emissions, has become the focus of the international community.

Guangdong is the largest economic and energy-consuming province in southern China. In the context of the new round of economic development, Guangdong is seeking a low carbon economical transition. There are four main pathways for Guangdong to develop low carbon economy: energy saving and efficiency improvement, development of low-carbon energy (such as renewable energy, nuclear, and natural gas), forestry and carbon offsetting, and Carbon Capture and Storage (CCS). There is an agreement reached in China that CCS should be regarded as an important backup low carbon technology worth more preliminary research. However the application of CCS in Guangdong depends on the energy usage and model of the province. Therefore an analysis of Guangdong's energy usage and $CO_2$ emission is helpful to decide whether Guangdong needs to explore utilising CCS technology.

In this report, we first assessed the energy consumption and $CO_2$ emission status of the Guangdong Province based on published data. Then the emission characteristics and trends of major point sources are analyzed. Finally the source to sink match analysis is carried out. All these will provide bases for the feasibility study of developing CCS in Guangdong and for compiling the CCS development roadmap for Guangdong.

The main conclusions from our studies are:

- In 2010, the total energy consumption of Guangdong reached 272 million TCE, which was 8.7% of the total national consumption. It increased 51.8% compared to 2005. Coal, crude oil and electricity are the main type of energy consumption, and facing great challenge due to shortages of domestic energy supply and high dependency on imports.
- As the development of renewable energy and nuclear energy cannot meet the increasing demand, the dominance of fossil fuels will continue in Guangdong at least to the year of 2030. According to the "12th five-year plan" and project modeling, the total installed power capacity in Guangdong will increase from 71 GW in 2010 to 103 GW in 2015, and 145GW in 2030, among which fossil-fueled power will account for more than 60%. Thus, the application of CCS would be necessary to achieve future large-scale emission reduction while using fossil-fueled energy.
- In 2010, the $CO_2$ emissions of the Guangdong Province were about 510 $MtCO_2$. The $CO_2$ emissions from power sector, industry sector (excluding emissions from their electricity consumption), transportation sector, building sector, agriculture and other sectors are 276, 153, 45, 20, and 16 $MtCO_2$ respectively. The emissions from power and industrial sectors are the largest and relatively concentrated, which accounted for 54% and 30% respectively.
- The $CO_2$ major emission point sources in this report cover those in electricity, steel and petrochemical industries of the Guangdong Province. The $CO_2$ emissions of major point

sources (MPSs) in Guangdong Province are about 252.5 $MtCO_2$ in 2010, which account for 49.5% of the total emissions in the province. The electricity enterprises are the major emission point sources in the Guangdong Province. The $CO_2$ emission from the MPSs of electric power industry in the database accounted for 40.5% of the provincial total emissions. Their emission characteristics imply that it is the main opportunity for the application of CCS in the future.

- The existing point sources of emissions in Guangdong are mainly located in the Pearl River Delta (PRD) Region, while the planning and under construction MPSs are mainly located in eastern and western coastal cities, such as Shanwei, Jieyang, Shantou, and Yangjiang. From the type of MPSs, Coal-fired power plants are the major point sources of $CO_2$ emissions in Guangdong, which covers all over the region. The large petrochemical plants are mainly located in Huizhou, Zhanjiang, Maoming, and the Iron & Steel plants of Guangdong are mainly located in Guangzhou, Zhuhai, Foshan, Shaoguan and Yangjian.
- Since the PRD region is the economically developed region of Guangdong, the difficulty and cost of plant retrofitting in the PRD region will be much higher than the coastal areas. Furthermore, carbon capture technology has become full-fledged in the areas of petrochemical, and the high-purity $CO_2$ flow produced from the petrochemical industry can decreases the cost of $CO_2$ capture. The early opportunities of CCS in Guangdong reside in $CO_2$ capture in petrochemical industry.
- In order to achieve the large-scale $CO_2$ emission reduction, $CO_2$ capture in power sector will be the focus of CCS development in Guangdong Province. In the short term the planning and under construction coal-fired power plants which located in the eastern coastal areas will be the most promising resources for $CO_2$ capture. But in the long term, as technologies and the international carbon market mature, the extensively retrofitting of existing coal-fired power plants in the PRD region with $CO_2$ capture can achieve massive emissions reductions.

# 1. Introduction

Guangdong is the most economically developed province in China. In 2010, the GDP of Guangdong has reached 720 billion dollars, ranking the first in China. The 2010 energy consumption of Guangdong has reached 272 million tce, ranking the third in China. Of the primary energy consumption, share of fossil energy is falling gradually benefiting mainly from the efforts in adjusting energy structure, but still covers 77.2% at 2010 (Statistics Bureau of Guangdong, 2011).

As the vanguard of China's reform and opening up, the Guangdong Province was designated as one of the 13 pilot low-carbon zones in China by the National Development and Reform Commission in 2010 (NDRC, 2010). Subsequently, a $CO_2$ intensity target of 19.5% and at least 45% reduction by 2015 and 2020 respectively compared to 2005 level was set by the Guangdong government, which is the first Low Carbon pilot implementation scheme approved by the Chinese Central Government (PGGP, 2012). It is not easy to reduce so large amount emissions, and much more difficult to maintain this reduction level each year from the planned years on.

At present, the emphasis of Guangdong's low carbon economy development has focused on the transformation toward higher-value manufacturing and strategic emerging industries, the promotion of energy conservation and efficiency, and the utilization of renewable energy (Ying Huang, et al., 2013). In the last five years, the energy intensity per GDP of Guangdong has decreased from 0.794 in 2005 to 0.664 tce per ten thousand Yuan in 2010, which is in the national leading position (NDRC and NBS, 2011).

CCS is an emerging technology to realize near zero emissions from using fossil fuels. As one of the strategic technological options for greenhouse gas emission abatement at large scale in the future, In order to study the feasibility and prospect of developing CCS in the Guangdong Province, the project "Feasibility Study of Developing CCS in Guangdong Province" (GDCCSR) was carried out from April 2010 to March 2013. The project is funded by the UK Government Foreign& Commonweal Office and Global Carbon Capture and Storage Institute (GCCSI), and implemented by the South China Sea Institute of Oceanology (SCSIO) of Chinese Academy of Sciences (CAS) allied with Energy Research Institute of National Development and Reform Commission, Guangzhou Institute of Energy Conversion(GIEC) of CAS, Institute of Rock and Soil Mechanics (IRSM) of CAS, University of Edinburgh, University of Cambridge, and Linkschina Investment Advisery Ltd.

This report is the first part of final reports of the GDCCSR project. In this report, the energy consumption, $CO_2$ emission, major emission point sources, and prospects for application of CCS in Guangdong Province are assessed to support the feasibility study and CCS development roadmap for the Guangdong Province. During the study, we have strived to represent the $CO_2$ emission level and characteristics of Guangdong accurately and comprehensively. The energy consumption and $CO_2$ emission researches are mainly based on published data, such as Guangdong statistical year book 2011. For the analysis of $CO_2$ emission point sources, the information was obtained through the investigation of companies and industries. We hope that this report can truly reflect the actual situation of Guangdong as an input to our project, although we realized there may be data gaps.

# 2. Energy Consumption of the Guangdong Province

As world's largest developing country, China is in its mid-term industrialization stage. Its energy production and consumption shares a large part of the world's total energy consumption and will continue growing in foreseeing years.

Since the economic reform and opening up, the southern China has been developing at a high speed, and becoming China's most economically vibrant region. The Pearl River Delta (PRD) region in the Guangdong Province is the key area of economic development in the southern China by producing 10% of the national GPD from only 0.25% of national land and 3.6% of national population (Zhao, et al., 2003). With the strong promotion of energy-saving technologies, the energy efficiency of Guangdong has been significantly improved. In 2010, the unit GDP energy consumption of Guangdong dropped to 0.664 tonnes of standard coal per ten thousand yuan, which is 10% decrease compared to 2005 (NDRC and NBS, 2011). Although this is at the national leading level, but compared to industrialized countries the economic development model in Guangdong is still based on high energy consumption.

In the context of a pilot low-carbon province in China, Guangdong is seeking a low carbon economical transition. There are four main pathways for Guangdong to develop low carbon economy: energy saving and efficiency improvement, development of low-carbon energy (such as renewable energy, nuclear, and natural gas), forestry and carbon offsetting, and CCS (Zhang, et al., 2010). There is an agreement reached in China that CCS should be regarded as an important backup low carbon technology worth more preliminary research (MOST, 2007, 2012, 2013). However the application of CCS in Guangdong depends on the energy usage and model of the province. Therefore an analysis of Guangdong's energy usage is helpful to decide whether Guangdong needs to utilize CCS technology.

## 2.1 Energy production and consumption

Since the economic reform and opening up, Guangdong's energy demand has soared with the rapid economic growth. In 2010, the total energy consumption of Guangdong reached 272 million tce (Fig. 2-1), which is 8.7% of the total national consumption. It increased 51.8% compared to 2005. Coal, oil and electric power occupy 11.4%, 18.9%, and 47% of the end energy consumption respectively (Statistics Bureau of Guangdong, 2011). Guangdong is a major energy consumption area in China. The fast development of automobile industry, co-operation with Hong Kong and Macau, and role of the world's manufacturing centre all require sustainable energy supply. Therefore the energy demand of Guangdong will not decrease and the pressure will grow dramatically.

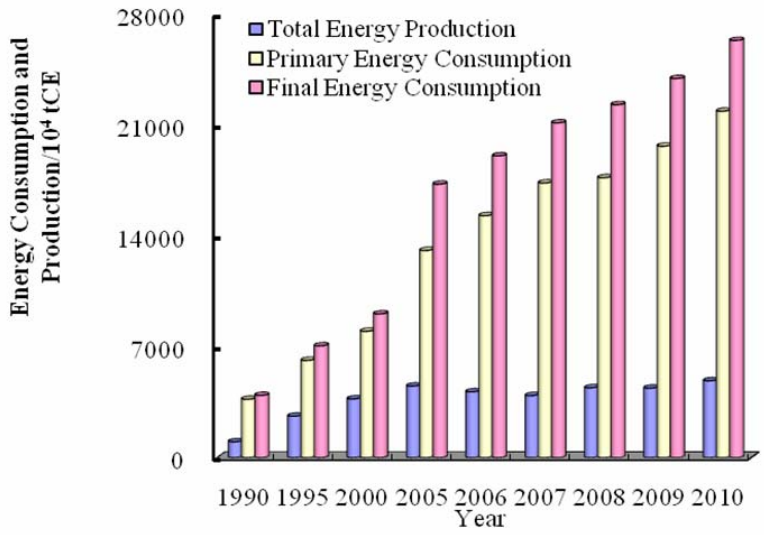


**Figure 2-1 Energy production and consumption in Guangdong** (Statistics Bureau of Guangdong, 2011)

In 2010, the energy production of Guangdong is 48.6 million tonnes, import from other provinces is 169.1 million tonnes, and import from other countries is 81.1 million tonnes. Guangdong's own energy production only occupies 18.4% of the energy consumption (Fig. 2-1). Statistics from 1990-2010 show that Guangdong's energy production increases about 8.2% every year (Fig. 2-2), while the consumption increases about 10% (Fig. 2-1). The conflict between demand and supply has been increasing.

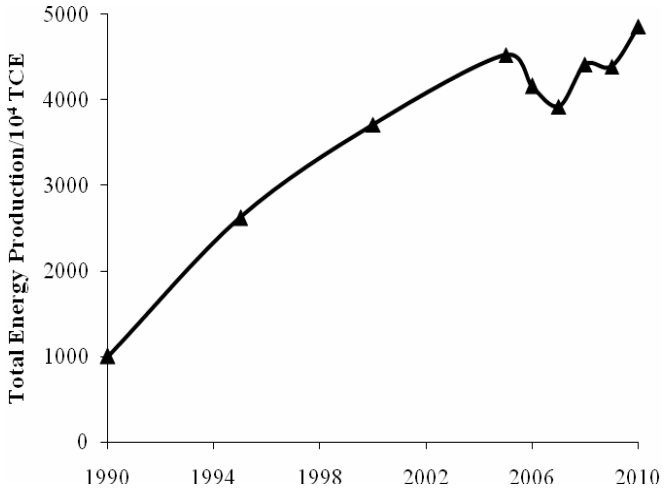


**Figure 2-2 Guangdong's energy production** (Statistics Bureau of Guangdong, 2011)

## 2.2 Energy production and consumption structure

In 2010 crude oil, electricity, and natural gas shares 37.9%, 40.7%, and 21.5% of the total energy production in Guangdong (Statistics Bureau of Guangdong, 2011). Crude oil and electricity are the main type of energy production, which accounted for 78.6% of the total.

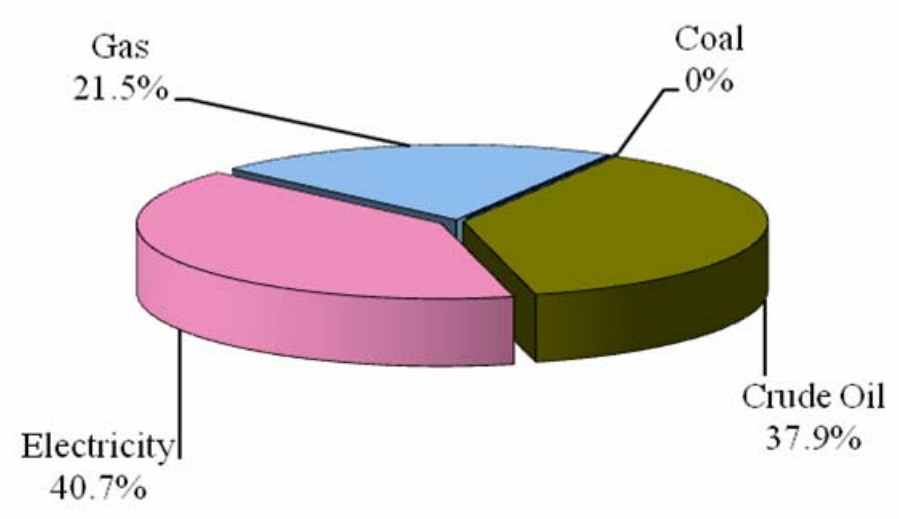


**Figure 2-3 Guangdong's energy production structure in 2010**

In 2010, Guangdong's primary energy consumption is 218.8 million tce (Statistics Bureau of Guangdong, 2011). Coal consumption reaches 105.2 million tce, accounted for 48.1% of the total primary energy consumption. Crude oil consumption reaches 63.7 million tce; accounted for 29.1% of the total. Electricity reaches 41.8 million tce; accounted for 19.1% of the total. The proportion of nature gas is smallest, which accounted for 3.7% of the total primary energy consumption (Fig. 2-4).

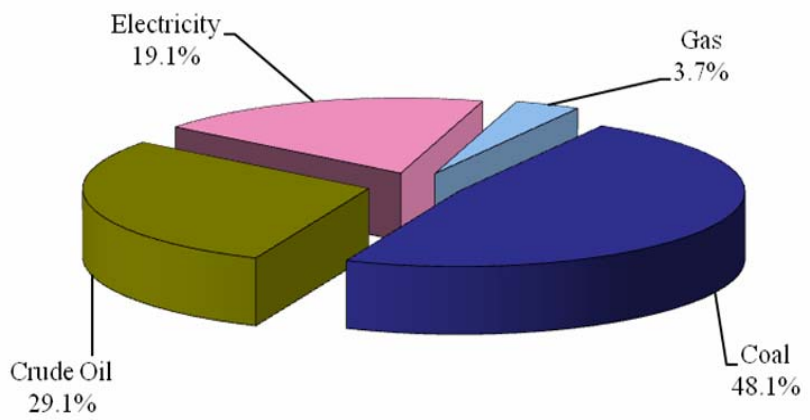


**Figure 2-4 Guangdong's energy consumption structure in 2010**

In 2010, Guangdong's final energy consumption is 263.5 million tce (Statistics Bureau of Guangdong, 2011). Electricity is still the largest type of energy consumption, which accounted for 47% of the total. Oil is the next large type with the consumption amount of 49.8 million tce and accounted for 18.9% of the total. The third one is coal, which accounted for 11.4% of the total. The proportion of electricity, oil and coal consumption reached 77.3%, which accounted for the most of Guangdong's final energy consumption (Fig. 2-5).

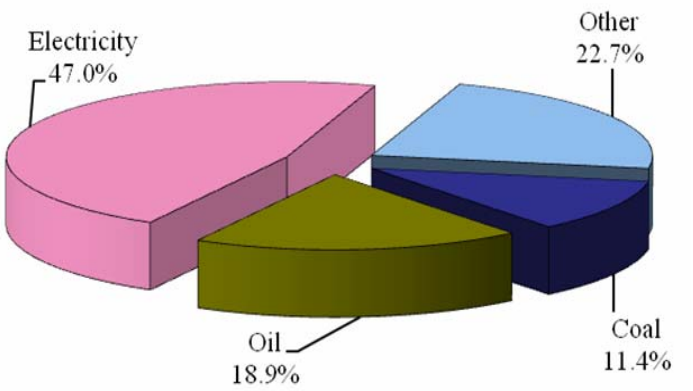


**Figure 2-5 Guangdong's final energy consumption structure in 2010**

## 2.3 Energy import dependency

Guangdong has a large population and a low reserve of energy resources. According to the statistics, Guangdong's per capita energy reserves is no more than 30 tce which is 1/20 of the national average. For years, Guangdong lacks internal energy supply and depends greatly on import. By importing energy Guangdong has the potential of keeping the diversity of energy supply and accessing cleaner energy in LNG and higher grade coal, compare to much of the country. However, as its own energy production cannot meet the increasing energy demand, Guangdong is facing the challenge of energy security.

In 2010, Guangdong expanded collaboration with other provinces and increased energy import to 250 million tce, which accounted for 92% of the total energy consumption (Fig. 2-5). This amount includes 169.1 million tce import from other provinces and 81.1 millions tce import from other countries. Import from other provinces dominates the total import amount with a share of 67.6%. Import from abroad remains 32.4%.

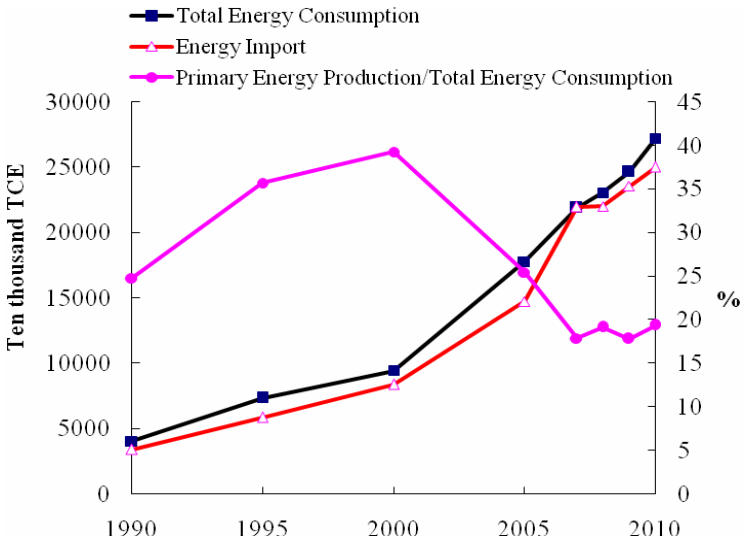


**Figure 2-6 Guangdong's energy supply import dependency**

The energies transferred from other provinces are mainly raw coal, crude oil and natural gas. In 2010, 100% of raw coal and natural gas, and 30% of crude oil need to be imported into Guangdong. The amount of raw coal, crude oil and natural gas transferred from other provinces

are 104, 457, and 523 million tce, and accounted for 38%, 16%, and 19% of total imported energy respectively. In addition, about 40% of electricity of Guangdong needs to transfer from the west of China. From figure 2-6, we can see that the proportion of primary energy production to total energy consumption is decreasing since 2000. From 2007 on this proportion is less than 20%.

### 2.4 Future trend of energy production and structure

Guangdong is now experiencing a rapid growth of industrialization and urbanization, and more power stations will be built to meet the increasing demand on electricity. The new power plants will be still dominated by fossil-fueled plants, as the development of renewable energy and nuclear energy cannot meet the increasing demand.

According to the "12th Five-Year Plan for economic and social development of Guangdong" (PGGP, 2011), the total installed power capacity in Guangdong will increase from 71 GW in 2010 to 103 GW in 2015, and fossil-fueled power will be 70 GW and account for 68% of the total installed capacity in 2015. The increase of installed capacity of fossil-fueled power plants is expected to be >17 GW, in which the coal-fired power will increase about 12 GW and gas-fired power will increase about 5 GW. In 2015 the hydro, nuclear, and other powers will account for 14.9%, 13.4%, and 3.7% of the total capacity, respectively.

The modeling in this project (ERI, 2013) predicts that in the baseline scenario (a scenario under the current development trend and policies), the total installed power capacity will rise from about 71 GW in 2010 to about 145 GW in 2030, among which coal-fired power will be 42%，coal and gas power will be 64%. Even in the scenario with more intensive energy saving and low-carbon energy policies (without CCS), to 2030 the total installed power capacity will rise from about 71 GW in 2010 to about 115 GW, among which coal-fired power will be 32%，coal and gas power will be 56%.

This indicates that the energy production will increase and the dominance of coal-fired power will continue in Guangdong at least to the year of 2030.

# 3. $CO_2$ Emissions in the Guangdong Province

## 3.1 Methodology of $CO_2$ emissions calculation

$CO_2$ emissions that cause climate change are mainly generated from large-scale utilisation of fossil fuels. In this section, the current status of the composition and total amount of $CO_2$ emissions in Guangdong are analysed. $CO_2$ emissions are calculated from its various fossil fuel consumptions multiplied by their emission factors which are recommended by IPCC (IPCC, 2006). Data used is from the "Statistical Yearbook of Guangdong Province in 2011".

This calculation assumes that the $CO_2$ emission from utilisation of renewable energy and nuclear is zero. The China Southern Power Grid baseline emission factors are used as the emission factors of electricity sent from outside region into Guangdong (that is, "purchased electricity"). The total emissions of Guangdong province and its various sectors are calculated as follows:

$$Em_{total} = \sum (\mathrm{En}_i \times \mathrm{EF}_i) \quad (1)$$

$$Em_{electricity} = \sum (\mathrm{En}_i \times \mathrm{EF}_i) \quad (2)$$

$$Em_{non-ele} = \sum (\mathrm{F}_i \times \mathrm{EF}_i) \quad (3)$$

Where $Em_{total}$ is the total $CO_2$ emissions of Guangdong province; $Em_{electricity}$ is the $CO_2$ emissions of electricity sector in Guangdong, the emissions caused by electricity consumption of other sectors are all included in the power sector; $Em_{non\text{-}ele}$ is the $CO_2$ emissions from other sectors, excluding emissions from their electricity consumption; $En_i$ is the energy consumption of species i; $F_i$ is the non-electricity energy consumption of species i; $EF_i$ is the default emission factor of $CO_2$ of the i-th fuel type.

## 3.2 Total $CO_2$ emissions of the Guangdong Province

In 2010, the $CO_2$ emission of Guangdong province is about 510 $MtCO_2$. The $CO_2$ emissions from power sector, industry sector (excluding emissions from their electricity consumption), transportation sector, building sector, agriculture and other sectors are 276, 153, 45, 20, and 16 $MtCO_2$ respectively. The $CO_2$ emissions from electricity power sector including local electrical production caused emission of 215 $MtCO_2$, and import electricity caused emissions of 61 $MtCO_2$.

**Table 3-1 $CO_2$ emissions by sector in Guangdong Province in 2010***

| Sector | | $CO_2$ Emissions (Million tonnes) | Proportion |
|---|---|---|---|
| Electricity Sector | thermal power generation | 215 | 42% |
| | electricity transfer from other province | 61 | 12% |
| Industry Sector | Industry(excluding electricity consumption) | 153 | 30% |
| Transportation Sector | Transportation, storage and postal services | 45 | 9% |
| Building Sector | Wholesale and retail trade, and catering | 5 | 1% |
| | Residential Consumption | 15 | 3% |
| Agriculture and Other Sectors | Farming, Forestry, Animal Husbandry and Fishery | 6 | 1% |
| | Other | 10 | 2% |
| Total | | 510 | 100% |

*Data source: China Energy Statistical Yearbook 2011 (China Statistics Press, 2011).

## 3.3 Sectoral $CO_2$ emissions of the Guangdong Province

In 2010, $CO_2$ emissions from power, industry, transportation, construction and agriculture sectors of Guangdong province were 54%、30%、9%、4% and 3% (Fig. 3-1). The emissions from power and industrial sectors are the largest and relatively concentrated.

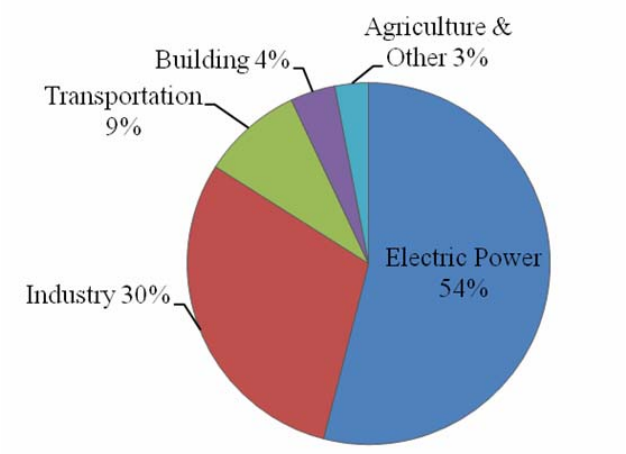


**Figure 3-1 Sectoral emissions of Guangdong**

### 1) Power Sector

In 2010, $CO_2$ emissions from power sector is about 276 $MtCO_2$, accounted for 54% of the total $CO_2$ emissions of Guangdong province. 78% of the electricity in Guangdong was from local thermal power, mostly from coal-fired power generation. Thermal power-based structure is the major reason for the high $CO_2$ emission of power sector in Guangdong.

### 2) Industry Sector

Industry is a major energy consumer. If excluding $CO_2$ emissions generated by electricity

usage, in 2010 the industry sector emission is about 153 $MtCO_2$, accounted for 30% of the total emissions of Guangdong, and is the second largest sector for $CO_2$ emissions. In the various industries, non-metallic (cement, ceramics, building materials, etc) industries emitted the largest amount of $CO_2$, which is about 45 $MtCO_2$. The amount of $CO_2$ emissions from petrochemical industry and metal product industry are 40 $MtCO_2$ and 25 $MtCO_2$ respectively. Fig. 3-2 and Table 2-3 show the $CO_2$ emissions from different industries excluding emissions from their electricity consumption.

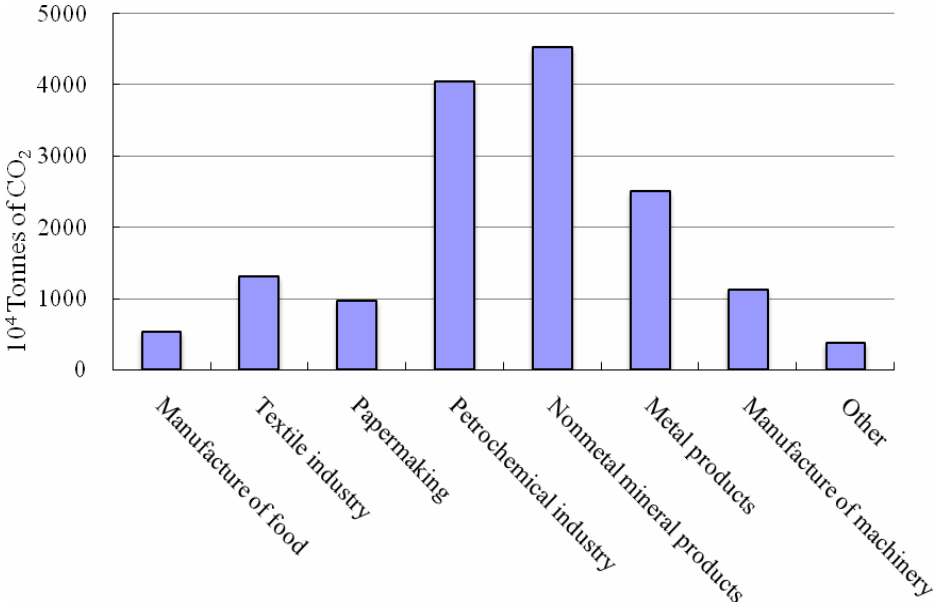


**Figure 3-2 $CO_2$ emissions from different industries in Guangdong (2010)**

### 3) Building Sector

Buildings include commercial buildings, public buildings and residential buildings. Building sector emission mainly comes from electricity consumption. In 2010, the $CO_2$ emissions from construction sector is about 20 $MtCO_2$, which accounts for 4% (if excluding electricity usage) of the total $CO_2$ emissions of Guangdong province. If including electricity usage, this amount reaches 74 $MtCO_2$, and accounts for 14.7% of the total. Electricity saving is the most important solution to reduce emissions from building sector.

### 4) Transportation Sector

In 2010, the $CO_2$ emissions from transportation sector reached 45 $MtCO_2$, accounting for 9% of total annual emissions of Guangdong Province.

**Table 3-2 $CO_2$ emissions from different industries in Guangdong in 2010***

| Sector | $CO_2$ Emissions ($10^4$ tonnes) | Item |
|---|---|---|
| Manufacture of Food, Beverages, and Tobacco | 528 | Processing of Food from Agricultural Products<br>Manufacture of Foods<br>Manufacture of Beverages<br>Manufacture of Tobacco |
| Textile, Apparel, and Leather | 1299 | Manufacture of Textile<br>Manufacture of Textile Wearing Apparel, Footwear, and Caps<br>Manufacture of Leather, Fur, Feather and Related Products |
| Papermaking and Printing | 959 | Manufacture of Paper and Paper Products<br>Printing, Reproduction of Recording Media |
| Petroleum, Chemical, and Medical | 4042 | Processing of Petroleum, Coking, Processing of Nuclear Fuel<br>Manufacture of Raw Chemical Materials and Chemical Products<br>Manufacture of Medicines<br>Manufacture of Chemical Fibers<br>Manufacture of Rubber<br>Manufacture of Plastics |
| Cement and pottery | 4513 | Manufacture of Non-metallic Mineral Products |
| Smelting and Pressing of Metals | 2494 | Smelting and Pressing of Ferrous Metals<br>Smelting and Pressing of Non-ferrous Metals<br>Manufacture of Metal Products |
| Manufacture of Machinery | 1115 | Manufacture of General Purpose Machinery<br>Manufacture of Special Purpose Machinery<br>Manufacture of Transport Equipment<br>Manufacture of Electrical Machinery and Equipment<br>Manufacture of Communication Equipment, Computers and Other Electronic Equipment<br>Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work |
| Other | 372 | |

*Data sources: China Energy Statistical Yearbook 2011; Guangdong Statistical Yearbook 2011.

# 4. Analysis of $CO_2$ Emission Major Point Sources

## 4.1 Methodology of point source $CO_2$ emissions calculation

The $CO_2$ emission point sources are the main target of CCS implementation. In this report, we defined the thermal power plants, steel and petrochemical plants with annual $CO_2$ emissions of more than 0.1 million tonnes in the Guangdong Province as the major point sources (MPSs). In this section, the composition and total amount of $CO_2$ emissions from MPSs in Guangdong province are analysed. $CO_2$ emissions of MPSs are calculated from their fossil fuel consumption multiplied by their emission factors which are recommended by IPCC. Data used are from China Southern Power Grid (RCC and SCBSE, 2011) and industry statistics. The emissions of major point sources in Guangdong province are calculated as follows:

$$Eps_{total} = \sum (\mathrm{Eps}_i \times \mathrm{EF}_i) \qquad (1)$$

Where $Eps_{total}$ is total emissions of MPSs in Mt, $Eps_i$ is the amount of fuel consumed of each point source; and $EF_i$ is the default emission factor of $CO_2$ of the i-th fuel type, and the carbon oxidation factor is assumed to be 1. $CO_2$ emissions from power sector MPSs are calculated from its design coal consumption multiplied by their annual power generation. Energy consumption data of steel and petrochemical industries are from the statistics of industry association.

## 4.2 $CO_2$ emission point sources of Guangdong

In this study, we first developed the "Guangdong Major Point Sources Database" by employing the information obtained from power sector, businesses and major industries in the Guangdong Province. The database includes fuel types, fuel consumptions, emissions, locations, and other information. The $CO_2$ emissions of MPSs in Guangdong Province are about 252.5 $MtCO_2$ in 2010, which account for 49.5% of the total emissions in the province. Among them, the $CO_2$ emissions of MPSs from electric power, petrochemical and steel industries are 81.8%, 13.6% and 4.6% respectively (Fig. 4-1).

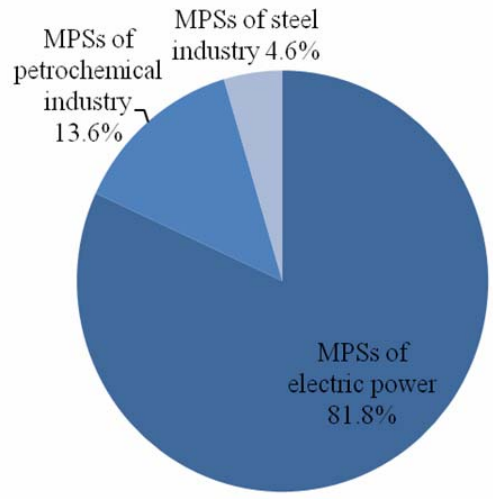


**Figure 4-1 The $CO_2$ emission structure of MPSs in 2010**

The point sources data of electric power industry covers all on-grid thermal power plants in Guangdong. The $CO_2$ emissions of these MPSs are about 206.6 $MtCO_2$, which accounts for 96% of the emissions of the power generation in the province. The $CO_2$ emissions from the MPSs of petrochemical industry and steel industry are about 34.2 $MtCO_2$ and 11.65 $MtCO_2$, account for 83.3% and 45.7% of the provincial petrochemical industry and steel industry respectively.

According to the database, power enterprises are the major emission point sources in the Guangdong Province. The $CO_2$ emission from the MPSs of electric power industry in the database accounted for 40.5% of the provincial total emissions. Its emission characteristics imply that it is the main carrier of the application of CCS related technologies such as CCS, CCSR and CCUS in the future. Therefore, this study mainly investigates the data of the MPSs of the electric industry of the Guangdong Province, and also considers the MPSs in steel and petrochemical industries.

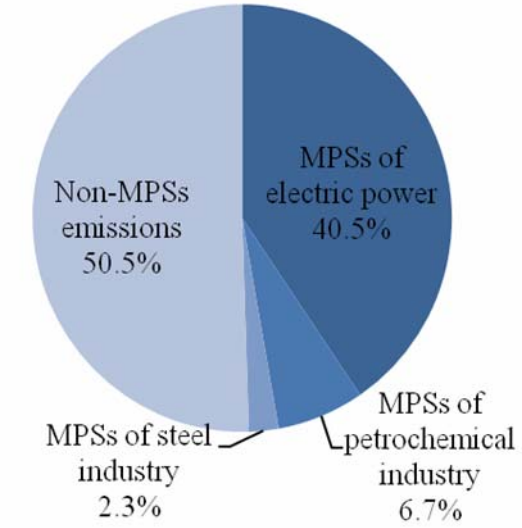


**Figure 4-2 The proportion of MPSs $CO_2$ emissions to the provincial total $CO_2$ emissions in 2010**

The electric industry of Guangdong has the characteristics as follows:

a） **Large amount of emissions and high rate of increase.** The $CO_2$ emission from local electricity generation has accounted for 42% of the total $CO_2$ emission in Guangdong Province in 2010. If calculating the emission amount by installed capacity, the $CO_2$ emission from power industry in 2010 has doubled than that in 2002.

b） **Concentrated emission.** In comparison to industry sector and transportation sector, the $CO_2$ emission from the electric industry is much more concentrated. Therefore, it is easier to implement comprehensive management, to eliminate the backward capacity, and to apply $CO_2$ emission reduction measures in power industry.

c） **Coal is the main fuel.** The installed coal fired power capacity accounts for more than 78% of the total capacity. So the proportion of low-carbon power is low. The carbon emission factor for electricity industry is about 225.85 g/kWh in 2010 (calculated according to the operating margin emission factor method, for more detail please see NDRC, 2012), which is much higher than that in developed countries (100 to 150 g/kWh) (Liu et al., 2011). Therefore, coal fired power plants dominated power sector is major reason of the high $CO_2$ emissions in Guangdong's power sector.

### 4.3 Emission structure of PMSs from power industry in Guangdong

As well as being the largest province in terms of electricity production and consumption, Guangdong has the largest total installed capacity of electricity in China. In 2010, the total installed capacity of Guangdong has reached 71 GW, accounting for 7.4% of China's installed capacity, ranking the first in China (CEPYEC, 2011). The emissions from electric power sector accounts for more than half of the province's total emissions, in which the local electrical production caused emission accounts for 78%, and imported electricity caused emission accounts for 22%. Thermal power plants dominated structure is the major reason of the high $CO_2$ emissions in Guangdong's power sector. The installed capacity of fossil-fueled power is dominant, which accounted for over 74% of the total, while that of renewable energy is still very small.

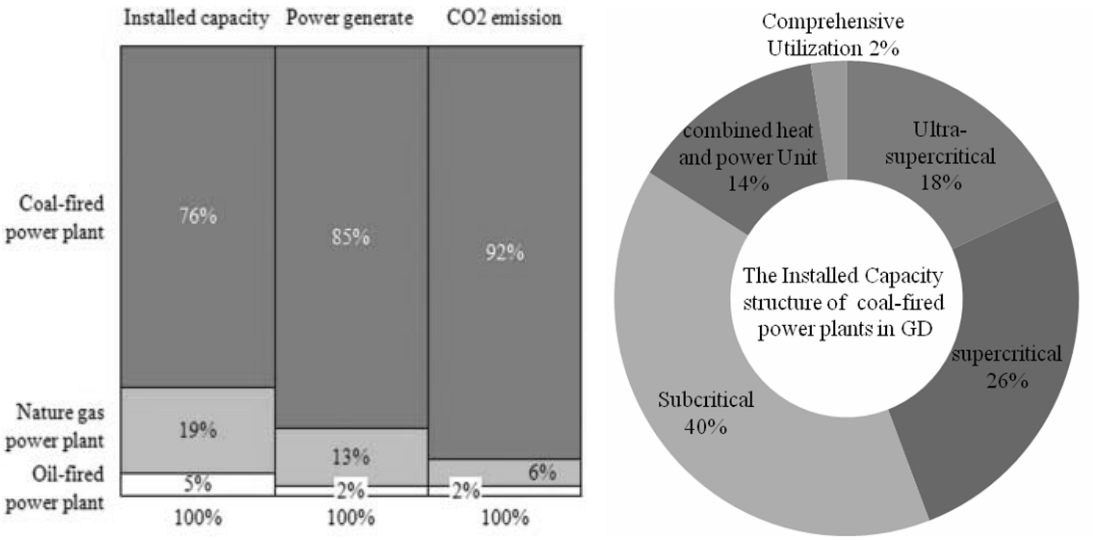


**Figure 4-3 Installed capacity and $CO_2$ emission structure of PMSs from power industry in 2010**

There are three main types of fossil-fueled power plant in Guangdong, coal-fired, gas-fired, and oil-fired. The emission composition of MPSs from power industry is showing in Fig. 4-3. Although the policy of 'eliminating backward power generation capacity' had been implemented for the coal-fired power plants since 2000, the installed capacity of coal-fired power plants is still dominant, which accounts for 76% of the total fossil-fueled power plants. The $CO_2$ emission from the MPSs of coal-fired power is about 190 $MtCO_2$, accounts for 92% of the total emissions from the MPSs of thermal power. The Ultra-supercritical unit, supercritical unit, subcritical, combined heat and power (CHP) unit, and comprehensive utilization resource (CUR) unit are the main types of coal-fired power unit, accounting for 18%, 26%, 40%, 14%, and 2% of the total. Since the construction cost of integrated gasification combined cycle (IGCC) plant is relatively high, there is only one 120 MW IGCC transformation project in Dongguan under construction (Dongguang News, 2012). The gas-fired power plant has a rapid development since 2006, and the installed capacity of these plants has reached 19% of the total fossil-fueled power plants in 2010. The reason is partly the exploitation of natural gas in the western China and the import of large quantities of liquefied natural gas from Australia. The oil-fired power plant has the smallest installed capacity mainly due to the high price of oil.

### 4.4 Spatial distribution of major point sources in Guangdong

In order to facilitate spatial analysis, we first divided the objective area into three regions according to the power consumption of the cities in 2010. The criteria for classification are shown in Table 3-1. Class I region covers Guangzhou, Shenzhen, Dongguan, and Foshan; Class II region includes Huizhou, Qingyuan, Jiangmen, Zhongshan, and Shantou; other cities belong to class III region. Then, we calculated the emissions of MPSs in each region.

**Table 4-1 The criteria and result of classification**

| Region | City | Electricity consumption of each city ($10^3$ GWh) | Installed capacity (GW) | $CO_2$ emissions of MPSs ($MtCO_2$) |
|---|---|---|---|---|
| I | Gz, Sz, Dg, Fs[1] | 40 to 60 | 21.8 | 95.12 |
| II | Hz, Qy, Jm, Zs, St[2] | 10 to 20 | 12.9 | 58.9 |
| III | Other 12 cities | 0 to 10 | 18.6 | 98.43 |
| Total | 21 cities | 406 | 53.3 | 252.45 |

Note: 1- Guangzhou, Shenzhen, Dongguan, Foshan;
2- Huizhou, Qingyuan, Jiangmen, Zhongshan, Shantou.

Fig. 4-4 shows the distribution of main emission point sources by size within Guangdong. It can be seen that fossil-fueled power plants are mainly located in class I and II regions, which covered the entire Pearl River Delta (PRD) Region. The installed capacity and $CO_2$ emissions of MPSs in these two regions are 34.7 GW and 154 $MtCO_2$, accounting for 65.1% and 61% of the total installed capacity and $CO_2$ emissions respectively. Class I region, which covers Guangzhou, Shenzhen, Dongguan, and Foshan, contributes to 40.9% and 37.7% of total installed capacity and $CO_2$ emissions within 8.6% of the area. It is the load center of Guangdong, and also will be the key area for $CO_2$ capture. Besides, coastal cities, Meizhou, and Shaoguan are also having comparatively large emission point sources.

By the end of 2010, there are 17 large fossil-fueled power plants in Guangdong with annual $CO_2$ emissions of $\geq$5 $MtCO_2$. The aggregate $CO_2$ emission of these large point sources is accounted for 48.2% of total $CO_2$ emission from electric power sector. From the type of unit, coal-fired power plants are the major point sources of $CO_2$ emissions in Guangdong, which covers all over the region. The number and scale of gas and oil power plants are much smaller.

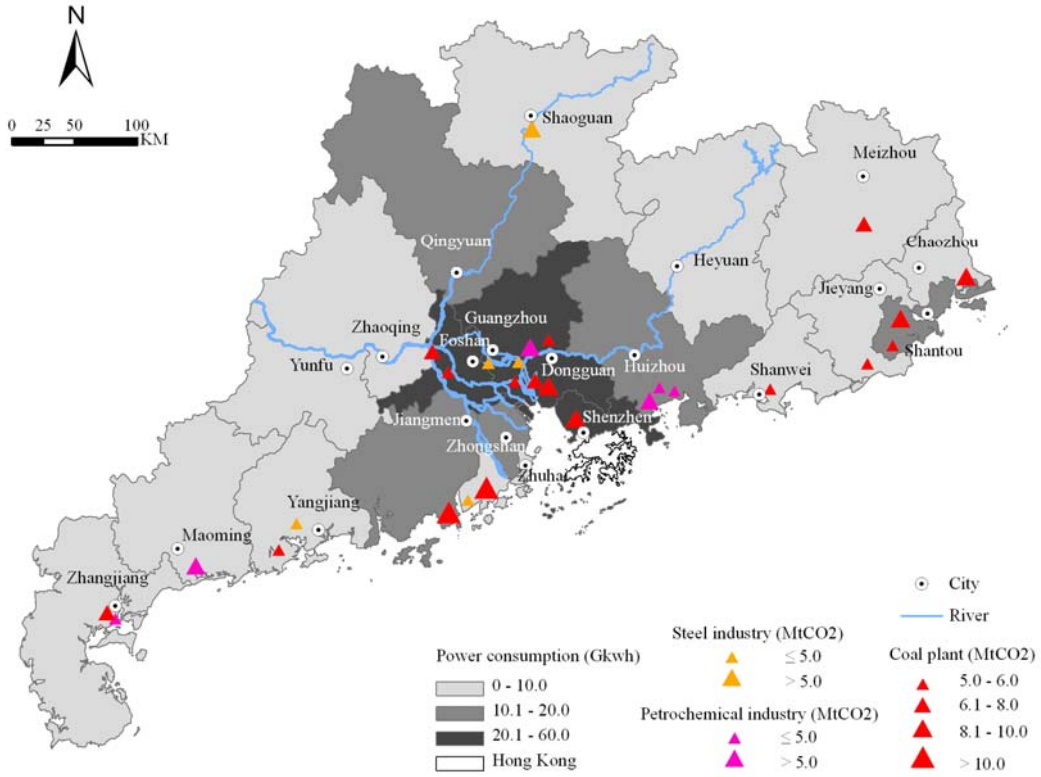


**Figure 4-4 The distribution of $CO_2$ emission major point sources in Guangdong**

The petrochemical industry in Guangdong has formed a relatively complete industrial system, including the upstream such as crude oil extraction, oil refining, and ethylene production, and the downstream such as synthetic materials, fine chemicals and rubber. It is one of the important petrochemical industrial bases of China. The petrochemical industry in Guangdong has concentrated energy consumption and $CO_2$ emission. Large petrochemical plants of Guangdong are mainly located in Huizhou, Zhanjiang, Maoming, and other coastal areas. The $CO_2$ emission of each plant is greater than 1 $MtCO_2$.

The Iron & Steel plants of Guangdong are mainly located in Guangzhou, Zhuhai, Foshan, Shaoguan and Yangjian. The three large-scale iron & steel plants in Guangzhou, Zhujiang, and Shaoguan respectively are the MPSs of Guangdong's iron & steel industry. Smaller enterprises are mostly focus on steel deep processing.

### 4.5 Future development trends of major point sources in Guangdong

According to the "12th five-year plan for economic and social development of Guangdong" (PGGP, 2011), the total installed capacity in Guangdong will increase to 103 GW by 2015, and fossil-fueled power will account for 68% of the total installed capacity. The increase amount of fossil-fueled power plants' installed capacity is expected to more than 17 GW. In which, coal-fired power will increase about 12 GW and gas-fired power will increase about 5 GW. The new power units being planned and constructed are mainly located in eastern and western coastal cities, such as Shanwei, Jieyang, Shantou, and Yangjiang. Generally, the harbors of the eastern cities are the key areas for future fossil-fueled power industry (Fig. 4-5). Meanwhile, relatively small units are mainly planned in undeveloped inland areas, such as Shaoguan and Meizhou. New power projects

in those regions are to rebuild and extend existing power plants to improve their efficiency in the future.

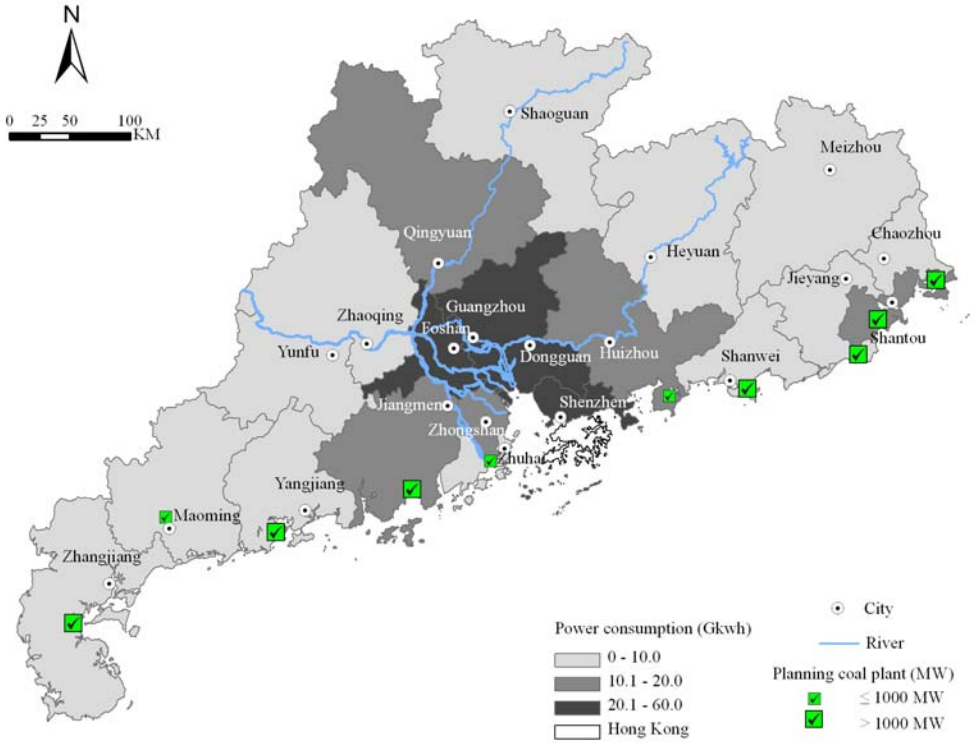


**Figure 4-5 The planning & under construction emission point sources in Guangdong**

### 4.6 Characteristics of major point sources

In order to analyse the feasibility for Guangdong to develop CCS and to find the targets to use CCS technology, we choose ten major point sources (MPSs) by considering the amount of $CO_2$ emissions, production scale and installed capacity to analysis their characteristics and to provide reference for the development of CCS in the province.

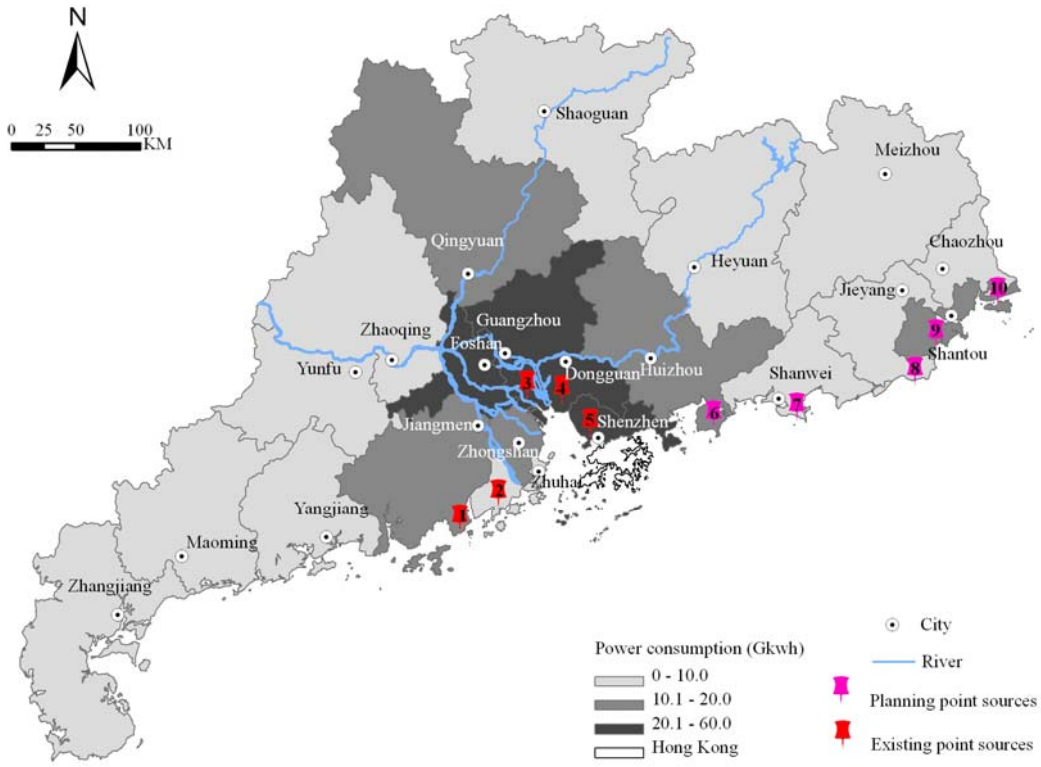


**Figure 4-6The distribution of major point sources in Guangdong**

Thermal power plants are the most important $CO_2$ emission point sources in Guangdong. The existing thermal power plants in Guangdong are mainly in the PRD region (Fig. 4-6). As shown in Table 4-2, the total emission of five MPSs is about 57 $MtCO_2$, accounting for 26% of total local thermal power emissions in 2010.

**Table 4-2 Characteristics of the existing major emission sources***

| No. | Location | Installed capacity (MW) | Annual power generation/ Billion kWh | Annual CO2 emissions/ $MtCO_2$ | Number of unit | Designed coal consumption for power generation (kg/kWh) |
|---|---|---|---|---|---|---|
| Plant 1 | Jiangmen | 3000 | 1.97 | 16.0 | 5 | 0.29 |
| Plant 2 | Zhuhai | 2600 | 1.62 | 13.1 | 4 | 0.29 |
| Plant 3 | Guangzhou | 1200 | 0.73 | 6.2 | 4 | 0.31 |
| Plant 4 | Dongguan | 1980 | 1.36 | 10.7 | 3 | 0.29 |
| Plant 5 | Shenzhen | 1840 | 1.27 | 10.6 | 6 | 0.30 |

*Data source: Calculated according to State Electricity Regulatory Commission data, industry survey data and enterprise website data.

Plant 1 is one of the largest thermal power plants in China Southern Power Grid, located in Jiangmen. The Installed capacity of this plant is 3000MW, designed coal consumption for power generation is 0.29kg/kWh, which can generating 19 billion kwh electricity per year, and the $CO_2$ emission is 16 million tonnes.

Plant 2 is located in Zhuhai, The Installed capacity is 2600MW, designed coal consumption for power generation is 0.29kg/kWh, which can generating 16 billion kWh electricity every year,

and the $CO_2$ emission is 13 million tonnes.

Plant 3 is the most important thermal power plant in Guangzhou grid, located in Nansha Economic and Technological Development Zone. The Installed capacity of this plant is 1200MW, designed coal consumption for power generation is 0.31kg/kWh, which can generating 8 billion kWh electricity every year, and the $CO_2$ emission is 6 million tonnes.

Plant 4 is one of the largest thermal power plant in Guangdong, located in Humen, Dongguan. The Installed capacity is 1980MW, designed coal consumption for power generation is 0.29kg/kWh, which can generating 13 billion kWh electricity every year, and the $CO_2$ emission is 10 million tonnes.

Plant 5 is located in Shenzhen, the Installed capacity of this plant is 1840MW, designed coal consumption for power generation is 0.3kg/kWh, which can generating 13 billion kWh electricity per year, and the $CO_2$ emission is 10 million tonnes.

The under construction and planning large power plants are mainly in the east part of Guangdong (Fig. 4-6), which is the mainly aim area of CCS/CCS ready technology application in power plant construction.

**Table 4-3 The under construction and planning large power plants**

| Project Name | Location | Phase | Planned Capacity/MW | Period |
|---|---|---|---|---|
| Plant 6# | Huizhou | In planning | 1000×4 | -- |
| Plant 7* | Shanwei | under construction | 660×6 | 2009-2011 |
| Plant 8* | Jieyang | under construction | 1000×2 | 2008-2013 |
| Plant 9# | Shantou | In planning | 1000×4 | -- |
| Plant 10* | Chaozhou | under construction | 900×0 | 2008-2013 |

*Data source: Accelerate the industry development and major project planning in east part of Guangdong
#Data source: http://gdprm.com/business_list.php?id=4#,
http://www.chng.com.cn/n93521/n93759/n93854/c94247/content.html.

Table 4-3 shows the largest planned or under construction MPSs. The overall plan of the Plant 7 is to build 4×600MW and 4×1000MW coal-fired units, in which the first 2×600MW units (Unit 1-2) have been in operation, and the other 2×660MW units (Unit 3-4) are under construction. Plant 8 belongs to the Guangdong Yuedean Group CO., Ltd. The overall planned capacity is 7200MW, including 2×600MW and 6×1000MW coal-fired units. The first 2×600MW units (Unit 1-2) have been in operation, and 2×1000MW units (Unit 3-4) are under construction. The construction period is from 2008 to 2013. Plant 10 belongs to China Datang Corporation. The overall planned capacity is 6000 MW, including 4×600MW and 4×900MW coal-fired units. From 2008, there are 2×900MW coal-fired units under construction, and expected to be completed and put into operation in 2013. Furthermore, there are also some power plants plan to expand their installed capacity, such as the Plant 6 and Plant 9. The planned capacity of each of these two plants is 4000MW.

# 5. Prospects for Application of CCS in the Guangdong Province

## 5.1 $CO_2$ capture opportunities

According to the preceding analysis, the electric power and industrial sectors contain the largest $CO_2$ emissions sources and will be the major users of $CO_2$ capture in the Guangdong Province.

Power plans are the major emission point sources in Guangdong Province. Taking the maturity and cost of the technology into consideration, retrofitting small coal-fired power (CFP) units with installed capacity of less than 200 MW with $CO_2$ capture capability is still highly uncertain (Henderson, C., et al. 2009; IEA, 2010). In addition, small CFP units are more likely to be eliminated because of low efficiency, Whereas combined heat and power (CHP) and comprehensive utilization resource (CUR) units are more complicated to be retrofitted (Chung, T., et al., 2011). Consequently, the emphasis of implementing $CO_2$ capture technology in the early stage should be focused on new power plants still being planned or constructed. Besides, $CO_2$ capture ready (CCR), a large-scale source of $CO_2$ which could and is intended to be retrofitted with CCS technology when the necessary regulatory and economic drivers are in place, is a promising way to facilitate $CO_2$ mitigation in the future (GCCSI, 2011). Some studies suggest that coal-fired power plants with CCR can greatly facilitate subsequent retrofitting to capture $CO_2$ and can significantly reduce the probability of 'carbon lock-in' throughout their lifetime (Reiner, D., et al. 2009; Liang X., et al., 2009). Thus, if CCR concepts, such as equipment space and land reserve are introduced to new plants, the means to prepare for a regional scale CCS will be great.

For industrial sector, the petrochemical industry is the major source of $CO_2$ emission among Guangdong's industrial sectors. It is the second largest industrial $CO_2$ emitter now (8% of the total industrial emissions) and is predicted to be the number one industry sector in 2020 (16.3%). The $CO_2$ produced by petrochemical industry are often high concentrations. Since the cost of $CO_2$ capture decreases with the increase in $CO_2$ concentration in the gas flow, the high-purity $CO_2$ flow produced from the petrochemical industry will enable cheaper capture. Considering the high maturity of the $CO_2$ capture technology of this sector, and the lower cost, $CO_2$ capture in petrochemical industry will be the early opportunity for Guangdong to develop CCS.

## 5.2 Prospects for application of CCS

As the largest economic province in China, Guangdong is facing the challenge of rapid increase in energy consumption and the pressure to achieve carbon reduction. Since the further advance of renewable energy, energy structure optimization, energy saving, and efficiency rising will be more and more difficult and expensive, the application of CCS would be necessary to achieve large-scale emission reduction while using fossil-fueled energy.

According to the research, the existing emission point sources in Guangdong are mainly located in the PRD Region, while the planning and under construction emission point sources are mainly located in the coastal cities. Since the PRD region is the economically developed region of Guangdong, the land resource is much less than the coastal areas. And correspondingly, the difficulty and cost of plant retrofitting in the PRD region will be much higher. Furthermore,

carbon capture technology has become full-fledged in the areas of petrochemical, such as natural gas, chemical, synthesis gas and fertilizer production. And the high-purity $CO_2$ flow produced from the petrochemical industry can decreases the cost of $CO_2$ capture.

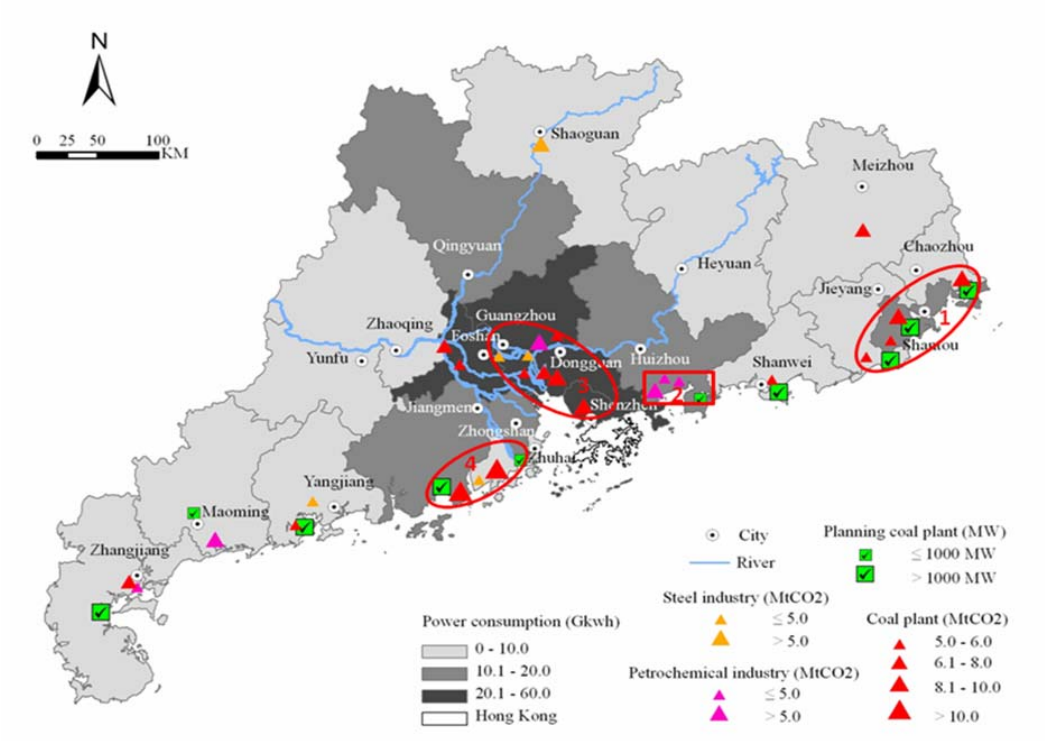


**Figure 5-1 $CO_2$ capture opportunities of Guangdong Province**

By considering the technology maturity, land resources and costs, the early opportunities of CCS in Guangdong reside in $CO_2$ capture in petrochemical industry (cluster 2 of Fig. 6-1). In order to achieve the large-scale $CO_2$ emission reduction, $CO_2$ capture in power sector will be the focus of CCS development in Guangdong Province. In the short term, the emphasis of implementing $CO_2$ capture technology should be focused on new power plants being planned or constructed (cluster 1). But in the long term, as technologies and the international carbon market becoming mature, the extensively retrofitting the existing coal-fired power plants (cluster 3 and 4) with $CO_2$ capture capability will become possible.

In order to promote the development of CCS in Guangdong, it is necessary for the government and related organizations to build up the database for CCS feasibility study. Then the related industries in Guangdong should carry out the R&D research and demonstration projects to master the technologies and to accumulate experience. Moreover, the extensively use of CCS also need the support of the policy, it is necessary for the government to formulate relevant incentive polices to promote the development of CCS in Guangdong.

# 6. Conclusions

This report assessed the energy consumption and $CO_2$ emission of the Guangdong Province based on published data. Then the emission characteristics and trends of major emission point sources are analyzed through the investigation of companies and industries. Based on the research results, the opportunity of CCS in the Province is discussed to support the feasibility study of developing CCS.

The main conclusions are:

- In 2010, the total energy consumption of Guangdong reached 272 million TCE, increased 51.8% compared to 2005. Coal, crude oil and electricity are the main type of energy consumption, and facing great challenge due to shortages of domestic energy supply and high dependency on imports.
- As the development of renewable energy and nuclear energy cannot meet the increasing demand, the dominance of fossil fuels will continue in Guangdong at least to the year of 2030. According to the "12th five-year plan" and project modeling, the total installed power capacity in Guangdong will increase from 71 GW in 2010 to 103 GW in 2015, and 145GW in 2030, among which fossil-fueled power will account for more than 60%. Thus, the application of CCS would be necessary to achieve future large-scale emission reduction while using fossil-fueled energy.
- In 2010, the $CO_2$ emissions of the Guangdong Province were about 510 $MtCO_2$. The $CO_2$ emissions from power sector, industry sector (excluding emissions from their electricity consumption), transportation sector, building sector, agriculture and other sectors are 276, 153, 45, 20, and 16 $MtCO_2$ respectively. The emissions from power and industrial sectors are the largest and relatively concentrated, which accounted for 54% and 30% respectively.
- The $CO_2$ major emission point sources in this report cover those in electricity, steel and petrochemical industries of the Guangdong Province. The $CO_2$ emissions of MPSs in Guangdong Province are about 252.5 $MtCO_2$ in 2010, which account for 49.5% of the total emissions in the province. The electricity enterprises are the major emission point sources in the Guangdong Province. The $CO_2$ emission from the MPSs of electric power industry in the database accounted for 40.5% of the provincial total emissions. Their emission characteristics imply that it is the main opportunity for the application of CCS in the future.
- The existing point sources of emissions in Guangdong are mainly located in the PRD Region, while the planning and under construction MPSs are mainly located in eastern and western coastal cities, such as Shanwei, Jieyang, Shantou, and Yangjiang. From the type of MPSs, Coal-fired power plants are the major point sources of $CO_2$ emissions in Guangdong, which covers all over the region. The large petrochemical plants are mainly located in Huizhou, Zhanjiang, Maoming, and the Iron & Steel plants of Guangdong are mainly located in Guangzhou, Zhuhai, Foshan, Shaoguan and Yangjian.
- Since the PRD region is the economically developed region of Guangdong, the difficulty and cost of plant retrofitting in the PRD region will be much higher than the coastal areas. Furthermore, carbon capture technology has become full-fledged in the areas of

petrochemical, and the high-purity $CO_2$ flow produced from the petrochemical industry can decreases the cost of $CO_2$ capture. The early opportunities of CCS in Guangdong reside in $CO_2$ capture in petrochemical industry.

- In order to achieve the large-scale $CO_2$ emission reduction, $CO_2$ capture in power sector will be the focus of CCS development in Guangdong Province. In the short term the planning and under construction coal-fired power plants which located in the eastern coastal areas will be the most promising resources for $CO_2$ capture. But in the long term, as technologies and the international carbon market mature, the extensively retrofitting of existing coal-fired power plants in the PRD region with $CO_2$ capture can achieve massive emissions reductions.

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