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Financing New Power Plants ‘CCS Ready’ in China – a case study of Shenzhen city

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Abstract

We evaluate the benefits of a ‘CCS Ready Hub’ approach, a regional ‘CCS Ready’ strategy, which not only includes a number of new coal-fired power plants but also integrates other existing stationary CO_2 emissions sources, potential storage sites and potential transportation opportunities into an overarching simulation model. A dynamic top-down simulation model was built based on economic decision criteria and option pricing theory. The model inputs and assumptions build on spatial sampling and analysis using a geographic information system (GIS) approach, engineering assessment of local projects and outputs of a CCS retrofitting investment evaluation through cost cash flow modelling. A case study of Shenzhen city in the Pearl River Delta area in Guangdong in southern China is presented, based on engineering and cost assessment studies and stakeholder consultations and building on existing geological surveys and infrastructure plans. The simulation results show that financing ‘CCS Ready’ at regional planning level rather than only at the design stage of the individual plant (or project) is preferred since it reduces the overall cost of building integrated CCS systems. On the other hand, we found the value of considering existing stationary CO_2 emissions sources in CCS ready design. Therefore, we recommended that making new plants CCS ready or planning a CCS ready hub should consider existing large emissions sources when possible.

Keywords: Carbon capture and storage; Capture ready; CCS ready; Finance; China

1. Introduction

More than 50GW of new coal-fired power plants have been constructed in China annually since 2005 and coal is estimated to supply over 60% of primary energy in the country through 2020 [1]. Carbon capture and storage is a promising technology option to decarbonise the Chinese energy sector while at the same time satisfying its fast growing energy demand [2]. Since about 1 GW new coal-fired power plant is built in China every week making new

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Chinese coal-fired power plants CO_2 capture ready (or 'CCS Ready') could greatly facilitate their subsequent retrofitting to capture CO_2 and can significantly reduce the probability of 'carbon lock-in' for the whole of their lifetime [3]

At the request of the Gleneagles G8 summit [4]*, the IEA Greenhouse Gas Programme published a study*[5] *which identified the following key elements for CCR power plants:*

- *A CO_2 capture ready power plant is a plant which can include CO_2 capture when the necessary regulatory or economic drivers are in place. The aim of building plants that are capturing ready is to reduce the risk of stranded assets and carbon lock-in.*
- *Developers of capture ready plants should take responsibility for ensuring that all known factors in their control that would prevent installation and operation of CO_2 capture have been identified and eliminated. This might include:*
  - *A study of options for CO_2 captures retrofit and potential pre-investments*
  - *Inclusion of sufficient space and access for the additional facilities*
  - *Identification of reasonable routes to storage of CO_2*
- *Competent authorities involved in permitting power plants should be provided with sufficient information to be able to judge whether the developer has met these criteria.*

In 2010, GCCSI (Global Carbon Capture and Storage Institute) releases an internationally-agreed definition of Carbon Capture and Storage Ready (CCSR) [6]:
A CCSR facility is a large-scale industrial or power 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. The aim of building new, or modifying existing, facilities to be CCSR is to reduce the risk of carbon emission lock in or of being unable to fully utilise them in the future without CCS (stranded assets). CCSR is not a CO_2 mitigation option, but a way to facilitate CO_2 mitigation in the future. CCSR ceases to be applicable in jurisdictions where the necessary drivers are already in place or once they come in place.

A number of studies have been conducted to investigate the engineering requirements of CCR [5; 7; 8], its political feasibility [9; 10] and techno-economic aspects in US and Chinese context [3; 11]. Though CCS technologies are at the demonstration phase, a number of studies have investigated the planning and integration of CCS into electricity system [12; 13; 14]. In China, Dahowski et al [15] estimated the basin-scale storage capacity and investigated the cost potential of capture and storage, while Chen et al [16] conducted a spatial analysis for source sink matching in Hebei province.

A limited number of studies are also available which investigated planning for CCS projects. Middleton and Bielicki [13] developed a cost-minimizing system (SimCCS) for integrated CCS projects. By demonstrating simCCS on 37 stationary CO_2 sources and 14 reservoirs in California, they found the importance of systematic planning for CCS infrastructure. Their results show that the greatest cost saving is a well-connected network rather than the economies of scale in pipeline construction. With regard to retrofitting potential at Chinese power plants, Li [17] investigated the retrofitting prospect of 134 existing thermal power plants with more than 1GW total installed capacity. She concluded that only 19% existing plants are likely available to be retrofitted.

Building on existing literatures, the aim of this study is to understand opportunities, economics and strategies in financing CCS ready in China, providing with a case study of Shenzhen area. Shenzhen city, a pioneer of economic system reform in China during 1970s, is now identified as one of ten pilot low carbon zones in China [18]. The city has a population of 8.9 million population and more than 11 GW power installed capacity (including 3.8GW nuclear).

2. Methodology

The paper first identified two scenarios forCCS ready investment strategies in Shenzhen city according to the level of investment-decision: CCS ready at individual project and CCS ready through planning authorities ('CCS ready hub'). A cost cash flow model is then developed to assess the economics of two CCS ready investment options. The detailed cost is based on the estimations by the CAPPCCO project. We also suggest potential financial strategies and evaluate immediate interests in local governments, power companies and oil companies for CCS ready investment and the CCS ready hub idea. The cost profile of CO_2 abatement for the whole city is assessed. The sequence in building and operating deploying CCS facilities will follow the least cost principle. When operating CCS facilities, those with the lower marginal cost of CO_2 abatement are assumed to have priority. The implementing process of simulation and analysis is highlighted in Figure 1.

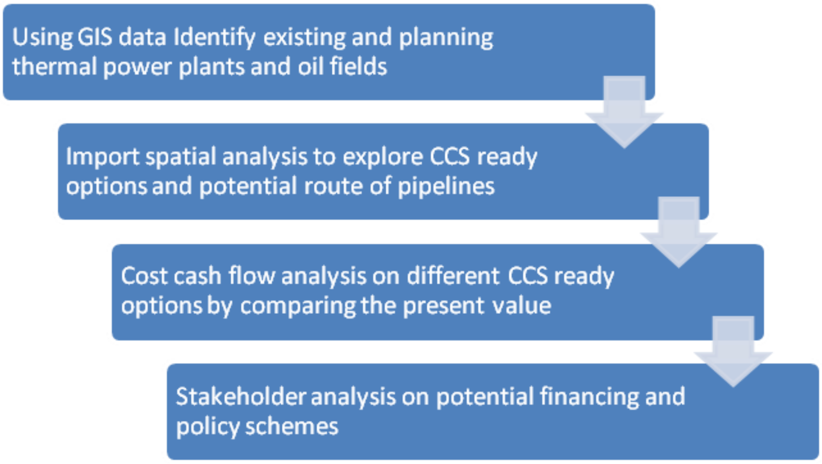

Figure 1 Methodology to investigate financing issues of CCS ready

We apply standard the cash flow model developed by [19] Liang et al (2010) and [11] for assessing capture ready investment. The cost cash flow of a power plant is composed of investment cash flow which includes fixed and working capital, and the cost component of operating cash flow includes all fixed and variable operating expenses. The cost of pipelines varies with the length, capacity, route and other technical factors. The cash flow of storage includes the cost of injection and monitoring. No tax and financing cash flow is assumed in cost cash flow analysis. The decision node assumption of retrofitting is different from the study by [3], since we investigated scenarios for retrofitting occurring in 2020 and 2025 respectively. Two existing coal and two existing natural gas power plants are retrofitable. The baseline of CO_2 emissions refers to the emissions per kWh electricity generated before capture. The total CO_2 abated is calculated by electricity generation multiplied by the difference between emissions/kWh before and after capture at individual plants.

The paper evaluated the profiles of cost cash flow in two CCS ready scenarios in Shenzhen city:

A. Consider making a 4 x 1000 MW new USCPC coal-fired power plants CCS ready and the route of backbone pipeline in project planning
B. Consider making a 4 x 1000 MW new USCPC coal-fired power plants CCS ready and the route of backbone pipeline in project planning and other stationary emissions sources in Shenzhen

Existing Power Plants	**New Power Plants**
Fuel type	Fuel type
Location	Location
Efficiency	Efficiency
Total installed capacity	Cost of CCS ready investment
Unit installed capacity	Lifetime
Current utilization hours (load factor)	Installed capacity
Future utilization hours (load factor)	Estimated utilization hours
Retrofitting feasibility	Expected average cost of retrofitting to capture
Remaining Lifetime	Expected average retrofitting year
Expected average cost of retrofitting to capture	Require rate of return (base plant, capture unit)
Expected average retrofitting year	Flexibility in capture

Require rate of return (base plant, capture unit)	
Flexibility in capture (if applicable)	
Potential Transportation (Pipeline)	**Potential Storage site**
Route options	Type
Length	Injection capital cost
Capacity	Injection operating cost
Capital cost	Monitoring cost
Operating cost	Estimated schedule for EOR (if applicable)

Table 1 Key issues considered in evaluating the cost of CCS ready

The key factors considered in the model are listed in Table 1. We assume the capture retrofit cost advantage of CCS ready according to [6] essential CO_2 capture ready definition. The cost of building onshore pipeline in scenario A will be 25% higher than scenario B in the future. Two existing coal-fired power plants and two existing natural gas power plants are able to be retrofitted in 20 years time.

Capture

Existing thermal power plants include natural gas combined cycle, heavy oil, subcritical and supercritical units. For evaluating the retrofitting potential, the remaining lifetime of these units are assessed through discussion with plants operators, because their design lifetime may not be the actual effective lifetime. For example, some operators of coal and natural gas plants claimed their units can operate 5 to 10 years longer than the lifetime, but heavy oil plants will be closed in the next 2 years, much earlier than designed life because of high operating costs and SOx emissions. The lifetime of new USCPC plants is assumed to be 30 years. The capture rate is 85%. The capital cost of new USCPC is set at CNY4250/kW while the capital cost of retrofitting capture with CCS ready investment is assumed to be 60% of original capital at CNY2550/kW (without capture).

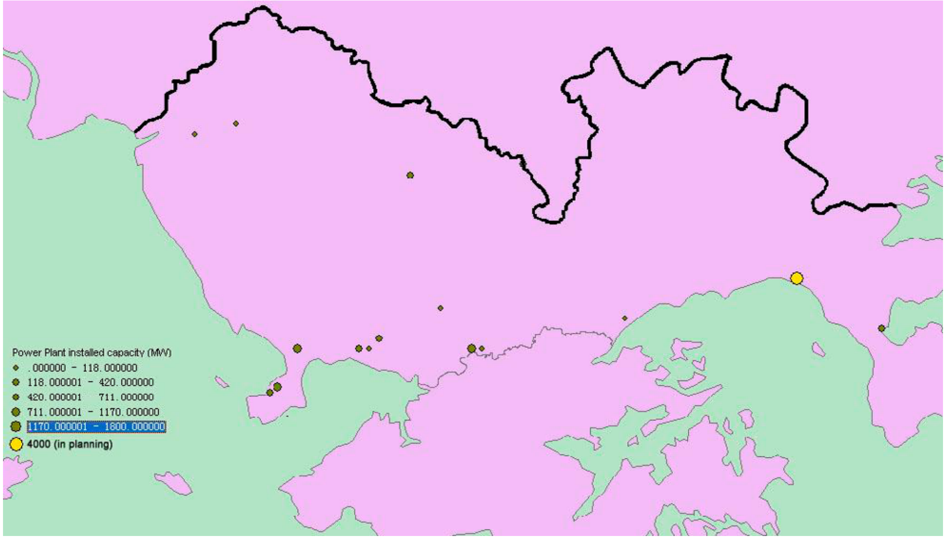

Figure 2 Location of existing and planning power plants in Shenzhen city

Pipeline

The cost estimation of pipeline considered factors in a study by McCoy and Rubin [20]. However, in the Chinese context, we also consulted offshore engineering companies and obtained cost estimates from local gas network operators. We assume a backbone pipeline to transport CO_2 from large stationary emissions sources. Scenario A, which does not consider existing emissions sources will only require a 250km offshore pipeline, with a flow rate of 25 million tonnes pa (based on 85% CO_2 captured). Scenario B, which considers existing emissions sources, will require additional onshore pipelines with a total length of 292km. The backbone onshore pipeline will be 69km with 18 million tonne capacity pa (based on 40% CO_2 captured). The backbone offshore pipeline will be designed at 43 million tonnes pa for scenario B. The operational cost of offshore pipeline will be CNY22000/km pa while the cost of onshore pipeline is assumed at CNY11000/km.

Storage

From the study by Wei et al [21], sufficient offshore storage capacity is estimated to be available for CO_2 storage in saline aquifer and EOR. The depth of the sea area is within 200 meters or less. The capital cost of injection is assumed to be CNY57 million in scenario A, and CNY62million in scenario B according to estimates by oil field operation companies in Shenzhen. The operational cost and monitoring cost is assumed to be CNY25 per tonne.

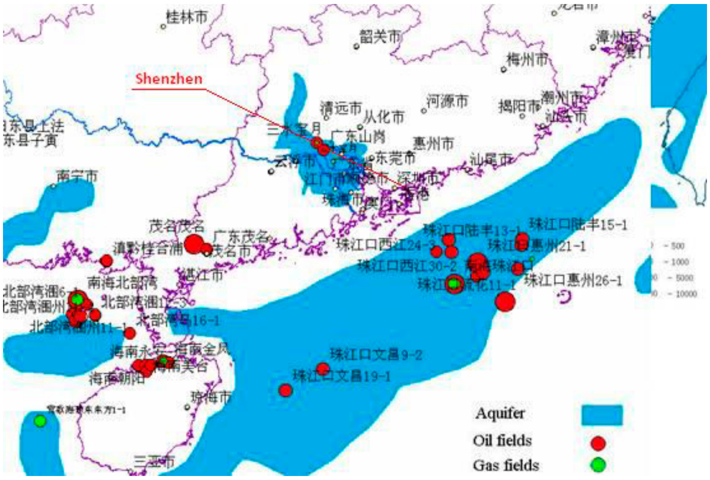

Figure 3 Potential storage capacity near Guangdong [21]

Financial assumptions

Based on a study on required return by [9], public stakeholders perceived that the required return for capture facilities is between 5% to 8%, but private sector required 12% to 20% to compensate for risk. To simplify, we apply a 12% capital charge factor in real terms for all capital cost of capture, transportation and storage facilities.

4. Result and Discussion

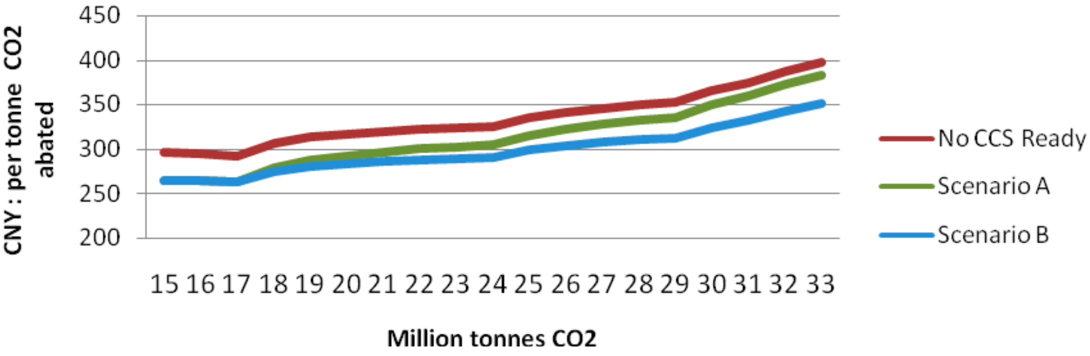

Figure 4 Average cost of CO_2 abatement of 2020 CCS retrofit

The simulation results show that CCS ready investment will reduce the average CO_2 abatement cost of CCS retrofit in 2020 by approximately 20% in Shenzhen city (Figure 4). In addition, CCS ready scenario B (CCS Ready hub), which considers the retrofit potential for existing coal and gas power plants and an optimised pipeline network, will have a significant cost advantage when capture rises above 17 million tonne per year, compared with scenario A which only makes the 4GW of new coal plant capacity CCS ready.

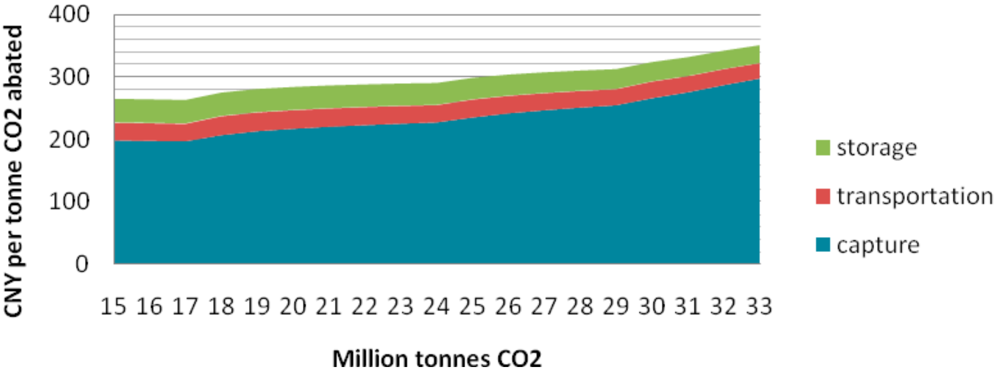

Figure 5 Structure of average cost of abatement of 2020 CCS retrofit in scenario B

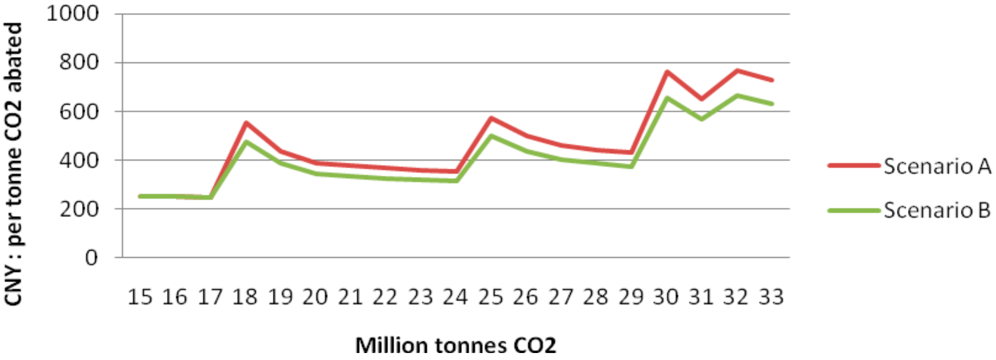

Figure 6 Marginal CO_2 abatement cost of 2020 CCS retrofit (assuming each decision involves an increase of 1 million tonnes)

The average cost of CO_2 abatement goes up when total amount of CO_2 avoided is above 17 million tonnes (Figure 5), because the remaining effective lifetime of existing plants will be less than 20 years and the efficiency of existing plants is not as high as new plants. The average cost of transportation and storage are generally lower when the total amount of CO_2 avoided is higher. Figure 6 presents the marginal cost of CO_2 abatement at every million tonne. The marginal abatement cost of scenario B is lower than scenario A in retrofitting exsiting coal or natural gas power plants.

In order to avoid more than 29 million tonnes CO_2 per year through CCS in Shenzhen, retrofitting natural gas power plants for capture will be required. However, the marginal cost of CO_2 avoidance mounts to CNY650 (about USD 100). In reality, the carbon emissions reduction target of Shenzhen and outlook of international carbon market may not be such strong that retrofit at natural gas power plants will take place. In other word, a careful evaluation on the value of CCS ready at natural gas power plants is needed before CCS ready policy or investment takes place.

To investigate implementation issues of CCS ready in Shenzhen, we held discussions with 12 energy officials from government, oil companies and power companies individually. Table 2 set forth with the immediate interests and concerns perceived by key stakeholders. Government stakeholders believed Shenzhen as a low carbon city pilot will benefit from CCS ready planning but they worried about the consumption of land resource quota allocated by the national governments. Oil companies welcome the deployment of CCS ready in the area, because it may secure CO_2 supply for EOR for offshore oil fields near Shenzhen. Power companies said it might be feasible to reserve a limited amount of land, but it definitely requires policy support rather than self-purchasing from the market.

Furthermore, as suggested by Chrysostomidis et al [22], without incentives project developers are likely developing point-to-point pipelines which do not allow for carriage of CO_2 from multiple sources to multiple sinks. To build a 'CCS ready hub' which considers all emissions sources and potential CO_2 pipeline network in Shenzhen, local governments need to provide financial and policy incentives.

	Local government departments	**Oil companies (incl.operating)**	**Power or chemical companies**
Like	demonstrate low carbon city	higher income for operation	more land in the area
	increase GDP potentially	secure CO_2 for EOR potential	avoid carbon lock-in
Dislike	consume land and finance	lack of operational capacity	cost of capture in future
	efficiency penalty in future	uncertainties in operation	efficiency penalty in future

Table 2 Immediate interests and concerns of developing CCS in China based on qualitative discussions with 12 stakeholders in Shenzhen city

5. Conclusions

The ‘CCS ready hub’, a concept for designing CCS ready systems at a regional planning level, may have significant economic benefits. A ‘CCS ready hub’ considers both new plants and existing stationary emissions sources in CCS ready planning and investment. By simulation, we found considering existing plants and a potential optimised pipeline network in CCS ready system designs can add significant value to CCS ready investments. To implement the CCS ready hub concept, local governments should provide the planning or guidelines for CCS ready to avoid ‘carbon lock-in’. Especially within the Chinese institutional framework [23], a top-down approach to implement CCS ready by local government is a possible path.

Limitations

The paper does not considered stationary emissions sources in nearby cities, such as Dongguan, Huizhou and Hong Kong. The potential of EOR is not yet built in the model. The distribution of generators may affect the cost of CCS [24], but the paper doesn’t consider the structure of power grids in Shenzhen and Guangdong. This may not be the best model for optimisation of new plants and say that you will consider minimising overall costs in the future.

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