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Prospective scenarios of CCS implementation in China's power sector: an analysis with China TIMES

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Abstract

Carbon capture and storage (CCS) has been considered a promising technology option for CO2 mitigation. This study evaluates the potential role of CCS in China's power sector under carbon emission reduction scenarios using the bottom-up optimization model China TIMES. Results show that CCS constitute an important technology option after 2025 within China's power sector in a case of stringent carbon mitigation. A greater penetration of CCS can be seen in power sector when a stronger emission reduction constraint or a cost reduction in CCS is applied.

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Keywords: China TIMES; power sector; carbon capture and storage; energy system modelling

1. Introduction

Power sector emitted 11 Gt CO2 in 2010 at the global level, sharing 37.5% of global energy-related CO2 emission [1]. The decarbonization of power sector is one of the key to achieve global CO2 mitigation. Carbon capture and storage (CCS) is one of the key low-carbon technologies in power sector. IEA estimated that in order to limit the average global temperature increase to 2°C, a total cumulative mass of 120 Gt CO2 need be captured by CCS from 2015 to 2050 globally, with China sharing around 35% of the total cumulative captured amount [2]. At present, China has some demonstration CCS projects in power sector, some of which have already been in operation, e.g. Huaneng Beijing CCS Project (3,000t CO2 captured annually), SINOPEC Shengli Oil Filed CCUS Demonstration Project (40,000t CO2 captured annually), Huaneng Shanghai Shidongkou CCS Demonstration Project (120,000t CO2 captured annually) and etc [3,4]. In this paper, we will undertake a model analysis with China TIMES to study the potential role of CCS in China's power sector in several mitigation scenarios.

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2. Model and scenario description

TIMES is a bottom-up partial equilibrium optimization model used to estimate energy dynamics in local, national or multi-regional energy systems over a long-term, multi-period time horizon, developed by Energy Technology Systems Analysis Program (ETSAP) [5]. China TIMES is developed in 5-year intervals extending from 2010 to 2050 based on China's reference energy system [6, 7]. It considers the full range of the energy system including exploitation, conversion, transmission, distribution and end-use. The supply side of the model covers electricity generation, including coal/oil/gas-fired power plant with/without CCS, hydro power, nuclear power, on/off shore wind power, photovoltaic, concentrated solar power, geothermal power, biomass with/without CCS, and etc.

The reference scenario (REF) is designed with Chinese government's target of reducing carbon intensity by the range of 40%-45% by 2020 compared to 2005 l. Some climate related policies, such as the development target of new and renewable energy, are also taken into account. In mitigation scenarios, namely 35-40-40 and 40-40-45, different carbon intensity reduction rates are designed in 10-year intervals extending from 2020 to 2050. For example, in 35-40-40 scenario, carbon intensity is set to reduce 35% during 2020-2030, 40% during 2030-2040, and 40% during 2040-2050.

3. Model results and analysis

3.1. Electricity mix in the future

Fig. 1. illustrates the electricity generation by fuel in different scenarios. The total electricity production in REF scenario is estimated to increase from 4216 TWh in 2010 to 12025 TWh 2050, with total installed capacity jumping from 962 GW in 2010 to 3051 GW in 2050. Electricity generation from fossil plants is expected to increase from 3360 TWh in 2010 to 7915 TWh in 2050, consisting 79.7% in 2010 and 65.8% in 2050 of the total electricity production. A growth in electricity production by renewable and nuclear power can be seen from 856 TWh in 2010 and 4110 TWh in 2050, with the proportion growing from 20% in 2010 to 34% in 2050. In this scenario, no CCS plants will be installed during the model period.

The carbon constraints result in the deployment of fossil plants with carbon capture in power sector. In scenario 35-40-40, CCS plants will appear just after 2030, while in scenario 40-45-45 a more stringent carbon constraint will lead to an early action in implementing fossil plants with CO2 capture in 2025. By 2050, electricity generated by coal/gas-fired CCS plants is estimated to be 777 TWh and 1710 TWh in scenario 35-40-40 and 40-45-45 respectively, sharing 6.8% and 14.6% of the total electricity production.

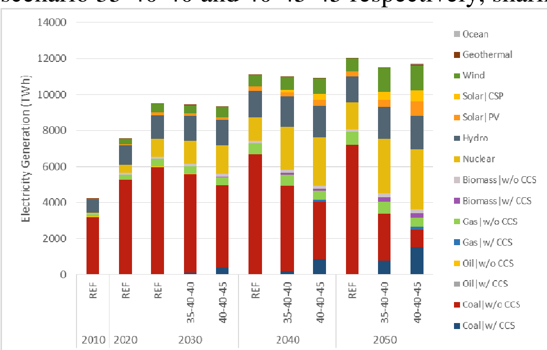

Fig. 1. Electricity production by scenarios

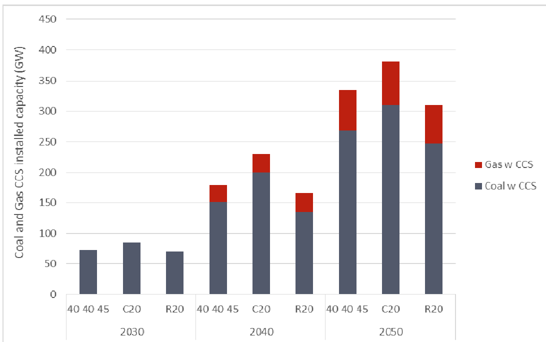

Fig. 2. Coal and gas CCS capacity in different scenarios

The CO2 mitigation constraint also induces an expansion of renewable and nuclear power in power sector, with electricity generation of 4397 TWh (renewable) and 3043 TWh (nuclear) in scenario 35-40-40 in 2050, 5159 TWh (renewable) and 3351 TWh (nuclear) in scenario 40-45-45 in 2050.

3.2. Impact of cost reduction in CCS and renewable technologies

Further evaluation of CCS implementation in power sector is conducted through additional scenario analysis, based on 2 variants of 40-45-45:

- Scenario C20: Carbon constraint is the same as in 40-45-45; the investment cost and operation & maintenance cost of CCS technologies in power sector are assumed 20% lower when compared with that in 40-45-45.
- Scenario R20: Carbon constraint is the same as in 40-45-45; the investment cost and operation & maintenance cost of renewable power technologies (wind, solar, biomass geothermal and ocean power) are assumed 20% lower when compared with that in 40-45-45.

Fig. 2. shows the installed capacity of fossil-fueled CCS plants in different scenarios. In scenario C20, a total amount of 381 GW coal/gas-fired power plants with CCS technologies are expected to be installed in 2050, which is 13.7% higher than that in 40-45-45 (335 GW). Nevertheless electricity production from fossil plants with CCS is estimated to be 1964 TWh in 2050, representing a 14.9% increase compared to that in 40-45-45 (1710 TWh). It shows that it is important to encourage research and development on CCS to lower its cost to promote the deployment of CCS technologies in China's power sector.

In scenario R20, both the installed capacity and electricity output from fossil-fired CCS plants are expected to drop around 7.5% compared to 40-45-45. But CCS is still expected to play an important role with its electricity output of 1584 TWh, sharing 19.6% of the total in 2050.

3.3. Energy-related CO2 emission

CO2 emission increases from 7.28 Gt in 2010 to 14.6 Gt in 2050 in REF scenario, with an annual growth rate of 1.6% (Fig. 3.). In scenario 35-40-40, CO2 emission reaches the peak of 12.2 Gt in 2030 and ends up at 9.9 Gt in 2050, achieving a 32% reduction compared to REF in 2050. While in scenario 40-45-45 the CO2 level peaks at 11.2 Gt in 2025 then gradually decline to 7.7 Gt in 2050, with a 47% emission mitigation compared to that in REF in 2050.

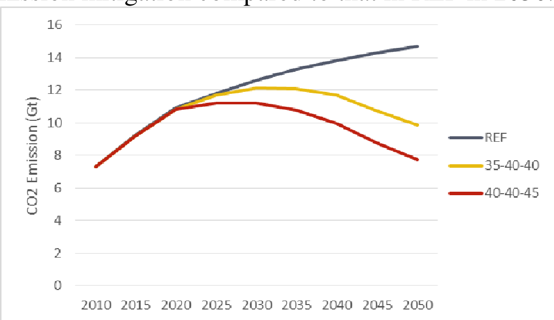

Fig. 3. CO2 emission pathways for different scenarios

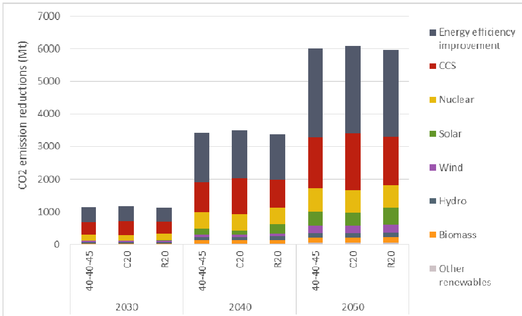

Fig. 4. Contributions of each factor to CO2 emission reduction

3.4. Role of CCS in carbon scenarios

In order to examine the role of CCS in carbon constraints, the CO2 reduction contributions of different factors are investigated. An extended decomposition approach is applied for the analysis for scenario 40-45-45, C20 and R20, compared to REF [7]. It is clear that energy efficiency improvement in both supply and demand sides constitutes the largest share of the total reduction, accounting for 44.2% to 45.4% in 2050 across scenarios (Figure 4). CCS plays a more important role beyond 2025, which is expected to contribute 24.9% to 28.6% of the total reduction in 2050 for different scenarios. Compared to the world's average level in 2050 (17% in 2050, proposed by IEA perspective in [2]), a greater reduction contribution of CCS can be seen in China, which is due to the dominant role of coal in China's energy system. Development of nuclear and renewables also contributes around 30% of the total reduction during the model period. No significant fluctuations on the contribution proportion is observed across the scenarios.

4. Conclusions

This paper aims to assess the potential role of CCS technologies in China's power sector in carbon mitigation scenarios. In CO2 mitigation scenarios, we find that there is a widespread deployment of CCS technologies, nuclear and renewable energy in China's power sector. Considering the relatively low capacity factor and instability of renewable energy, CCS is expected to become a competitive technology option under carbon constraints. A greater reliance on CCS can be seen in power sector under a stronger emission reduction constraint. Results suggest that CCS plays an important role beyond 2030, which contributes greatly to carbon mitigation across scenarios. This paper also illustrates that decrease in the costs of renewable technologies has restricted impacts on CCS penetration in power sector, because in 40-45-45 scenario there is already a high use of renewable technologies. However, expectation on decline in CCS cost may represent an opportunity for CCS expansion in power system. To make it happen, government should make effective policies to encourage research and development of CCS technologies in order to decrease investment cost and energy penalty.

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Biography

Huang Weilong is a doctoral student from Institute of Energy, Environment and Economy, Tsinghua University. His research focuses on energy system modelling and policy analysis.