Pathways to Shrink CO₂ Emissions in China's Coal Industry

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Abstract: While coal fueling China's economic growth it has already been causing severe pollution and amounts of CO₂ emission. How to make deep reductions in carbon emission is not only a huge challenge for the greatest consumer of coal, but also a revolution for China's coal industry. The paper explores how to shrink CO₂ emissions during the lifetime of coal. The paper points out that increase of coal mine efficiency and productivity, green mining, utilization of coal mine methane and environment-friendly disposal of coal gangue can reduce CO₂ during coal mining; coal preparation and coal by wire can decrease CO₂ during coal preparation and transportation; improving combustion efficiency, CO₂ capture and storage (CCS) and coal transformation can lessen CO₂ during coal utilization. The paper also points out that Circular Economy Park is a practical way to develop a low carbon economy for coal industry. An econometric model for total coal industry and each sector are constructed to measure carbon emissions based on CO₂ equivalent emissions, then with detailed calculations, based on potential greenhouse-gas emission's reduction, a most likely low carbon roadmap of China's coal industry is depicted with scenario analysis method.

Keywords: CO₂ emissions, low carbon economy, coal industry

1. Introduction

Global warming poses a profound threat to humanity and the natural world and is one of the most serious challenges humankind has ever faced. According to the 2007 Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), global surface temperature increased $273.89 \pm 273.33\text{K}$ during the 20th century (IPCC 2007). Increasing concentrations of greenhouse gases have caused most of the observed temperature increase since the middle of the 20th century (United States National Academy of Sciences 2008), and CO₂ is the most important cause of global warming. In 2005, CO₂ contributed 76% of global greenhouse gas emissions, CH₄ contributed approximately 16%, N₂O contributed approximately 6% and the combined F-gases contributed approximately 2% (IEA 2010). Among the many human activities that produce greenhouse gases, energy use is by far the largest source of emissions. Since 1870, CO₂ emissions from fuel combustion have risen exponentially (IEA 2009). Of the three types of fossil fuels - coal, natural gas and petroleum - coal constituted only a quarter of the world total primary energy consumption in 2007.

The situation is even more critical in China than in the rest of the world, as energy-intensive industrial production is growing rapidly, and large coal reserves exist in combination with limited reserves of other energy sources. The development and production of the coal industry provide stability in China's economic growth. There are more than 7000 coal enterprises in China; the coal

enterprises are the main contributor to China's "economic miracle".

However, due to its heavy carbon content per unit of energy released, in 2008, coal produced 43% of global CO₂ emissions from fuel combustion. Oil contributed 37% of emissions, and gas added 20%. Compared with gas, coal is nearly twice as emission intensive, on average. BP statistics indicate that coal discharges 1.08×10^3 kg of carbon per ton of oil equivalent, while natural gas and oil produce 0.64 and 0.84×10^3 kg of carbon, respectively (BP 2006).

The unsustainability of China's economic growth path, in combination with alarming evidence of rapid climate change, has led Chinese leaders to consider seriously how the country can move towards a low-carbon economy in the interests of both China and the world (UNDP 2010). In 2009, China committed to reducing CO₂ emissions per unit of GDP in 2020 by 40% to 45% below 2005 levels.

2. Literature Review

To avoid the serious effects of coal use, the world's countries are struggling to reduce CO₂ emissions. Paul explored the potential for improving the energy performance of coal fired power plants with post-combustion capture of carbon dioxide (Paul 2010); Adams introduced an environmentally friendly generation process using coal gasification and solid oxide fuel cells (SOFCs) to produce electricity with high efficiency, a 99.95% carbon capture rate and essentially zero atmospheric emissions (Thomas and Barton 2010). Chikkatur proposed several options that can still be instituted to position the Indian coal-power

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sector appropriately for an eventual deeper carbon mitigation strategy: (a) improve the efficiency of generation, transmission, distribution and end-use systems; (b) aggressively deploy more efficient coal combustion technologies; (c) develop a strategic plan for technology innovation; (d) improve environmental regulations to keep economic carbon capture options open; and (e) invest in detailed geological assessment of carbon storage sites (Chikkatur and Sagar 2009). Ogawa concentrated on the development of low-cost CO₂ capture technology aimed at flue gas and pointed out that the chemical absorption method is suitable for thermal power plants (Ogawa et al 2009). Schreiber discussed the environmental effects of carbon capture and storage (CCS) implementation strategies on a national level in Germany (Schreiber et al 2010). Malaysia and Indonesia benefited in various ways by participating in CDM and from investments in the GHG emission reduction projects and, inter alia, technology transfers, such as carbon capture (CC) technology, for existing and future coal-fired power plants (Othman et al 2009). Sekar focused on two coal-fired technologies, pulverized coal (PC) and integrated coal gasification combined cycle technology (IGCC), as current choices for future power plants in the US (Sekar et al 2007). Adam also argued that the US should use natural gas as a low-carbon bridge from dirty coal to clean renewable power, as gas fired power plants emit, on average, 37% less CO₂ than coal-fired plants (Adam 2009). Silva quantifies the CO₂ emission reduction, and economic cost associated to the technical improvement (Silva et al 2013).

This paper analyzes some measures to reduce carbon emissions during the lifetime of coal. Based on the current energy consumption of the coal mining industry, transportation, energy consumption, and the technological level of power generation in China, an econometric model is conducted to estimate carbon emissions reduction in the coal industry. Suggestions are proposed for the reduction of GHG emissions for the coal mining industry.

3. Pathways to Shrink CO₂ Emissions in Coal Industry Pathways during coal mining

a) Increase of coal mine efficiency and productivity

The use of advanced coal mining technology is one of the most basic ways to reduce CO₂ emissions during coal mining process. Improve coal mining methods can increase coal mine efficiency and productivity and reduce coal products unit consumption. Besides the Chinese government has made efforts to improve and manage large coal mines and combine or shut down small coal mines.

b) Green mining

The essential of green mining is to view and treat coal, coal-bed methane, water and any other useful resources in abroad sense as "resources". Its basic starting point is to prevent or to alleviate the adverse influence of coal mining on other resources and the environment, as far as possible. Green coal mining techniques including: Water resources protection - "water conservation mining" technique; land and buildings protection - "filling mining" technique; gas

extraction and emission - "co-mining of coal and gas" technique, etc., the application of which lies in: 1) To minimize the environment pollution in mining area from the source, to promote gangue filling technique, and to build lanes and fill the mined-out area with gangue. 2) To use the pillar and strip mining method for shallow-layer coal seams production, and to use the interval mining and matched mining method for other coal seams to prevent ground subsidence. 3) Further research the technique for gas quality improvement, the technique for under well coal and gas mining and mine gas use.

c) Develop and utilize coal mine methane

Coal mine methane is a potent greenhouse gas that contributes to climate change if emitted to the atmosphere, it is one of GHG emissions far worse than CO₂, the global warming potential (GWP) of methane is 23 times greater than that of CO₂. However, methane is also a kind of clean energy resource. China has rich coal mine methane (CMM). The volume of CMM resources with buried depth of 300-2,000m in onshore bituminous and anthracite coal fields is up to 31,460 billion m³, 12.5% of the world's total, ranking the third in the world. The government and industry are beginning to see CMM as a valuable resource which can be used as a feedstock for industrial chemicals and clean energy for power and heat generation. Development and utilization of coal mine methane can not only reduce greenhouse-gas emissions but also save energy resources.

d) Environment-friendly disposal of coal gangue

Increasingly enlarged coal mining scale brings about more coal gangues; At least 200 million tons of coal gangue are discharged and stockpiled in China every year, stockpiled coal gangue, usually dumped near coal mines, can have drastic negative effects on the surrounding environment. The ecological restoration of coal gangue can prevent spontaneous combustion and increase the carbon storage of the natural ecosystem of coal gangue hill, which has a good carbon emission reduction benefits (Liao et al 2010).

In fact coal gangue can be screened or washed for differentiated use, such as power generation. In 2007, China began the development of at least 50 coal gangue-fired power plants which will add at least 20×10⁹ watts of installed electricity to the national grid. Besides coal gangue also can be used to make coal gangue brick, fill the mined-out area and subsided land of well mines, reclaim farms and construct road.

3.1 Pathways during coal preparation and transportation

a) Coal preparation

Coal preparation is a strategy for improving both energy efficiency and environmental quality. This procedure should help relieve pressure on the overburdened freight network and improve the quality of the coal supplied to power stations and industrial consumers, thereby improving thermal efficiency and reducing boiler maintenance costs. Coal preparation can increase coal combustion efficiency by over 20%, with efficiencies of 28% when a pulverized coal boiler burns raw coal and up to 35% when it burns cleaned

coal (IEA 1990). A 1% improvement in thermal efficiency can yield a 2% to 3% reduction in greenhouse gas emissions (Energy Business Reports 2010). Thus, coal preparation contributes significantly to reductions in CO₂ emissions.

b) Coal by wire

The construction of mouth power plant in the coal mining areas, with the 2×600 MW power plant exporting its electricity over transmission lines to the booming east coast, contrasts with the historical approach of building power plants close to the population centers and transporting coal to them. The transportation of coal from the mines to the eastern population centers presents a formidable challenge. The railroad system is already hard pressed. Coal by wire demonstrates a significant improvement over the conventional overland transport of coal; it is far more cost-effective to move coal by wire than by rail (Oudalov and Reza 2008). Coal by wire versus rail transportation eliminates the need to transport coal to demand centers and the necessity of upgrading railway or trucking facilities. From a global-climate perspective, this strategy will also mean lower CO₂ emissions (though this is not the ultimate solution to the pollution problem).

3.2 Pathways during coal utilization

a) Improve combustion efficiency

An important step in reducing CO₂ emissions from coal combustion involves improvements in the thermal efficiencies of coal-fired power stations. Table 1 illustrates the coal-fired route to CO₂ reductions. The higher the efficiency levels, the greater the energy the fuel produces. Technological innovation and advancement offer many opportunities for tackling CO₂ emissions from coal use (World Coal Institute 2005).

Efficiency improvements at existing power plants could achieve thermal efficiencies of up to 40% thus could reduce CO₂ emissions by as much as 22%, especially in non-OECD countries (World Coal Institute 2003). To upgrade China's power industry, inefficient small units were decommissioned from 2007 and FGD systems were required to be installed on all new coal power projects and desulphurization retrofits were accelerated to all coal based generating units larger than 135×10⁶ W. More than 150 supercritical or ultra-supercritical units with capacities of 600×10⁶ W or more have been put into operation or are under construction (Deng 2008).

While more advanced technologies such as integrated gasification combined cycle (IGCC) has potential to achieve up to 25% CO₂ reductions higher than SC or USC pulverized coal boilers. In 2006, the IGCC was selected as one of the key technologies for future power generation in China according to the National Program for Medium-to-Long-Term Scientific and Technological Development (2006–2010) issued by the State Council of China.

b) CO₂ capture and storage (CCS)

The option of burning fossil fuels while storing CO₂ instead of releasing it unto the atmosphere is referred as CO₂ capture and storage (CCS). It is one of the potentially most important technological options to address climate change in the future. CCS applied to a modern conventional

power plant could reduce CO₂ emissions to the atmosphere by approximately 80-90% compared to a plant without CCS (IPCC 2005). In principle, CO₂ capture can be applied to all fossil fuel and biomass combustion processes (IEA 2004). The CCS presents one of the most promising options for large-scale reductions in CO₂ emissions from energy use and is forecasted to be competitive with other future carbon mitigation options (NPC 2007).

Table 1. The coal-fired route to CO₂ reductions.

Efficiency improvements of existing plant	Advanced technologies
Subcritical, supercritical and ultra supercritical generation	Integrated gasification combined cycle (IGCC), pressurized fluidized bed combustion (PFBC) and integrated gasification fuel cells (IGFC).
Up to 22% CO ₂ reductions	Up to 25% CO ₂ reductions

c) Coal transformation

Coal gasification is a clean and efficient way to convert coal to energy with low emissions of mercury and other air pollutants, while allowing CO₂ to be captured for underground storage. Coal gasification technology is now attracting considerable interest among energy industry experts and appears to be at a strategic crossroad. The primary gasification technologies being developed in China are ashes agglomerating fluidized bed coal gasification, non-slag and slag two-stage entrained flow bed coal gasification, two stage dry feed entrained flow bed coal gasification, coal water slurry gasification with opposed multi-burners, and coal-water slurry gasification with multiple materials.

Besides, Circular Economy Park is also a practical way to develop a low carbon economy for coal industry, which features "emission reduction, making a maximum use of resources and resource reutilization" has given a "Chinese definition" of the low carbon economy of coal industry (Li 2015).

In a Circular Economy Park, all the raw coal is transported to the coal preparation plant for washing. The washed coal is transported via the special railway. Projects engaged in the chemical processing of coal to produce methanol utilize the middling and duff dust. The resulting coal gangue is then transported to the coal gangue plant to produce bricks, and coal with a low calorific value is transported to the power plant to generate electricity. At the same time, the excess heat the power plant produces is used for heating in residential areas.

By engaging in these practices, these enterprises operate in coordination, as each uses as raw materials another enterprise's waste. Thus, circular economic industrial chains such as "coal-electricity-building materials" and "coal-chemical industry" are formed; through extension of industrial chain, the goal of low consumption, low emission and high efficiency can be realized and more than one industry is developed at the same time. In this way, resources can be used more efficiently, and the environment can be protected.

4. Low-carbon Roadmap of China's Coal Industry

Combining with the economic structure adjustment, the energy conservation, emission's reduction, energy transformation and the development of the coal industry technology, based on greenhouse-gas emission's reduction potential accounting model, a most likely low carbon roadmap of China's coal industry is depicted using scenario analysis method, as shown in Figure 1.

In 2010, the regular emissions in coal mining, coal transportation and coal gas release were up to 53×10^9 kg

CO₂ equivalent, and the planning coal chemical industry discharged 6.5×10^9 kg CO₂ equivalent; In addition, the construction of upstream and downstream of the coal industry such as the power plant, railway, port and so on also released 6.5×10^9 kg CO₂ equivalent. Through energy saving during the production process, coal mine methane utilization and coal preparation, the amount of CO₂ emission's reductions was 5.5×10^9 kg CO₂ equivalent; this is startup phase of a low-carbon economy of China's coal industry.

Figure 1. Low carbon roadmap of China's coal industry.

Source: China's coal industry low carbon economy development approach (Niu 2010).

The period from 2010 to 2020 is the development stage of the China's coal industry, through saving energy, consumption reduction, energy structure optimization, renewable-energy sources, greenhouse-gas emissions in coal production growth, coal industry will have a little down to 52.8×10^9 kg CO₂ equivalent by 2020; newer coal chemical industries will be put into production, which will increase 18.1×10^9 kg CO₂ equivalent. Energy saving, consumption reduction in coal production, gas utilization and washing processing technology will decrease 11.9×10^9 kg CO₂ equivalent; With carbon sequestration and application of CCS technology, more CO₂ emissions will be reduced.

The period from 2020 to 2030 is a mature stage of the China coal industry to develop a low-carbon economy. Through the application of energy-saving technology, CCS, and comprehensive optimization of energy structure energy, renewable energy (such as wind power and solar) development and the promotion of low carbon consumption concept and patterns, low carbon transformation of the coal industry has been basically achieved. By 2030, with coal

output reaching the peak, the greenhouse-gas emissions of coal industry increase a little to 58.7×10^9 kg CO₂ equivalent; new coal chemical industry is in large-scale development, and will replace part of oil and natural gas. Through energy saving, mine methane utilization and coal preparation greenhouse gas emissions reduction will achieve 22.2×10^9 kg CO₂ equivalent; Large-scale application of CCS technology will decrease another 20 million tons CO₂ equivalent (Niu 2010).

5. Conclusions and Discussion

Coal is finite and non-renewable, develop renewable energy is definitely a strategic choice for China to develop a low carbon economy. However, China has little oil and much coal; the coal-dominated energy mix will long exist in China. There has been widespread recognition that coal will continue to increase for power generation in China. In parallel, it has become increasingly urgent to reduce CO₂ emissions because of its impact as a greenhouse gas on climate change.

However, the coal industry has a proven track record of developing technology pathways to reduce CO₂ emissions from coal mining, transportation to utilization. Pathways for energy conservation and emission reduction from coal mining, transportation to utilization are:

- a) Increase coal mine efficiency and productivity which can reduce coal products unit consumption;
- b) Green mining which can prevent or to alleviate the adverse influence of coal mining as far as possible;
- c) Develop and utilize coal mine methane which can reduce greenhouse gas emissions and saving energy resources;
- d) Environment-friendly disposal of coal gangue can prevent drastic negative effects on the surrounding environment;
- e) Coal preparation which increases coal quality and reduces coal wastes to improve energy combustion efficiency;
- f) Coal by wire instead of conventional overland transport of coal to save energy;
- g) Improve combustion efficiency which increases thermal efficiencies;
- h) CO₂ capture and storage (CCS) which can store CO₂ instead of releasing it unto the atmosphere;
- i) Coal transformation converts coal to energy with low emissions.
- j) The circular economy park can reduce, recycle and reuse coal to realize energy conservation and CO₂ emission reduction.
- k) CO₂ emission's reductions of China's coal industry in 2020 and 2030 will achieve 11.9 and 22.2×10⁹ kg CO₂ equivalent respectively based on scenario analysis.

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