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Exploring the potential of introducing technology innovation and regulations in the energy sector in China: a regional dynamic evaluation model

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ABSTRACT

The Chinese government has introduced stricter environmental regulations to address the rapid increase in Greenhouse gas (GHG) emissions and environmental deterioration associated with energy demand. In this research we analyze the potential environmental and socio-economic benefits of introducing such regulations coupled with the promotion of advanced technological innovation for power generation. We selected Chongqing city, one of the most polluted cities in China, as the case study. The study proposes 5 scenarios that range from baseline to technology promotion through the introduction of carbon tax and subsidy schemes and the implementation of regulations for regional air emissions reduction. We constructed a dynamic evaluation model based on an Input–Output (I/O) analysis for the period 2010–2025. The results show an overall benefit on the quality of the environment and energy conservation efforts. The study demonstrates that the introduction of regulations without promotion of technological innovation will dramatically affect economic growth. The results also show that innovations in the energy sector alone will reduce both air pollutants and energy intensity to a certain extent. In this regard the promotion of innovation in other economic sectors is necessary. Another important finding is the fact that the introduction of regulations will actually curb air emissions and energy consumption. This research provides a strong platform for policy makers to realize the urgency and importance of promoting technology innovation through environmental regulations.

1. Introduction

China quadrupled its GDP while only doubling its energy consumption in the last two decades of the 20th century effectively doubling its energy efficiency. However this trend started to change from the late 1990's and it was attributed to the rapid growth in power demand and an increase in energy intensive sectors especially steel, cement and chemicals (Hara et al., 2011). Due to rapid energy demand growth China overtook the USA as the largest emitter of CO_2 in 2007 accounting for 21.7% of the global emission (UNSD, 2010). Obviously the current trends in energy supply and demand in China are far from sustainable. The high reliance on coal to meet the increasing energy demand has triggered not only a rapid increase in GHG emissions but also led to deterioration in the quality of the environment in many parts of the country.

The electricity supply sector is one of the main sources of CO_2 emissions. Power generation in China relies heavily on coal as the primary energy fuel accounting for 79% of supply and the electricity sector accounts for more than 44% of the total CO_2 emissions (Baron et al., 2012). In addition to the large CO_2 emissions coal-based power generation is also associated with air pollution and health damage (see Kanada et al., 2013; Liu and Wen, 2012 for details). Chinese Academy of Environmental Planning, which is part of the Ministry of Environmental Protection, reported that the cost of environmental degradation in China was about 230×10^9 USD in 2010, or 3.5 percent of the nation's GDP (NYTAP, 2013). To address these challenges the Chinese government has placed special emphasis on promoting energy efficiency and improving energy intensity by boosting cleaner technologies.

The decrease of the quality of the environment has caused discomfort in many parts of China. Chongqing is one of the most affected cities in this regard. The reason for major air pollution in the city is the use of high sulfur and ash content coal as the main fuel. In fact the proportion of coal in total energy utilization reached

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70% in 2010 (BSC, 2011). Chongqing city is one of the Acid Rain Control Zones designated by the Chinese Central Government. The main factors responsible for acid rain are SO_2 and NO_x emissions due to utilization of low quality coal in the power sector combined with the lack of emission control systems (Zhou et al., 2013).

Technology development and innovation play a central role in reducing GHG and pollutant emissions by promoting renewable and cleaner fossil fuels (Hascic et al., 2009; Cravinho Martins et al., 2011; Liu and Liang, 2013; Shi and Lai, 2013). However, due to the existence of externalities, effective policies and regulations are necessary to induce environmental innovations (Popp, 2006; Yabar et al., 2013). Various studies have addressed the issue of the impact of regulations on GHG and pollutant emissions in China. Liu et al. (2009) employed a bottom-up model to analyze the impact of new energy technologies under China's GHG mitigation scenario and found that high-efficiency coal power and nuclear power will have a positive impact in the short term only. Wang and Nakata (2009) explored the policy potential of carbon tax/subsidy for promoting clean coal technologies in the Chinese electricity sector and found that such policies can actually shift China's electricity structure in the mid-term. These and other studies have addressed this issue at a national level but, as we know, China is a vast country with regional disparities and national-level policies need to be adapted to incorporate regional characteristics before their implementation. In addition, many of the previous studies have used a bottom-up approach that assessed regulations and technology innovation in the power sector only, ignoring the interrelationships of different economic activities (industrial sectors, household and government) and the state of national economy-energy-environment system. A regional top-down model takes into consideration the inner interrelationships between these sectors resulting in a comprehensive understanding of the mechanisms of regulation and technology innovation. Therefore, in this study we focus on a regional level and utilize a dynamic model that can simulate the interrelationships between different sectors and comprehensively evaluate the effectiveness of the proposed policy. Tools such as input–output (I/O) and Computable General Equilibrium (CGE) are widely used to analyze government policies (see for instance Stoven and Whalley, 1992; Wiedmann et al., 2007). In theory CGE models could reduce the shortcomings of I/O models because they more realistically represent relationships in the economy and thus more accurately project the impact of a new activity on the whole economy (Berck and Hoffmann, 2002). However data requirements for CGE models are enormous requiring the same type of data as I/O models and much more (Cansino et al., 2014). Although the complex parameters (such as prices for every good, every service, consumption patterns, inter-industry purchasing and so on) included in the CGE model significantly improve the model's ability to adapt to exogenous changes in the economy, it also substantially increases the data requirements (Charney and Vest, 2003). That is why CGE models are mostly applied at national level studies. In the case of China, for instance Dai et al. (2011, 2012) employ a CGE model to study China's future energy policy and in the model they consider the industrial structures and the change in socio-economic conditions over time. In studies like this it is easier to obtain data such as input–output tables, future population forecasts, etc. For regional studies, on the other hand, much of the data for CGE models are not regularly collected. For a regional area such as Chongqing, since the forecasting data is difficult to obtain and the uncertainties are much higher than the national data (for example, population projections) it is more practical to use I/O model. Additionally, this study uses Chongqing's latest I/O table available (2010) to forecast socio economic and environmental indicators for the period 2010–2025 (the short time period of study and latest data can improve the accuracy of forecast indicator as the industrial structure and many socio-economic conditions change in the time horizon).

The purpose of this paper is to estimate the socio-economic and environmental impacts derived from a policy of regional regulation and promotion of advanced technological innovation in the energy sector by means of a carbon tax/subsidy system through a regional dynamic input output model. Simulation results allow policy makers and the public to understand the potential for air pollution and GHG emission reduction and the necessity for technology innovation in other sectors. The study suggests that introducing more flexible regional regulations combined with promotion of technology innovation in the energy sector will likely maintain a moderate economic growth and promote energy conservation and pollution reduction. This research also contributes to improving public policy design for implementing air emissions reduction policies that can guarantee a sustainable economic development.

The rest of the paper is organized as follows. Section 2 introduces the potential of fossil fuel energy technology options in the future. The model framework including mathematical equations in the dynamic I/O model and scenarios description is illustrated in Section 3; and the main results as well as discussion are presented in Section 4. Finally, the conclusion and policy implications are presented in Section 5.

2. Global trends in power generation: coal dependency and the role of cleaner technologies

Coal is the world's most abundant and widely available fossil fuel, with proven reserves reaching nearly 1 trillion tons (IEA, 2010a). Given these characteristics, coal has been a key component of the electricity generation mix worldwide supplying more than 40% of the world's electricity (IEA, 2010a). Moreover, since the energy needs of the developing world will continue growing coal will remain an important component of the power generation mix in the future (IEA, 2010a; IEA, 2010b).

Efficiency is a very important performance parameter in coal-fired power generation because it provides benefits such as (IEA, 2011):

- CO_2 emission reduction where 1% overall efficiency improvement can reach up to 3% CO_2 emissions reduction;
- conventional pollution emission reduction; and
- Resource conservation.

Chinese energy supply relies heavily on coal as the primary energy fuel. Sub-critical technology (SUB), which is less energy efficient and more polluting, accounts for more than 70% of the coal power generation in China (Platts, 2011). Recently advanced coal power generation technologies including supercritical (SUP) and ultra supercritical (USC) have received special attention due to their high energy efficiency and low emissions. Integrated Gasification Combined Cycle (IGCC) has also gained popularity due to its high efficiency and low carbon emissions characteristics. In addition to power generation from cleaner fossil fuels, Carbon Capture and Storage (CCS) is gaining attention in recent years. CCS is a series of technologies and techniques that capture CO_2 from combustion or industrial processes, then transports it via pipelines or ships and finally stores it underground. Some studies suggest that CCS will be a key option to cut CO_2 emissions in the mid to long term accomplishing up to one sixth of the CO_2 emissions reduction in 2050 and 14% of the cumulative emissions reductions between 2015 and 2050 (IEA, 2012).

The main alternatives to improve both energy efficiency and reduce emissions based on fossil fuel power generation are