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Can China achieve its 2020 carbon intensity target? A scenario analysis based on system dynamics approach

Bowen Xiao*, Dongxiao Niu, Xiaodan Guo

School of Economics and Management, North China Electric Power University, Hui Long Guan, Chang Ping District, Beijing 102206, China

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ABSTRACT

Since Chinese government put a target to decrease carbon intensity 40–45% in 2020 than that of 2005, a series of emission mitigation measures has been implemented. Against this backdrop, we established a system dynamics model to investigate the energy consumption, CO_2 emission and mitigation options in China. The results show that the carbon intensity will reduce by 22.68%, 26.84%, 43.77%, and 46.65% in BaU (Business as usual), NEP (New energy policy), CTP (Carbon tax policy) and IP (Integrated policy) scenarios in 2020 compared with 2005. Obviously, Chinese government can accomplish the target under CTP and IP scenarios. Moreover, the "inflection point" in CTP and IP scenarios reveals the decision-making process between tax burden and emission reduction behavior. A brief analysis of interactive effect is accomplished by equilibrium theory and simulation results. It shows that the interactive effect of two policies, which act on the same object with same action direction, is weaker than the aggregation of two separated effects, whereas it is larger than any individual effect. In a nutshell, these findings are helpful for policymakers to optimize their policy decision-making to cut CO_2 emissions.

1. Introduction

Although the Chinese people are proud of the rapid development of the economy, the heavy reliance on fossil fuels causes severe environmental problems. In 2005, China's carbon emissions surpassed the United States for the first time. Several reports which were issued by IPCC (Intergovernmental Panel on Climate Change) pointed out that climate change is closely related to human activities (Edenhofer and Seyboth, 2013; Michael, 2015), and the IPCC fifth assessment report confirmed that the global CO_2 concentration has risen to the highest level, the greenhouse gas emissions have become the main reason of global warming since the mid-20th century.

There are growing calls here to reduce pollutant emissions. Countries have committed to participate in international efforts to combat climate change (Zhu et al., 2014). Hence, mounting pressure from the international requires that a series of emission reduction targets and emissions mitigation policies should be implemented by the Chinese government. In recent years, China has begun to attach importance to by-products caused by roaring economic growth (Huisingh et al., 2015). Chinese government declared an emission reduction target in United Nations Climate Change Conference in Copenhagen that the CO_2 intensity in 2020 will be reduced by 40% to 45% compared to 2005. Following the commitments, a series of measures was implemented to achieve the mitigation target (Liu et al., 2015a,b). Among those measures, the most profound policies are carbon tax policy (Liu and Lu, 2015) and the new energy legislation and development policy (Zhang and Yan, 2015).

Along with the growth awareness of energy conservation and emissions reduction, the State Council of China has promulgated many policies to guide the structure transformation of coal-fired power into new and efficient power. *"Energy development strategic action plan 2014–2020"* is the overall strategy and action plan of energy development over a period of time in the future. Moreover, a series of new energy planning, such as *"Renewable energy medium and long-term development plan"*, *"The 12th five-year plan of renewable energy development"* were implemented. Furthermore, the legislative package towards green taxation system is another effective way to curb pollutants emissions and attract substantial attention. Carbon tax, as a part of the environmental tax, can exert influence on market mechanism, thus cutting the CO_2 emissions eventually. On December 2, 2013, the carbon tax scheme has been submitted to the State Council, and on July 9, 2015, *"The environmental protection tax law (Exposure draft)"* has been finished, which

* Corresponding author.
E-mail address: 15353638996@163.com (B. Xiao).

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cleared the tax-for-fees reform. The carbon tax policy is just around the corner.

Recently, the government indeed took steps to achieve international commitments and made a remarkable success at the end of the 12th five-year. It is necessary to measure the emission condition in the last five years. Thus, this paper conducted the system dynamics model and scenario analysis to comprehensively investigate the development of economy, the energy consumption and CO_2 emissions under different scenarios in 2005–2020. In this way, this paper makes several contributions to previous studies in four folds, from both practical and theoretical perspectives: (1) A policy package consisting of carbon tax and new energy policy is analyzed as a possible solution to help Chinese government achieve its 2020 carbon intensity target; (2) The general equilibrium theories combined with simulation results are applied to analyze the interactive effect of policy package; (3) Additionally, in order to compare the different policy transmission mechanism, the individual policy effects are measured separately; (4) At last, we answered the question “How might China achieve its 2020 CO_2 emissions target?” and provided policy implications for Chinese government to achieve its target.

2. Literature review

China is undeniably the largest developing country, and it bears the expectations of the whole world, notably as regards reducing carbon emissions (Tang et al., 2015). Therefore, it attracted a wealth of attention both at home and aboard. In the context of pursuing climate policy targets for 2020, a number of economists exceptionally value market-based climate management tools, to strive to minimize the economic costs in realizing the given emission reduction goals. The relevant literatures can be separate into three categories based on the modeling approach.

The top-down models, focusing on the relationship between national economy departments, energy production and consumption, are widely applied for macro economy energy analysis and energy policy planning research. The typical top-down model mainly contains CGE (Computable General Equilibrium), macroeconometric model, system dynamics model. The CGE was initially put forward by Walras (1954). Recently, the CGE model emerged rapidly and there were increasing number of researches focused on China (Dai et al., 2016; Guo et al., 2014). Liang and Wei (2012) set up a model named CEEPA to examine the distributional impacts of mitigating CO_2 through a carbon tax. Liu and Lu (2015) explored the impact of a carbon tax and different tax revenue recycling schemes on China’s economy. In addition, National Institute for Environmental Studies of Japan established AIM/CGE model, which is widely accepted to assess the impacts of CO_2 mitigation measures (Thepkhun et al., 2013; Li et al., 2015). The macroeconometric model (Tinbergen, 1974) such as Mercure et al. (2014) presented an analysis of climate policy instruments for the decarburization of the global electricity sector in a non-equilibrium economic and technology diffusion perspective. And system dynamics model (Forrester, 1969, 1971) such as Saysel and Hekimoğlu (2013) explored the options for carbon dioxide mitigation in Turkish electric.

Top-down models evaluate the system from aggregate economic variables, whereas bottom-up models consider technological options or project-specific climate change mitigation policies (Nakata, 2004). Recently, the bottom-up models are also widely applied in energy-economy-environment (3E) system analysis, which primarily includes LEAP, POLES, MARKAL, AIM/End-use, MESSAGE models. For example, Tsai and Chang (2015) analyzed the effects of nine long-term carbon reduction pathways in Taiwan by MARKAL model. Amorim et al. (2014) set up TIMES (The integrated MARKAL-EFOM system) to design the low carbon roadmap for 2050 in Portugal. Ates (2015) explored the energy efficiency and CO_2 emission reduction potential of the iron and steel industry in Turkey by LEAP. Huang et al. (2011) applied LEAP model to compare future energy demand and supply patterns, as well as greenhouse gas emissions, for several alternative scenarios of energy policy and energy sector evolution. Moreover, the MESSAGE and AIM/End-use are also applied to evaluate the energy savings and emission reductions (Capros and Vouyoukas, 2000; Wen et al., 2015).

The hybrid model, as the name implies, is based on the coupled linking between top-down and bottom-up models. On the whole, hybrid methods combine the advantages of top-down and bottom-up methods. The most popular hybrid model around the world mainly includes NEMS, IPAC, and other models linked top-down and bottom-up such as MESSAGE-MACRO, MARKAL-MACRO. NEMS, whose full name is National Energy Modeling Systems, is developed by U.S. Energy Information Administration and widely accepted by research institutes. Morrow et al. (2010) examined different sector-specific policy scenarios for reducing GHG emissions and oil consumption in the US transportation sector under economy-wide CO_2 prices. Moreover, consulting groups, such as McKinsey & Company, also used the NEMS model to analyze the U.S. energy-economy (Choi et al., 2009; Creyts et al., 2007). What is noteworthy is that the coupled linking can be divided into “hard link” and “soft link”. The MESSAGE-MACRO is a typical “soft link” and the MARKAL-MACRO is “hard link” (Nakata, 2004). The main difference is that MARKAL-MACRO is a fully integrated single model, whereas MESSAGE-MACRO is solved by running each part separately and iterating their inputs until consistency between the macroeconomic part and the energy part is reached (Messner and Schrattenholzer, 2000). Moreover, Dai et al. (2016) discussed the linkage between top-down and bottom-up methods and selected soft-linking to “narrow the gap” between results from top-down and bottom-up approaches

Bottom-up methods perform economic analyses poorly, which can generally overestimate the potential for economic progress (Nakata, 2004). The top-down methods seem to be more suitable for our aim and analysis. Of these approaches, the system dynamics (SD) model is suitable for modeling dynamic environments on a muti-dimensional scale with time-dependent variables, such as energy-economy-environment system (Ford, 1999; Shih and Tseng, 2014). Currently, SD has been widely applied in various research fields, including societal and economic systems research (Ge and Fan, 2013), ecosystem research (Tsolakis and Anthopoulos, 2015), transportation research (Liu et al., 2015a,b) and so on. For instance, in the field of energy management, SD was widely applied to national energy policy-making and evolution (Shih and Tseng, 2014; Barisa et al., 2015; Jeon et al., 2015; Qudrat-Ullah, 2013).

The development of energy consumption, CO_2 emissions and mitigation options is a complex dynamic evolution process, which concerns many fields. SD approach takes into account time delays and feedback loops, showing a good performance in understanding and exploring the feedback mechanism in complex systems (Nastaran and Abbas, 2013). It is popular in analyzing energy policy as it is able to link observable patterns of a system with micro-level structure and decision making process. Despite the previous literatures’ contributions, the influencing mechanism between variables are not explicitly stated, especially the transmission mechanism of policy effect. In addition, there has been no effort toward cumulative and interactive effect of policy package. Given this, we established a comprehensive system dynamics model to investigate the energy consumption, CO_2 emissions and mitigation options in China. Then we analyzed the interactive effects of different policies and the transmission mechanism of policy effects in detail based on the simulation results.