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Green growth: The economic impacts of large-scale renewable energy development in China

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HIGHLIGHTS

- We assessed the economic impacts of renewable energy (RE) development in China.
- Using a CGE model with novel improvement in investment behavior of power sector.
- Large-scale RE development by 2050 would not incur a significant macroeconomic cost.
- Developing RE benefits the upstream industry and have environmental cobenefits.

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ABSTRACT

This study assesses the economic impacts and environmental co-benefits of large-scale development of renewable energy (RE) in China toward 2050 using a dynamic computable general equilibrium (CGE) model with distinguished improvements in the power sector. Two scenarios are constructed: a reference scenario assuming conventional development of RE and an REmax scenario assuming large-scale RE development by tapping China's RE potential. The results show that large-scale RE development would not incur a significant macroeconomic cost. On the contrary, it would have significant green growth effects that benefit the growth of upstream industries, reshape the energy structure, and bring substantial environmental co-benefits. If the share of RE reaches 56% in the total primary energy in 2050, then non-fossil power sectors will become a mainstay industry with value added accounting for 3.4% of the GDP, a share comparable to other sectors such as agriculture (2.5%), iron and steel (3.3%), and construction (2.1%). In RE max scenario, the large scale RE development will stimulate the output worth of $1.18 trillion from other RE related upstream industries and create 4.12 million jobs in 2050. In addition to economic benefits, it could substantially reduce the emissions of CO_2 and air pollutants such as NO_x, SO_2.

1. Introduction

Many countries regard energy efficiency improvement and the development of renewable energy (RE) as two of the most effective measures for addressing environmental and climate challenges [1,2]. Improved energy efficiency can reduce total energy consumption and emissions of greenhouse gasses (GHGs) and air pollutants while ensuring economic growth. Meanwhile, the substitution of fossil energy with RE can result in a cleaner and low-carbon energy structure, particularly in light of the abundant resource potential of RE [3,4]. The rapid market penetration of renewable energy in recent years suggests that a fundamental revolution will come in the next decades and that RE may gradually become the main energy source.

Energy has supported China's economic growth in the past three decades. However, environmental destruction and China's limited fossil fuel resource endowment pose growing challenges as China becomes the world's largest energy consumer and producer. To compound the challenge, China faces increasing international pressure to control its rising GHG emissions. In 2009 China responded by announcing an ambitious goal of lowering its carbon intensity in terms of GDP and increasing its share of non-fossil fuels [5]. In the latest submission of Intended Nationally

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Determined Contributions to the United Nations Framework Convention on Climate Change (UNFCCC), China pledged to increase the share of non-fossil energy in primary energy consumption to about 20% by 2030 [6]. These commitments have been reflected in China's actual policymaking. By the end of 2012, the total installed capacity of RE power was 323 GW, accounting for 28.2% of the total power generation capacity, 19.9% of the total power generated and 9.0% of the total primary energy supply. In the long-term RE could change from a supplementary energy to a main energy source (CAE [7], CAE [8].

Developing RE may affect the economic development. Previous studies indicate that the formulation of a long-term energy roadmap and strategy requires ex-ante analysis to evaluate the technological costs and economic costs of different pathways [2,9,10]. Some studies explored the technical feasibility of achieving high share of RE in the energy system in Ireland [11], Portugal [12], Denmark [13]. However, they did not analyze the full macroeconomic impacts of such high penetration of RE. By applying econometric models, some studies analyzed the relationship between renewable energy development and economic growth in some specific countries, e.g. Turkey [14], Germany [15,16], USA [17] and Brazil [18], or multi-countries such as Sub-Sahara African countries [19], emerging market economies [20], Central America [21], Latin American countries [22], low-, middle and high income countries [23], and 116 economies [24]. Ocal and Aslan [14] argue that the messages from the country-specific and multi-country studies are inconsistent, and there is no agreement on the existence or the direction of causality between renewable energy consumption and economic growth.

Computable general equilibrium (CGE) model is widely used to assess the impacts of RE development on macroeconomy, energy consumption and emissions. Sue Wing [25], Sue Wing [26] incorporated technology detail into the electricity sector of a CGE model and tested how the mitigation cost would change compared to the conventional CGE model without technology details in the power sector. Dai et al. [27] constructed a hybrid CGE model to assess the role of China's non-fossil energy plan on achieving its Copenhagen Commitment. Böhringer et al. [28] argued that RE development in Germany had quite limited prospects for employment and welfare gains. Rivers [29] used a three-sector general equilibrium model to analyze the impact of renewable electricity support policies on the rate of equilibrium unemployment in the US, and found that RE support policies would lead to higher rates of unemployment. By using a hybrid CGE model, Fortes et al. [30] showed that the relation between renewable energy development and economic growth is not straightforward. Ruamsuke et al. [31] developed a global CGE model incorporating a bottom-up module for power generation sector and used it to analyze the energy and economic consequences in nine Southeast Asian countries under the uncertain global climate constraints. Cai et al. [32] developed global hybrid CGE model with the bottom-up engineering details of energy production, as an application, this model was used to assess the U.S. clean power plan [33]. Fujimori et al. [34] hard-linked a global CGE model with an energy end-use technology optimization model. Dai et al. [35] soft-linked a hybrid CGE model with bottom-up TIAM model to project the future regional energy and emissions of China toward 2050. Hwang and Lee [36] incorporated the bottom-up details of the power generation technology in a top-down type CGE model for Korea, and analyzed Korea's electricity industry reform.

Based on the review of the literature we found two research gaps which are addressed in this study. Firstly, in the econometric studies RE is treated as a whole, and the effects by RE type (hydro, solar, wind etc.) are not differentiated. Secondly, the hybrid CGE models with power technology details have been used to analyze the impacts of RE development on carbon emissions, carbon mitigation costs, or the impacts on the aggregate economic indicators such as GDP growth; however, no economic impacts at the sectoral level are identified. This may be the reason for the mixed message that there is no agreement on causality between renewable energy consumption and economic growth. Consequently, none of the above studies has provided an in-depth assessment of the impacts of long-term and large-scale RE development on the economy, especially at the sectoral and RE type levels. The present study seeks answers to some fundamental questions in this context. First, will the large-scale development of RE cause a significant negative shock to the macro economy? Second, how will the development of RE affect other sectors? Third, how will RE development affect employment, environmental emissions, and carbon emissions? Since energy plays a vital role in all economic sectors and aggressive energy policy will have widespread effects across the whole economic system, we used a CGE model with distinguished modifications for the power sector to capture the effects of RE development across all economic sectors.

The remainder of this paper is organized into five sections. Section 2 introduces the model structure with a special focus on how the power sector is represented. Section 3 specifies two scenarios considering different levels of RE development. Section 4 demonstrates how RE development can be expected to impact future economic development, energy demand, and the environment. Section 5 discusses the results and provides policy recommendations. The paper ends with conclusions in Section 6.

2. Treatment of the power sector in the renewable energy CGE model

The CGE model applied in this study is a multi-sector, recursive dynamic CGE model jointly developed by the National Institute for Environmental Studies (NIES, Japan), China National Renewable Energy Center (CNREC), and Energy Research Institute of National Development and Reform Commission (ERI of NDRC, China). The model covers 41 economic commodities and corresponding sectors, and the eight power-generation technologies listed in Table A1. This CGE model is solved by MPSGE/GAMS [37] at a five-year time step. The key technical features of the conventional module of this model are introduced in the Appendix. Most important, fundamental improvements in modeling the technologies for generating power non-fossil energy allow this CGE model to better assess the economic impacts of renewable energy development.

2.1. Disaggregating the power sector in input–output table

In traditional CGE models, electricity production is a single sector without disaggregation into different technologies. Hence, our first step is to disaggregate the single power sector in China's conventional input–output table into input–output data for eight technologies (coal-, oil-, gas-fired power, nuclear, hydro, wind, solar PV and biomass power). We follow the methodology developed by Sue Wing [26] and use data that have been used earlier to assess China's non-fossil energy plan toward 2020 [27].

2.2. Production function

The power sector is modeled by three fossil-firing technologies (coal, gas and oil, Eq. (2-2)) and five non-fossil technologies (nuclear, hydro, wind, solar PV, and biomass, Eq. (2-3)). Different power-generation technologies compete in the manner shown in Eqs. (2-1)–(2-5). Each power plant aims to maximize its profit π_{tech} (Eq. (2-1)), subject to the CES production technology (Eq. (2-2)). Fossil-fired power generation requires the energy input of coal, fuel oil, or gas, and the unit costs of labor and investment are lower.