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What is the optimal power generation mix of China? An empirical analysis using portfolio theory

Shuang Zhang[a,b], Tao Zhao[a], Bai-Chen Xie[a,b,*]

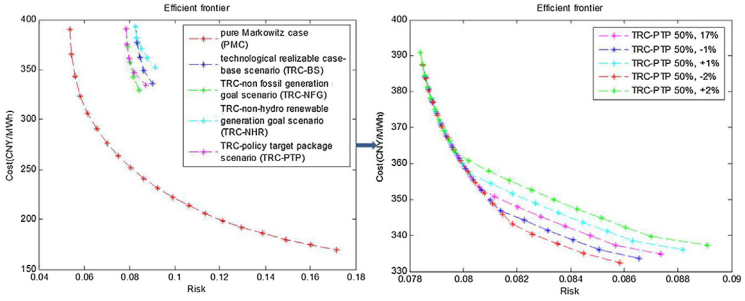
[a] College of Management and Economics, Tianjin University, Tianjin 30072, China
[b] Key Laboratory of Efficient Utilization of Low and Medium Grade Energy (Tianjin University), Ministry of Education, Tianjin 300072, China

HIGHLIGHTS

- China's optimal power generation mix of 2030 is explored using portfolio approach.
- Grid availability is used to reflect the risk for non-fossil generation technologies.
- Fossil fuel forms have no priorities when considering technological restrictions.
- Positive effects exist for a non-fossil generation goal or a policy target package.

GRAPHICAL ABSTRACT

In exploring China's optimal power generation mix, we employ scenario analysis to investigate the influence of cost, risk factors, technological development restrictions and different policy targets. Under the technological realizable case, the risk minimization portfolio remains unchanged while the cost and risk of cost minimization portfolio increase when the policy target package improves.



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ABSTRACT

This paper employs portfolio theory to explore China's optimal power generation mix in 2030, which considers the possibilities of technological developments, and the government's non-fossil generation and non-hydro renewable generation policy targets. The aim of this paper is to investigate China's efficient generation portfolios by comparing the portfolio costs, risks, efficient frontiers, and diversification levels under different cases and scenarios. The results show that fossil fuel generation technologies have no advantages when considering the technological restrictions. In addition, various preferences for non-fossil generation technologies are influenced greatly by the goals of pursuing cost or risk minimization and different policy targets. Positive effects exist for a non-fossil generation goal or a policy target package from the perspectives of minimizing cost and risk, as well as for improving the diversification level.

1. Introduction

As a pillar industry of the national economy and a key sector for reducing emissions, the power industry has a crucial role in achieving economic development and meeting the emissions reduction targets proposed in policy documents [1]. As shown in Fig. 1, although the economic growth rate of China has declined recently, it has still remained above 6.5%. Meanwhile, there was a growing trend for the total power generation, which increased from 1654.20 TWh in 2002 to 6053.10 TWh in 2016 [2]. During this period, China made remarkable

* Corresponding author at: College of Management and Economics, Tianjin University, Tianjin 30072, China.
E-mail address: xiebaichen@tju.edu.cn (B.-C. Xie).

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Nomenclature

Acronyms

LEAP	long-range energy alternative planning
CGE	computable general equilibrium
PPOM-CHINA	power planning optimization model of China
EU	European Union-27
IEA	International Energy Agency
CCS	carbon capture and storage
EF	efficient frontier
RM	risk minimization
CM	cost minimization
NFG	non-fossil generation
NHR	non-hydro renewable generation
HHI	Herfindahl–Hirschman index
SWI	Shannon–Wiener index
PMC	pure Markowitz case
TRC	technological realizable case
TRC-BS	technological realizable case-base scenario
TRC-NFG	technological realizable case-non fossil generation target scenario
TRC-NHR	technological realizable case-non hydro renewable generation target scenario
TRC-PTP	technological realizable case-policy target package scenario

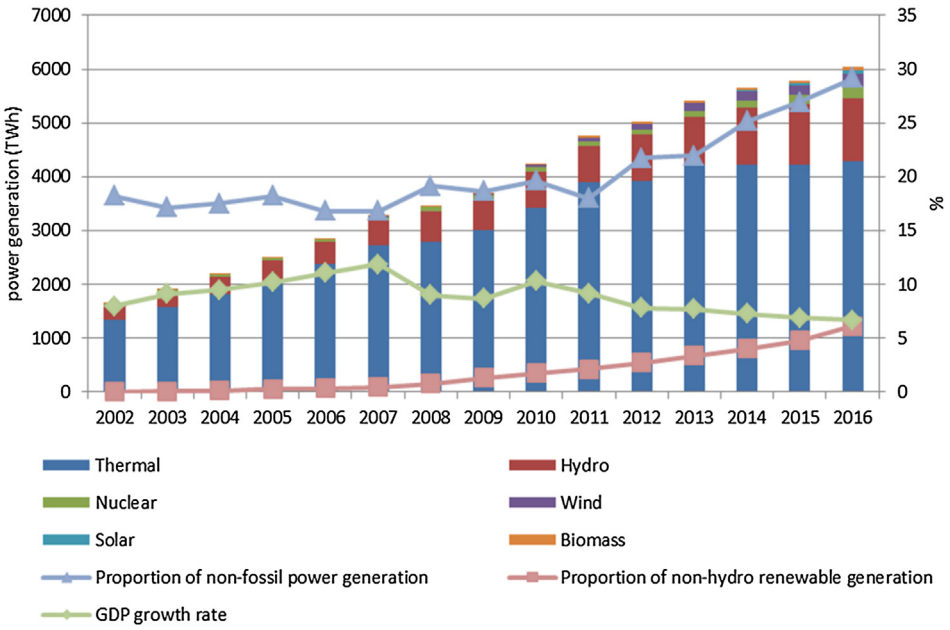

Fig. 1. Changes of power generation and economic growth rate in China during 2002–2016. Source: China Electric Power Yearbook 2003–2017 [2] and China renewable energy industry development report 2016 [3].

progress in the development of clean power generation, where the proportion of non-fossil generation increased from 18.25% to 29.15%, and the proportion of non-hydro renewable generation increased from 0.05% to 6.12% [2]. Particularly, solar power increased rapidly in recent years, with an annual growth rate of 124.40% during the period of 2010–2016, while hydropower, nuclear power, wind power, and biomass power had annual growth rates of 9.35%, 19.07%, 30.41%, and 16.96% respectively [3].

Despite these achievements, China must still overcome many new challenges. Coal-fired generation still has an absolutely dominant position [4], where it supplied 65.21% of the total power in 2016 [5]. Because the fuel is mainly sourced from the domestic raw coal supply and is less dependent on the import, the coal price is determined by the domestic market and in turn greatly affects the supply and demand conditions. Therefore, the over-reliance on coal-fired generation may make the power system highly vulnerable because a slight fluctuation in the coal price could affect the security of the power supply significantly [6]. The growth rate of power consumption has declined in the past decade, but the absolute amount of power demand is likely to increase further in China due to the growing economy, which also exacerbates the risk of excess coal-fired generation. In addition, the coal price is always volatile in the short-term, which leads to a high level of uncertainty regarding the production costs for coal-fired enterprises and increasing the risk related to fuel costs. In terms of the environment aspect, the high proportion of coal-fired generation leads to large amounts of greenhouse gas emissions and severe environmental pollution [6], thereby highlighting the environmental costs related to power generation.

Compared with coal-fired generation, gas-fired generation is generally considered greener and cleaner. However, the known reserves of natural gas in China only accounted for 2.9% of the world's recoverable reserves in 2016 [7], which limits the possibility of substituting gas-fired generation for coal-fired generation. Moreover, due to the widening gap between limited resource reserves and the rapid growth in demand, the reliance on natural gas import in China increased to 36.72% in 2016 [7]. This overdependence increases the cost of gas-fired generation, and it also makes the domestic gas price highly vulnerable to fluctuation in the international market, thereby increasing the risk related to fuel costs for gas-fired enterprises. Therefore, the development of gas-fired generation in the future requires further study and discussion.

In addition to different forms of fossil fuel generation, the clean generation technologies developed in China must address some new challenges. Due to the limited resource endowment and grid availability, the emergence of “wind and solar power curtailments” has recently become a critical concern, which has led to wasted investment in clean power. In 2016, the average rates of wind and solar power curtailments in the five northwest provinces reached 33.34% and 19.81%,