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Analyses of CO_2 mitigation roadmap in China's power industry: Using a Backcasting Model

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HIGHLIGHTS

- Backcasting Model is used in CO_2 mitigation roadmaps in China's power industry.
- CO_2 mitigation targets in power industry are feasible and practical in China.
- Policies for technologies are put forward according to the results.

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ABSTRACT

CO_2 mitigation roadmap is important for the total amount control of CO_2 emission. However, as the connection and priority are being absent in some present CO_2 mitigation roadmaps, technology policies may sometimes be invalid or unable to reach the mitigation target. Therefore, this research explores an innovative method of Backcasting Model (BCM) which is helpful to solve the problems. Since the Power industry is the essential department to realize the peak target of greenhouse gas emission in 2030 for China, the research takes the power industry as an example to analyze the CO_2 mitigation roadmap based on BCM. According to 2020 and 2030 mitigation targets, this research selects 13 power generating technologies and calculates their implementation scales. Concrete timelines of 70 direct and indirect CO_2 mitigation measures related to these technologies are derived, in which CO_2 mitigation roadmaps from BCM are distinguished in terms of technique choices and implementation periods. Moreover, various types of accelerating measures provide different acceleration rates to the related direct measures. This study evaluates the feasibility and practicality of realizing mitigation targets by the 2020 and 2030 deadlines under present technologies and policies, and introduces options and roadmaps with high enforceability through the Backcasting Model.

1. Introduction

1.1. Current situation of China's CO_2 mitigation

To reduce CO_2 emissions, the Chinese government has put forward explicit CO_2 emissions constraints. *The Thirteenth Five-Year Plan* requires the proportion of non-fossil energy in primary energy consumption be increased to about 15% of the total in 2020. In addition, energy intensity should be decreased by 15%, and CO_2 intensity should be reduced by 18% before 2020 [1]. Current technologies related to energy conservation and CO_2 mitigation should also get government support.

The power industry is responsible for large amounts of energy consumption [2], making it a main target for CO_2 emissions reductions. It was estimated that China's thermal power generation sector counted 50.19% of the carbon emissions in 2012 [3]. According to the data from China Electricity Council [4], in 2014, 67% of China's 1360.19 gigawatt (GW) power capacity came from thermal power generation. If the trends of power generation continue without changing industrial structure and technology, China's power industry CO_2 emissions will significantly increase. Therefore, it is essential to prioritize the power industry and target for absolute mitigation (total amount) instead of relative abatement (intensity) [5].

In conformity with China's current situation, this article selects the power industry as a case study, and aims to make suitable mitigation roadmaps to achieve important CO_2 emission reductions with high enforceability, utilizing the Backcasting Model (BCM).

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Abbreviations

BCM	Backcasting Model
BPG	Biomass Power Generation
CCS	Carbon Capture and Storage
CHP	Cogeneration of Heat and Power
HE	Hydroelectricity
IGCC	Integrated Gasification Combined Cycle
NP	Nuclear Power
PP	Photovoltaic power
RPU	Retrofit of established thermal Power Unit
USC	Ultra-supercritical
WP	Wind Power
WHP	Waste Heat Power Generation

1.2. Researches on technology roadmap

Technology roadmap is a general method for CO_2 mitigation. An industry technology roadmap, the most general time planning method for technology routes in specific industries, can be defined as an extracted look at the future in a chosen field of industry [6]. For most countries, effective technology measures are essential for CO_2 mitigation plans. Rasiah et al. assessed the low carbon scenarios for Malaysia via the "Empirical Regional Downscaling Dynamic Integrated model of Climate and the Economy" to reduce the climate damage [7]. Ashina et al. found out feasible pathways for Japan to reach a low-carbon society via backcasting methodology [8]. Doukas et al. designed a qualification roadmap for the building sector workforce in Greece [9]. Gallegos Rivero and Daim identified the barriers and solutions for cattle farming sustainability in Germany via technology roadmap approach [10]. Höglund-Isaksson et al., Hübler and Löschel, and Jonsson et al. explored the low carbon roadmap 2050 [11], decarbonisation roadmap 2050 [12], and energy security matters in energy roadmaps [13] for EU. In China's cases of CO_2 mitigation, some researchers focused on the technology roadmap for CCS. Xu et al. focused on the CCS technology roadmap in China's cement industry [14], Zhang et al. both from the aspect of economic and technological conditions [15], Tsai and Chang from the combination of technology and tax measures in Taiwan using MARKAL model [16], and Liu et al. from the whole perspective of CCS roadmap for China [17]. Some other researchers focused on the CO_2 mitigation in different industries [18–20].

Since the researches of mitigation roadmap are quite sufficient, this article mainly focuses on how to achieve the mitigation roadmap via backcasting model.

1.3. Paper structure

This paper is structured in four sections. Following this introduction, Section 2 provides an overview of BCM. Section 3 presents the application of BCM in the design of mitigation roadmaps in the power industry and discusses technology options. Section 4 summarizes the research on the basis of roadmap exploration and analysis and provides suggestions for utilizing BCM in the process of roadmap design.

2. Methodology and BCM model

2.1. Overview and feasibility of BCM

Contrary to forecasting, Backcasting Model (BCM) mainly focuses on roadmap exploration rather than confirmation of a designated proposition [21]. According to the definition of Robinson [22,23], BCM is "working backwards from a particular desired endpoint to the present in order to determine the physical feasibility of that future and what policy measures would be required to reach that point." Thus, the Backcasting Model can be divided into two steps [24]. In the first step, the expected targets are set up in which researchers describe the change of key technology parameters via a static model. The second step demands a dynamic model to work out constraint specification of the target year and make a mitigation roadmap out of the status quo to realize the target.

Some studies on backcasting focus on scenario analysis of energy and sustainable development. Researchers utilized this ideology to estimate the policy efficiency on renewable energy sources [25], to deal with issues in energy systems [26], to develop and select scenarios on strategic planning for city sustainable heating [27], to compare different scenarios for sustainable energy prices [28], and to transform into a sustainable society in terms of energy and ecology [29]. Present studies of BCM application in CO_2 mitigation mainly focus on the first step [8,30–36]. Despite different stages and constraints, they adopt the same method of describing scenarios, estimating CO_2 emissions, and calculating mitigation options to realize their goals. Nevertheless, researches on the second stage of setting concrete roadmaps from mitigation data seldom appear. In fact, in order to successfully achieve time target, policy makers should also make a series of prerequisite options as indirect measures to ensure the completion of direct ones, such as regulations, subsidies, and incentives, representing numerous categories and quantities of mitigation options and complicated relationships.

Therefore, the paper aims at researching on the second step of BCM to establish mitigation roadmaps in China's power industry by defining and quantifying the relationships between direct and indirect options. Data for the first step come from the National 973 Basic Research Program of China, the 12th Five-Year National Key Technology R & D Program by Tsinghua University [37], which another article was finished by our research group.

Dreborg proposed the feasibility of BCM for complex problems of dominant trends in need of major system changes, emphasizing externalities in a long time period [38]. In conformity with his theory above, this article discusses and designs a CO_2 mitigation roadmap in the power industry. Firstly, mitigation in the electricity sector is complicated since it influences many aspects of the economy. Moreover, referring to the strictness of mitigation objectives, only when the government makes major changes in technology and policy of power industry can we achieve the goals. Moreover, the energy consumption and CO_2 emission trends are of vital importance. Finally, CO_2 mitigation could be a long-term problem lasting for decades [36,39], while the time horizon of this study spans 20 years. Based on the situations mentioned above, it is suitable to utilize BCM in the exploration of a mitigation roadmap for the power industry.

2.2. Relevant concepts of CO_2 mitigation options

A "mitigation option" is an individual action reducing CO_2 directly or indirectly [40]. The process of mitigation can be described as an option that "starts" in certain year, and "penetrates" to the target level until "completion" when penetration finishes. Some options may "continue" after completion, while others stop. In this process, "penetration" means the diffusion and implementation of a technological policy, and in BCM, it is transformed into a number from 0 to 1, where "1" denotes maximum implementation. This transform allows all mitigation methods, including direct and indirect ones, to be measured under unified standards.

Mitigation options can be categorized as direct options and indirect options. A "direct option" is an action that can reduce CO_2 emissions in itself, while an "indirect option" is a measure that can be a prerequisite for or accelerator of direct options, but it cannot mitigate CO_2 emissions by itself. Indirect options can be divided into prerequisite options,