Energy Policy 122 (2018) 300–312

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Realizing China's goals on energy saving and pollution reduction: Industrial structure multi-objective optimization approach

Shiwei Yu[a,b,*], Shuhong Zheng[a], Xuejiao Zhang[a], Chengzhu Gong[a,b], Jinhua Cheng[a,b,*]

[a] School of School of Economics and Management, China University of Geosciences, Wuhan 430074, China
[b] Center for Resources and Environmental Economic Research, China University of Geosciences, Wuhan 430074, China

ARTICLE INFO

Keywords:
Energy saving and pollutant reduction
Industrial restructuring
Dynamic input-output model
Multi-objective optimization
Reduction goals

ABSTRACT

The issue of achieving the twin goals of energy saving and pollution reduction by 2020 is important for transforming China's approach to economic growth. From the perspective of source control, this study investigates the impact of industrial structure adjustment on China's energy saving and pollution reduction goals by developing a new energy-environmental-economy model, integrating a dynamic input-output model and multi-objective model. The three best solutions are screened from the Pareto-optimal front conforming to decision-makers' preferences. The results show that for China to successively achieve its set goals, it needs to modify and optimize the country's industrial structure. By optimizing its industrial structure, China's energy intensity of the three preferred solutions can be reduced by 17.7%, 17.0%, and 17.5% compared with 2015 levels, which helps to attain the target energy-saving goal. Emissions of COD, SO_2, and NO_x are significantly reduced; however, the reduction goal of NH_3-N is barely realized. In the restructuring process, GDP can be maintained at 6.6–6.8% from 2013 to 2020. These findings could alleviate local governments' concerns that implementation of stringent energy-saving and pollution-reduction mechanisms would harm their local economies.

1. Introduction

The universal adoption of sustainable development goals and the Paris Agreement in 2015 have marked milestones in multilateralism and environmental governance (Kowarsch et al., 2017). However, as the world's largest energy consumer and emitter of anthropogenic air pollutants (IEA, 2016; Lin et al., 2014), China is combating formidable challenges in transitioning its growth model. In 2015, China consumed 4.3 billion tce (tons of standard coal equivalents). China's industrial production created 254.2, 19.6, 1556.7, and 11.89 million tons of chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), sulfur dioxide (SO_2), and nitrogen oxides (NO_x), respectively (NBSC, 2016). A series of environmental problems (e.g., widespread acid rain, haze, and water eutrophication) continue to affect people's daily life and China's sustainable socio-economic development (Chen and Chen, 2017; Huang et al., 2014; Liu et al., 2016; Wang et al., 2018; Yu et al., 2015; Zhang et al., 2016). To change its mode of economic growth, protect the environment, and achieve sustainable development, China defined a series of mandatory energy-saving and pollutant-reducing strategies in the 11th Five-Year-Plan for the National Economy and Social Development (11th FYP) (2006–2010). The 13th FYP clearly indicated that by 2020, compared to 2015 levels, energy consumption per unit of gross domestic product (GDP) (regarded as energy intensity [EI]) should be reduced by 15%, and total emissions of COD, NH_3-N, SO_2, and NO_x reduced by 10%, 10%, 15%, and 15%, respectively. The issue of effectively implementing these energy saving and pollution control targets has emerged as an important agenda for both the Chinese government and academia.

The three aspects of the implementation strategies are source control, process management, and end-of-pipe treatment to achieve energy conservation and emission reduction. For decades, end-of-pipe treatments have played a critical role in environmental protection. For example, end-of-pipe treatment was the dominant factor for industrial SO_2 reduction in China from 1995 to 2014 (Yang et al., 2016). Similar effects of end-of-pipe treatment have also been reported for preventing increase in China's SO_2 emissions from 1998 to 2009 (Fujii et al., 2013) and for controlling emissions at the provincial level (Wang et al., 2017). In recent years, however, limitations of end-of-pipe treatment have been exposed showing that the treatment does not affect the production process itself but represents the last stage of a process where the stream is addressed and disposed of before being released into the environment (Hammar and Löfgren, 2010). In terms of co-control effectiveness and

---

* Corresponding authors at: School of School of Economics and Management, China University of Geosciences, Wuhan 430074, China.
E-mail addresses: ysw81993@sina.com (S. Yu), chengjinhua100@126.com (J. Cheng).

https://doi.org/10.1016/j.enpol.2018.07.034
Received 31 January 2018; Received in revised form 13 June 2018; Accepted 16 July 2018

cost-effectiveness, energy-saving technologies and structural adjustment measures are the most favored options, whereas end-of-pipe measures are least favored (Mao et al., 2014; Yang and Teng, 2018). Thus, China's commitment to reducing air pollutant emissions cannot be immediately fulfilled by relying on end-of-pipe abatement efficiency or a decrease in the intensity of pollutant generation unless industry structure (Yang et al., 2016; Zhang et al., 2015), technology level (Qin et al., 2017), or economic growth patterns (Huo et al., 2014) are reformed.

China's strategies of energy conservation and pollution reduction, included in its energy-environmental policies, changed from end-of-pipe treatments to source control, the latter has made substantial contribution toward reduced energy intensity and pollutant emissions (Fujii et al., 2013; Zhao et al., 2010). However, the problems of significant structural pollution and high-energy consumption remain serious. In 2015, for example, the proportion of energy consumed by the chemical industry, metallic and mineral products, and equipment manufacturing sectors represented 43.1% of China's primary energy consumption. Of all industrial emissions, SO_2 and NO_x emissions from petroleum processing, and chemical industry and metallic mineral products represented 87.2% and 93.5%, respectively. Intuitively, reducing the output of these sectors would reduce energy consumption and pollutant emissions from the source. Therefore, the contributions of industrial structural reforms in reducing pollution emissions have been investigated. For example, based on China's provincial panel data from 2006 to 2013, Ding et al. (2017) asserted that industry structure played a significant role in reducing NOx emissions after 2011. Hu (2016) reported that industrial structure adjustment canceled out nearly one-third of the CO_2 emissions caused by economic growth during the 12th FYP. Using the Asian-Pacific Integrated Model (AIM), Wen et al. (2015) concluded that industrial structural adjustment is the most important approach to reducing CO_2 emissions from the cement industry. Based on historical data, these studies provide strong evidence of the strategic role of industrial structure adjustment in energy saving and pollutant emissions reduction. However, these studies did not examine how to adjust the output of economic sectors in the future.

Reducing output is the key approach for realizing China's goal of energy saving and emissions reduction, established in the 13th FYP, through source control by adjusting industrial structure. However, merely reducing the output of these sectors will affect the stability of the entire economic system, likely resulting in reduced total output caused by the interrelationship between sectors. Clearly, reducing total output to achieve energy conservation and emissions reduction is not desirable for any country. It is necessary to consider the objective of economic growth and the constraints of input-output balance, sector production capacity, and energy supply in the process of structural adjustment. This consideration is evidently a constrained multi-objective decision-making optimization problem.

Multi-objective decision-making optimization is an integral part of optimization activities and has tremendous practical importance, since almost all real-world optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. Multi-objective optimization models usually support decision making in economy-energy-environment interactions (Cortés-Borda et al., 2015; de Carvalho et al., 2016; Feng et al., 2017; Yu et al., 2017). Thus, a few studies have discussed the effects of industrial structure reconstruction on energy saving from the perspective of multi-objective optimization. However, there are gaps in the research. First, the constraint of the sectoral dynamic input-output balance is ignored. A few studies consider the balance constraint (Chang, 2015; Fu et al., 2017) or assume a static input-output equilibrium balance (de Carvalho et al., 2016; Mi et al., 2015). This finding leads to optimized results for an industrial structure that cannot be improved through policy implementation because it does not consider the mutual restraint and interaction links across sectors. Second, the solutions are contextually specific and have a large degree of subjectivity because they transform multiple objectives into a single objective through linear weighting (H and Chou, 2010; Pascual-González et al., 2016; Nazarpour et al., 2017; Oliveira and Antunes, 2011) and fuzzy weighting (Fu et al., 2017) or by converting objectives into constraints (Yu et al., 2011). Moreover, this transformation process does not enable trade-off decisions because it cannot obtain a Pareto-optimal curve or surface. Finally, energy saving and pollutant reduction have not been considered simultaneously. Multi-objective models primarily focus on minimizing water consumption (Yu et al., 2011), energy consumption (Yu et al., 2016), or carbon emissions (Chang, 2015; Mi et al., 2015). These studies fail to discuss the feasibility of targeting declines in energy intensity and the four major pollutant emissions through industrial restructuring.

Therefore, the present study proposes a new energy, environmental, economy multi-objective model to explore the goal of achieving energy conservation and emissions reduction in the 13th FYP by adjusting China's industrial structure with considerable GDP growth. The objectives of the model include minimization of energy consumption and major pollutant emissions, and maximization of GDP. The Pareto-optimal front of the proposed model is obtained by applying the intelligent multi-objective solution algorithm, namely non-dominated sorting particle swarm optimization (NSPSO). The final solutions, that is, the output structure of the 17 sectors, are screened according to preference decisions.

The contributions of this study are multifold. First, from the perspective of source control method, namely industry restructuring, the present study has explored the issue of China's set goal of saving energy and reducing emissions by 2020. Second, the constraints of sectoral dynamic input-output balance and sector output capacity have been considered in the proposed multi-objective model, making optimization of industrial structure in the adjustment for operability. Third, energy saving and four major pollutant emissions reduction are simultaneously considered rather than just focusing on reducing energy consumption or single pollutant emissions. Fourth, NSPSO is applied to solve the proposed model instead of transforming multiple objectives into single objectives subjectively. Finally, the direction and intensity of industrial structure adjustment have been clarified in detail by analyzing the effects of the sectoral output changes on energy conservation and emissions reduction.

2. Methods and data

2.1. Model assumptions

The model proposed in this study is based on the following assumptions:

a) Technological progress from 2015 to 2020 continues to follow the pattern of change from 2005 to 2014. Consequently, exogenous variables involved in the model such as sectoral energy consumption per unit value added are based on historical data trend forecasting.
b) The basic assumptions of the input-output model are also valid in our study, in which one sector produces a specific homogeneous product, and the returns to scale remain constant.
c) Non-quantifiable factors such as market demand are not considered independent variables or constraints in the optimization of economic structure model because it is difficult to forecast future demand.

2.2. Objective functions

Our study focuses on China's realization of energy saving and pollutant reduction targets for 2020 from the perspective of industrial structure adjustment. In addition to energy conservation and emissions reduction targets, economic growth targets must be considered. Therefore, the following three objectives are included in the proposed model.