Applied Energy xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Impacts of emission reduction and external cost on natural gas distribution

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HIGHLIGHTS

- A new method based on external cost is developed to optimize gas distribution.
- Impacts of gas distribution on external cost and CO_2 emission are studied.
- Sensitivity analysis is been done to study the key parameters in the model.
- China is selected as case study, results provide insights to other studies about energy systems.

ARTICLE INFO

Article history:
Received 16 February 2017
Received in revised form 30 May 2017
Accepted 7 June 2017
Available online xxxx

Keywords:
Natural gas
Distribution optimization
External costs
Emission reduction

ABSTRACT

Natural gas, as a cleaner fossil fuel energy resource, is playing an increasingly important role in the future energy mix to achieve emission reduction target globally. In this study, a new method based on the external cost is developed to identify an optimal solution for natural gas distribution. China is selected for a case study. Both the economic cost and the external cost of pollutant emissions have been considered. The provincial distribution of natural gas and other energy resources is optimized with the aim to minimize both economic and external costs. Results show that the supply of natural gas should be prioritized for Beijing, Tianjin and Shanghai, owing to higher external costs and the optimized distribution can reduce the overall external cost by 4% in China. The optimization of natural gas distribution will also influence CO_2 emissions, therefore, the determination of the reduction target for each province should consider the external cost. Sensitivity study also shows that the minimum energy demand, the maximum natural gas supply and the minimum natural gas demand are the key parameters that impact the optimized distribution for each province.

1. Introduction

The environmental pollution due to the use of fossil fuel energy and the resulted climate change become more and more serious both in China and globally. China's emissions of pollutants have dramatically increased over the past decades along with the economic growth. Geographic differences in pollutant emissions have also resulted in different degrees of environmental and health issues. For instance, Beijing, the capital of China, suffers from serious air pollution especially during the winter, which has brought deep concerns on health or even life expectancy [1].

The utilization of clean energy instead of conventional energy to control the social, economic and environmental problems is essential. For example, emissions have been shown to be exponentially reduced when introducing renewable energy [2]. Renewable energy releases little carbon dioxide and other pollutants, with minimal impact on the environment. However, electricity production with renewables, such as wind or solar, often depends on the weather, resulting in intermittent energy supply.

To some extent, natural gas is regarded as a clean energy resource due to its lower emission compared with coal or oil. The availability of natural gas is widespread and can be supplied reliably through different forms such as pipeline gas, liquefied natural gas and compressed natural gas. Natural gas plays an important role in satisfying regional demand and transition to a low carbon economy [3]. The gap between the demand and supply of natural

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http://dx.doi.org/10.1016/j.apenergy.2017.06.005
0306-2619/

Nomenclature

Decision variables
$fuel_j$ distribution of energy j

Indices
i province
j energy resources
h pollutants
min minimum amount
spl supply
uti maximum utilization capacity

Acronyms
D demand
IC investment cost

Parameters
e emission factor
ecf external cost factor
E emissions
Ec external cost
n conversion factor
r^e CO_2 emission reduction

gas will be increasingly scrutinized, which highlights the significance of natural gas supply security [4]. In Europe, the increased utilization of natural gas has been pinpointed through the third EU gas directive as an important way for achieving emission reduction goal. The life cycle assessment methodology was used to analyze the type and origin of environmental impacts related to natural gas distribution networks [5]. At present, China's energy mix is reliant on fossils fuels, especially coal and oil. Natural gas accounted for only 4.9% of China's energy consumption in 2012. It will be significant for emission reduction by reducing coal consumption while increasing the utilization of renewable energy and natural gas [6,7]. The Chinese government plans to increase the natural gas share to around 10% by 2020 [8]. In order to develop natural gas market and promote natural gas use, policies on the utilization of natural gas have been proposed in 2012. These policies are formulated in order to encourage, guide and regulate the utilization of natural gas.

In this context, more research is initiated to promote natural gas utilization in different field and in different way. An efficient computational methodology was developed to reduce the impact that failure events in the natural gas (NG) network impose on the electricity market operation [9]. Besides, the adoption of natural gas vehicles could play a large role in improving air quality, so Kerzmann et al. [10] optimized fueling station based on traffic volume using a Monte Carlo algorithm to promote the use of natural gas. Tomasgard et al. [11] optimized the natural gas value chain to assist decision makers in a natural gas company. They focused on how to model natural gas transportation and storage and presented a stochastic portfolio optimization model for the natural gas value chain in a liberalized market. Considering the problem of designing a new natural gas distribution network while minimizing the total investment and operating costs, an integrated optimization model was developed to optimize the pipeline network, the location of compressor stations and the corresponding capacities, and scheduling in a multi-period planning horizon [12]. Chen and He [13] considered how to distribute natural gas in China based on efficiency and fairness objective, and showed that natural gas distribution could be more harmonious after optimization.

In most of the research on the utilization of natural gas, the common method applied is economic assessment. However, natural gas has additional social benefits. The concept of external cost is commonly used to reflect the impacts of pollutant emissions to measure social benefit. There have been some studies regarding external costs of energy utilization. For example, the negative externalities apart from carbon emissions are often neglected in most power generation planning models, but will still have an impact on health, biodiversity and crop yield [14]. The external costs about health of the electricity generation alternatives associated to a sugar ethanol factory were investigated by Casas-Ledon et al. [15]. The finding shows that accounting the external costs can essentially influence the structure and generation matrix of future power generation. External costs of electricity generation in China were also estimated under different scenarios of long-term energy and environmental policies. If both energy and environmental policies can be implemented, the gross external costs will decrease by 58.2% [16]. From the social point of view, the government seeks to internalize the external costs, and it would be an incentive for investors to behave more responsibly to the environment and society [17].

The objective of this study is to develop a new model to optimize natural gas distribution. Although, the external cost can play a significant role in the distribution optimization, existing studies on the optimization of natural gas distribution have rarely considered it. Most studies about natural gas distribution focus on transportation problem, consumption minimization or economic cost minimization. This paper presents a new method to optimize the regional distribution of natural gas based on comprehensive consideration of the external cost of natural gas and other fossil fuels. China has been used as a case study to investigate the impact of external cost on the optimized natural gas distribution. According to National Development and Reform Commission, a new policy on natural gas was released in 2012 emphasizing the consideration of various factors such as social benefits, environmental benefits and economic benefits arising from the utilization of natural gas in China [18]. Under such a circumstance, in order to further promote the use of natural gas, the new developed model will be applied to China to analyze the effects of external cost on the optimized distribution of natural gas.

2. Model description

2.1. Objective function

Fig. 1 shows the framework of the optimization model proposed in this paper. The objective function, as expressed by Eq. (1), consists of two terms: economic costs ($F_1(Q)$) and the external costs ($F_2(Q)$) of pollutant emission.

$$Min\ F(Q) = Min\ (F_1(Q) + F_2(Q)) \quad (1)$$

where Q stands for decision variables (provincial distribution amount) for each kind of energy resources. The constraints of the optimization are defined by energy utilization, which puts limitations on energy demand, supply and other requirements about energy utilization.

Please cite this article in press as: Yang X et al. Impacts of emission reduction and external cost on natural gas distribution. Appl Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.06.005