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Research article

An optimization model for regional air pollutants mitigation based on the economic structure adjustment and multiple measures: A case study in Urumqi city, China

Xiaowei Sun [a], Wei Li [a], Yulei Xie [b], Guohe Huang [a, *], Changjuan Dong [c], Jianguang Yin [d]

[a] MOE Key Laboratory of Regional Energy and Environmental Systems Optimization, S-C Resources and Environmental Research Academy, North China Electric Power University, Beijing 102206, China
[b] School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China
[c] China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[d] State Grid Shandong Electric Power Research Institute, Jinan 250002, China

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ABSTRACT

A model based on economic structure adjustment and pollutants mitigation was proposed and applied in Urumqi. Best-worst case analysis and scenarios analysis were performed in the model to guarantee the parameters accuracy, and to analyze the effect of changes of emission reduction styles. Results indicated that pollutant-mitigations of electric power industry, iron and steel industry, and traffic relied mainly on technological transformation measures, engineering transformation measures and structure emission reduction measures, respectively; Pollutant-mitigations of cement industry relied mainly on structure emission reduction measures and technological transformation measures; Pollutant-mitigations of thermal industry relied mainly on the four mitigation measures. They also indicated that structure emission reduction was a better measure for pollutants mitigation of Urumqi. Iron and steel industry contributed greatly in SO_2, NO_x and PM (particulate matters) emission reduction and should be given special attention in pollutants emission reduction. In addition, the scales of iron and steel industry should be reduced with the decrease of SO_2 mitigation amounts. The scales of traffic and electric power industry should be reduced with the decrease of NO_x mitigation amounts, and the scales of cement industry and iron and steel industry should be reduced with the decrease of PM mitigation amounts. The study can provide references of pollutants mitigation schemes to decision-makers for regional economic and environmental development in the 12th Five-Year Plan on National Economic and Social Development of Urumqi.

1. Introduction

Environmental pollution has been a global problem for many decades and is associated with adverse effects on human health and people's life quality. Especially air pollution (e.g. haze weather, photochemical smog, and acid rain) might not only result in the living environment damage and even the whole ecology destruction, but also could lead to some diseases related to the skin, breath and cancer, which has affected the normal life of people severely. In addition, emission amounts of pollutants (e.g. SO_2, NO_x and PM) have increased greatly with the rapid development of the economy. Moreover, owing to the unreasonable industry structures and the ineffective pollution management measures extreme weather has appeared frequently, which aggravated the environmental pollution and the harm to the health of people (Liu et al., 2012; Gough et al., 2014; Tao et al., 2014). For example, in China, there appeared eleven serious and wide-range haze weather, most of which happened in November and December. Particularly, the haze episode, which happened on November 27th to December 1st, was the most serious haze weather and was characterized by strong

* Corresponding author. MOE Key Laboratory of Regional Energy and Environmental Systems Optimization, S-C Resources and Environmental Research Academy, Faculty of Engineering, North China Electric Power University, Beijing 102206, China.
E-mail address: huang@iseis.org (G. Huang).

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intensity, wide range, and integrated fog and haze, covering Beijing-Tianjin-Hebei (BTH), Shandong province, and Henan province. (http://news.xinhuanet.com/local/2016-01/13/c_128623265.htm). Therefore, it is extremely urgent for effective and feasible pollution-mitigation strategies, in order to support regional economy, environmental, and social sustainable and health development.

Many efforts have been previously taken to abate the pollutants emission and to mitigate the regional air environmental problems (Yi et al., 2007; Monks et al., 2009; Minihan and Wu, 2012; Wang et al., 2012; Hu et al., 2014; Song et al., 2014). For example, Kaneko et al. (2010) explored empirical evidence for two hypotheses and addressed the financial allocation strategy for regional pollution abatement based on SO_2-mitigation in a thermal power sector of China. Nazari et al. (2010) analyzed the emission factors of CO_2, SO_2 and NO_x emitted from Iran's thermal power plants and compared them to obtain the conditions of the emission factor decline. Liu and Wang (2013) identified the main pathways of pollution reduction, analyzed their contributions on the regional level and the national level based on the SO_2 emissions reduction of China for 1995–2010 and yielded important hints for pollution emission control in China. Jiang et al. (2015) studied the influence of particulate matter (PM) transported from surrounding regions on the high $PM_{2.5}$ pollution levels in Beijing using the GRAPES-CUACE model. However, most of them focused on the measures of pollutant-mitigation and modeling simulation analysis for pollution treatment strategies, neglecting macro economical problems. In fact, there existed problems of unreasonable regional economic structures in China, which was another important reason for air pollution in China and has brought adverse impacts on the national economy. For example, many regions in China remained the same industry structure, and local distinctive economy didn't gain better development. Furthermore, there were a large percentage of industries possessing backward manufacturing processes and being located scattering distribution, which not only led to resources waste but also exacerbated blind competition. Meanwhile, the unreasonable economic structure could increase both pollutants emission amounts and extreme weather frequency, which would aggravate the environmental pollution and the harm to the health of people (Liu et al., 2012; Gough et al., 2014; Tao et al., 2014).

Researches on the economic structure adjustment have gained some achievements. Zhang and Ren. (2011) investigated the relationship between CO_2 emissions and industrial structure adjustment, and gained that the change in the total economy is the most important factor to promote the CO_2 emissions; Wu and Zeng (2013) observed the relationship between structure adjustment with the change of SO_2 emissions intensity and gained that contributions of structure adjustment to SO_2 emissions reduction is significant and will be the major contributor in the future; Guo et al.(2008) constructed a multiobjective optimization model of western energy input-output and gained the optimized results indicating that industrial structure adjustment is an effective method in accomplishing the aim of energy saving. However, less attention were paid on the pollutants mitigation measures combined with economic structure adjustment. As an extension of previous studies, this paper formulated an optimization management model to adjust the regional economic structure for regional pollution-mitigation management. However, uncertainty problems in parameters are usually pressing problems for researchers to deal with in order to gain more reliable results. Many methods were investigated and applied to address the uncertainty problems, including interval linear programming (ILP), stochastic linear programming (SLP), fuzzy linear programming (FLP) and some hybrid methods (Huang and Moore, 1993; Huang and Loucks, 2000; Xie et al., 2014; Yang et al., 2016). Particularly, interval linear programming method combined with Best-worst case analysis was applied in the study to address the uncertainties problems of interval parameters. The model was then applied in an important northwest city in the initiative of the Silk Road Economic Belt and the 21st-Century Maritime Silk Road, Urumqi, where the environmental pollution problem was serious and typical in China. In addition, multiple industries (e.g. power sector, thermal industry, iron and steel industry, cement industry and the traffics) and different mitigation measures (e.g. structure emission reduction, technologies emission reduction) were considered in the model. The model would gain the optimal regional economic structure adjustment schemes and multiple alternatives under various emission reduction scenarios. The results are valuable for supporting regional decision makers in making cost-effective environmental system management schemes.

2. Methodology

2.1. ILP model and best-worst case analysis

There exist uncertainties in the model parameters, the values of which couldn't be certain numbers. They would be expressed within a certain interval range, including the minimum and maximum value, to be directly communicated into the optimization process and the resulting solution. The ILP model can be formulated as follows (Huang and Moore, 1993):

$$Min\ f^{\pm} = C^{\pm}X^{\pm} \tag{1}$$

Subject to

$$A^{\pm}X^{\pm} \leq B^{\pm} \tag{1-a}$$

$$X^{\pm} \geq 0 \tag{1-b}$$

where $A^{\pm} \in \{R^{\pm}\}^{m \times n}$, $B^{\pm} \in \{R^{\pm}\}^{m \times 1}$, $C^{\pm} \in \{R^{\pm}\}^{1 \times n}$, $X \in \{R^{\pm}\}^{n \times 1}$, and $R^{\pm}$ denotes a set of interval numbers. There are many single algorithms, hybrid algorithms and improved algorithms for the solution of the ILP model. Huang et al. (1995) proposed a two-step method to solve the ILP model and achieved relatively reasonable and useful solutions; Zou et al. (2010) proposed a risk explicit ILP (REILP) approach to overcome the limitations of existing ILP approaches and the approach can be able to efficiently explore the interval uncertainty space and generate an optimal decision; Huang and Cao (2011) developed three-step method (ThSM) and used Monte Carlo simulations to further explore the detailed solutions for ILP; Allahdadi and Nehi (2013) proposed a best and the worst case (BWC) method to determine the optimal solution set of the ILP problem, and compared this method with Enhanced-ILP model presented by Zou et al. (2010); Allahdadi and Golestane (2015) used Monte Carlo simulation to explore the solutions for the ILP model, and compared the results obtained through the simulations. In this study, best-worst case analysis method was applied in optimization model to mitigate effects of some missing data for a rational suggestion. In the best-worst case analysis, the best condition means the most optimistic condition where the constraints are slack at the largest possible solution space. On the other hand, the worst condition means the most pessimistic condition where the constraints are tightened at the smallest possible space. Thus, the results could include all the possible space, which would give the decision makers overall information for a better decision. For example, in the model (1) if the constrains are slack and tightened, the decision makers could gain information of the economic structure adjustment for every industry. Therefore, the decision makers could make better decisions to achieve a desirable tradeoff between system