

A Stochastic-Fuzzy Optimization Model for Adjustment of Urban Industrial Layout and Environmental Regulation in Beijing City under Uncertainties

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Abstract. In this study, a stochastic-fuzzy optimization model (SFM) is developed for adjusting current urban industrial layout and environmental regulation in Beijing under uncertainties. The SFM can not only handle uncertainties expressed as probability and possibility distributions, but also reflecting the infeasibility risks between expected targets and random second-stage recourse penalties. The results of adjustment of production, industrial layout pattern, pollutant mitigation and system benefit under various Laplace criterion scenarios are analyzed. Tradeoff between industrial development and pollution mitigation can support policymakers generating a sustainable mode to alleviate air pollution issue.

1. Introduction

In some rapid-developed city such as Beijing City, disorder and drastic exploitation of industry and production would result in pollutant emission exceeding the limits of environmental load, leading air crisis. It has brought about huge pressures for human being to confront unprecedented risk of live and development [1]. On the pressures of hazard air pollution issues, the pollutant emission-permit trading can be introduced to provide incentives to adopt pollution abatement, which can drive industrial companies to improve the efficiency of pollutant treatment technology. Therefore, an optimized strategy associated with the adjustment of industrial layout and environmental regulation under emission-permit trading mechanism (OSET) is desired to coordinate relationship between economic development and environmental protection [2].

However, an OSET system is complicated with a variety of uncertainties [3-5]. Previously, many research works have been developed for handling uncertainties in the decision process of an OSET issue, which can reduce the difficulties and risk levels of decision-making [6-7]. Among them, two-stage stochastic programming (TSP) can solve decision-making problems associated with objective randomness, which can rectify initial decision with probabilistic event. However, in a practical OSET issue, the economic and environmental strategies with scenario assumption can be also expressed as probabilistic distributions, leading more stochastic situations. Thus, a Laplace criterion is introduced to handle the probability of each scenario occurrence under the supposition of no data available [8-10]. Meanwhile, numbers of fuzzy occurrences can be handled by a fuzzy credibility constraint programming (FCP) [11]. Previously, few works have focused on multiple uncertainties in hybrid formats in an OSET planning issue.



Therefore, a stochastic-fuzzy optimization model (SFM) is developed for adjusting current urban industrial layout and environmental regulation in Beijing under uncertainties. The SFM can not only handle uncertainties expressed as probability and possibility distributions, but also reflecting the infeasibility risks between expected targets and random second-stage recourse penalties. Results of emission-permit transactions, production reductions, pollution mitigation schemes, adjusted industrial structures and system benefits under various Laplace criterion scenarios are analyzed. These findings can support policymakers to identify optimized industry-environment policies for coordinating relationship between economic development and environmental protection

2. Application

Beijing city as a capital of China, which has undergone rapid urbanization/industrialization, corresponding to accelerated population expansion and high-speed economic growth. The population of city has exceeded 21.14×10^6 people; the growth rate of population has reached 8.93% per year [12]. Until 2013, the GDP of Beijing city has reach 1215.3 billion Yuan, which maintains high growth rate about 9% in recent years. With the industrial expansion, large-scale pollutant emission has exceeded the self-purification capacity of atmosphere. Therefore, a comprehensive strategy associated with a combination of a series of strategies is desired, which concludes adjustment of industrial structure, command of production scale and reduction of pollutant emission.

The enterprises would reduce the scale of production to confront the environmental penalty. However, a single political plan cannot conserve the environment at the extreme due to “governance failure”. Thus, a market approach can be introduced to correct these weaknesses, which can reallocate emission-permit from lower- to higher-value to increase economic efficiency but also provide incentives to adopt pollution abatement measures [13-14]. However, in an OSET system, numbers of factors such as on-site survey and monitoring, analysis of main affected factors, determination of pollution-source emission standards, partition of functional zones and design of their respective environmental capacities, as well as generation of control measures. Thus, a stochastic fuzzy model is introduced to handle the uncertainties and complexities. Based on the SFM method, an OSET is formulated as follows:

$$\max f_{Laplace} = \left\{ \frac{1}{m_1} * \begin{pmatrix} LPS_{11} & LPS_{12} & \dots & LPS_{1n} \\ LPS_{21} & LPS_{22} & \dots & LPS_{2n} \\ \dots & \dots & \dots & \dots \\ LPS_{m_1 1} & LPS_{m_1 2} & \dots & \dots \end{pmatrix} + \frac{1}{m_2} * \begin{pmatrix} LCS_{(m_1+1)1} & LCS_{m_1 2} & \dots & LCS_{(m_1+1)n} \\ LCS_{(m_1+2)1} & LCS_{(m_1+2)2} & \dots & LCS_{(m_1+2)n} \\ \dots & \dots & \dots & \dots \\ LCS_{m_2 1} & LCS_{m_2 2} & \dots & \dots \end{pmatrix} \right\} * \quad (1)$$

[(1)-(2)-(3)-(4)+(5)-(6)]

(1) Income from various industrial production activities based on expected economic development:

$$\sum_{t=1}^3 \sum_{j=1}^4 \left(\sum_{m=1}^5 BFH_{mj} \cdot WH_{mj} \cdot hr_{mj} + \sum_{n=1}^3 BFM_{mj} \cdot WM_{mj} \cdot mr_{mj} + \sum_{i=1}^2 BFL_{ij} \cdot WL_{ij} \cdot lr_{ij} \right) \quad (2)$$

(2) Penalty for excessive emission from various industrial production activities:

$$\sum_{h=1}^3 \sum_{t=1}^3 \sum_{j=1}^4 \left[\sum_{m=1}^5 PH_{mj} \cdot (WH_{mj} - RH_{hmj}) \cdot hr_{mj} + \sum_{n=1}^3 PM_{mj} \cdot (WM_{mj} - RM_{hmj}) \cdot mr_{mj} + \sum_{i=1}^2 PL_{ij} \cdot (WL_{ij} - RL_{hitj}) \cdot lr_{ij} \right] \quad (3)$$

(3) Loss for reduced production activities based on adjustment of industrial structure:

$$\sum_{h=1}^3 \sum_{t=1}^3 \sum_{j=1}^4 \left(\sum_{m=1}^5 LLH_{mj} \cdot RH_{hmj} \cdot hr_{mj} + \sum_{n=1}^3 LLM_{mj} \cdot RM_{hmj} \cdot mr_{mj} + \sum_{i=1}^2 LLL_{ij} \cdot RL_{hitj} \cdot lr_{ij} \right) \quad (4)$$

(4) System benefit from emission-permit transaction:

$$\sum_{h=1}^3 \sum_{t=1}^3 \sum_{j=1}^4 \left(\sum_{n=1}^5 p_{tjh} \cdot TCM_{hmj} \cdot BM_{mj} \cdot hr_{mj} + \sum_{m=1}^2 p_{tjh} \cdot TCH_{hmj} \cdot BH_{mj} \cdot mr_{mj} + \sum_{i=1}^3 p_{tjh} \cdot TCL_{hitj} \cdot BL_{ij} \cdot lr_{ij} \right) \quad (5)$$

(5) Cost for emission-permit transaction:

$$\sum_{h=1}^3 \sum_{t=1}^3 \sum_{j=1}^4 \left(\sum_{n=1}^5 p_{tjh} \cdot TCM_{hmj} \cdot BM_{mj} \cdot hr_{mj} + \sum_{m=1}^2 p_{tjh} \cdot TCH_{hmj} \cdot BH_{mj} \cdot mr_{mj} + \sum_{i=1}^3 p_{tjh} \cdot TCL_{hitj} \cdot BL_{ij} \cdot lr_{ij} \right) \quad (6)$$

There are numbers of constraints as follows:

(1) Constraint of available emission-permit for transaction:

$$\sum_{h=1}^H \sum_{t=1}^3 \sum_{j=1}^4 [\sum_{m=1}^2 TCH_{hmt} \cdot hr_{mj} + \sum_{n=1}^5 TCM_{hnt} \cdot mr_{nj} + \sum_{i=1}^3 TCL_{hit} \cdot lr_{ij}] \leq [(\sum_{h=1}^H \sum_{t=1}^3 \sum_{j=1}^4 PA_{htj}^{SO_2} + \sum_{h=1}^H \sum_{t=1}^3 \sum_{j=2}^2 PA_{htj}^{NO_2} + \sum_{h=1}^H \sum_{t=1}^3 \sum_{j=3}^3 PA_{htj}^{PM10} + \sum_{h=1}^H \sum_{t=1}^3 \sum_{j=4}^4 PA_{htj}^{PM2.5})] \tag{7}$$

(2) Constraint of ambient air quality requirement:

$$Cr\{[\exp(-\frac{\delta + \mu}{2\delta})] / \{\pi \cdot (\frac{\delta H^2}{s^2(\delta + \mu)})\} \cdot [\sum_{h=1}^H \sum_{t=1}^3 \sum_{j=1}^4 (\sum_{m=1}^2 (WH_{mj} - RH_{hmt} - TCH_{hmt}) \cdot hr_{mj} + \sum_{n=1}^5 (WM_{nj} - RM_{hnt} - TCM_{hnt}) \cdot mr_{nj} + \sum_{i=1}^3 (WL_{ij} - RL_{hit} - TCL_{hit}) \cdot lr_{ij})] \leq \{[\sum_{h=1}^H \sum_{t=1}^3 \sum_{j=1}^4 \theta_{htj}^{SO_2} + \sum_{h=1}^H \sum_{t=1}^3 \sum_{j=2}^2 \theta_{htj}^{NO_2} + \sum_{h=1}^H \sum_{t=1}^3 \sum_{j=3}^3 \theta_{htj}^{PM10} + \sum_{h=1}^H \sum_{t=1}^3 \sum_{j=4}^4 \theta_{htj}^{PM2.5}]\} \geq \alpha, \quad \forall i, j, h \tag{8}$$

(3) Constraint of industrial production scale:

$$CME_{mj\min} \leq \sum_{m=1}^2 WH_{mj} \cdot hr_{mj} \leq CME_{mj\max} \tag{9}$$

$$CDE_{mj\min} \leq \sum_{n=1}^5 WM_{nj} \cdot mr_{nj} \leq CDE_{mj\max} \tag{10}$$

$$ICR_{ij\min} \leq \sum_{i=1}^3 WL_{ij} \cdot lr_{ij} \leq ICR_{ij\max} \tag{11}$$

(4) Constraint of non-negativity:

$$WH_{mj}, WM_{nj}, WL_{ij} \geq 0, \quad hr_{mj}, mr_{nj}, lr_{ij} \geq 0, \tag{12}$$

Model (7) presents available emission-permit for transaction, where the demand of air pollutant emission can not exceed the maximum emission-permit allowance. Model (8) shows that the requirement of ambient air quality in study region, which is built on Gaussian dispersion model (GDM). Models (9) to (11) are industrial development scales, which can reflect the minimum / maximum development scale of production in study region. Model (12) is non-negativity restrictions. The parameters for model are calculated based on government reports, statistical yearbooks, and related research works [12]. There are 10 cases associated with Laplace criterion to be assumed in this study as follows: (a) case 1 is basic plan, which equal to current plan; (b) cases 2, 3, 4 and 5 are conservative plans, which adopt to environmental regulation; (c) cases 5, 6, 7 and 8 are progressive plans, which focus on economic development; (d) case 10 is plan under Laplace criterion.

3 Results analysis

Figure 1 presents optimized reduced production among various industrial sectors under cases 1, 4, 8 and 10 when ϵ and α levels are 0.95 and 0.99. The results show that the higher wind velocity would be suitable for pollutants diffusion, thus the reduced production scale would be lower; vice-versa. The relative higher reduction amount would occur in petroleum refining (denoted as “PR”) and power generation (denoted as “PG”) due to their higher pollutant emissions.

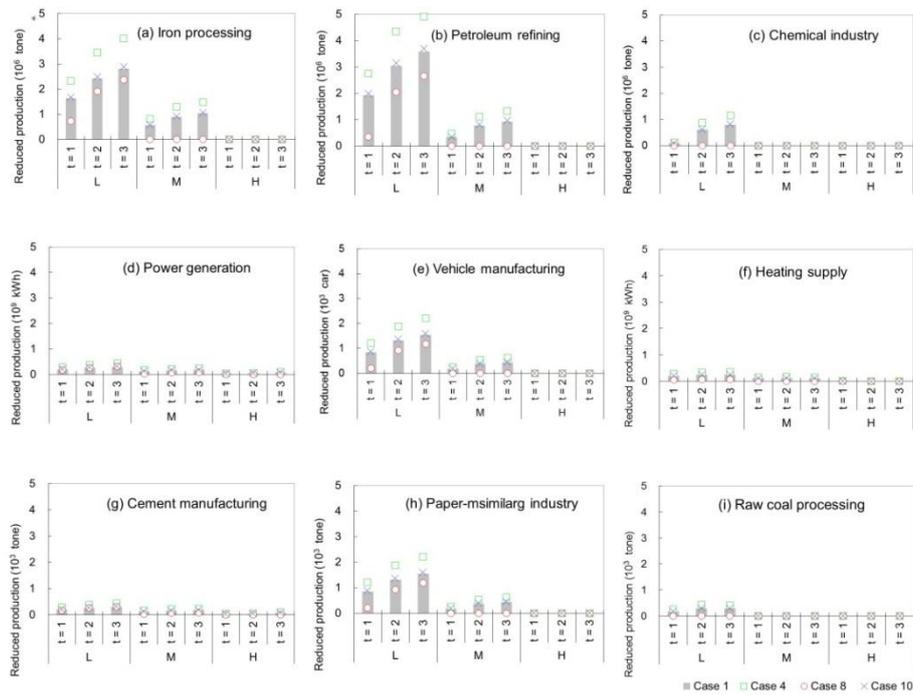


Figure 1. Optimized reduced production among various industrial sectors under cases 1, 4, 8 and 10 when ϵ and α levels are 0.95 and 0.99

Figure 2 presents total excess pollution emissions under various cases when α level is 0.99. In this study, excess pollutant emission would result in ultra concentration of pollution in the air. The results present that under case 1 in period 1, when meteorological condition is bad for diffusion, the ultra concentration ratio of SO_2 and NO_2 would be more than 6 times, and PM_{10} and $\text{PM}_{2.5}$ would reach 3 times at highest. It implies that current pollution emission pattern and industrial production mode in Beijing city would not suitable for future higher environmental regulation.

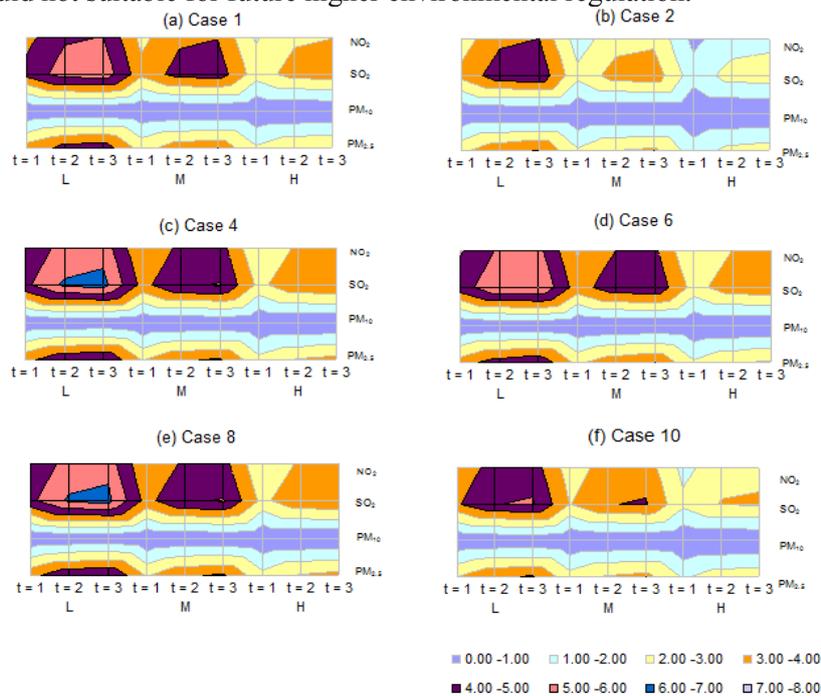


Figure 2. Total excess pollution emissions under various cases when α level is 0.99

Figure 3 presents the system benefits under cases 1, 5, 7, 9, 10 and optimal state when α level is varied ($\varepsilon = 0.95$). The results indicate that a lower α level can result in a lower benefit; vice versa. The results present that case 1 (basic plans) would generate higher system benefit than conservative and progressive cases. For example, when α level is 0.9, system benefit would be RMB ¥ 3.87×10^{12} under case 1, while system benefits are RMB ¥ 3.45×10^9 and $\$ 1.05 \times 10^9$ under case 5 and case 7. The highest system benefit would be obtained under Laplace scenario (case 10), which can generate a reliable and optimal results with consideration of all risks of scenarios.

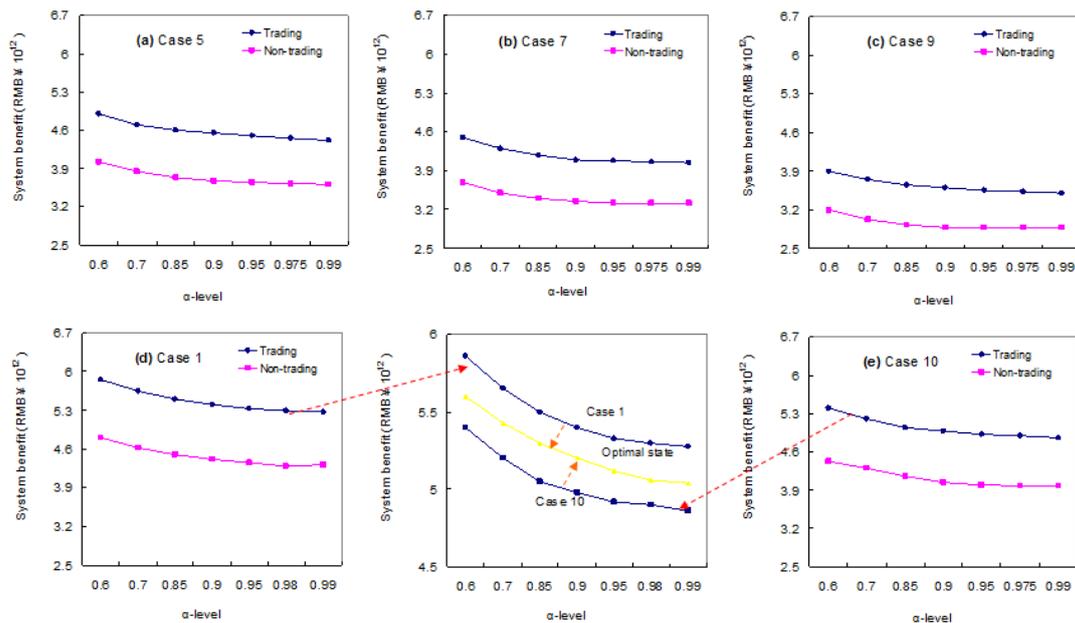


Figure 3 System benefits under cases 1, 5, 7, 9, 10 and optimal state when α level is varied ($\varepsilon = 0.95$)

4 Conclusions

In this study, a stochastic-fuzzy optimization model (SFM) embedded into an optimized strategy associated with the adjustment of industrial layout and environmental regulation under emission-permit trading mechanism (OSET) is proposed for confronting air crisis in Beijing City under uncertainties. The developed SFM model will be applied to a real case study of OSET issue in Beijing city of China. The results disclose that emission-permit trading would be an effective manner to adjust industrial layout and air quality management, which should be encouraged to coordination of economy and environment in the future. Meanwhile, the improper industrial layout is a main reason for air crisis in study region, which requires adjustment of local industrial structure and improvement of treatment technologies could lessen pollutant emissions to reduce environmental penalties, leading higher system benefits.

Acknowledgements

This research was supported by the National Social Science Foundation of China (Grant Nos. 14BFX107), Beijing Natural Science Foundation (L160011), National Key Research and Development Program (2016YFC0207800) and National Natural Science Fund (51608422).

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