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A two-stage stochastic programming model for industrial adjustment on water and energy resources in Guangdong Province, China

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Abstract. A two-stage stochastic programming (TSP) model is effective for industrial adjustment under limited and varied capacities of water and energy resources. In this paper, industrial adjustment in the future (i.e., the 13th five-year plan) was evaluated by a eatablished TSP model under limited and uncertain supply of water and energy resources. The developed method was demonstrated in Guangdong Province of China. The results indicated that the first-stage industrial planning would not be influenced by water and energy supply capacities when water supply would be sufficient (i.e., 8938 million m^3). When the probability of water supply capacities would be 4491 million m^3, economic benefits of three types of industries (i.e., manufacture of electrical machinery and equipment, textile garments, footwear and headgear, as well as food and tobacco) would reduce over 70 billion yuan.

Introduction

Over the past decades, with the rapid trends of urbanization and industrialization, many cities in China face dual challenges from resource shortage and industrial development. Thus, allocation of energy and water resources was extensively paid attention to by many studies throughout the world[1]. Mathematical programming methods, such as two-stage stochastic programming (TSP), were widely applied for addressing problems of resource allocation[2]. For example, Zhen et al.[3] developed a TSP model for supporting regional electric power system management. Wang et al.[4] developed a TSP model in consideration of imprecise probabilities for supporting water resources management. However, water and energy supply capacities was seldom considered in industrial adjustment. Therefore, the objective of this study is to develop a two-stage stochastic programming model for supporting comprehensive decision-making in industrial adjustment under uncertain supply of water and energy resources. The developed method will then be demonstrated in Guangdong Province of China.

Methods

Consider a problem in which a manager is responsible for allocating water and energy to multiple industrial users[1]. The manager can formulate the problem of industrial adjustment in water and energy resources respective through maximizing the economic benefits of industrial products in consideration of economic benefits, water and energy demands, and economic goals. A two-stage stochastic programming model is effective for industrial adjustment under limited and varied capacity of water and energy resources. In the first-stage decision-making process, it is assumed that amount of water and energy supply could meet demands of all water and energy users before any random changes[5]. Under occurrences of random seasonal flows, adjustment need be taken to balance multiple industrial users as a result of the first-stage decision. Thus, the problem can be described by the following equations:

$$\max f = \sum_{j=1}^{22} t_j - \sum_{j=1}^{22}\sum_{i=1}^{3} p_i x_{ij} \tag{1a}$$

s.t.

$$t_j - x_{ij} \geq 0, \ \forall i, j \tag{1b}$$

$$\sum_{l=1}^{3} C_{il} \geq \sum_{j=1}^{22} c_j \times (t_j - x_{ij}) + C_A + C_R, \forall i \tag{1c}$$

$$E \geq \sum_{j=1}^{22} e_j \times (t_j - x_{ij}) + E_A + E_R \tag{1d}$$

$$x_{ij} \geq 0, \ \forall i, j \tag{1e}$$

$$y_j \geq 0, \ \forall j \tag{1f}$$

where f: Economic benefit of industrial production;
t_j: Plan for the j^{th} industry;
x_{ij}: Shortage of Output on the j^{th} industry in the second-stage decision making when water available probabilities is p_i;
C_{il} : Water supply capacity of the l^{th} water source when water available probabilities is p_i;
c_j: Water consumption intensity of the j^{th} industry;
C_A: Amount of water for agriculture;
C_R: Amount of water for social user (e.g., residents, schools, and hospitals);
E: Energy supply capacity;
e_j: Energy consumption intensity of the j^{th} industry;
E_A: Amount of energy for agriculture;
E_R: Amount of energy for social user (e.g., residents, schools, and hospitals).

Case study

Located in southern China, Guangdong Province has been the largest contributor of GDP among all the provinces in China since 1989[6]. For example, Guangdong's GDP accounts for 10.6% of the total GDP of Mainland China in 2015. Also, the province consumed large amount of energy and water resources with rapid trends of urbanization and industrialization[8]. Under this situation, Guangdong Province faces dual challenges from resource shortage and industrial development. Also, there will be tremendous pressure on Guangdong to realize this goal during the period of the 13th five-year plan (2016–2020)[7].

Data preparation Water and energy supply capacities are shown in Table 1. Parameters on industrial plans of Guangdong Province are described by Tables 2 to 4.

Table 1 Water and energy supply capacities of Guangdong Province

Item	Probabilities	Unit	2020
Water supply	10%	100 million m^3	89.38
	50%		64.48
	90%		44.91
Energy supply capacity	-	10000 t of SCE*	19103

*Note: SCE - standard coal equivalent

Table 2 Industrial plans of Guangdong Province

Item	Unit	2010	2015	2020
Water Consumption per 10000 Yuan of Value-added of Industry	m^3/10000 yuan	65	37	25.90
Energy Consumption per 10000 Yuan of Value-added of Industry	1t of SCE	0.66	0.49	0.42

Table 3 Code numbers of industries in case study

Types of industries	Number	Types of industries	Number
Extraction of Petroleum and Natural Gas	1	Smelting and Pressing of Metals	12
Mining and Dressing of Metal Ores	2	Metal Products	13
Mining and Dressing of Nonmetal Ores	3	Manufacture of General-purpose Machinery	14
Manufacture of Food and Tobacco	4	Manufacture of Special-purpose Machinery	15
Textile Industry	5	Manufacture of Transport equipment	16
Manufacture of Textile Garments, Footwear and Headgear	6	Manufacture of Electrical Machinery and Equipment	17
Timber Processing, Bamboo, Cane, Palm Fiber & Straw, and Furniture	7	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	18
Papermaking, Printing	8	Manufacture of Instruments and Meters	19
Petroleum Refining, Coking and Nuclear Fuel Processing	9	Other Manufactures	20
Manufacture of Chemical Products	10	Comprehensive Utilization of Waste	21
Nonmetal Mineral Products	11	Manufacture of Metal Products, Machinery and Equipment Maintenance	22

Table 4 Industrial demands and plans in Guangdong Province

Types of industries	Water consumption intensity	Energy consumption intensity	Plan for economic benefits in 2020
	Unit: m^3/10000 yuan	1 ton of SCE/10000 yuan	100 million yuan
1	0.07	0.18	383
2	23.21	0.39	67
3	8.70	0.51	128
4	14.91	0.39	2386
5	30.85	1.26	751
6	7.22	0.30	2184
7	12.03	0.40	1010
8	14.33	1.01	2246
9	0.90	1.91	811
10	12.56	0.83	2185
11	12.13	2.94	1236
12	37.89	3.61	365
13	16.57	0.47	1354
14	6.74	0.24	806
15	7.88	0.29	697
16	2.37	0.18	1706
17	5.50	0.25	3618
18	3.12	0.21	6500
19	4.18	0.30	253
20	5.76	0.78	65
21	2.66	0.16	247
22	10.86	0.37	77

Table 5 Planning modifications (i.e., x_{ij}) of industries in Guangdong Province

Types of industries	Probabilities (p_i)		
	10%	50%	90%
1	0.00	0.00	0.00
2	0.00	28.90	29.57
3	0.00	0.00	56.23
4	0.00	0.00	749.84
5	0.00	259.27	259.27
6	0.00	0.00	754.46
7	0.00	0.00	296.18
8	0.00	0.00	673.76
9	0.00	0.00	0.00
10	0.00	0.00	655.58
11	0.00	0.00	545.04
12	0.00	160.75	160.75
13	0.00	0.00	597.08
14	0.00	0.00	355.46
15	0.00	0.00	307.19
16	0.00	0.00	0.00
17	0.00	0.00	1113.39
18	0.00	0.00	0.00
19	0.00	0.00	0.00
20	0.00	0.00	28.48
21	0.00	0.00	0.00
22	0.00	0.00	18.85

Results and discussion The solutions for planning modifications of industries in Guangdong Province are showed in Table 5. The results indicated that the first-stage industrial planning would not be influenced by water and energy supply capacities when water supply would be sufficient (i.e., 8938 million m^3). When the probability of water supply capacities would be 4491 million m^3, economic benefits of three types of industries (i.e., manufacture of electrical machinery and equipment, textile garments, footwear and headgear, as well as food and tobacco) would reduce more than 70 billion yuan.

Conclusions

A two-stage stochastic programming model is effective for industrial adjustment under limited and varied capacities of water and energy resources. In this paper, industrial adjustment in the future (i.e., the 13th five-year plan) was evaluated with limited water and energy resources under occurrences of random seasonal flows. The results indicated the first-stage industrial planning would not be influenced by water and energy supply capacities. When the probability of water supply capacities is 4491 million m^3, economic benefits of three types of industries (i.e., manufacture of electrical machinery and equipment, textile garments, footwear and headgear, as well as food and tobacco) would reduce more than 70 billion yuan.

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