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Coal Mining Strategy of Energy Saving and Emission Reduction Based on Multi-objective Planning

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Abstract. This paper considers the three objectives which are coal production, ecological environment and energy consumption. In order to meet the constraints of project investment funds, the mining capacity constraints, the total amount of resources in the mining area, the mutual restraint between the various processes, and the related energy in the “13th Five-Year Plan”. Under the common constraints of consumption and pollution emission standards, a static model for energy conservation and emission reduction in coal mining areas based on multi-objective optimization was constructed. The model is solved by designing the algorithm, and the model is applied to the case of Hongyan Coal Mine in Junlian County. The validity, scientificity and rationality of the model and algorithm are verified.

1. Introduction

With the continuous development of global economy and society, frequent human production activities have caused serious damage to the natural environment and ecology. Smog weather has gradually become the main way to affect people's lives, and this trend is increasing [1]. Air pollution is one of the major environmental problems that human beings need to face at present and even in the future, especially the waste gas and dust pollution from the development of fossil energy.

In recent decades, China's economic and social development mainly depends on the extensive development of energy resources. The development and utilization of energy resources are irrational. While developing coal mining areas, they have brought about specific impacts on the environment. On the one hand, economic and social development must rely on coal, oil and other resources; On the other hand, the exploitation of coal, oil and other resources will discharge pollutants such as waste gas and dust into the environment. The contradiction between economic development and the environment is becoming increasingly prominent [2]. If the environment cannot be protected while resources are being exploited and scientific and reasonable exploitation methods are formulated, great harm will be brought to the air. Mining in coal mining area is a huge hierarchical system, with a lot of complexity and uncertainty, which has an impact on the scientific effectiveness of mining management decisions in coal mining area [3]. Therefore, in the target management of modern coal mining areas, how to formulate scientific and reasonable policies and systems, arrange production rationally and reduce unnecessary energy waste in order to relieve environmental pressure is often a complicated dynamic hierarchical decision-making process for the balanced development of economy, society and ecology in coal mining areas [4].

How to carry out comprehensive and in-depth theoretical research and case analysis on issues such as energy conservation and emission reduction in coal mining areas so as to formulate a scientific and reasonable decision-making plan, which is not only conducive to solving the problem of environmental pollution emission during coal mining and saving energy; It is also conducive to enriching the relevant theoretical knowledge of energy conservation and emission reduction in coal mining areas, and making in-depth analysis of the model by using modern algorithm design, thus enabling energy conservation and emission reduction in coal mining areas to embark on a scientific development road.

2. The key problem statemate

The goal of coal mining in coal mining areas is to achieve economic and ecological balance, and production and investment conflicts need to be resolved. It can be seen from Figure 1 that reducing coal production will significantly reduce pollutant emissions and reduce environmental damage. However, this production strategy will not only reduce overall income but also damage profits. On the contrary, if coal mines increase coal production to obtain greater income, pollutant emissions will increase, which will inevitably lead to further damage to the ecological environment. In addition, although management has recognized that the simultaneous investment in energy conservation and emission reduction projects is conducive to the ecological environmental protection and economic benefits of coal mining, the limited available capital means that coal mine managers carefully select energy conservation and emission reduction investment projects. Therefore, to determine the balance between maximizing economic and ecological goals, both need to be considered simultaneously.

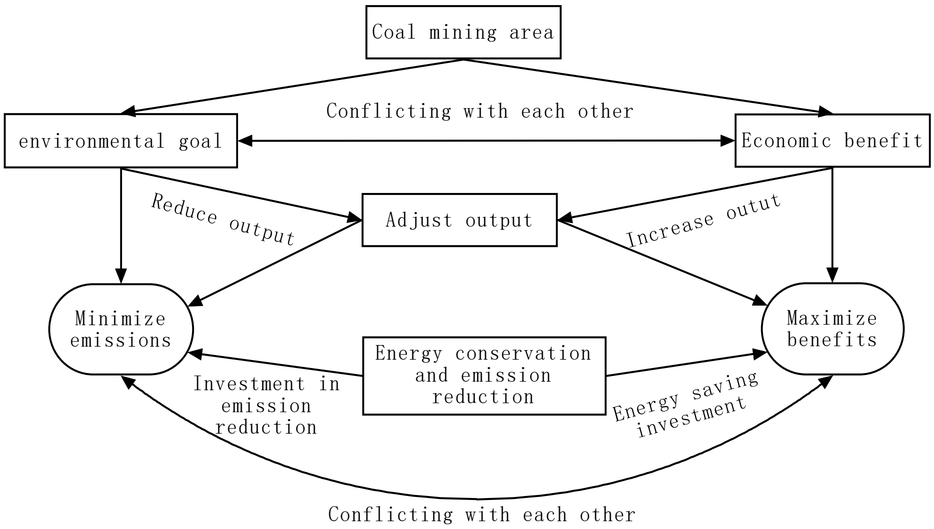

Fig 1. Logic Diagram of Ecological and Economic Conflict in Production and Investment

3. Model building

3.1 Assumed conditions

In order to build the model of the multi-objective optimization of energy saving and emission reduction in coal mining areas, the following basic assumptions need to be made before modeling:

(1) The ecological environment of the coal mining area is mainly affected by the production process from the mining area, and the impact of other external environments is temporarily ignored.

(2) In a certain research area, this paper only selects coal mining enterprises with typical representation as the research object.

(3) The government's energy conservation and emission reduction policies and other related policies regarding the mining area are determined.

3.2 Model Symbol

In order to facilitate the construction of models and expressions, some parameters and variables used in the full text are explained. Partial correlation statistics are shown in Table 1, Table 2**,** Table 3.

Table 1. Subscript parameter

Variable	Explain
i	It indicates the types of energy needed in coal mining, i is equal to 1, 2, and 3, which respectively represent electricity, raw coal, and oil;
l	It indicates the types of pollutants discharged into the environment during coal mining, l is equal to 1, 2, and 3, which respectively represent SO_2, coal gangue and mine water.
t	It indicates the planned number of years in the coal mining area, t is equal to 1, 2, 3,4, and 5.
n	The process of coal mining, here, n is equal to 1,2,3, and4, which respectively represent tunneling, mining, transportation, coal preparation;
k	The number of types of projects that need to treat or recycle pollutants during coal mining;

Table 2. Decision variable

Variable	Explain
x_{tn}	The output of coal after the n-th step in the t-year, for example, the output of coal after the coal preparation step in the first year;
Y_{tn}	Whether to carry out energy-saving transformation on the n-th working procedure in the t-year is a 0-1 decision variable, and if the n-th working procedure is transformed in the t-year, its value is 1; Otherwise, it is 0;
Z_{tk}	Whether or not to invest in the K-type pollutant treatment or recycling project in the T-year is a 0-1 decision variable. If investment is made in the K-type pollutant treatment or recycling project in the T-year, its value is 1; Otherwise, it is 0;

Table 3. Deterministic parameter

Variable	Explain
R^{max}	The amount of coal stored in a mining area;
C^{max}	The maximum mining capacity of the coal mining area;
γ	Recovery rate of coal in coal mining area;
μ	Loss rate in raw coal mining;
$ECIY_{tn}$	Investment cost for the energy saving project of the n-th process in the t year;
$ERIZ_{tk}$	Investment cost for the k-type pollutant treatment or recycling project in the T-year;
TIC	Total investment cost of energy saving and emission reduction projects during the whole planning period;
d_{tni}	Unit consumption of type i energy before Energy Saving Transformation;
d^{1}_{tni}	Unit consumption of type i energy for the n process in the t year after the energy-saving renovation;
h_{tnl}	Unit emissions of pollutant type L in the N process in the T year before the investment in emission reduction;
β_{tnl}	Reduction or utilization rate of type l pollutant in the n process in the t year after investment in emission reduction;

3.3 Objective function

In the past, the coal enterprises often pursued the maximization of corporate profits, neglected environmental protection and energy conservation, but continuously maximized the coal production and economic benefits at the expense of ecology. It turns out that this The type of mining is unscientific. Therefore, this paper takes economic benefits, energy efficiency and environmental benefits as the main objectives, and rationally optimizes the investment in energy saving and emission reduction in coal mining areas and the output of coal mining areas.

(1) Economic benefits

Enterprises pursue profit maximization. In general, production profit is the difference between total income (the product of price and output) and total cost [5]. Coal prices are subject to large fluctuations in the market. Therefore, for the convenience of research, the economic benefits are mainly measured by the output in the coal mining area. On the other hand, the coal mining area can directly use the last stage in the key processes in the mining process. Coal production is the object of measurement, so the economic benefit objective function constructed is as follows:

$$\max f_1 = \sum_{t=1}^{T} x_{t4} \tag{1}$$

(2) Energy efficiency

In the research process, the smaller the energy consumption value, the better, and the energy consumption is divided into energy-saving transformation and energy-saving transformation, the specific calculation is as follows:

For energy consumption before energy-saving retrofit, it can be expressed as the product of unit energy consumption and output:

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{i=1}^{I} d_{tni} x_{tn} \tag{2}$$

Once the investment in energy-saving renovation is carried out, the unit energy consumption will inevitably change. The capital consumption of the energy-saving transformation can be estimated by using the capital and equipment basic conditions of the investment project. Therefore, the energy consumption expression after energy-saving transformation is:

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{i=1}^{I} d_{tni}^{1} x_{tn} Y_{tn} \tag{3}$$

According to Eq.2 and Eq.3, it can be concluded that the expression of energy consumption in coal mining during the planning period is:

$$\min f_2 = \sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{i=1}^{I} (d_{tni} x_{tn} + d_{tni}^{1} x_{tn} Y_{tn}) \tag{4}$$

(3) Environmental benefits

Coal mines will produce mine water, solid waste, S02, soot, dust and other pollution in the coal production process. [6]. The pollutant discharge needs to be strictly controlled, so in order to promote the friendly development of the environment, the ecological balance in the mining area is guaranteed. The use of emission reduction project investments to comprehensively control pollutants, so environmental benefits can be expressed by the amount of pollutants discharged:

$$\min f_3 = \sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{l=1}^{I} \left[h_{tnl} x_{tn} (1 - \sum_{k=1}^{K} \beta_{tnl} Z_{tk}) \right] \tag{5}$$

3.4 Restrictions

(1) Total limit

In the long run, the total amount of production cannot exceed the amount of coal stored [7]. In addition, due to underground mining technology and cost constraints, some resources cannot be mined. Therefore, some of the loss of raw coal in the process of coal mining can not be ignored, using the relationship between the total amount of mining and mining in the coal mining process and the recovery rate to build the constraint, the total mining limit is calculated as follows:

$$\frac{\sum_{t=1}^{T}(x_{t1} + x_{t2})}{\gamma} \le R^{\max} \tag{6}$$

(2) Process relationship

The main steps of coal mining have been described in the previous article. It is only necessary to know that the excavation and mining are the main channels for obtaining coal, and the third process only plays the role of transportation from the mine. Therefore, there are constraints on this relationship:

$$x_{t3} \le x_{t1} + x_{t2} \tag{7}$$

The condition obtained by the equal sign is that there is no loss in the third process. On the other hand, in the fourth process, since the coal is processed, the raw coal is processed and some solid impurities are removed. Meet the following constraints:

$$x_{t3} > x_{t4} \tag{8}$$

(3) Mining capacity

In every decision decision, the total amount of coal mining cannot exceed its maximum excavation capacity [8]. In general, the actual amount of mining is determined by the planned amount of mining and the rate of recovery.In the research process, the two processes of excavation and mining are the main sources of coal mining, so tunneling and mining can be used. The relationship between the total loss rate of coal is expressed, so the mining capacity limit is as follows:

$$\frac{x_{t1}+x_{t2}}{\mu} \le C^{\max} \tag{9}$$

(4) Investment constraints

In order to comprehensively improve the energy and environmental benefits of coal mining areas, it is necessary to invest in energy saving and emission reduction in coal mining areas. If only energy consumption or environmental benefits are considered alone, then sufficient funds can be used for investment in one of these, but the reality It is often impossible, which requires screening these projects. According to the actual situation, the energy conservation and emission reduction investment projects are judged, and the use of funds is also limited. Therefore, for investment constraints, it can be divided into energy saving investment and reduction. There are two types of investment, the two specific calculations are as follows:

Energy-saving investment funds are mainly expressed as the product of the project investment funds and the 0-1 variables of whether or not to invest:

$$\sum_{t=1}^{T}\sum_{n=1}^{N} Y_{tn} ECIY_{tn} \tag{10}$$

The investment fund for emission reduction is mainly expressed by the product of the project investment funds and the 0-1 variable of whether or not to invest:

$$\sum_{t=1}^{T}\sum_{k=1}^{K} Z_{tn} ERIZ_{tk} \tag{11}$$

The investment capital constraint is that the comprehensive investment fund for energy conservation and emission reduction during the whole coal planning period cannot exceed its budget value, that is, the investment constraint can be expressed as:

$$\sum_{t=1}^{T}\sum_{n=1}^{N} Y_{tn} ECIY_{tn} + \sum_{t=1}^{T}\sum_{k=1}^{K} Z_{tk} ERIZ_{tk} \le TIC \tag{12}$$

(5) Efficiency constraints

In practice, for pollutant discharge treatment and recycling, whether it is the recycling of solid materials generated in coal production process or the treatment of pollution, its cumulative utilization rate or treatment efficiency cannot exceed 100%, so its efficiency constraints as follows:

$$\sum_{k=1}^{K} (\beta_{tnl} Z_{tk}) \le 1 \tag{13}$$

(6)Non-negative constraint

$$x_{tn} \ge 0 \tag{14}$$

3.5 General Model

Based on the above discussion, based on the comprehensive analysis of energy saving and emission reduction in coal mining areas, a nonlinear 0-1 mixed integer programming model was established.

$$
\begin{cases}
\max f_1 = \sum_{t=1}^{T} x_{t4} \\
\min f_2 = \sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{i=1}^{I}(d_{tni}x_{tn} + d^1_{tni}x_{tn}Y_{tn}) \\
\min f_3 = \sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{l=1}^{I}\left[h_{tnl}x_{tn}(1-\sum_{k=1}^{K}\beta_{tnl}Z_{tk})\right] \\
s.t \begin{cases}
\sum_{t=1}^{T}\sum_{n=1}^{N} Y_{tn}ECIY_{tn} + \sum_{t=1}^{T}\sum_{k=1}^{K} Z_{tk}ERIZ_{tk} \le TIC \\
\dfrac{\sum_{t=1}^{T}(x_{t1}+x_{t2})}{\gamma} \le R^{\max} \\
x_{t3} > x_{t4} \\
x_{t3} \le x_{t1} + x_{t2} \\
\dfrac{x_{t1}+x_{t2}}{\mu} \le C^{\max} \\
\sum_{k=1}^{K}(\beta_{tnl}Z_{tk}) \le 1 \\
x_{tn} \ge 0, t = 1,2,\cdots,5, l = 1,2,3, n = 1,2,3,4 \\
Y_{tn} = \begin{cases} 1 \\ 0 \end{cases} \\
Z_{tk} = \begin{cases} 1 \\ 0 \end{cases}
\end{cases}
\end{cases}
\quad (15)
$$

4. Algorithm

Multi-objective solving is complicated and cumbersome. In the actual calculation, in order to facilitate the calculation, and combined with the actual situation of the model application, the multi-objective optimization model can be transformed into a single-objective model, and it is convenient to solve the single-objective model. The multi-objective optimization model algorithm is relatively more, but the specific algorithm should be selected according to the actual situation of the model. In this model, because different investment schemes have certain uncertainties on the energy conservation and emission reduction effects of coal mines, on the other hand, the opportunities for projects with good energy conservation and emission reduction investment are relatively large, so this model has opportunities. Constrained implied conditions are more suitable for solving by artificial bee colony algorithm (IABCbasedFRS) [9].

In 2005, Karaboga proposed the Artificial Bee Colony algorithm (ABC). Therefore, this algorithm is relatively new. It mainly simulates the process of bee colony searching for nectar. The colony is more organized and efficient in searching for nectar. The algorithm also has higher search efficiency [10]. The following are the specific steps of the artificial bee colony algorithm:

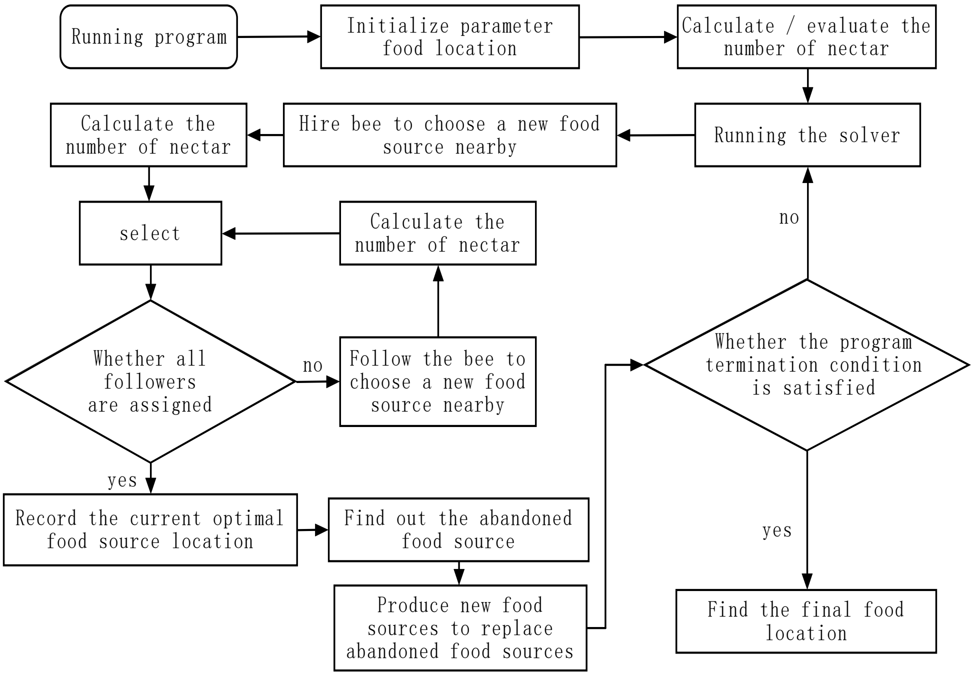

Fig 2. Artificial bee colony algorithm flow chart

5. Case study

Junlian County is located in Yibin City. The county's coal resources and shale gas resources are relatively abundant. Therefore, this paper mainly selects the Hongyan Coal Mine of Patong Town, Junlian County as the research object. After years of development and technology of mine exploitation capacity, the mine has been developed. Reconstruction, the mine now produces about 360,000 tons of raw coal per year. The annual production capacity is up to 420,000 tons.

Table 4 shows the coal production from 2010 to 2015 in Hongyan Coal Mine of Junlian County. The data is mainly from the investigation report of the 13th Five-Year Plan of Junlian County.

Table 4. Coal Production of Hongyan Coal Mine from 2010 to 2015 (Unit: 104 Tons)

time	2010 year	2011year	2012 year	2013 year	2014 year	2015 year
Coal output	34	40	39	37	36	32

The total amount of resources that can be utilized in Hongyan Coal Mine is about 32.43 million tons, and the annual mining capacity is up to 420,000 tons. According to the previous data, the recovery rate is about 0.49, as shown in Table 5.

Table 5. Basic Parameters of Hongyan Coal Mine

Parameter	$R^{max}(10^4t)$	$C^{max}(10^4t)$	γ
Data	3243	42	0.49

According to the survey data, the data on the pollution discharge of the Hongyan Coal Mine during the 12th Five-Year Plan period are shown in Tables 6 and 7.

Table 6. Unit Energy Consumption of Hongyan Coal Mine in 2015

Mining process	Raw coal (ton/ton)	Oil (litres/ton)	Electricity (KWH/ ton)
tunnelling	0	0.0673	14.2354
mining	0	0.0527	7.6523
transportation,	0.0021	0.0301	5.6381
coal preparation	0.0033	0.0151	2.8762

Table 7. Pollution Emission from Hongyan Coal Mine in 2015

Mining process	Exhaust gas (10^{-5} tons/ton)	Mine water (ton/ton)	Coal Gangue (Ton/Ton)
tunnelling	0.4357	0.1879	0.1321
mining	0.4278	0.1246	0.0194
transportation,	0.4012	0	0
coal preparation	0.3756	0	0

Some deterministic parameters in the model are as follows:T=5，N=4，I=3，L=3，TIC=40 million RMB，K=3.

The unit energy consumption after transformation is shown in Table 8, and the unit emission amount after transformation is also reduced. The parameter data after conversion of pollution emission standards of coal mining enterprises are shown in Table 9.

Table 8 Unit Energy Consumption after Energy Saving Reform

Mining process	Raw coal (ton/ton)	Oil (litres/ton)	Electricity (KWH/ ton)
tunnelling	0	0.0137	10.1334
mining	0	0.0097	4.3583
transportation,	0.00021	0.0121	2.7382
coal preparation	0.00133	0.0081	1.9635

Table 9 Emission reduction rate of pollutants

emission	2016 year	2017 year	2018 year	2019 year	2020 year
S02	0.8138	0.8295	0.8467	0.8594	0.8602
Mine water	0.5830	0.6180	0.6270	0.718	0.833
Coal gangue	0.699	0.707	0.761	0.764	0.802

The government issued relevant policies requiring enterprises to reduce their annual pollutant emissions. Therefore, after comprehensively considering the actual situation, the coal mining enterprises plan to invest 40 million RMB in energy conservation and emission reduction within five years. The planned investment amount is shown in Table 10.

Table 10 Investment in Energy Saving and Emission Reduction Expenses (Unit:104 RMB)

Investment projects	2016 year	2017 year	2018 year	2019 year	2020 year
Energy saving investment	400	380	525	380	410
Investment in emission reduction	320	450	404	420	311

6. Conclusion

After the above data is standardized, it is brought into the model, and the program is run by Matlab software. Calculated by software, the calculated coal output is between [180.14, 202.34] tons.It can be known from the data in the table that the function value is continuously decreasing as the number of iterations increases. This is consistent with the aim of continuous optimization of the algorithm.

(1) Production and investment plans have different effects in order to meet the standards required by the ecological environment, but are not completely independent of each other. When the total sewage discharge standard is high, it is necessary to further reduce production to reduce pollution emissions, but significantly affect profits. Therefore, investment in emission reduction projects can improve pollution discharge capacity. Energy-saving investment projects can only reduce the cost of the project if there is sufficient coal production.

(2) Project investment is sensitive to the energy conservation and emission reduction standards required by the government. Different projects also have different sensitivities. In the emission reduction projects, the investment plans for coal gangue and waste gas projects are relatively stable. However, the investment in mine water renovation projects is most sensitive to changes in emission reduction standards. The impact of investment wastewater treatment projects on total emission standards is not very big.

(3) Investment in energy-saving projects can not only reduce energy consumption, but also reduce production costs and bring about obvious economic profits, both of which can benefit both ecology and economy. However, the projects all have a capital recovery period, so when the capital recovery period is completed, the project does not seem to have any benefits in the short term. However, as an energy-saving investment project, it can improve efficiency and improve the sustainable development of coal mines. This is an effective way to expand the long-term profit margin of coal mines. Although emission reduction investment projects cannot directly increase economic benefits, they can effectively improve the cleanliness of coal and thus reduce pollution sources. Therefore, from the perspective of the long-term sustainable development of coal mining enterprises, investment in energy conservation and emission reduction technologies is necessary.

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