Analysis of Ecological Footprint and Ecological Rucksack of a Open-pit Coal Mine

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Abstract: Coal is China's major energy, the composition of it has more than 70% at primary energy consumption, on the one hand, coal mining provides us with the main energy, on the other hand, it gives a tremendous pressure on ecology in the mining process. Analysis the ecological pressure of a open-pit coal mine with using the method of ecological footprint and ecological burden, the result shows that the ecological footprint of open-pit is the fossil energy land and woodland. Main ecological footprint is the fossil fuel energy land, The best way to restore the ecological carrying mainly to afforest. Meanwhile, pay attention to the mining areas and improve technology to reduce the amount of stripping and tunneling (for example, by optimizing design to increase the final pit slope angle and decline stripping ratio), lower power consumption and increase water recycling, the use of cleaner energy and biological energy and other measures can reduce the ecological pressure of open-pit coal mine.
Keywords: Open-pit coal mine, Ecological pressure, Ecological footprint, Ecological rucksack

1. Introduction

As China's Joined WTO in 21st century, the world economic globalization and the further opening up, China's coal industry will face more severe challenges, facing fierce market competition and stringent environmental constraints, it needs to a comprehensive study on coal industry measures from a strategic perspective to ensure our energy security and sustainable development of coal industry[1]. This requires new understanding of the relationship between coal mining and ecological resources and finds out all aspects of coal brought by ecological stress. Re-shaping a cycle of development system of "resource conservation, less pollution, low energy consumption." Ecological footprint and ecological burden indicators are widely used to study the metabolic characteristics of social - economic system, the ecological footprint of human consumption and the impact on the ecology, quantitative ecological pressure.

This article analyses ecological stress of a open-pt coal mine with ecological footprint and ecological rucksack method and reveals their recent developments law in this paper, and reaches its best way to restore the ecological carrying is afforestation.

2. The Ecological Footprint of a Open Pit Coal Mining

2.1 About ecological footprint

Ecological footprint is a developing and popular important method to measure sustainable development, resource efficiency, eco-efficiency in recent years [2,3]. The existing calculation methods of ecological footprint are synthetic method and component analysis [4]. Synthesis method based on various substances macroeconomic statistics to various types of material macro-statistics to calculate a region or group of overall consumption of various substances and its corresponding ecological footprint, it fits for studying global and national and regional levels of the ecological footprint. component analysis based on form the composition of monomer consumption measurement to calculate and study the object's material consumption and ecological footprint, it ‘s suitable for small units of ecological footprint calculation,

such as towns, villages, companies, primary and secondary schools, individuals or individual activities [5, 6].

This study uses the ecological footprint of coal open-pit mining and analyses the ecological pressure of coal during the application of ecological footprint model and component analysis of energy ecological footprint model to calculate the ecological footprint of coal mining.

The variety of consumption will be converted into the six types of basic ecological productive land, such as cultivated land, pastureland, wood land, building sites, ocean (water), and fossil fuels land. A_k is any one of the needed 6 classes of ecological productive land area that supported for human consumption in a particular region.

$$A_k = \sum_{i=1}^{n} A_{ki} = \sum_{i=1}^{n} C_{ki} / Y_{ki} \qquad K = 1, 2, 3, \ldots\ldots, 6 \qquad (1)$$

Where n is the number of K type of land to provide consumer items of human consumption in the region, A_{ki}, C_{ki} and Y_{ki} is Provided by the demand for area of i kind of land consumption of the K type of land(hm^2), annual consumption($t \cdot a^{-1}$) and world average productivity($t \cdot hm^2 \cdot a^{-1}$) respectively.

2.2 Component analysis of energy ecological footprint

Energy includes coal, oil, gas and electricity, the ecological impact of energy consumption mainly for the CO_2 emissions of the greenhouse effect. To offset the impact on the need for adequate forest to absorb CO_2, so the energy consumption on the land use is forest. Since these lands are devoted to absorbing CO2, not for the purpose of producing forest products, it will list independently, called as the "fossil fuel energy land." The four kinds of fossil energy consumption of fossil fuel energy required area are:

$$A_c = Q_c \eta C_c \beta / P_a \qquad (2)$$

$$A_o = Q_o O_c \beta / P_a \qquad (3)$$

$$A_g = Q_g \rho G_c \beta / P_a \qquad (4)$$

$$A_e = Q_e E_{CO_2} / P_a \qquad (5)$$

Where A_c, A_o, A_g, A_e are the required areas of fossil energy of calculated coal, oil, natural gas and electricity consumption respectively during the year; Q_c, Q_o, Q_g, Q_e are the consumption of calculated coal, oil, natural gas and electricity respectively during the year; η is the average burn rate of combustion boiler; C_c, O_c, G_c are coal, oil, natural gas emission factor of carbon respectively; β is the conversion factor of carbon and CO_2; ρ is the density of natural gas; E_{CO_2} is CO_2 emissions of per unit capacity of a general thermal power plant; P_a is the quantity of absorb CO_2 of per hectares of forest a year(the average productivity of fossil fuel energy land).

2.3 Data processing

Collectting of 5 years' (from 2004 to 2008) required data in the categories of a open-pit coal mine. There are several needs of data processing description:

(1)Material input coefficients adopt the tabular statement on ecological rucksack by German Wuppertal Institute.

(2) As the consumption of transport belt, explosives and gasoline is relatively small, and the related material input coefficient is hard to find, so use the weight of its own when calculating the ecological burden.

(3) Timber in units of cubic meters of statistical data, timber in accordance with the coefficient of $1m^3$ = 0.8t converted their weight in the paper.

2.4 The material input of open-pit coal mining

The material input of open-pit coal mining is mainly electricity, coal, diesel, gasoline, steel, timber, transport belt, explosives, fresh water and cement.

2.5 Ecological footprint and its analysis of a open-pit coal mining

According to classification of items and data processing methods, and using the energy emission factor in Table 1, calculating the ecological footprint of open-pit in Table 2. According to coal producer, the ecological footprint of per ton of coal obtained in Table 3. The changes of the ecological footprint of per ton of coal shown in Figure 1.

Table 1 Discharge factors of the energy ecological footprint

Nmae	Eemission factor of C	Conversion factor from C to CO_2	Per unit CO_2 emission（t）	Pa（t/hm^2）
Raw coal(t）	0.725	3.67	2.13	5.2
Natural gas(10^3m^3)	0.409	3.67	1.12	5.2
Fuel type（t）	0.583	3.67	1.61	5.2
electric power (Gwh)			964	5.2

Table 2 Resources consumption ecological footprints of open-pit coal mine (hm^2)

The total footprint	Year 2004	Year 2005	Year 2006	Year 2007	Year 2008	Land type
Electricity	12246.508	11692.208	11451.208	8599.992	4638.323	Fossil energy land
Coal	6637.548	6499.598	6034.581	4585.496	2444.615	Fossil energy land
Steel	2191.504	1346.368	1105.659	180.241	89.231	Fossil energy land
Fuel	154.315	169.824	200.622	214.334	269.518	Fossil energy land
Timber	2009.974	1623.130	2249.712	832.509	108.386	Wood land
Total	23239.849	21331.128	21041.782	14412.572	7550.073	Ecological footprint

Table 3 Per ton of coal ecological footprints of open-pit coal mine

Footprint of per ton of coal（hm^2/t）	Year 2004	Year 2005	Year 2006	Year 2007	Year 2008
Electricity	0.007	0.007	0.007	0.004	0.002
Coal	0.004	0.004	0.003	0.002	0.001
Steel	0.001	0.001	0.001	0.000	0.000
Fuel	0.000	0.000	0.000	0.000	0.000
Timber	0.001	0.001	0.001	0.000	0.000
Total	0.014	0.012	0.012	0.006	0.003

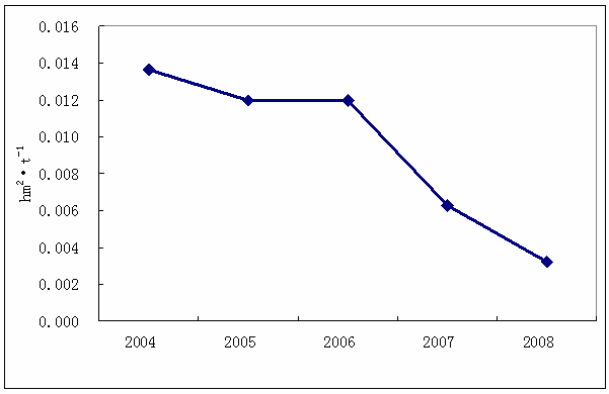

Fig 1 Per ton of coal ecological footprints of open-pit coal mine

The corresponds of open-pit mine's ecological footprint is fossil energy land and woodland. Fossil energy land and forest land accounts for more than 89.3% and 1.44% -10.69% of total ecological footprint respectively. Electricity and coal ecological footprint accounts for 52.7% - 61.43% and 28.56%-32.38% of total ecological footprint respectively, with the exploitation of both arerising. Steel and wood ecological footprint accounts for 1.18%-9.43% and 1.44%-10.69% of total ecological footprint respectively, with the exploitation of both are declining. As the ecological footprint of the fuel type for mining increased slightly, but it accounts for less than 4% of the total footprint. The ecological footprint of per ton of coal with the conduct of mining to a downward trend, indicating that as the conduct of mining, open pit mine ecological stress decreased.

3. The Ecological Rucksack of A Open Pit Coal Mining

3.1 About ecological rucksack

The concept of ecological rucksack was first proposed by Weizsaecker, ecological rucksack is the economic system of an important part of metabolism, about 50% of total material requirement in EU is the ecological rucksack [7]. The ecological rucksack vividly express humanity in order to obtain a useful material that caused additional ecological pressure. Ecological rucksack is human access to useful materials and production of products that are not directly entered the trade and production processes of the material, the material flow account also known as the hidden flow [8]. For example, it's necessary to dug many large rock tunnel and peel in ordre to mine the exploitation of coal, these do not directly enter the production process and the product itself, it is known as the hidden stream, that is, ecological rucksack. Ecological rucksack can fully reveal from the product input consumption of natural resources and environment impact. The ecological rucksack of a product equivalent to the total weight of the material input weight difference with the product itself, its ecological rucksack factor is the total weight of the material ratio of its own weight.

Generally speaking, direct use of material of products is not a single, Its ecological rucksack calculations need to consider of all the substances involved, including direct and indirect use of the material. All material quantity by weight. Production of a product containing the various substances consumed, the weight (W_i) of the substances multiplied by their ecological rucksack factor (γ_i), the total weight of material input of the product is the sum, then minus the weight of the product itself is the product of the ecological rucksack(R). That is:

$$R = \sum_{i=1}^{n} \gamma_i W_i - W \qquad (6)$$

Ecological rucksack factor is:

$$\gamma = \frac{1}{W}\sum_{i=1}^{n}\gamma_i W_i \qquad (7)$$

The key of calculation ecological rucksack is to find all the inputs, and stress two points:(1) Take energy consumption (e.g. electricity) as a "material" inputs;(2) Need to track the "input into" and their ecological rucksack, such as power input due to coal into and the ecological rucksack of the coal, and steel input caused by the ecological rucksack of iron ore.

It requires to keep track of their processes into the previous process in order to find all the inputs, the benefits of ecological rucksack factor is not necessary to repeat the calculation for each process. However, the application of ecological rucksack factor is limited, not all data are obtained. Therefore, the ecological rucksack factor need be calculated separately. The natural material input is divided into five parts by German Wuppertal Institute: non-biological material, biological material, soil movement, water and air.

Non-biological material including minerals, carry energy , non-use of excavation, soil excavation; Biological materials including cultivated plants, non-cultivated plants, non-farmed animals; Soil movement including the use of agricultural and forest land, soil erosion; Water including process water (extraction of surface water, groundwater extraction, extraction of deep groundwater), cooling water (extraction of surface water, groundwater extraction, extraction of deep groundwater); Air including combustion gas, chemical conversion gas, the physical transformation of gas (condensed state), the other taking the air.

This material input coefficient using the ecological rucksack of computation by German Wuppertal Institute, as shown in table 4.

Table 4 Some material input coefficient

Name	Non-biological material	Biological material	Water	Air
Electricity	4.22kg/Kwh	None	72.5kg/Kwh	0.607kg/Kwh
Diesel fuel	1.36t/t	None	9.7t/t	3.238t/t
Coke	4.22t/t	None	22t/t	3.1t/t
Carbon piece	20.06t/t	None	306.25t/t	5.7t/t
Coal	2.36t/t	None	9.1t/t	0.05t/t
Cement	2.42t/t	None	None	None
Steel	6.90t/t	None	None	None
Timber	0.13t/t	4.37t/t	0.27t/t	0.1t/t

3.2 Ecological rucksack and its analysis of a open-pit coal mining

According to the production data of the open-pit coal mine, calculate its ecological rucksack, as table 5. Calculated ecological rucksack factors according to coal producer in table 6, the changes in figure 2.

Table 5 Various kinds of total ecological rucksacks of open-pit coal mine

Grass weight：t	Year 2004	Year 2005	Year 2006	Year 2007	Year 2008
Solid non-biological	329875.143	311841.273	302591.797	226334.285	121070.852
Stripping capacity	5500720.000	5454239.000	5201146.000	4203214.000	2876057.000
Biological	13983.472	11292.181	15651.340	5791.795	754.045
Water	9373951.930	9080497.223	8978482.339	7297737.562	4496492.519
Air	42419.027	40658.277	40142.924	30846.721	17609.608
Others	1386.077	1404.255	1454.540	1300.085	1115.646
Total：t	15262335.649	14899932.209	14539468.94	11765224.449	7513099.670

Table 6 Ecological rucksacks' coefficients of open-pit coal mine

Ecological rucksack factor：t/t	Year 2004	Year 2005	Year 2006	Year 2007	Year 2008
Solid non-biological	0.194	0.175	0.172	0.099	0.052
Stripping capacity	3.229	3.058	2.960	1.834	1.227
Biological	0.008	0.006	0.009	0.003	0.000
Water	5.503	5.091	5.110	3.185	1.918
Air	0.025	0.023	0.023	0.013	0.008
Others	0.001	0.001	0.001	0.001	0.000
Total：t	8.959	8.354	8.275	5.134	3.205

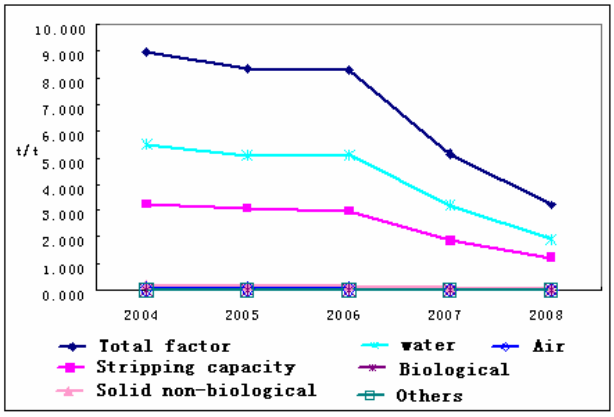

Fig 2 Ecological rucksacks coefficeients' variation of open-pit coal mine

Stripped, Other solid non-biological substances, water and air Ecological rucksack accounts for 35.73%-38.28%, 1.62%-2.17%, 59.85%-62.03% and 0.23%-0.28% of total ecological rucksack respectively of open-pit coal mine. Solid non-biological and water ecological rucksack composing the main part of the total ecological rucksack. Ecological rucksack factor of the solid material is the biggest and its value between 1.279 and 3.424 among all the ecological rucksack factors of open-pit mine. As mining progresses, the ecological rucksack coefficient showed a downward trend, indicating that for per ton of coal used for a variety of resources decreased.

4. Conclusion

Based on the methods of ecological footprint and ecological rucksack, the ecological stress of an open-pit coal mining is calculated and analysed, and then obtain the the ecological pressures of the open-pit coal mine.

(1) By calculating the ecological footprint of the consumed materials in the process of mining, the results of their ecological footprint is fossil fuel energy land and forest land, mainly fossil energy land. In order to restore its ecological carrying better, in the reclamation should be based mainly afforestation.

(2) By calculating of the ecological rucksack of the op-pit mine, stripping ecological rucksack, electricity ecological rucksack, new water ecological rucksack are the main ecological rucksack of the open-pit mine. Reduce the stripping ratio, lower power consumption, increased water recycling, use of clean energy and bio-energy could effectively reduce the ecological pressure on open-pit mine.

(3) With the progress of mining, per ton of coal of the ecological footprint and ecological rucksack coefficient decreased, indicating the ecological pressure and per ton of coal using a variety of resources decreased of open-pit coal mine.

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