Ecological Footprint Evaluation Model of Petrochemical Industry Based on Energy Theory

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Abstract. This paper establishes an ecological footprint model based on energy theory to calculate the ecological footprint of petrochemical industry. The results show that the industrial structure of petrochemical industry is single and the ecological environment is seriously damaged. The economic and social benefits created cannot compensate for the ecological environment cost of industrial development.

1. Introduction
In recent years, the research on ecological footprint has been deepening both at home and abroad, mainly in three aspects [1]: Model construction of ecological footprint. Hanley constructed an ecological footprint model to measure the sustainability of Scotland's national development by combining social, economic and demographic indicators. Kurt K combined the ecological footprint with the value of ecosystem services, and constructed an ecological system with added ecological value, i.e. a composite model of economic input and output. On the application of ecological footprint model. Gerbens Leenes used the ecological footprint model to study the relationship between human food consumption patterns and agricultural land demand. Manfel L studied the relationship between the differences in household income and consumption expenditure and the ecological footprint in Australia. Andersson uses the ecological footprint model to study the unequal exchange between international trade and ecology. Martinez Alier introduced ecological footprint into the study of international debt and environmental damage, and used the concept of "ecological responsibility allocation" to analyze different types of environmental impacts. Krivtsov V applied ecological footprint to study the relationship between recycling of glass and plastic wastes and national energy consumption. On the relationship between ecological footprint. Gernot Stoglehner et al. studied the impact of energy consumption patterns on ecological footprint. Mathis Wackernagel studied the relationship between national economic development and ecological footprint through time series, thus changing static ecological footprint model into dynamic model. Federici M measures the energy consumption and utilization efficiency of Siena's highway and railway transportation system, and its impact on regional ecological footprint and sustainable development through the ecological footprint model [2].
2. Research methods of ecological footprint

2.1. Ecological carrying capacity and ecological footprint
The connotation of ecological carrying capacity. Bearing capacity is a concept borrowed from the field of engineering geology. Its original meaning is the capacity of foundation strength to bear the weight of buildings. It has become the most commonly used concept to describe the degree of development restriction. Ecology first introduced this concept into the field of this discipline. In 1921, Parker and Burgess put forward the concept of carrying capacity in the relevant journals of human ecology, that is, "the highest limit of an individual's existence quantity under a specific environmental condition (mainly referring to the combination of ecological factors such as living space, nutrients and sunshine). Ecological carrying capacity, also known as environmental carrying capacity, is defined mostly by the concept that carrying capacity is a function of both geographical region and organism.

2.2. The relationship between ecological carrying capacity theory and Ecological Footprint Theory
The theory of ecological carrying capacity and the theory of ecological footprint constitute an important part of the theory of sustainable development. The theory of ecological footprint and the theory of ecological carrying capacity not only support the application of basic theory, but also develop and improve under the guidance of sustainable economic development theory. The relationship between ecological footprint and ecological carrying capacity is the function and the function. The ecological footprint describes the amount of environmental resources occupied by human beings from the perspective of consumption, expressing the concept of pressure of strong sustainability, while the ecological carrying capacity examines the population that the environmental system can afford from the perspective of supply, expressing the concept of stress of strong sustainability. In application, the two are linked together through the discrimination of ecological surplus, and together constitute an important part of the discrimination system of sustainable development.

3. Relevant calculation of Ecological Footprint Theory

3.1. Basic assumptions
Human beings can estimate the vast majority of resources consumed by themselves and the amount of waste generated by them.

These resources and wastes can be converted into the corresponding bio-productive land area. Different countries and regions have different types of land with different yield levels. By introducing equilibrium factors and yield factors, land with global average biological productivity can be directly added and compared [3].

When using biological productivity to measure land, land between different regions can be expressed by the same unit (hectare).

All kinds of land are mutually exclusive in space. That is, it can only be one of the six categories of fossil energy land, cultivated land, grassland, woodland, and construction land and water area.

3.2. Relevant calculation of Ecological Footprint Theory
The calculation of ecological footprint per capita of various consumption items, that is, the area of ecological productive land per capita occupied for the production of various consumption items.

\[
EF = Nef = N \sum_{i=1}^{n} (a_{i} e_{i}) = N \sum_{i=1}^{n} (c_{i} p_{i})
\]

\(EF\)——the total ecological footprint;
\(N\)——Total population;
\(ef\)——per capita ecological footprint;
$a_i$ — the area of biological production converted from the first commodity per capita;
$C_i$ — the per capita consumption of the first commodity;
$P_i$ — the average production capacity of consumer goods of type $i$;
$i$ — Types of consumer goods and inputs.

Or expressed as:

$$E_f = c_i / Y_i = (P_i + I_i - E_j) / (EP_i \times N)$$  \hspace{1cm} (2)

$ef$ — the per capita annual consumption, i.e. the per capita ecological footprint.

The total ecological footprint is $EF = Nef$;

$N$ — Total population;

In calculating the trade adjustment of energy sector, the following calculation methods are used:

$$N_i = M_i \times \left[ H_i / G_i \right] W_i$$  \hspace{1cm} (3)

$N_i$ — commodity energy carrying capacity;
$W_i$ — the net value of trade in the first commodity;
$H_i$, $G_i$ — the physical and value of net trade in such commodities;
$M_i$ — the energy density of such commodities.

Calculate the equivalent amount of all kinds of Eco-productive land occupied per capita. $r_j$ is the equilibrium factor.

$$ef = \sum r_j A_j = \sum r_j (P_i + I_i - E_j) / EP_i \times N \hspace{1cm} (j = 1, 2, 3 \ldots 6)$$  \hspace{1cm} (4)

The total ecological footprint is as follows:

$EF = N \times (ef)$;

$N$ — Total population.

The calculation of ecological capacity or ecological carrying capacity.

Per capita ecological capacity of a certain type = per capita area of all kinds of Eco-productive land × equivalent factor × productivity coefficient.

$$Ec = a_j \times r_j \times y_j \hspace{1cm} (j = 1, 2, 3 \ldots 6)$$  \hspace{1cm} (5)

$ec$ — per capita ecological carrying capacity;
$a_j$ — per capita biological production area;
$r_j$ — equilibrium factor;
$y_j$ — yield factor.

Regional ecological carrying capacity:

$$EC = N \times (ec)$$  \hspace{1cm} (6)

$EC$ — the ecological carrying capacity of the population in the region.

4) Ecological deficit and surplus

Ecological deficit (ecological surplus) = ecological carrying capacity — ecological footprint

$$ED = EF - EC$$  \hspace{1cm} (7)

The negative value is the ecological deficit and the positive value is the ecological surplus.
4. Ecological Footprint Evaluation of Petrochemical Industry

4.1. Collection and processing of raw data
The concrete steps and calculating formulas of establishing the Ecological Footprint Evaluation Model of petrochemical industry. Collect information on natural environment, social resources and economic activities in the studied area [4].

- Define the types of materials (materials and energy) input by the main departments of petrochemical industry;
- Study time consumption of energy in petrochemical development process;
- Waste disposal in petrochemical development process;
- Consumption of coal, natural gas, water and electricity resources;
- The production of building materials and labor input used in the development of petrochemical industry are huge, which have a fundamental change to the natural environment. A large number of harmful gases, dust, noise and vibration are produced in the process of petrochemical development [5].

The ecological footprint of petrochemical industry in operation stage includes: the consumption of coal, natural gas, water, electricity and other resources in the operation process; garbage treatment and sewage discharge in the operation process.

4.2. Drawing detailed energy maps of analytic objects
Figure 1 shows the energy cycle diagram of petrochemical industry. Because the petrochemical industry is divided into projects in the development stage and projects in the operation and maintenance stage, two subsystems of development and operation projects are plotted in the diagram to evaluate the ecological footprint separately.

![Figure 1: Energy Cycle Diagram of Petrochemical Industry](image-url)
4.3. Calculating the ecological footprint EF of petrochemical industry

The monetary value of economic and social benefits created by petrochemical industry in the study area is divided by the energy/money ratio, converted into the total energy of solar energy, and then divided by the total area of construction land in the region (Gsej/hm²) [6]. The average energy density of petrochemical industry in the region is obtained. Therefore, the ecological footprint EF of petrochemical projects is as follows:

\[ EF = \frac{e}{\rho_i} \]  

(8)

4.4. Calculating EC of Ecological Bearing Capacity

Natural resources can be divided into renewable resources and non-renewable resources. With the continuous use of resources in petrochemical industry, non-renewable resources will eventually be exhausted. Only by using renewable resources can regional development be sustainable and ecological carrying capacity be sustainable. The ecological carrying capacity is as follows:

\[ EC = \frac{e}{\rho} \]  

(9)

4.5. Calculate ecological deficits or surpluses.

The ecological footprint obtained by adding all the solar energy values in the construction and operation stages of petrochemical industry was compared with the ecological carrying capacity to measure the sustainable development of regional petrochemical industry. The calculation formulas expressed by ecological deficit and ecological surplus are as follows:

\[ ED = EC - EF \]  

(10)

ED is the ecological deficit (ecological surplus), the negative value is the ecological deficit, and the positive value is the ecological surplus.

- If \( ED < 0 \), it indicates that the project is in the state of ecological deficit. The petrochemical industry in this region is in a state of unsustainable development.
- If \( ED = 0 \), the project is in the state of ecological balance.
- If \( ED > 0 \), the project is in the state of ecological surplus. The bigger ED, the better economic and social benefits the petrochemical industry can get at the smaller environmental cost.

5. Conclusion

By establishing the ecological footprint model of petrochemical industry based on emergy theory and calculating the ecological footprint, it can be concluded that the petrochemical industry structure is single, the structure is unbalanced, the infrastructure is insufficient, the economic radiation is weak, and the ecological environment is seriously damaged. Therefore, whether in the economic sense or in the ecological sense, the sustainable development of petrochemical industry has become an unavoidable major practical problem.

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