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The E2-efficiency and Its Intuitionistic Fuzzy Measurement in Petrochemical Enterprises

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With the emerging global ecological environment crisis, petrochemical enterprise operation and its supply chain should set up a win-win target of both environment protection and economic benefit realization, which means, a higher ecological-economic efficiency. This paper establishes the E2-efficiency quantitative model for petrochemical enterprise based on the theory of intuitionistic fuzzy set, and conducts intuitionistic fuzzy measurement of petrochemical enterprise E2-efficiency, in order to be beneficial to the achievement of the win-win target for petrochemical enterprise on environment protection and economic benefit improvement.

1. Introduction

Confronted with the global environmental crisis, all enterprises were required to clearly identify these realistic problems, such as how to better adapt to natural environment, to make full use of limited natural resources and to protect the ecological environment in order to achieve sustainable development. This is all the more to petrochemical enterprise. The operation strategies of petrochemical enterprise for sustainable development have to be set up based on the relationship between the enterprises and ecological environment. The realization of strategic target in ecological competition and the acquirement of ecological and economic benefits have to take the petrochemical enterprises competitive development as precondition. All these works must premise on the definition of the E2-efficiency of petrochemical enterprises, and depend on the petrochemical enterprises E2-efficiency measurements. Therefore, the ways to define the E2-efficiencys and to measure the benefits of petrochemical enterprises become the core problem concerning to the survival and profitability, competition and development of the petrochemical enterprises, which has both academic value and practical significance.

2. Petrochemical Enterprise and the Significance to Its E2-efficiency Measurement

2.1 Petrochemical Enterprise and the seriousness of its environmental pollution problem

Petrochemical enterprises are based on the comprehensive utilization of petroleum or natural gas resources, in order to improve the economic benefits of production. Products are necessary for industry, agriculture, transportation, military affairs, science and technology and people’s life. Therefore, enterprises have great influence on the economic development of a country as well as the people's livelihood. However, projects are seriously polluted and difficult to control. The types and concentrations of pollutants produced in the industry are relatively large. If no effective measures for pollution prevention are taken, serious damage to the ecological environment will be produced.

Given the great importance of enterprises on the development of the national economy and the great impacts on the ecological environment, the concept of E2-effciency should be introduced to industry. Hence, it can eliminate the adverse effects of enterprise production and cultivate the core competitive ability of enterprises.

According to the concept of E2-efficiency put forward by WBCSD, E2-efficiency represents the economic output of unit environmental load. In order to realize the dual goal of ecology and economy, enterprises should constantly improve E2-efficiency. In this paper, enterprises’ E2-efficiency is defined as the ratio of cumulative environmental impact in the process of production and management to the economic profits obtained by the enterprises. The measurement of enterprises impacts on the environment is based on the dual relationships

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between environmental factors and economic factors. In this regard, it can evaluate their efforts on environmental protection and their economic effects comprehensively.

Petrochemical Enterprise is a production and operation complex which combines petrochemical industry and the petroleum refining industry altogether. It is established based on the comprehensive utilization of petroleum resources, and aims at improving the production economic benefits. As being the necessities for industrial engineering, agriculture, transportation, military, science and technology innovation, petrochemical industry and their products possess great significance to the national economic development and citizen's daily life. (Wang and Xie, 2014) But meanwhile, petrochemical project also has serious pollution problems. Petrochemical industry generates great varieties of pollutants with high concentration, which could lead to severe detrimental consequence to the ecological environment. Air pollution is the major output of petrochemical industry pollution. The main emission of air pollution caused by petrochemical industry including sulfur dioxide (SO2), nitrogen oxides (NOX), dust and organic volatiles. Compare to air pollution, waste water and solid waste have relatively minor noxious impact to the environment, but they also required to be eliminated by effective controlling approach and reasonable cost (Arabi and Doraisamy, 2016).

2.2 Significance of petrochemical enterprise E2-efficiency measurement

The concept of "Eco-Efficiency" put forward by Schaltegger and WBCSD is constituted by the prefix of "Economic" and "Ecological", and the word "efficiency", which means "ecological economic efficiency" or "economic ecological efficiency". It can also be called "E2-efficiency" for short. E2-efficiency reflects the concept of the environmental protection and the reduction of environmental loads, which is the combination of the environment, resource investment and the economic activities with maximum output. All along, the pursuit of economic benefits always stands opposite to the protection of ecological environment. And enterprises take actions by weighing pros and cons all the time. However, the concept of E2-efficiency put forward by WBCSD initially combines them together.

The new economic model fundamentally changes the way of competition of enterprises by utilizing technological innovation, takes the ecological green as the standard of competitiveness, and considers the realization of win-win situation between ecological protection and economic growth as the organic and integrated target of economic development. In the new economic model, only enterprises radically alter their traditional conception of benefits and adhere to realizing E2-efficiency can ecological competitive edges be achieved. Enterprise competitive advantages in the traditional economic model can be reflected by making more economic values than that of competitors. However, under new economy, business operation turns into the model of environmental management and ecological operation. Enterprise competitive advantages are reflected by making more ecological economic values instead. Therefore, E2-efficiency is the direct indicator to measure enterprises competitive advantages in the new economic model. The strategy that can bring truly competitive advantages enterprises is the one that reflects the maximum benefits of E2-efficiency.

Given great importance to petrochemical enterprises on national economy development and serious impacts on ecological environment, E2-effciency should be introduced to petrochemical industry to motivate enterprise to regulate its operation behavior, to consciously take social responsibility of contamination abatement and environmental protection, and to eliminate the adverse effects to the environment (Lu, 2017).

In order to realize the dual goal of ecology and economy, and seek to higher economic benefit under the precondition of surmount its detriment to ecology, petrochemical enterprises should constantly improve E2-etfficiency.This paper takes the binary relationship and the further synthetic relationship of environmental factors and economic factors as the basement, take full account of the fuzzification and sets of ecological environment factors and ecological economy benefit, apply intuitionistic fuzzy set to the measurement of petrochemical enterprises eco-efficiency, hereby to evaluate their efforts on environmental protection and economic effects more objectively, reasonably, and comprehensively.

3. Petrochemical Enterprise E2-efficiency theoretical model and measurement system

3.1 Petrochemical Enterprise E2-efficiency theoretical model

According to definition and containing of enterprise E2-efficiency, the theoretical formula of petrochemical enterprise E2-efficiency is: E2-efficiency = Ecological and Economic Benefit / Ecological Environment Capital

The ecological and economic benefit in formula (1) contains not only the output of economic capital, but also the extra benefit brought by pollution prevention and environmental governance. (Gao, 2015) The ecological environment capital is depicted by the amount of "three waste" that emitted during the production process, with taking into account of the external environment detrimental cost. Ecological environment capital (environmental capital) in formula (1) is formed by the capital transformation of environmental protection investment and environmental governance cost. As exceed environmental benefit, external environment detrimental cost and ecological environment capital are all having the fuzzy property, the theoretical formula could be described as:

E2-efficiency = (Pure economic Benefit + Exceed Ecological Benefit – Environmental Pollution Cost) / Ecological Environment Capital

Corresponding to the traditional financial assessment DuPont system, theoretical models of petrochemical enterprise E2-efficiency based on the environmental-economic factors integration and environmental multiplier function was established.

The environmental multiplier of enterprise E2-efficiency assessment can be defined as:

Environmental Multiplier = Total Capital / Environmental Capital.

In there, Total Capital = Environmental Capital + Pure Economic Capital.

Based on the theoretical function of enterprise E2-efficiency, the decomposition model of petrochemical enterprise E2-efficiency is as follows:

E2-efficiency = Ecological and Economic Benefit / Environment Capital

= [(Pure economic Benefit + Exceed Ecological Benefit – Environmental Pollution Cost) / Total Capital] × (Total Capital / Environmental Capital)

= (Economic ROE + Exceed Ecological Benefit / Total Capital – Environmental Pollution Cost / Total Capital) × Environmental Multiplier

As the ratio of Exceed Ecological Benefit and Environmental Capital could be defined as the return of environmental capital, the ratio of environmental pollution cost and total capital could be defined as environmental capital cost rate, the above theoretical decomposition model could be depicted as:

E2-efficiency = (Economic ROE + Environmental ROE + Environmental Capital Cost Rate) × Environmental Multiplier

3.2 Petrochemical Enterprise E2-efficiency Measuring System

Aiming at analyzing the determinate factors of E2-efficiency and revealing the motivative requirement on prevention and governance of environmental pollution, the measuring system of petrochemical enterprise E2-efficiency is established as figure 1:

The above E2-efficiency Measuring System represents the dualistic intuitionistic fuzzy relationship of the interfusion and interaction between environmental factors and economic factors, and thus requires intuitionistic fuzzy set for its description and measurement.

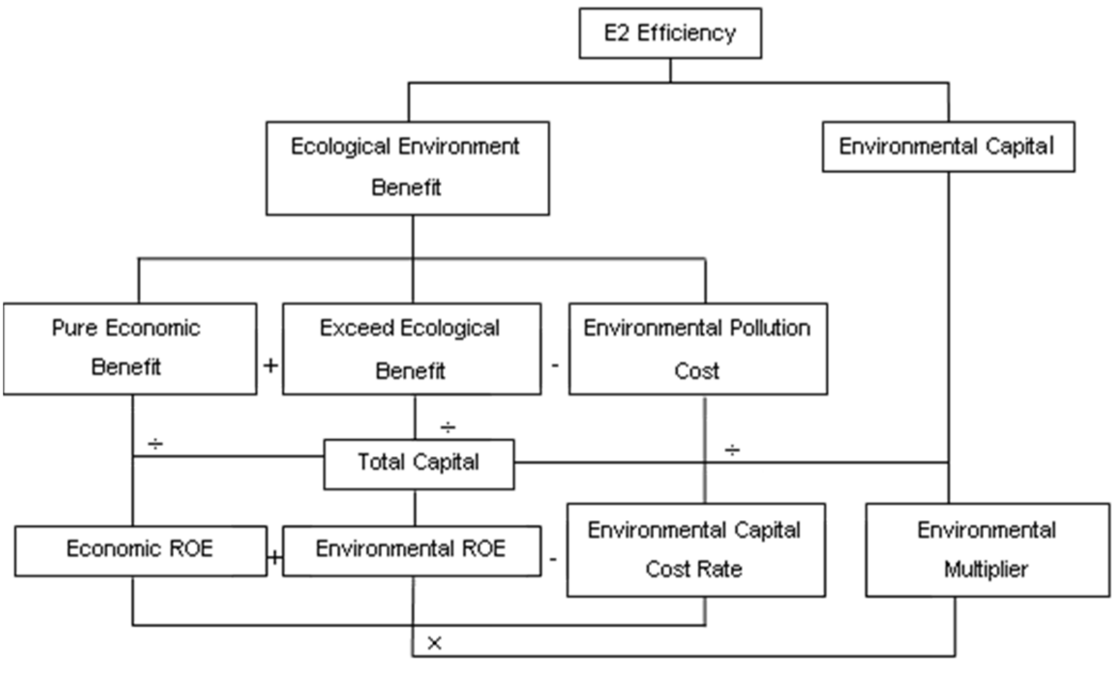

Figure 1: Petrochemical Enterprise E2-efficiency Measuring System

4. Petrochemical Enterprise E2-efficiency Measurement Based on Intuitionistic Fuzzy Set

4.1 Intuitionistic Fuzzy Set Theory

Definition 1: Have given domain U, One of the intuitionistic fuzzy sets A is:

$$A = \{\langle x, \mu_A(x), \gamma_A(x)\rangle \mid x \in U\} \tag{1}$$

Among them $\mu_A(x): U \to [0,1]$ and $\gamma_A(x): U \to [0,1]$, Representing membership function and nonmembership function of A, and for all A $x \in U$, $0 \le \mu_A(x) + \gamma_A(x) \le 1$ set up.

Set on U all constitute a collection of intuitionistic fuzzy sets are IFS(U).For every an intuitionistic fuzzy subset of U, say $\pi_A(x) = 1 - \mu_A(x) - \gamma_A(x)$ is A which x intuition index, It is x to A's hesitation degree of measure.

For $0 \le \alpha, \beta \le 1$, $A_{(\alpha,\beta)} = \{x \mid \mu_A(x) \ge \alpha, \gamma_A(x) \le \beta, x \in U\}$ set $A_{(\alpha,\beta)} = \{x \mid \mu_A(x) \ge \alpha, \gamma_A(x) \le \beta, x \in U\}$ is (α, β) cut set of intuitionistic fuzzy sets A.

Definition 2: Set U and V is common, the theoretical field, defined in the direct product space of intuitionistic fuzzy subset called from U to U×V which V binary between intuitionistic fuzzy relations. Write for:

$$R = \{\langle (x,y), \mu_R(x,y), \gamma_R(x,y)\rangle \mid x \in U, y \in V\}, \tag{2}$$

$0 \le \mu_R(x,y) + \gamma_R(x,y) \le 1,$ of $\mu_R: U \times V \to [0,1]$ and $\gamma_R: U \times V \to [0,1]$ meet conditions.

By a binary intuitionistic fuzzy relation, the definition of the intuitionistic fuzzy relation is a kind of intuitionistic fuzzy sets, and is a multiple cross-product between intuitionistic fuzzy sets (Mondal and Roy, 2015).

Definition 3: Mapping T: [0,1]×[0,1]→[0,1] , Is the function that transfer membership and nonmembership function of intuitionistic fuzzy subsets A and B to membership and nonmembership function of intersection of A and B. Mapping S: [0,1]×[0,1]→[0,1] , Is the function that transfer membership and nonmembership function of intuitionistic fuzzy subsets A and B to membership and nonmembership function of union set of A and B.

Intuitionistic fuzzy operational rule:

$$\mu_{A \cap B}(x) = \min[\mu_A(x), \mu_B(x)], \gamma_{A \cap B}(x) = \max[\gamma_A(x), \gamma_B(x)] \tag{3}$$

$$\mu_{A \cup B}(x) = \max[\mu_A(x), \mu_B(x)], \gamma_{A \cup B}(x) = \min[\gamma_A(x), \gamma_B(x)] \tag{4}$$

4.2 Intuitionistic fuzzy set measurement for Petrochemical Enterprise E2-efficiency

Environmental factors and their relevant information have the property of fuzziness and uncertainty. Information fusion based on intuitionistic fuzzy set theory has the edge of the measurement and appraisal on such factors, thus is able to adapt to the measurement of petrochemical enterprise E2-efficiency and intuitionistic fuzzy relationship of the environmental factors and economic factors within their production process (Hernandez and Uddameri, 2010). This paper based on the above established enterprise E2-efficiency model, selects applicable indicators, and applies intuitionistic fuzzy set approach, to conduct the measurement of petrochemical enterprise E2-efficiency.

The specific measurement method could be implemented by the following steps:

Step1: Determine the intuitionistic fuzzy subset that relevant to petrochemical enterprise E2-efficiency measurement system and their dualistic intuitionistic fuzzy relationship.

Step2: Determine the intuitionistic fuzzy set and the cut set according to each intuitionistic fuzzy subset and their dualistic intuitionistic fuzzy relationship.

Step 3: Based on the intuitionistic fuzzy relationships of the environmental factors and economic factors within petrochemical enterprise E2-efficiency measurement system, conduct intuitionistic fuzzy set measurement.

5. Case Study of intuitionistic fuzzy measurement for Petrochemical Enterprises E2-efficiency

5.1 HEB Refinery environment pollution and governance

HEB Refinery is a subordinate enterprise of Petrol China on oil refinery and chemical engineering, with 17 sets of oil refining and chemical engineering plants, over 4 million tons annual processing capacity of crude oil and dozens of products such as gasoline, kerosene, diesel and liquefied petroleum gas. HEB has three main operational departments: A refinery department, B refinery department and chemical engineering department.

The main emissions of its production are: liquid waste - mineral oil, COD, sulfide; waste gas- SO2, HS, nitrogen oxides; solid waste - sludge and other waste catalyst. The enterprise has implemented environmental responsibility system at all levels, actively implemented pollution control projects, and achieved relatively good ecological and economic benefits. In 2016, 3.89 million tons of crude oil was processed, with 9.1058 million RMB benefit, and 154.33 million RMB financial capitals.

5.2 Intuitionistic fuzzy set measurement of HEB E2-efficiency

Set exceed environmental benefit, environmental pollution cost and environmental capital in the decomposition theoretical model of enterprise E2-effeciency as intuitionistic fuzzy sets A1, A2 and A3. For the intuitionistic fuzzy subsets and the components, see table 1:

Table 1: HEB E2-efficiency relevant intuitionistic fuzzy sets, subsets and subsets elements

Intuitionistic Fuzzy sets	Intuitionistic Fuzzy Subsets	Intuitionistic Fuzzy Subsets Elements (million RMB)
A1	A11 Actual Environmental Benefit	A111 Sulfur recycle (2.45) A112 Gasoline vapour recycle (2.1525) A113 Effluent oil recycle (0.5468) A114 Emission reduction of VOCs (0.6082) A115 Waste water treatment and reutilization (6.2479) A116 Condensed water recycle (9.495)
A2	A12 Potential Environmental Benefit	A121 Indirect influence to economic benefit improvement (-) A122 Lagged influence to economic benefit improvement (-)
	A21 "Three Wastes" Emission Cost	A211 Emission cap expense (1.9594) A212 Excess emissions penalty (2.12)
	A22 Contingent Loss cost	A221 Compensation expense (1.2728) A222 Goodwill Loss (-)
A3	A31 Pollution Abatement Cost	A311 EP management expense (3.454) A312 Treatment equipment operation cost (4.439) A313 Waste disposal expense (4) A314 Monitoring expense (1) A315 LDAR testing expense (4.72 million RMB)
	A32 EP Investment	A321 EP equipment investment (30) A322 EP technology R&D investment (15) A323 Government environmental subsidy (8)

Determines the intuitionistic fuzzy relationship of Ai (i=1,2,3) and Aij (i=1,2,3; j=1,2, and takes A21 and A22 for example to present the corresponding intuitionistic fuzzy relationship matrix:

$$A_{21}=\frac{\langle\mu_{21}(x_{211}),\gamma(x_{211})\rangle}{x_{211}}+\frac{\langle\mu_{21}(x_{212}),\gamma(x_{212})\rangle}{x_{212}}+\frac{\langle\mu_{21}(x_{221}),\gamma(x_{221})\rangle}{x_{221}}$$
$$=\frac{\langle 0.79,0.21\rangle}{x_{211}}+\frac{\langle 0.92,0.07\rangle}{x_{212}}+\frac{\langle 0.67,0.32\rangle}{x_{221}} \quad (5)$$

$$A_{22}=\frac{\langle\mu_{22}(x_{221}),\gamma(x_{221})\rangle}{x_{221}}+\frac{\langle\mu_{22}(x_{222}),\gamma(x_{222})\rangle}{x_{222}}=\frac{\langle 0.59,0.29\rangle}{x_{221}}+\frac{\langle 0.55,0.23\rangle}{x_{222}} \quad (6)$$

$$R_2=\begin{bmatrix}\langle\mu(x_{211},x_{221}),\gamma(x_{211},x_{221})\rangle\langle\mu(x_{211},x_{222}),\gamma(x_{211},x_{222})\rangle\\ \langle\mu(x_{212},x_{221}),\gamma(x_{212},x_{221})\rangle\langle\mu(x_{212},x_{222}),\gamma(x_{212},x_{222})\rangle\end{bmatrix}=\begin{bmatrix}\langle 0.89,0.05\rangle\langle 0.78,0.25\rangle\\ \langle 0.65,0.15\rangle\langle 0.53,0.34\rangle\end{bmatrix} \quad (7)$$

Matrix R2 measures the relevancy of elements in "three wastes" emission cost subset and contingent loss cost subset, and the contribution degree of it to environment pollution forming and transforming. According to the intuitionistic fuzzy operation rule, get intuitionistic fuzzy set A2.

$$A_2=A_{21}\cup A_{22}=\{\langle x,\mu_{A_{21}\cup A_{22}}(x),\gamma_{A_{21}\cup A_{22}}(x)\rangle\}=\{\langle x,\max[\mu_{A_{21}}(x),\mu_{A_{22}}(x)],\min[\gamma_{A_{21}}(x),\gamma_{A_{22}}(x)]\rangle\}$$
$$=\frac{\langle 0.79,0.21\rangle}{x_{211}}+\frac{\langle 0.72,0.17\rangle}{x_{212}}+\frac{\langle 0.67,0.29\rangle}{x_{221}}+\frac{\langle 0.55,0.23\rangle}{x_{222}} \quad (8)$$

Following the same principle, get intuitionistic fuzzy set A1, A3.

$$A_1 = A_{11} \cup A_{12} = \{\langle x, \mu_{A_{11} \cup A_{12}}(x), \gamma_{A_{11} \cup A_{12}}(x)\rangle\} = \{\langle x, \max[\mu_{A_{11}}(x), \mu_{A_{12}}(x)], \min[\gamma_{A_{11}}(x), \gamma_{A_{12}}(x)]\rangle\}$$
$$= \frac{\langle 0.79,0.18\rangle}{x_{111}} + \frac{\langle 0.76,0.19\rangle}{x_{112}} + \frac{\langle 0.69,0.16\rangle}{x_{113}} + \frac{\langle 0.96,0.04\rangle}{x_{114}} + \frac{\langle 0.83,0.24\rangle}{x_{115}} + \frac{\langle 0.85,0.15\rangle}{x_{116}} + \frac{\langle 0.79,0.21\rangle}{x_{121}} + \frac{\langle 0.90,0.07\rangle}{x_{122}} \quad (9)$$

$$A_3 = A_{31} \cup A_{32} = \{\langle x, \mu_{A_{31} \cup A_{32}}(x), \gamma_{A_{31} \cup A_{32}}(x)\rangle\} = \{\langle x, \max[\mu_{A_{31}}(x), \mu_{A_{32}}(x)], \min[\gamma_{A_{31}}(x), \gamma_{A_{32}}(x)]\rangle\}$$
$$= \frac{\langle 0.94,0.02\rangle}{x_{311}} + \frac{\langle 0.76,0.18\rangle}{x_{312}} + \frac{\langle 0.85,0.17\rangle}{x_{313}} + \frac{\langle 0.86,0.11\rangle}{x_{314}} + \frac{\langle 0.92,0.04\rangle}{x_{315}} + \frac{\langle 0.72,0.25\rangle}{x_{321}} + \frac{\langle 0.79,0.21\rangle}{x_{322}} + \frac{\langle 0.59,0.37\rangle}{x_{323}} \quad (10)$$

Comprehensively weighs the value of membership and nonmembership degree of each intuitionistic fuzzy set, selectsα=0.75，β=0.15 respectively to determine the cut sets of intuitionistic fuzzy set Ai（i=1,2,3）.

$$A_{1[0.60,0.15]} = \frac{\langle 0.79,0.18\rangle}{x_{111}} + \frac{\langle 0.76,0.19\rangle}{x_{112}} + \frac{\langle 0.69,0.16\rangle}{x_{113}} + \frac{\langle 0.83,0.24\rangle}{x_{115}} + \frac{\langle 0.85,0.15\rangle}{x_{116}} + \frac{\langle 0.79,0.21\rangle}{x_{121}} \quad (11)$$

$$A_{2[0.60,0.15]} = \frac{\langle 0.79,0.21\rangle}{x_{211}} + \frac{\langle 0.72,0.17\rangle}{x_{212}} + \frac{\langle 0.67,0.29\rangle}{x_{221}} \quad (12)$$

$$A_{3[0.6,0.15]} = \frac{\langle 0.76,0.18\rangle}{x_{312}} + \frac{\langle 0.85,0.17\rangle}{x_{313}} + \frac{\langle 0.92,0.04\rangle}{x_{315}} + \frac{\langle 0.72,0.25\rangle}{x_{321}} + \frac{\langle 0.79,0.21\rangle}{x_{322}} \quad (13)$$

Consequently, the measurement value of HEB refinery E2-effieciency is:
E2-effieciency = (Economic ROE + intuitionistic fuzzy value Environmental ROE + intuitionistic fuzzy value Environmental Capital Cost Rate) × intuitionistic fuzzy value Environmental Multiplier=3.6%+9.9%-1.3%×2.52=30.7%
From this it can be seen that the HEB refinery has created comprehensive ecological and economic benefit which is much higher than the economic benefits due to its efforts in pollution prevention and control

6. Conclusion

To achieve the win-win target of environment protection and economic benefit realization, petrochemical enterprises have to take E2-efficiency as critical index for operating performance evaluation. The measurement of E2-efficiency of petrochemical enterprise should adopt the appropriate methods based on intuitionistic fuzzy theory because of the complex and fuzzy ecological environment impact on economy, and the complicated relationship between environment and economy, which presented by the E2-efficiency model of petrochemical enterprise. The intuitionistic fuzzy approach is beneficial to reasonably determine the target of petrochemical enterprise operation and petrochemical supply chain, to objectively evaluate petrochemical enterprise operating performance, and to effectively control the complex and fuzzy relationship between economy and environment in the production process of petrochemical enterprise operation and petrochemical supply chain.

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