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Optimization of Industrial Energy Structure Based on Non-equilibrium Thermodynamics

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Abstract: Since the reform and opening up, my country's economic development has made great achievements. But at the same time of economic development, there is also the problem of insufficient energy, which has become one of the main factors restricting the continued development of my country's economy and society. The purpose of this work is to study the optimization of industrial energy structure based on non-equilibrium thermodynamics. Firstly, it discusses the current situation of energy consumption, the non-equilibrium thermodynamics of energy system and the relevant industrial construction optimization theory, and then selects the indicators of economic development, industrial structure and energy consumption structure. Then adopt the minimum energy consumption constraint scheme based on non-equilibrium thermodynamics, the environmental pollution minimum constraint scheme and the industrial energy structure optimization scheme, and finally provide empirical data for the model based on the statistical yearbook of M province and the input-output table of M province. The model comparison analysis shows that, After the optimization of the industrial energy structure optimization scheme based on non-equilibrium thermodynamics proposed in this paper, the total energy consumption of M province is reduced by 6.2%. Compared with the baseline period, sewage discharge in Province M decreased by 4.9%, exhaust gas emissions decreased by 3.5%, and solid waste decreased by 1.5%. At this time, the economy has grown by 3.7% compared to the base period, and the optimization result is greater than the other two figures.

1. Introduction

At present, my country is in a critical period of industrial structure optimization and upgrading, and the academic circles have been discussing effective ways to optimize the industrial energy structure. The transformation of the industrial structure, on the one hand, will inject new vitality into the rapidly growing economy [1]. The acceleration of the industrialization process, especially the increase in the proportion of heavy industry, has a direct consequence of the surge in energy demand. Therefore, the change in the industrial structure is the essential reason for the surge in energy consumption. Which industries will be affected by the aggravation of the contradiction between energy supply and demand, whether energy constraints will hinder the optimization and upgrading of the industrial structure, and how to continue to promote the optimization of the industrial structure under the energy constraints are worthy of in-depth research and discussion. Therefore, this paper tries to make some efforts based on non-equilibrium thermodynamics, hoping to make suggestions for the optimization of industrial structure under energy constraints [2].

At the level of theoretical research, domestic and foreign scholars have conducted various researches on non-equilibrium thermodynamics and industrial energy structure optimization. Widom M reviews electron density functional theory of total energy applied to super batteries and alloys with special quasi-random structures. Contrast these with coherent potential approximations and semi-empirical approximations. Statistical mechanics methods include cluster expansion, hybrid Monte Carlo/molecular dynamics simulations, and entropy extraction from correlation functions. A first-principles approach is also compared with computational phase diagrams (CALPHAD), and the need to augment the experimental database with first-principles-derived data is highlighted. Numerous example applications are given, highlighting recent advances utilizing the concepts and methods introduced [3]. Ghoneim thermodynamic theory is used to assess failure severity in terms of the energy associated with each FT. Therefore, an energy-weighted DGA is proposed, in which the individual gas concentrations are multiplied by a relative factor related to the enthalpy change of the reaction. A fuzzy logic system is constructed based on IEC code rules, transformer condition codes reported in IEEE Standard C57.104-2008, and thermodynamic theory. In order to improve the network fault diagnosis ability of power transformers in the whole distribution network, the proposed fuzzy logic method is used to integrate them according to the distributed agents of distribution substations. This intelligent system helps to evaluate the decisions of distributed agents and provides higher decision-making levels when needed [4]. Tovar-Facio J developed a flexible linear mixed integer multi-objective programming model that can be applied to any national power system. The proposed optimization framework takes into account technical operational constraints, availability of renewable energy at different locations, freshwater consumption as a function of technology and location characteristics, direct GHG emissions, life cycle and total annual costs [5]. It can be seen that there are not many studies on the application of non-equilibrium thermodynamics to the optimization of industrial energy structure, so this paper has certain innovative significance.

Based on non-equilibrium thermodynamics, this paper selects energy optimization indicators, builds an industrial energy structure optimization model, conducts an empirical analysis of energy industry structure optimization, and proposes to explore and build an energy industry structure optimization framework, thereby proposing a multi-dimensional policy and regulation system to promote the optimization of energy industry structure. It provides decision-making reference for promoting the construction of ecological civilization, realizing the sustainable and healthy development of the energy industry and the sound and rapid development of the economy and society. How to build an industrial structure with low energy consumption and economic growth under non-equilibrium thermodynamics, and provide theoretical support and practical guidance for the optimization of my country's industrial structure and the sustainable development of social economy.

2. Research on Optimization of Industrial Energy Structure Based on Non-equilibrium Thermodynamics

2.1. Status Quo of Energy Consumption

(1) There is a large gap between energy supply and demand

Since the reform and opening up, the economy of M province has developed rapidly, and sustained economic growth requires a large amount of energy consumption to support, so its total energy production and energy consumption are on the rise. Especially since the 21st century, the gap has been increasing, and the proportion of total energy gap in total consumption has increased from 49.63% in 2000 to 66.64% in 2020. In order to meet the needs of economic development, a large amount of energy needed by Province M can only be transferred from other provinces or imported from abroad [6-7].

(2) It is difficult to adjust the energy consumption structure

From the perspective of energy production structure, coal production accounts for the largest proportion of total energy production, increasing from 67.9% in 2018 to 85.33% in 2020, and has been stable at around 85% since 2018. It can be said that coal production To a large extent, it determines that the total energy output is more unbalanced than the energy production structure, and its consumption structure is more unbalanced: coal consumption also accounts for the largest proportion of total energy consumption, which has been maintained at about 90%; the proportion of oil consumption has increased from The 12.9% in 2018 decreased to 7.70% in 2020, but there has been a rebound since 2020, but the proportion is still small; the proportion of natural gas consumption is also the smallest. This phenomenon is related to the current energy structure of province M, which is “rich in coal, poor in oil, and less in gas”, and the scale of new energy industries such as wind energy, solar energy, and biomass energy is still small [8-9].

(3) Small scale of new energy development

Province M has a unique natural and geographical environment, is relatively rich in clean energy resources, and has great potential for energy conservation. Despite the huge potential, due to technical bottlenecks, some key equipment still needs to be imported, resulting in an incomplete wind power industry chain and low technical content of products. At the same time, the proportion of new energy is relatively low, and the diversified structure of energy has not been formed, so the task of developing new energy is arduous and long [10-11].

2.2. Non-equilibrium Thermodynamics of Energy Systems

Classical thermodynamics solves the relationship between the properties of material balance and energy conversion, but in reality, the state and process of material transfer in the system are often not in a strict sense of equilibrium, but irreversible. This introduces the entropy production per unit time, i.e. the irreversible process reduces to an expression that couples the product of the thermodynamic flux and the driving force. In essence, its goal is to achieve the minimum entropy production, which means that the process reaches a steady state, the energy dissipation is minimal, and a large effective work can be obtained [12-13]. At present, non-equilibrium thermodynamics has powerful prediction and quantification functions, (for example, accurately describing the coupled transport process, quantifying the entropy production and work loss in the transport process, discriminating the constructed experimental framework and the thermodynamic equation of the detection system model from the second one. Whether the law is consistent) is increasingly applied in industries, living systems, processing industries, electrochemical industries, biological systems, and laboratory experiments involving heterogeneous systems that are not in global equilibrium. Non-equilibrium thermodynamics have been extensively and deeply studied in lithium iron phosphate fuel cells to describe the intercalation and transition of lithium ions, and to determine the phase transition process of lithium ion battery materials [14-15].

2.3. Optimization of Industrial Structure

(1) Rationalization of industrial structure

The positioning of the company system is mainly the static optimization process of the company, which refers to the establishment of close connections between multiple companies, the development of the same company, and the development of local companies. Therefore, it is necessary to improve the overall level, increase the share of resources through technological innovation work, and increase the effectiveness of this optimization. People will raise new questions due to the gradual reform of the enterprise system, and changes in demand will also lead to further changes in the enterprise system. With the continuous improvement of human quality, the adaptation to the unequal industrial system is also accelerating. As long as social resources are limited, the most important and fundamental area of corporate innovation is how to allocate these resources wisely to different companies and different sectors of industries to improve performance, increase productivity, and increase productivity. economic development. The policy emphasizes that the corporate system of a country or region should be adapted to the local social system [16-17].

(2) Advanced industrial structure

The advanced industrial structure is also called the advanced industrial structure. The specific manifestation is the reform and transformation of the industrial structure of the national economy from a low-level system dominated by intensive enterprises to a high-level system dominated by technology and technology-intensive enterprises process and culture. In the development and progress of the industrial system, technological progress and technological innovation play an important role. Due to technological innovation, industry enterprises compete in the product and service market, the output is greatly increased, and the game level is improved. has always been advanced. The scale continues to expand. Large-scale development will eliminate small enterprises with backward technology, improve the overall level of industrial technology, and increase the contribution of the enterprise system to the economic value of the manufacturing industry. Among the reasons for the improvement of the enterprise structure, the most direct reason is innovation, which provides the ability for the optimization of the enterprise system. External factors include product demand system, raw material supply chain and international trade scale [18].

3. Model Construction of Industrial Energy Structure Optimization Based on Non-equilibrium Thermodynamics

3.1. Indicator Selection

(1) Economic growth

Energy is the main driver of economic growth. Domestic scholars agree that in the process of China's economic development, energy consumption is positively correlated with GDP. Although energy consumption has declined to a certain extent, my country's energy utilization efficiency is relatively low, and it is still in the stage of increasing energy consumption. This article uses GDP as an indicator of economic growth.

(2) Industrial structure

Industrial structure is also an important factor affecting energy consumption. The energy consumption of the secondary industry is often much higher than that of the primary industry and the tertiary industry, especially in the stage of high industrialization rate, the tertiary industry is mainly low-energy-consumption industries. If the proportion of the secondary industry changes, it will have a corresponding impact on the structure of the energy industry. This paper uses the ratio of the output value of the secondary industry to GDP to measure the industrial structure.

(3) Energy consumption structure

Changes in the energy consumption structure will affect the changes in the energy industry structure. Raw coal consumption is the most important type of energy consumption in Hunan Province, and raw coal consumption accounts for a relatively high share of the total energy consumption. Changes in the proportion of raw coal consumption will affect changes in the structure of the energy industry.

3.2. Data Sources

The statistical yearbook of M province and the input-output table of M province provide empirical data for this model. Since the production cycle of the input-output table is 5 years, the latest data of the input-output table of M province is in 2020. Considering the uniformity of statistical data characteristics, this paper adopts the data in 2020 for the data in the model. The results simulated by the model are suitable for the rational industrial structure allocation after the industrial structure optimization of M province in 2020.

3.3. Construction of the Optimization Model

(1) Minimal energy consumption constraint scheme

The goal of this scheme is to achieve the minimum value of energy consumption in various industries and maximize economic benefits under the condition that the energy does not exceed the total energy consumption of the base period. Therefore, it is called an energy-saving plan.

$$G(X) = \min \sum_{i=0}^{n} E_i . X_i \tag{1}$$

In the formula, Xi is the total output value of the ith industry sector, and Ei is the energy consumption per unit of the total output of the ith industry sector.

(2) The least restrictive scheme of environmental pollution

The goal of this scheme is to use the weighted summation of pollutant emissions not to exceed the environmental pollution emissions of the base period, so as to achieve a minimum state and maximize economic benefits. Therefore, it is called a plan that attaches importance to environmental protection.

$$\Phi(X) = \min[\sum_{i=1}^{n} \lambda_1(\alpha_{wi})X_i + \sum_{i=1}^{n} \lambda_2(\alpha_{gi})X_i + \sum_{i=1}^{n} \lambda_3(\alpha_{si})X_i] \tag{2}$$

In the formula, αwi, αgi, αsi are the pollution coefficients of water pollution, air pollution and solid pollution, respectively, λ1, λ2, λ3 are the weighting coefficients of the three pollutants, respectively.

(3) Optimization scheme of industrial energy structure based on non-equilibrium thermodynamics

This scheme is based on comprehensive consideration of not exceeding the original total energy consumption and not exceeding the original total amount of pollutants, and based on non-equilibrium thermodynamics to maximize economic benefits. This program model strives to achieve a balance between the two goals.

$$U(F)=\{\theta_1\sum_{i=1}^{n}E_i.X_i+\theta_2[\sum_{i=1}^{n}\lambda_1(\alpha_{wi})X_i+\sum_{i=1}^{n}\lambda_2(\alpha_{gi})X_i+\sum_{i=1}^{n}\lambda_3(\alpha_{si})X_i]\} \quad (3)$$

4. Empirical Analysis of Industrial Energy Structure Optimization Based on Non-equilibrium Thermodynamics

4.1. Model Comparison Analysis

In this paper, the reduction ratio of total energy consumption, the reduction ratio of waste water discharge, the reduction ratio of exhaust gas emission, the reduction ratio of solid waste and the ratio of economic growth are used to compare and analyze the optimization schemes of the three optimization models. Among them, M1 represents the minimum energy consumption constraint scheme, M2 represents the environmental pollution minimum constraint scheme, and M3 represents (3) the industrial energy structure optimization scheme based on non-equilibrium thermodynamics. The comparison results of the schemes are shown in Table 1.

Table 1. Model comparison results

	Total energy consumption	Wastewater discharge	Exhaust emissions	Solid Waste	Economic growth
M1	5.3%	4.1%	3.1%	1.3%	3.5%
M2	4.8%	3.8%	2.9%	1.2%	3.4%
M3	6.2%	4.9%	3.5%	1.5%	3.7%

The industrial energy structure optimization scheme based on non-equilibrium thermodynamics reduces the total energy consumption of M province by 6.2% compared with the energy consumption after optimization. Compared with the base period, the wastewater discharge amount in M province decreased by 4.9%; the exhaust gas emission decreased by 3.5%; the solid waste decreased by 1.5%. At this time, the economy has increased by 3.7% relative to the base period.

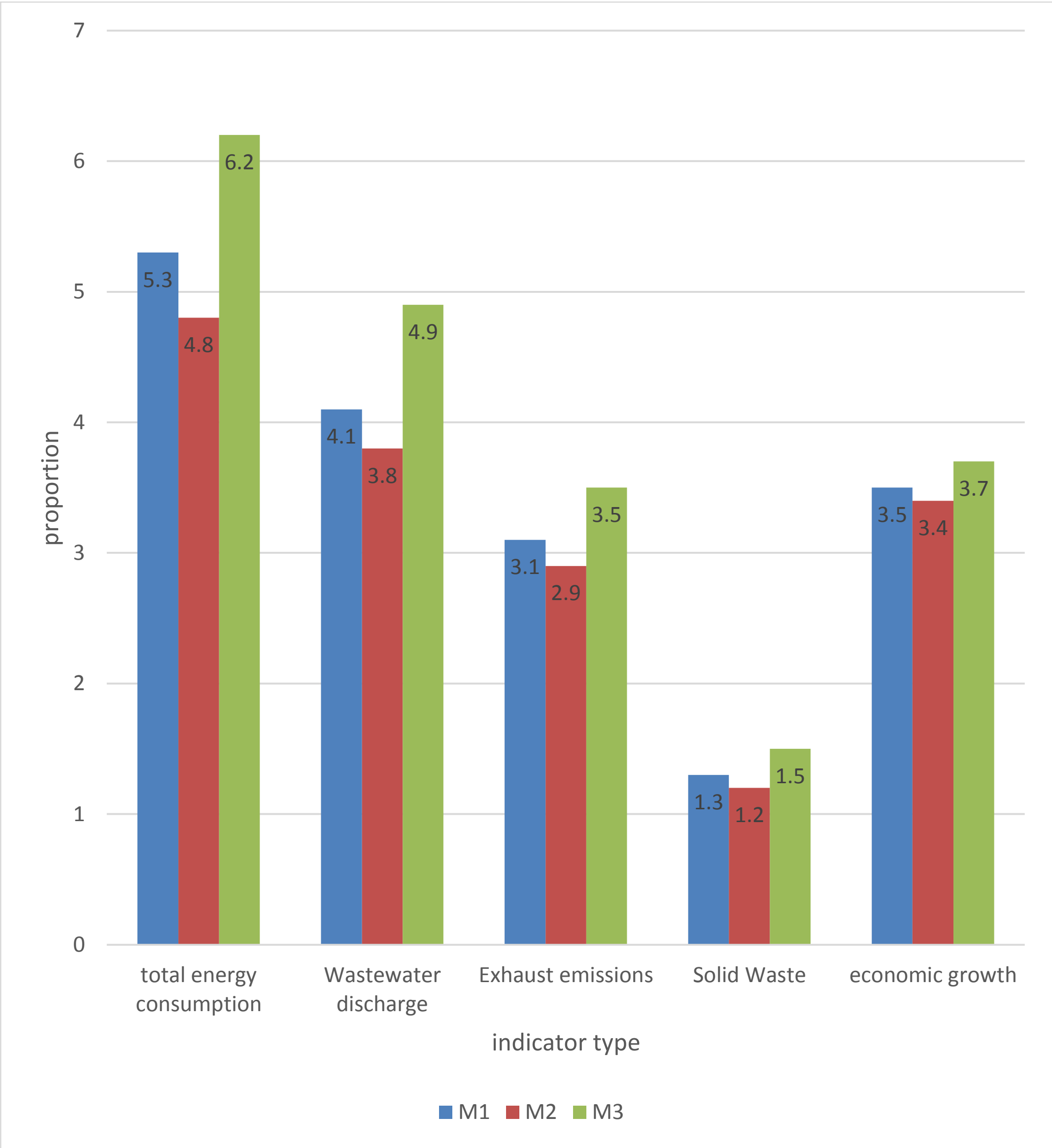

Figure 1. Model comparison analysis

According to the comparison results in Figure 2, it can be seen that the industrial energy structure optimization scheme based on non-equilibrium thermodynamics proposed in this paper is larger than the other two schemes in terms of the influence ratio of the five indicators. On the one hand, it realizes the reduction of energy consumption and pollutant emission, and also realizes the improvement of economic added value. Although this model is similar to the adjustment of the industry share of the energy constraint scheme, the adjustment range of the two schemes is different in each industry. Comparing the energy and environment dual constraint scheme with the former two schemes, both the energy constraint scheme and the environmental constraint scheme are realized by cutting off a part of the economy while reducing pollution. The third scheme is the optimal solution achieved with moderate reduction of energy consumption and pollutant emissions. Therefore, the optimal structure under the dual constraints of energy and environment in the third scheme achieves the purpose of economic development and ecological protection, and the industrial structure achieved in this case is reasonable.

4.2 Model Optimization

(1) Granger causality test

Carrying out the Granger causality test on the selected variables with lags=3, we can get:

Table 2. Granger causality test results

Null hypothesis	Lags	Obs	F value	P value
Y is not JJFZ Granger	3	15	2.5164	0.0648
JJFZ is not Y Granger.	3	15	14.1648	0.0348
Y is not DECY Granger	3	15	0.4164	0.4891
DECY NOT Y Granger	3	15	18.4978	0.0164

The analysis in Table 2 shows that △JJFZ, △DECY, △YMBL and △NYTZ are the Granger causality of △Y, while △CSHL, △DWKF and △JSJB are not the Granger causality of △Y. From this, it can be concluded that the level of urbanization, the degree of opening to the outside world, and technological progress do not play a significant role in the optimization of the energy industry structure. Therefore, the model is modified, and the modified model is as follows:

$$Y = \alpha + \beta_1 JJFZ + \beta_2 YMBL + \beta_3 DECY + \beta_4 NYTZ + \varepsilon \quad (4)$$

(2) Analysis of regression results

After the model is modified, the linear regression model is analyzed, and the OLS method is used to estimate, and the following measurement results are obtained, as shown in Table 3.

Table 3. Measurement result table after model modification

Variable	Coefficient	T value	P value
JJFZ	2.14	-10.12	0.0002
DECY	-0.04	-8.04	0.0004
YMBL	2.78	5.14	0.0018
NYTZ	0.98	-5.64	0.0007
C	1.69	5.48	0.0016

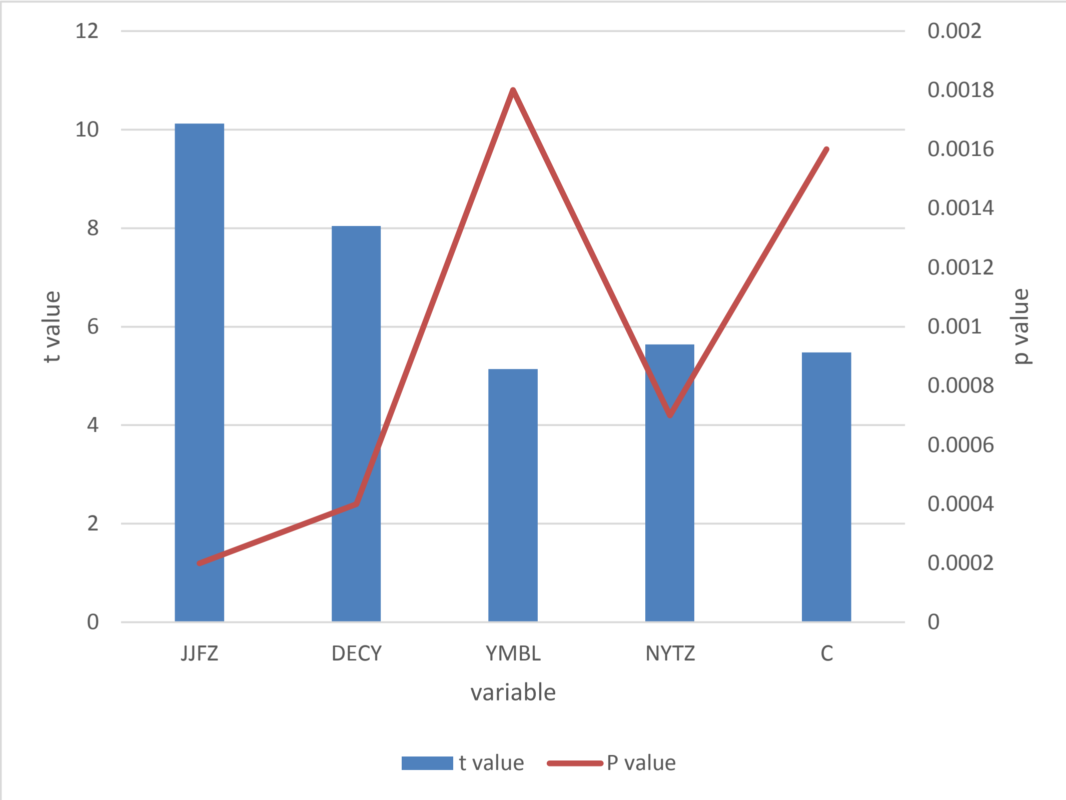

Figure 2. Model measurement results

It can be seen from Figure 2 that the coefficient of determination R2 is 0.95, the overall linear relationship of the regression equation is significant, and the model fitting degree is high. 95% of the change in Y was explained by changes in MTBL, DECY, JJFZ, and NYTZ. That is, changes in the proportion of raw coal consumption and the proportion of the secondary industry, energy industry investment, and economic development have a significant impact on the optimization of the energy industry structure.

5. Conclusion

This paper mainly starts from the perspective of non-equilibrium thermodynamics, focuses on the influence of non-equilibrium thermodynamics on the industrial structure, and optimizes the industrial structure under the condition of non-equilibrium thermodynamics, so as to construct an energy-saving and environment-friendly industry. structure, and further enrich the related theories between non-equilibrium thermodynamics and industrial structure. The discussion on the relationship between non-equilibrium thermodynamics and industrial structure is helpful to reveal whether the optimization and upgrading of industrial structure will be hindered under non-equilibrium thermodynamics, and provide theoretical support for energy conservation and emission reduction. Therefore, how to build an industrial structure with low energy consumption and economic growth under non-equilibrium thermodynamics provides theoretical support and practical guidance for the optimization of my country's industrial structure and the sustainable development of society and economy.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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