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Article

Sustainability Assessment of the Natural Gas Industry in China Using Principal Component Analysis

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Abstract: Under pressure toward carbon emission reduction and air protection, China has accelerated energy restructuring by greatly improving the supply and consumption of natural gas in recent years. However, several issues with the sustainable development of the natural gas industry in China still need in-depth discussion. Therefore, based on the fundamental ideas of sustainable development, industrial development theories and features of the natural gas industry, a sustainable development theory is proposed in this thesis. The theory consists of five parts: resource, market, enterprise, technology and policy. The five parts, which unite for mutual connection and promotion, push the gas industry's development forward together. Furthermore, based on the theoretical structure, the Natural Gas Industry Sustainability Index in China is established and evaluated via the Principal Component Analysis (PCA) method. Finally, a conclusion is reached: that the sustainability of the natural gas industry in China kept rising from 2008 to 2013, mainly benefiting from increasing supply and demand, the enhancement of enterprise profits, technological innovation, policy support and the optimization and reformation of the gas market.

Keywords: natural gas industry; sustainable development; sustainability assessment; principal component analysis

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1. Introduction

Concerns over carbon emissions have made the Chinese government become interested in developing natural gas, which is regarded as a clean, efficient, and low-carbon energy source. Natural gas has been broadly introduced for heating, cooking, transportation, and power generation in China [1]. The Chinese natural gas industry was developed relatively late, although it has expanded rapidly in recent decades. In 2013, domestic gas output in China reached 112.9 billion cubic meters (bcm), making China the sixth largest gas producer in the world [2]. In the same year, domestic gas consumption reached 163.1 bcm, with an annual growth rate of 15.4 percent [3], which has made China the fourth largest global natural gas consumer after the USA, Russia, and Iran [4]. According to the International Energy Agency, Chinese natural gas consumption will reach 240 bcm in 2015, and later 600 bcm in 2035, equivalent to that of all Europe [5].

The development of the gas industry in China can be divided into three stages [6]. During the primary stage, the output of natural gas increased from 0.01 bcm in 1949 to 17.9 bcm in 1997, with an average annual growth rate of only 0.4 bcm [7]. During this stage, exploration was the main focus of the natural gas industry and the domestic production was very low. Gas markets only concentrated around gas fields as cross-regional pipelines had not been built yet.

The second stage spans from 1997 to 2004 and is characterized as a transition stage with rapid development. During this period, the gas production continued to grow. The first interprovincial gas pipeline, the Shanxi-Beijing pipeline, became operational and extended gas market availability far outside gas production areas. Furthermore, both imported liquefied natural gas (LNG) projects and exploration of unconventional natural gas resources were initiated.

The third stage is a stage of rapid development that started in 2004, when the West-East gas pipeline was constructed. Multiple cross-regional pipeline networks increased from 24,000 kilometers in 2008 to 55,000 kilometers in 2013 [8]. Gas production increased significantly and large state-owned gas corporations also began to acquire gas abroad. Furthermore, domestic gas consumption surged from 37.9 bcm in 2004 to 163.1 bcm in 2013, which made China become a net gas importer in 2006 [9]. Gas enterprises started to put more emphasis on unconventional natural gas exploration and production. The specific details of the three stages are summarized in Table 1.

Despite all these developments, there are still challenges for the gas industry in China. Firstly, China still falls far behind many developed countries in terms of exploration, production and infrastructure construction. For instance, China's natural gas pipeline density is only 5.2 M/km^2, which is just 1/20 of that of France and 1/32 of that of Germany [10]. Furthermore, advanced exploitation technologies for unconventional and deep-sea natural gas need to be further introduced from the US and Europe [11].

Secondly, Chinese natural gas market is still highly monopolized by few major gas companies and lack of sufficient competitive markets. Since 2003, the upstream market has long been occupied by three big companies, namely CNPC, Sinopec and CNOOC, whose combined market share has been over 96% [12]. This situation is also typical in the highly monopolistic midstream transportation market of gas, where CNPC, Sinopec, CNOOC hold market shares of 89.3%, 4.9%, 2.2% respectively [13]. When the pipeline business is controlled by several large companies, these companies may prevent other gas sources from entering the pipeline network, such as shale gas, coal gas, and imported gas. In this way they can suppress the emerging unconventional gas companies to maintain their competitive advantage. Decreased development of unconventional gas will not be helpful for the sustainability of gas industry. Furthermore, a monopolistic market may lead to a reduction in the operational efficiency of the market and a lack of development momentum for gas companies. Therefore, breaking up monopolies and diversifying market participants are very important factors in promoting gas industrial development.

Table 1. Stages and features of the natural gas industry in China.

Period	First Stage 1949–1997	Second Stage 1997–2004	Third Stage 2004 to Present
Market Supply	Low output	Domestic production was basic self-sufficiency; gas import and initial explorations of unconventional natural gas was started	Domestic gas output surged; large-scale gas started to be imported; the exploration of unconventional gas was accelerated
Pipeline construction	Pipelines were mainly provincial and there were no cross-regional pipelines	Construction of pipelines and infrastructure started in the large-scale development period and the first cross-regional pipelines were put into operation	Gas supply pipelines covered big cities and formed networks
Consumption market	Markets concentrated around gas field areas	Formation of regional markets	Formation of a nationwide market
Market structure	Few companies monopolized the construction of infrastructure and gas supply defined as part of public service	Several magnates monopolized the upstream and midstream market	More competitors appeared and formed a competitive market
Governance	Lack of governance	Governance was strengthened	A specific department was founded to conduct, supervise and govern

Thirdly, natural gas price is still determined by the government [14]. Under this pricing mechanism, the natural gas price is relatively low and it fails to reflect the real market value. The enforced low gas price reduced profits of enterprises as well as creating economic hindrances.

Fourthly, environmental regulations and security emergency management for industry have not been improved in China. The rapid growth of the gas industry has been coupled with substandard management and ecological concerns in recent years. For production and transportation of gas, there has been serious damage done to the environment due to legal deficiency. It is vital to attribute responsibility to industry for frequent security incidents [15].

It is vital to address the challenges faced by the natural gas industry in China and determine a way to find a more sustainable development path. Several scholars have discussed these issues before. Zhai Guangming put forth some suggestions for the Chinese oil and gas industry involving strengthening exploration, developing unconventional resources, implementing energy saving and emission reduction, and expanding international cooperation [16]. Shi Xingchun recognized that sustainable development of the gas industry requires a stable gas supply, high operational efficiency, methodical peak-shaving systems, and potent demand-side management [17]. Liu Yijun summarized international experiences and concluded that four measures contribute to sustainable development: stable supply, reasonable property right mechanisms, competitive market structure, and improved infrastructure [18].

Others have paid more attention to the environmental aspects of sustainable development. Gavin Hilson examined Canadian policies on the sustainable development of mining industries and concluded that the government and enterprises should cooperate to strengthen legislation and regulations on environmental protection [19]. Roger Harris and Anshuman Khare studied the oil industry in Alberta, and found that it is necessary for oil enterprises to find low-cost environmental protection strategies to achieve sustainable development of the oil industry [20].

Previous studies on sustainable development of oil or gas industry were often dissimilar in terms of underlying theory and chosen case studies. They have the following insufficiencies: (1) most of the research is based on qualitative analysis and lacks quantitative analysis and data support; (2) for the factors affecting China's gas industry's sustainable development, most of scholars have only involved increasing supply, enhancing the construction of infrastructure and advancing price mechanism reform, and ignored the driving effects of science and policy, and the factor of sustainable consumption; (3) the above literature did not conduct a comprehensive evaluation of the sustainable capacity of the gas industry in China through quantitative analysis.

In this thesis, the most important research contributions are a new sustainable theory for resource-based industry and a sustainable evaluation index for the gas industry. Combined with the fundamental ideas of sustainable development, industrial development theories and features of the natural gas industry, a sustainable development theory for the industry has been developed in this paper by considering factors including resources, market, enterprise, technology and policy. Furthermore, based on the theoretical structure, the Natural Gas Industry Sustainability Index in China has been established and evaluated with the PCA method.

Principal Component Analysis (PCA) can be used as an effective method to minimize the limitations of previous studies. For example, Zhu implemented PCA to evaluate the economic performance of 18 cities in China [21]. Chevalier applied several indicators to measure the dependency on oil and gas of countries within the European Union [22]. EC [23] and OECD [24] guideline have been referred in constructing the composite indicator by using the method of PCA. Tsatsarelis *et al.* have used PCA as an assessment tool to estimate the status of open dumps in Laconia prefecture of Peloponnese in southern Greece [25]. Therefore, to the best of our knowledge, PCA is a preferable method to evaluate the sustainability of natural gas industry. Using the PCA, the Natural Gas Industry Sustainability Index (NGISI) of China from 2008 to 2013 will be examined in this thesis.

2. Theoretical Framework

The Club of Rome put forth the notion of "sustainable growth" in the famous book "The Limits to Growth" 1972. In the same year, a similar concept of "sustainable development" first appeared at the United Nations Conference on Human Environment (UNCHE) hosted in Stockholm. The latter appeared on 27 April in 1987, when the World Commission on Environment and Development (WCED) released the landmark report entitled "Our Common Future". Here, sustainable development was defined as development that "satisfies the needs of the present without compromising the ability of future generations to meet their own needs" [26]. Other scholars later further developed this definition.

2.1. Definition of Sustainable Development in the Natural Gas Industry

In a broad sense, Redelift indicated that pursuing a dynamic balance between economy and environment is a vital requirement of sustainable development [27]. As outlined in the *Rio Declaration and Agenda 21*, which evolved from the United Nation Conference on Environment and Development held in Rio de Janeiro, Brazil in 1992, sustainable development became an important goal for the global society, and impacted the development of national socio-economic strategies [28]. The World Summit on Sustainable Development in 2002 described sustainable development as three pillars—social, environmental, and economic—as symbolized by the summit motto, "People, Planet, Prosperity" [29]. Hopwood *et al.* proposed that sustainable development can be achieved through increasing environmental awareness and improving social and economic conditions to eliminate poverty and inequality [30]. *The United Nations Secretary's 2012 Report* underscored that "sustainable development provides the best opportunity for people to choose their future" and "eradicating poverty, reducing inequality and making growth inclusive can promote the production and consumption more sustainable" [31].

The concept of sustainable development has been introduced to the industrial field by many researchers and it has formed a wide range of ideas related to industrial sustainable development: industrial ecology [32], industrial symbiosis [33], sustainable consumption and production (Sorrell, 2010) [34]. Bonilla *et al.* claim that sustainable development is driving industrialization to a new road, which features high-tech manufacturing, cleaner production, low resource consumption, less environmental pollution, and a full display of the advantages in human resources [35]. Fang *et al.* state that natural resources serve as basic needs for human survival and fundamental drivers of sustainable socio-economic development [36].

Specialized research on sustainable development of the natural gas industry has previously been presented at the *World Gas Conference (WGC)*. In 2003, a report released at the 22nd WGC established a strategic plan for natural gas industrial sustainable development, defining natural gas as a transitional resource and highlighting that major countries are paying more attention to unconventional gas exploration [37]. The 23rd WGC in 2006 released a lifecycle analysis report about the whole gas industrial chain [38]. The guiding principles of sustainable development were proposed on the 24th WGC in 2009, proposing a sustainable evaluation standard for measuring gas company behavior [39]. The 25th WGC report states that unconventional gas resources become more and more important in gas trading systems, and the effects of geopolitics should be taken seriously when people exploit and trade gas resources [40]. In June 2012, the International Gas Union (IGU) released a report entitled *From Natural Gas Global Vision—Future Approaches for Energy Sustainable Development*, which aimed to provide a specific approach for the future sustainable development of energy [41]. Three feasible principles were proposed in this report: sustainability, security of supply, and affordability.

Shi Xingchun claimed that the goal of sustainable development in natural gas industry is to improve efficiency, effectiveness and stability of the natural gas industrial chain. Liu Yijun defined sustainable development of gas industry as a dynamic process in which people utilize finite gas resources in a stable, sustainable and safe way through comprehensive integration of the industrial chain and considered natural gas a transitional resource from traditional fossil fuels (coal and oil) to renewable energy sources (wind and solar energy).

Based on this literature review, this paper views the sustainable development of the natural gas industry as a process in which people produce and use natural gas continuously in a safe, stable, and efficient way through technological improvements, administrative regulatory reform, coordination of the overall gas industrial chain and optimization of gas market structure. In this process, companies serve as the main participants and the market acts as a driving force.

2.2. Theoretical Framework of Sustainable Development of Natural Gas Industry

Based on the definitions of natural gas industry sustainability, it can be concluded that the theory of gas sustainability is composed of five parts: sustainable supply of natural gas resources; sustainable utilization of natural gas resources; sustainable development of natural gas enterprises; sustainable progress of natural gas technologies; and sustainable promotion of natural gas policies. These parts form a unity of mutual connection and promotion (Figure 1).

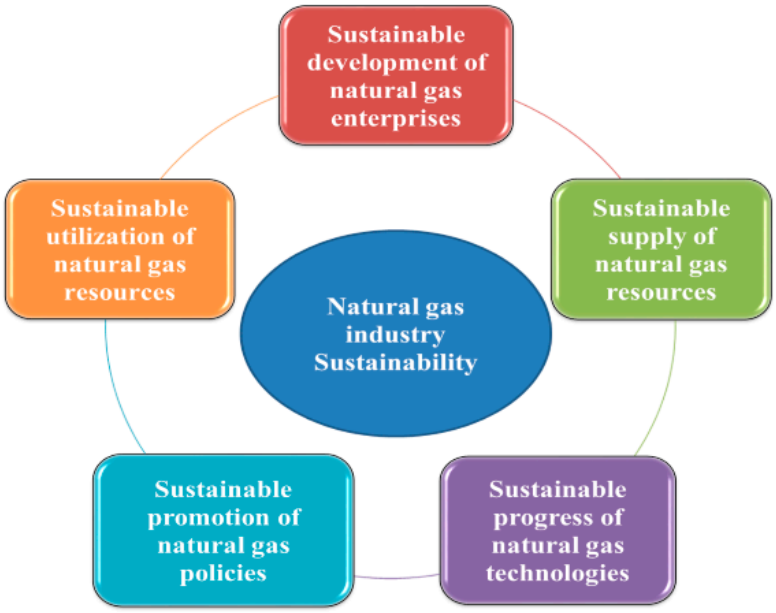

Figure 1. Theoretical framework for the sustainable development of the natural gas industry.

(1) Sustainable supply of natural gas resources serves as the foundation for the sustainable development of the gas industry. As indicated in sustainable development ideas, resource sustainability is the major goal of sustainable development. Only when an economic supply of natural gas is available can the industrial chain be activated potentially and contribute to overall sustainable development. It is important to note that the sustainable supply of natural gas resources not only includes sufficient supply from domestic gas occurrences, but also sustainable acquirement from suppliers abroad as well as strategic stockpile [42]. Hence, this factor consists of both geological and geopolitical aspects. Major factors involve proven reserves, reserve and production ratio, production and importation, pipeline transporting capacity, LNG terminal receiving capacity, and the level of gas storage.

(2) Sustainable utilization of natural gas resources acts as a driving force for gas industry development. It refers to sustainable market demand, which stimulates gas enterprises to strengthen their efforts to promote profit sustainability. Furthermore, it also implies that gas utilization should be clean, efficient and safe to minimize damage to the environment [43]. Major measurement factors include: gas consumption, proportion of gas in primary energy consumption, growth of consumption, consumption intensity, carbon dioxide emissions, price level and the number of security incidents.

(3) Sustainable development of natural gas enterprises plays a crucial role in gas industry development. As the main participants in the gas market, gas companies will have to undertake most work to develop the gas industry. Firstly, business activities can connect supply and demand in the gas market to promote industry operation. Through the profit-seek behaviors of gas enterprises, related industries and the national economy will get more opportunities for further improvement [44]. Evaluation factors include: annual value of production, amount of investment, exploration and production cost, rate of return on investment and management efficiency.

(4) Sustainable progress of natural gas technology is the key to the sustainable framework. Science and technology constitute a primary productive force for the natural gas industry. The progress and implementation of technologies can directly improve operational efficiency, ensure utilization security and minimize environmental impacts. The factors include: research funding, the number of achievements, application rate of achievements, proportion of staff engaged in research.

(5) Sustainable promotion of natural gas policies is defined as the importance of exterior policies for industry development. Policies and regulations are important for creating a good development environment for the entire gas industry. Environmental regulations affect innovation, consumption patterns and competitive strategies of hydrocarbon companies [45]. Assessment factors include preferential policies, financial subsidies, administrative power; diplomacy promotion, market concentration ratio, market liquidity, and construction of security emergency systems. The specific factor system can be seen in Table 2.

Table 2. Evaluation factor system of the natural gas industry.

Capacities	Factors
Sustainable gas supply	Proven reserves; Reserve and production ratio; Production; Importation; Pipeline transporting capacity; LNG receiving capacity; Level of gas storage
Sustainable gas utilization	Consumption; Proportion of gas in primary energy consumption; Growth of consumption; Consumption intensity; Carbon dioxide emissions; Price level; Number of security incidents
Gas enterprises sustainable development	Annual value of production; Investment; Exploration and production cost; Rate of return on investment ; Management efficiency
Gas technologies sustainable progress	Research funding; Number of achievements; Application rate of new technologies; Proportion of staff engaged in research
Sustainable promotion of gas policies	Preferential policies; Financial subsidies; Administrative power; Diplomacy promotion; Market concentration ratio; Market liquidity; Security emergency system

3. Natural Gas Industry Sustainability Index (NGISI)

Several approaches have been developed to conduct a study on sustainability assessments. Based on a relevant theoretical framework, one or several indicators will be usually selected by some assessment methodologies and evaluated to obtain a final verdict on the sustainability of a studied system. Such indicators are often called "Sustainable Development Indicators" (SDIs), and are recognized as a useful tool for policy-making and evaluation. These indicators may be simple or composite in nature. Composite indicators are constructed by aggregating different dimensions through recognizing, classifying, restructuring or aggregating methods with the aim of obtaining a more holistic description of sustainability. Multivariate techniques are often applied in processing these indicators, such as Factor Analysis, Cluster Analysis, Principal Component Analysis, and Multivariate Analysis, *etc*.

Principal Component Analysis (PCA) or Proper Orthogonal Decomposition (POD) was first proposed by Pearson and frequently used to construct SDIs [46]. It is a multivariate statistical approach which was aimed at reducing data dimensions by using linear orthogonal transforms of multiple highly correlated variables into a new set of independent uncorrelated variables, called "principal components." The principal components are orthogonal because they are the eigenvectors of the covariance matrix, which is symmetric. PCA is effective in compressing data dimensionality without too much information loss and can identify data patterns and highlight similarities and differences. However, PCA is sensitive to the relative scaling of the original variables.

Based on the theoretical framework of natural gas industrial sustainability, it can be found that the NGISI evaluation system involves large data amounts in need of simplification. PCA can reduce the dimensionality data to a smaller number of principal components that can account for most of observed variables. The application of PCA in calculating NGISI consists of multiple steps.

Step 1: Indicator normalization. Normalization is carried out when observed variables are in different dimensions. They will be divided into two groups—positive and negative indicators—according to their characteristics. Positive indicators are defined as indicators where high numerical values indicate higher goal fulfillment. Negative indicators are inversely proportional to goal fulfillment. All indicators are normalized on the interval [0, 1] according to the Equations (1) and (2), where 0 implies the minimum and 1 represented the maximum level for NGISI.

$$x_{ik} = \frac{X_{ik} - MIN(X_i)}{MAX(Xi) - MIN(X_i)} \tag{1}$$

$$x_{ik} = \frac{MAX(X_i) - X_{ik}}{MAX(Xi) - MIN(X_i)} \tag{2}$$

Step 2: Covariance matrix (R) of indicators. The covariance matrix (*R*) represents the interrelations of the indicators. If an element of this matrix is close to 1 (or −1) then the corresponding indicators are strongly related positively (or negatively), meaning that only one of them can be considered a variable. Assume that the normalization data is expressed in terms of *X*, the correlation coefficient of can be calculated with Equation (3). In this paper, the software SPSS17.0 was used for calculations.

$$r_{ij} = \frac{1}{n-1}\sum_{t=1}^{n} x_{ti}x_{tj} \ (i, j = 1, 2, \cdots, p) \tag{3}$$

Step 3: Computing the eigenvalues and eigenvectors. Based on the covariance matrix of the normalized indicators, eigenvalues can be obtained with Equation (4):

$$|R - \lambda I| = 0 \tag{4}$$

where R represents the indicators correlation matrix, λ depicts the eigenvalues, I is the unit matrix. The largest eigenvalue is the one that holds the most variation, while smaller eigenvalues are usually ignored to simplify the problem. Solving these equations, one obtains several eigenvalues that allow a matrix equation to be formulated. Finally, the corresponding eigenvectors can be obtained by solving Equation (5):

$$(R - \lambda_j I)F_j = 0 \tag{5}$$

where F_j is the matrix of the eigenvector corresponding to the λ_j eigenvalue.

Step 4: Confirming Principal Components. The principal component variables are determined by the cumulative variance contributions, which can be calculated by the proportion of the one eigenvalue with the sum of all eigenvalues, as shown in Equation (6). If the cumulative variance of the first j exceeds 80%, the first i principal components will be retained. By calculating, the outcome of total variance is explained and a component matrix can be produced.

$$Contributions\ of\ variance = \frac{\lambda_j}{\sum_{j=1}^{p} \lambda_j} \tag{6}$$

Step 5: Constructing the Natural Gas Industry Sustainability Index (NGISI). The corresponding coefficient of each variable in the principal components can be calculated by dividing the eigenvectors by the square root of corresponding eigenvalues. Then, one get j expressions F_1, F_2, …, F_j corresponding to j principal components. Finally, the NGISI can be calculated by using the variances of the Principal Components as weights. The details are shown in Equation (7):

$$(NGISI_k) = \frac{\lambda_1 F_1 + \lambda_2 F_2 + \cdots + \lambda_j F_j}{\lambda_1 + \lambda_2 + \cdots + \lambda_j} \tag{7}$$

where k represents the year, $NGISI_k$ is the Natural Gas Industry Sustainability Index of year k and $\lambda_j F_j$ is the multiplication of an eigenvalue with its corresponding principal components. A rearrangement of the weighted components of NGISI enables determination of the final score (−1 to1).

4. Results

Based on the principle that the data variables should be systematic, available, quantified and operable, we consulted industrial experts and selected 14 representative indicators, of which each can highlight one aspect features of the five parts (supply, utilization, enterprise, technology and policy) to assess the sustainability of China's gas industry. Fourteen indicators for a capacity assessment of gas industrial development from 2008 to 2013 were selected and divided into two types: quantitative variables and qualitative variables. For the quantitative variables, the data can be obtained from relevant organizations such as the Chinese National Bureau of Statistics (NBS) [47], China Petroleum and Chemical Industry

Federation (CPCIF) [48], the Ministry of Commerce (MC) [49], General Administration of Customs (GAC) [50] and other energy research institutions. Qualitative variables, such as preferential policy, were obtained by consulting experts and scholars using a Delphi method with the scores between 0 and 10 [51]. Delphi is based on the principle that decisions from a structured group of individuals are more accurate than those from unstructured groups. Delphi has been widely used for business decisions and has certain advantages over another structured decisions approach, prediction markets. Therefore, in this thesis, the Delphi method has been used to assess the preferential policy effort of the gas industry in China to get an objective result. These 14 indicators can be found in Table 3. Based on step 1, the indicator data from 2008 to 2013 should be normalized. The normalized values are presented in the Table 4. Based on steps 2–3, the correlation matrix R, eigenvalues, and eigenvectors are calculated. The results are shown in Table 5 (eigenvalues) and Table 6 (eigenvectors).

Table 3. Selected indicators.

Indicators	Measurement
Reserve Replacement Ratio (M1)	New net reserve/total gas production
Production (M2)	Billion cubic meters/year
Imports (M3)	Billion cubic meters/year
Pipelines transportation capacity (M4)	Billion cubic meters
Gas storage (M5)	Billion cubic meters
Consumption growth rate (M6)	Consumption growth/Total consumption
Consumption intensity (M7)	Total consumption/GDP
Price level (M8)	Yuan/cubic meters
Net profits (M9)	Billion yuan
Return on investment (M10)	Net profit/total investment
Investment cost of technology (M11)	Billion yuan
Scientific and technical achievements (M12)	Application projects/total research projects
Market concentration (M13)	Market shares of three gigantic Chinese oil companies
Preferential policy effort (M14)	Score 0–10

Table 4. Normalized indicators.

	2008	2009	2010	2011	2012	2013
NM1	0.75	0.62	0.67	0.68	1.00	0.00
NM2	0.00	0.13	0.40	0.68	0.81	1.00
NM3	0.00	0.09	0.25	0.56	0.75	1.00
NM4	0.00	0.09	0.25	0.58	0.62	1.00
NM5	0.00	0.00	0.06	0.09	0.13	1.00
NM6	0.46	0.00	0.89	1.00	0.24	0.46
NM7	0.20	0.25	0.00	0.36	0.70	1.00
NM8	1.00	0.83	0.70	0.25	0.00	0.06
NM9	0.01	0.00	0.70	0.93	0.70	1.00
NM10	0.55	0.00	0.92	0.69	0.65	1.00
NM11	0.00	0.29	0.43	0.59	0.82	1.00
NM12	0.00	0.49	0.69	0.75	0.79	1.00
NM13	0.00	0.14	0.44	0.72	0.51	1.00
NM14	0.00	0.29	0.57	0.64	0.86	1.00

Date Sources: Chinese National Bureau of Statistic (NBS), National Energy Administration (NEA), Ministry of Commerce (MC), General Administration of Customs (GAC) and Reports of CNPC, Sinopec and CNOOC [47–50].

Table 5. Calculation of eigenvalues.

	F1	*F2*	*F3*
Eigenvalue	10.35	1.79	1.25
Variability (%)	73.94	12.76	8.94
Cumulative (%)	73.94	86.70	95.64

Table 6. Calculation of eigenvectors.

	F1	*F2*	*F3*
M1	−0.14	−0.96	−0.11
M2	0.94	0.24	0.24
M3	0.93	0.32	0.13
M4	0.89	0.41	0.19
M5	0.52	0.84	0.06
M6	0.00	−0.07	0.98
M7	0.79	0.49	−0.26
M8	−0.98	−0.07	−0.10
M9	0.78	0.17	0.60
M10	0.41	0.31	0.74
M11	0.95	0.27	0.10
M12	0.87	0.21	0.22
M13	0.80	0.42	0.40
M14	0.94	0.21	0.21

In Table 5, the first three eigenvalues are all greater than 1 with values of 10.35, 1.79, and 1.25 respectively. Furthermore, the cumulative variance contributions of these eigenvalues reach 95.64%, implying that they contain the vast majority of information. Therefore, the first three principal components (F_1, F_2, F_3) corresponding to three eigenvalues of λ_1, λ_2, λ_3 should be retained. In addition, as presented in Table 6, the results indicate that the variables of *M2*, *M3*, *M4*, *M7*, *M8*, *M9*, *M11*, *M12*, *M13* and *M14* have an evident correlation and the principal component of F_1 contains most of the information of these indicators. For *M1* and *M*5, there is overlapping information described by the second principal component, F_2. *M6*, *M9* and *M10* are also correlated and described by the third principal component, F_3.

The corresponding coefficient of each variable in the three principal components can be calculated by dividing the eigenvectors from Table 4 by the square root of corresponding eigenvalues. Three expressions are obtained (Equations (8)–(10)). Finally, the Natural Gas Industry Sustainability Index can be calculated using Equation (7) and is illustrated in Figure 2.

$$F1 = 0.22NM_1 + 0.14NM_2 + 0.13NM_3 + 0.09NM_4 - 0.09NM_5 - 0.11NM_6 + 0.1NM_7 - 0.21NM_8 + 0.07NM_9 - 0.07NM_{10} + 0.15NM_{11} + 0.13NM_{12} + 0.04NM_{13} + 0.15NM_{14} \quad (8)$$

$$F2 = -0.16M_1 - 0.08NM_2 - 0.02NM_3 + 0.05NM_4 + 0.43NM_5 - 0.05NM_6 + 0.13NM_7 + 0.20NM_8 - 0.08NM_9 + 0.11NM_{10} - 0.06NM_{11} - 0.08NM_{12} + 0.08NM_{13} - 0.10NM_{14} \quad (9)$$

$$F3 = -0.04NM_1 + 0.01NM_2 - 0.05M_3 - 0.02NM_4 - 0.04NM_5 + 0.53NM_6 + 0.24NM_7 + 0.08NM_8 + 0.22NM_9 + 0.35NM_{10} - 0.07NM_{11} + 0.01NM_{12} + 0.11NM_{13} - 0.01NM_{14} \quad (10)$$

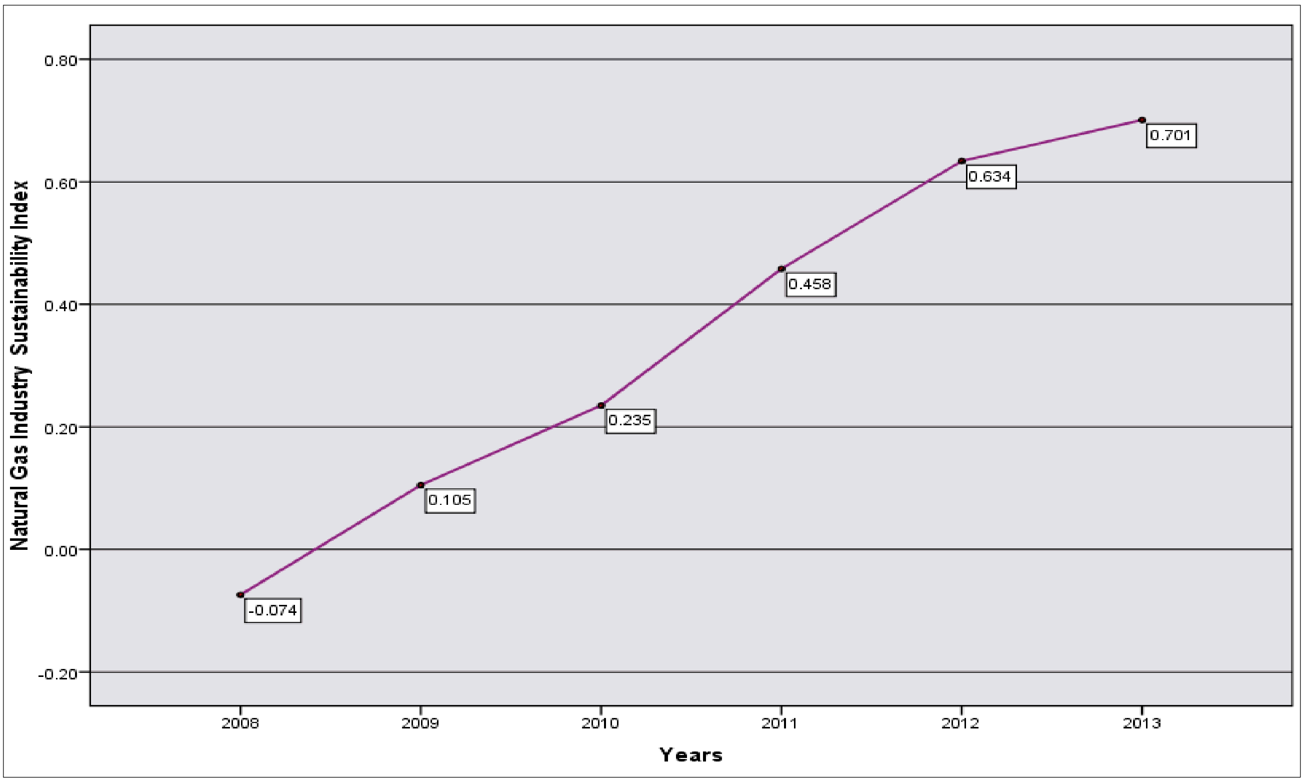

Figure 2. Natural gas industrial sustainability index of China from 2008 to 2013.

5. Discussion

The NGISI of China presents an increasing tendency from 2008 to 2013, rising from −0.074 to a high point of 0.071 (Figure 2). It shows that the natural gas industry in China has an increasingly strong sustainable development capacity. Since 2008, the Chinese government has stimulated the gas industry with a series of preferential policies, such as increasing investment for gas exploration and pipeline construction, improving gas prices and similar. Furthermore, high oil prices have made natural gas more attractive than oil for many companies whose behaviors have helped to drive NGISI upwards year by year. Moreover, affected by the macroeconomic recession in 2009 and 2013, the gas consumption and corporate profits of China were reduced, which made the gas industry experience a small reduction in growth rate.

Closer analysis of the eigenvectors, principal components and normalized indicators from Table 4 reveals that the indicators *M2*, *M3*, *M4*, *M5*, *M11*, *M12*, *M13* and *M14* positively impact the gas industry's development. The indicator *M8* shows that gas price has a negative correlation with increased industry sustainability and a high price is not helpful for stimulating gas consumption. Furthermore, the factors of reserve replacement ratio *M1* declined rapidly in 2013, reducing the growth rate of the NGISI.

Finally, the average contributions of each indicator can be calculated to measure the impact of each indicator on the gas industry's sustainable development (Figure 3). It can be seen that the five largest contribution indicators are the reserve replacement ratio (*M1*, 12.82%), gas price (*M8*, 10.48%), production (*M2*, 9.71%), return on investment (*M10*, 8.41%), and consumption growth rate (*M6*, 8.01%). Their total contributions to NGISI are nearly 50% and they should be the focus points for future studies. Reserve replacement ratio represents the sustainability of gas resources, which acts as the foundation of the gas industry, so it is the biggest contributor to gas industrial development. The factors of gas price, production and consumption growth rate reflect the status of market supply-demand together; only when supply and demand continue to grow and reach market equilibrium can the gas industry develop sustainably. Thus, the three factors contribute greatly to gas industrial sustainability. Improving return on investment is the ultimate goal of gas enterprise. High return on investment can stimulate gas companies to increase investment and boost the whole industry. Therefore, return on investment is also one of the most important factors and greatly contributes to the gas industry's development. Based on the above results, it can be concluded that the factors of market supply-demand and basic resources are more important than the factors of technology and policy. Gas storage (*M5*, 3.17%) and imports (*M3*, 5.35%) have the smallest influence on the NGISI. This is mainly because the construction of gas storage has just begun and the status of gas import dependence is still safe. However, the gas stockpile will reach a certain size and gas imports will continue to increase in the future. As the gas industry matures in China, these two factors are likely to play a greater role in gas industry development.

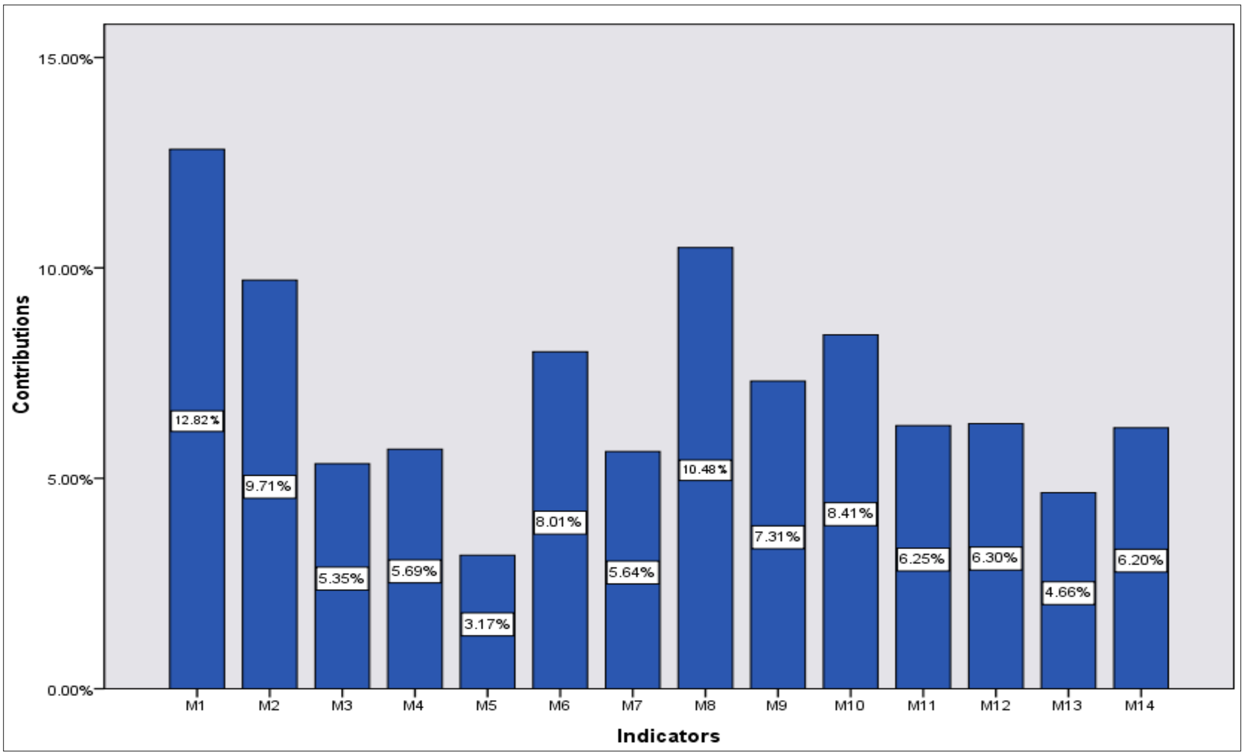

Figure 3. Average contributive ratios of each indicator.

6. Conclusions and Policy Suggestions

Natural gas has become increasingly important to the Chinese energy supply, especially in the last few years. The Chinese government has launched a series of programs and policies to encourage further development of the natural gas industry. Therefore, it is valuable to study the issue of how to achieve sustainable development of China's natural gas industry. In this thesis, the theoretical framework of gas industry sustainability has been discussed and analyzed through five aspects: resources, market, enterprise, technology, and policy. A Natural Gas Industry Sustainability Index (NGISI) has been established using the PCA method to conduct an empirical assessment of China's gas industry from 2008 to 2013.

The results indicate that the natural gas industry of China is improving its sustainable development capacity, although there are still issues to be resolved. Some factors, including reserve replacement ratio, gas price, production, return on investment and consumption growth rate, make a significant contribution to the gas industry's development and should be emphasized in the future. The results help us understand the natural gas industry's development status in China and provide support for decision makers.

Based on the results, some suggestions for gas industry development are summarized as follows: (1) reinforce of natural gas exploration, which should not be limited to just conventional gas, but should also include shale gas, coal gas, tight gas and other unconventional gas sources, to provide sufficient gas reserves for future exploitation [52]; (2) increase investment and accelerate construction of gas pipelines and infrastructure to improve industrial chains; (3) stress the importance of diversification in gas imports, including pipeline gas and liquefied gas, and improving gas storage capacities to prevent supply interruptions; (4) accelerate research and implementation of technologies and improve the management and operational efficiency of gas companies to reduce the production cost; (5) speed up the reformation of gas pricing and distribution to gradually adjust gas prices to a suitable market level as well as strengthening market vitality and economic efficiency [53].

However, some deficiencies need to be improved and perfected in this paper. We should consider more factors and use several composite indicators as one part, such as the Shannon index [54], the S/D index [55], and the oil vulnerability index [56], to assess the sustainability of the gas industry in future research.

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Author Contributions

Xiucheng Dong made contributions to the design of the article; Jie Guo wrote and modified the whole paper; Mikael Höök modified the language and provided much valuable advice; Guanglin Pi collected and analyzed the data.

Conflicts of Interest

The authors declare no conflict of interest.

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