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Industrial Electrical Energy Efficiency Research Based on DEA Optimization Model

Zhao Jianna*, Wang Xin
North China Electric Power University, Baoding, China, 13785241759
*Corresponding author, e-mail:tmcad2007@126.com

Abstract

Traditional DEA does not take into account the environmental variables when analysis the electrical energy efficiency. In order to weigh the objective and subjective factors' impact on industrial electrical energy efficiency, this paper attempts to analyze the China's 2011 industrial electrical energy efficiency step by step using DEA optimization model. The results showed that, electrical energy efficiency value in considering the case of environmental factors was increased, effect of the external environment on electrical energy efficiency indeed have a significant impact, On these analysis, the paper proposed some feasible recommendations like increasing the scale of industrial energy utilization, eliminating monopolies as soon as possible, allocating the science and technology funding actively and feasibly.

Keywords: *electrical energy efficiency, DEA optimization model, environmental factors*

1. Introduction

In recent years, China is in an important stage of industrialization, industrial economy is developing rapidly, industrial electricity consumption have been increasing rapidly as the industry expanding. Seen in Figure 1, industrial electricity consumption accounted for more than 70% of the total social consumption of the electric power, heavy industry is an energy guzzler. Besides, energy resource endowment conditions and ecological environment carrying capacity is difficult to sustain, the conflict between the limited power resources and rapid industrial development and environment restrictive factor appear gradually.In order to achieve both to ensure adequate supply of electricity, but also to meet the electricity needs of the rapid development of industrialization, to ensure sustainable development of the industrial economy is imperative. in this case, vigorously promoting energy efficiency is an effective way to solve the problem of equilibrium of supply and demand in power supply.

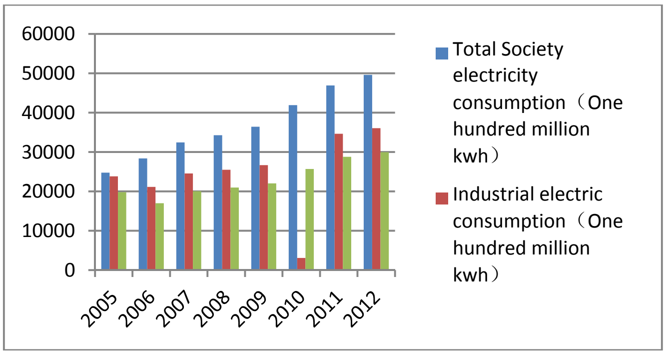

Figure 1. 2005-2012 Industrial Consumption Situation

Polemis M L [1] used cointegration approach to study the Greek industrial energy demand, research shows that industrial energy consumption both in the short and long term is inflexible, power energy and oil energy can substitute for each other; Shiu and Lam [2] (2004)

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used cointegration and error correction model technology to study the data for the period 1971 to 2000, estimated the relationship between China's power consumption and GDP, conclusions show that there is cointegration relationship between the two, and unidirectional causality exists between electricity consumption and economic growth; Liu Xiaoxin [3] (2011) used bootstrap DEA approach to analyze energy efficiency in 36 industrial sectors between 1998 to 2008, the results show that industrial energy efficiency presents "U"-shaped trend, the inter-industry differences in energy efficiency gradually narrowed; Huangde Chun, Dong Yuyi, Liu Bingsheng [4] (2012) usd three-stage DEA model to analyze the 2009 China's inter-provincial energy, the results show that the proposed environmental variables affect the efficiency largely.At present, electricity for industrial energy efficiency research is still very limited, and most scholars DEA using traditional research methods, the vast majority of these studies and analyzes from an efficiency value calculation for the influencing factors two industrial power perspective drawn some meaningful conclusions. However, DEA evaluation unit mainly for starting the internal indicator of efficiency, a number of external factors (macro factors, industry characteristics factors) was not taken into account, the efficiency may result in measurement error. In order to weigh the subjective and objective factors, analyze the external environment of industrial energy use efficiency level, this optimization model using DEA, the external environmental factors into the model, for 2011 of 34 industrial sectors for energy efficiency by electricity layer optimization analysis.

2.Introduction of DEA Optimization Model

2.1. The First stage: DEA Traditional Model Analysis

In this stage,used the traditional DEA model, this model made constant returns to scale which is put forward by Charnes, Coopern and Rhodes,they named the model BCC-DEA.The first stage estimated industrial electrical energy utilization efficiency of 34 industries from investment perspective using BBC-DEA .

There are n DMU evaluation system, x_0 kind of input, y0 kinds of output. σ is the efficiency value of the decision-making unit. x_j is input feature collection of DMU_j, yj is output feature collection of DMU_j; λ_j is the combination ratio of j-th DMU in a valid DEA combination which is constructed relative to DMU_{j0} .s^- and s^+ are the slack variables,All the variable construct the BCC-DEA under the non-Archimedean infinitesimal and VRS ,the model is shown as follows.

$$\min\theta \quad st.\begin{cases}\sum_{i=1}^{n}\lambda_i x_i + s^- = \theta x_0 \\ \sum_{j=1}^{n}\lambda_j x_j - s^+ = y_0 \\ \sum_{j=1}^{n}\lambda_j = 1 \\ \lambda_j, s^-, s^+ \geq 0, j = 1,2,...,n\end{cases} \quad (1)$$

In the optimal solution, if θ = 1, the decision-making unit is the DEA efficient, if θ <1, the decision-making unit is DEA inefficient.

2.2. The Second Stage: Tobit Regression Analysis

The first stage DEA estimated efficiency value derived from the internal index of the evaluation unit, but this efficiency value is also affected by environmental variables, management factors and the random errors. In order to measure the factors which influnece the electrical energy efficiency objectively and subjectively, and analyze the degree that the external impact factors on the efficiency, This stage used Tobit model to make regression analysis. Concrete modell is as follows:

$$\hat{\theta}_i = \beta_0 + \sum_{j=1}^{m} \beta_j x_{ij} + \varepsilon_i \text{ ,} \tag{2}$$

i=1,2,…,n;j=1,2,…,m

$$\theta_i = \begin{cases} \hat{\theta}_i \text{ , } \hat{\theta}_{i \in [0,1]} \\ 0 \end{cases} \tag{3}$$

In the model above, θi is the i-th DMU effective value, xij is the independent variables which is composed by environmental factors. β_0, β_j are the estimated coefficient of the model. ε_i is random disturbance term, (θ_i) is normally distributed. At this stage, introduced integrated environmental impact factors, that is those factors which affected industrial electric energy efficiency but not in the controllable scope of the subjective factors.formula of evironmental factors is as follows:

$$C_i = \sum_{j=1}^{m} \beta_j x_{ij}, i = (1, 2, ..., n; j = 1, 2, ..., m) \tag{4}$$

2.3. The Third Stage: DEA Analysis Added in Comprehensive Environmental Factors

Through the Tobit regression of the second stage,added the comprehensive environmental factors to the traditional DEA and estimated the efficient values again, got the final value of industrial efficiency. Three stage output value considered both internal factors, and the external environmental factors, the analysis result is more comprehensive, the final value is more accurate and effective efficiency.

3. Index Selection and Data Sources

According to China's industrial standard division, this paper selected 34 industries to study, Because the data is missing or difficult to obtain, this paper excluded the industrial data of other mining industry, food processing industry, food industry, handicrafts and other manufacturing, waste resources and mterials rcovering industry,and divided the 34 industrial sectors into extractive industries, light industry, heavy industry and electricity, gas and water industries.

3.1. Selection of the Input and Output Indicators

In the analysis of industrial electical energy efficiency,the most commonly output variables we used to measure the efficiency is industrial value-added value,relative data from "China Statistical Yearbook" 2012 and "China City (town) Life and Price Yearbook 2011". selected the annual average net value of fixed assets in 2011, electrical energy consumption and labor as indicators.

Selected the annual average number of employees as the value of labor indicator, value of labor and electricity consumption data are both from "China Statistical Yearbook," 2012.

3.2. Selection of Environment Variables Index

Since the principal aim of second stage is to analysis the influence degree environmental factors on the industrial electric efficiency, selected the environment variables is needed.

Environmental impact factors is those factors which affected industrial electric energy efficiency but not in the controllable scope of the subjective factors.The selection should satisfy the "separation hypothesis." Environmental impact factors can include Macro-environmental factors(such as Government funding, the macro environmental factors, weather changes,etc) and industry's own characteristic factors(such as Industry scale, market structure, etc), there are a lot of external factors to influence the electrical energy efficiency,this paper selected the following four environmental indicators based on industries themselves and a large number of other references.Enterprise number of industry(x_1), this indicator reflects the state of the market structure, number of enterprises in the industry increased, they can improve the industrial electric efficiency through the competition with each other. Scientific and technical personnel ratio(x_2), this indicator not only reflects the level of wohle industrial technology development, but also reflects the each industry's level of technological development,high technology industry is more conducive to the improvement of electrical energy efficiency. Average enterprise scale(x_3). This reflects the market scale state of the industry, the average enterprise scale is the ratio of each industrial output value and enterprises number.Government grants (X_4), this indicator reflects the government's support and encourage degree on electrical efficiency, it signified by the goverment raise funds of science and technology activities to the medium and large size enterprises. These data of the four indicators derived from "China Statistical Yearbook," 2012 and "China Science and Technology Yearbook, 2012.

4. Empirical Analysis

In order to analysis the electrical energy efficiency more comprehensive and objective, this paper used optimum DEA model, considered the environmental factors and analysised in three stage, at last calculated the efficiency value of 34 industries in 2011.

4.1. Caculating Results Using the Traditional DEA in First Stage

In the first stage, used Deap 2.1 software to realize a preliminary efficiency evaluation which belonged to the input type VRS-DEA, the results is shown in Table 1.

Table 1. Electrical Energy Efficiency Estimate with Traditional DEA Model

Number	Industry	TE	PTE	SE	
1	Coal mining and washing industry	0.332	0.628	1	drs
2	Oil and gas exploration industry	0.992	1	1	drs
3	Ferrous metal mining industry	0.276	0.308	1	irs
4	Non-ferrous metal industry	0.455	0.603	1	drs
5	Nonmetal mining industry	0.517	0.824	1	irs
6	Beverage Manufacturing	0.243	0.343	1	irs
7	Tobacco industry	1	1	1	-
8	Textile industry	0.236	0.581	0	drs
9	Textile and garment, shoes, hat manufacturing	0.404	0.463	1	irs
10	Leather, fur, feathers (down) and its products industry	0.503	0.66	1	irs
11	Timber Processing, Bamboo, Cane, Palm manufacturing	0.301	0.499	1	irs
12	Furniture Manufacturing industry	0.892	1	1	irs
13	Paper and Paper Products	0.169	0.221	1	irs
14	Printing and reproduction of recorded media industry	0.22	0.829	0	irs
15	Educational and Sports Goods Manufacturing	0.358	1	0	irs
16	Petroleum processing, coking and nuclear fuel processing industry	0.537	0.651	1	drs
17	Chemical materials and chemical products manufacturing	0.136	0.426	0	drs
18	Pharmaceutical Manufacturing	0.218	0.257	1	irs
19	Manufacture of Chemical Fibers	0.136	0.512	0	irs
20	Rubber	0.241	0.437	1	irs
21	Plastic products industry	0.243	0.274	1	irs
22	Non-metallic mineral products industry	0.151	0.404	0	drs
23	Ferrous metal smelting and rolling processing industry	0.277	0.61	0	drs
24	Non-ferrous metal smelting and rolling processing industry	0.295	0.651	0	drs
25	Fabricated Metal Products	0.251	0.368	1	drs
26	General equipment manufacturing	0.223	0.53	0	drs
27	Special equipment manufacturing industry	0.207	0.252	1	drs
28	Transportation Equipment Manufacturing	0.166	0.395	0	drs
29	Electrical machinery and equipment manufacturing	1	1	1	-
30	Communications equipment, computers and other	0.231	0.41	1	drs
31	Instrumentation and culture, office	0.32	0.689	0	irs
32	Electricity, heat production and supply industry	0.267	0.301	1	drs
33	Gas production and supply	0.138	1	0	irs
34	Water production and supply industry	0.098	0.541	0	irs

In the Table 1, Table 3 and Table 4, 1-5 is the mining industries, 6-15 is light Industry, 16-31 is heavy industry, 32-34 is electricity, gas and water industries.

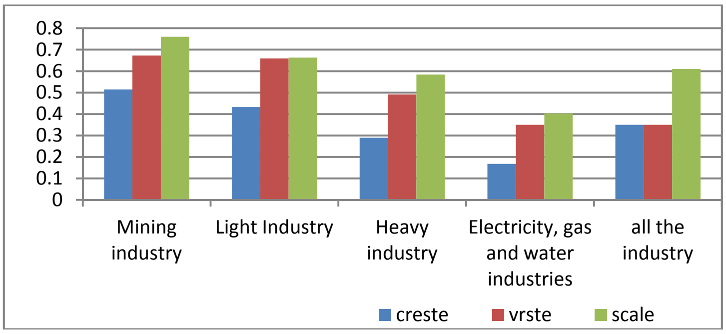

Figure 2. Four Categories Industrial Energy Efficiency and All the Industrial Energy Efficiency in 2011

From Table 1 we can see that electrical energy utilization efficiency of each industrial sectors is generally low in 2011, only Tobacco industry, Leather, fur, feathers (down) and its products industry, furniture manufacturing industry and electrical machinery and equipment manufacturing reach above 0.5, their technical efficiency value are 1, 0.503, 0.892, 0.537 and 1; efficiency values of the rest industry are below 0.5, the average technical efficiency of whole industry is 0.45. Pure technical efficiency of various industrial sectors is similar to their technical efficiency, their mean value is also not reaching 0.5. The scale efficiency of industry is generally high, most of them is reaching above 0.5, scale efficiency values are significantly greater than technical efficiency values. electrical energy efficiency of mining industry is higher than the other three industries, while the technical efficiency value of electricity, gas and water industry is only 0.18.

Analysis the table carefuly, we can find some problems which are difficult to explain. Firstly, 2/3 heavy industry are in a scale decreasing stage, while with the continuous development of industrialization today, scale of heavy industry is gradually expanding, its electrical energy utilization scale is also expanding, such a common phenomenon that scale of most heavy industries is decreasing does not match with the actual situation. What’s more, the technical efficiency of most industries is far from their frontier, the values are only floating between 0.1-0.3, while looking from China’s industrialization process, the phenomenon that efficiency value of the industrial sector is serious lower than its production frontier is difficult to explain. Different industrial sectors of production scale and size vary widely between industries.

In China, production scale of different industrial sectors is different gereatly, their development will be influnved by different external environment, therefore, adding external environmental factors to the industrial electrical energy efficiency study is really necessary.

4.2. Tobit Regression Analysis of the Second Stage

In this stage, considering the external environment variables as independent variables, considering the efficiency values which was obtained from the first stage as dependent value, and then took them into Tobit model,using Eviews 6.0 we could get the regression value. According to industrial sectors, this paper established Tobit model whichi is about external environmental factors of industrial electrical energy efficiency is as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon \quad (5)$$

In this model, y is the efficiency values which is measured on first stage DEA, x_1 is the enterprises number of industry, x_2 is the ratio of the scientific and technical personnel, x_3 is average enterprise scale,x_4 is government grants. β0 is a constant, ε is a random disturbance term, The results is shown as below.

Table 2. Tobit Regression Results in the Second Stage

Variable	Coefficient	Standard Error	Z	Prob.
x_1	0.019236	0.032561	5.907462	0.0055
x_2	-0.12775	0.056141	-4.98759	0.0061
x_3	0.063924	0.017287	3.697864	0.0002
x_4	-0.12452	0.040241	-3.65975	0.0114
C	0.290243	0.088504	3.279438	0.001

The above table shows that the number of enterprises and the power efficiency is positively correlated, and through the significant test, indicate that industrial sectors increasing the number of enterprises is conducive to the improvement of energy efficiency, increase a unit of the number of industries and enterprises, industrial electrical energy efficiency will increase 1.92 percent. Increasing number of industries and enterprises, to a certain extent, has led to various companies competing with each other. Enterprises aiming to adapt to market competition environment, making itself in an advantageous position in the market, must reduce electricity energy waste, thereby improving electrical energy efficiency.

The average firm size and industry sector electricity energy efficiency is positively correlated and statistically significant, the average enterprise scale a unit, industrial energy efficiency will increase 1.73 percent. This indicates that the current size of China's industrial sector enterprises did not reach the optimal size, moderately expanding the scale of industry enterprises can improve the energy efficiency of industrial electric power.

Scientific and technical personnel ratio, government-sponsored are negatively correlated with energy efficiency, statistically significant, this is opposite the expected results. These two factors did not play a positive role is due to inadequate government funding, funding and staff investment does not meeting the requirements of technology, or irrational allocation of financial and human resources, which makes the investment of money and manpower does not play a fundamental role, and cause electrical energy utilization efficiency.

4.3. The Third Stage: Adjusted DEA Efficiency Evaluation

Table 3. Environmental Impact Factor Calculations

1	Coal mining and washing industry	0.3087	18	Pharmaceutical Manufacturing	0.2191
2	Oil and gas exploration industry	1.0056	19	Manufacture of Chemical Fibers	0.3302
3	Ferrous metal mining industry	0.3305	20	Rubber	0.3086
4	Non-ferrous metal industry	0.3064	21	Plastic products industry	0.3146
5	Nonmetal mining industry	0.2704	22	Non-metallic mineral products industry	0.3461
6	Beverage Manufacturing	0.3088	23	Ferrous metal smelting and rolling processing industry	0.4891
7	Tobacco industry	0.6564	24	Non-ferrous metal smelting and rolling processing industry	0.3517
8	Textile industry	0.3718	25	Fabricated Metal Products	0.3233
9	Textile and garment, shoes, hat manufacturing	0.3582	26	General equipment manufacturing	0.2486
10	Leather, fur, feathers (down) and its products industry	0.3326	27	Special equipment manufacturing industry	0.2386
11	Timber Processing, Bamboo, Cane, Palm manufacturing	0.3000	28	Transportation Equipment Manufacturing	0.2340
12	Furniture Manufacturing industry	0.3071	29	Electrical machinery and equipment manufacturing	0.3077
13	Paper and Paper Products	0.3280	30	Communications equipment, computers and other	0.3133
14	Printing and reproduction of recorded media industry	0.3015	31	Instrumentation and culture, office	0.2441
15	Educational and Sports Goods Manufacturing	0.3076	32	Electricity, heat production and supply industry	0.4289
16	Petroleum processing, coking and nuclear fuel processing industry	0.6084	33	Gas production and supply	0.3413
17	Chemical materials and chemical products manufacturing	0.3012	34	Water production and supply industry	0.2895

Based on the above analysis, composed the external environment factors which affected the industrial electrical energy efficiency significantly to a composite environmental factors, the result is Table 3.

Bring the above calculated result into Deap2. 1again ,get the final results shown in Table 4.

Table 4. Value of Industry Electrical Energy Efficiency Using Traditional DEA Model

Number	Industry	TE	PTE	SE	
1	Coal mining and washing industry	0.669	0.821	1	drs
2	Oil and gas exploration industry	1	1	1	drs
3	Ferrous metal mining industry	0.567	0.866	1	irs
4	Non-ferrous metal industry	1	1	1	drs
5	Nonmetal mining industry	0.821	1	1	irs
6	Beverage Manufacturing	0.536	0.839	1	irs
7	Tobacco industry	1	1	1	-
8	Textile industry	0.726	0.77	1	drs
9	Textile and garment, shoes, hat manufacturing	0.675	0.79	1	irs
10	Leather, fur, feathers (down) and its products industry	0.644	0.836	1	irs
11	Timber Processing, Bamboo, Cane, Palm manufacturing	0.503	0.841	1	irs
12	Furniture Manufacturing industry	1	1	1	irs
13	Paper and Paper Products	0.45	0.758	1	irs
14	Printing and reproduction of recorded media industry	0.296	1	0	irs
15	Educational and Sports Goods Manufacturing	0.365	1	0	irs
16	Petroleum processing, coking and nuclear fuel processing industry	0.648	0.816	1	drs
17	Chemical materials and chemical products manufacturing	0.307	0.784	1	drs
18	Pharmaceutical Manufacturing	0.316	1	1	irs
19	Manufacture of Chemical Fibers	0.284	0.892	0	irs
20	Rubber	0.483	0.843	1	irs
21	Plastic products industry	0.478	0.798	1	irs
22	Non-metallic mineral products industry	0.437	0.659	1	drs
23	Ferrous metal smelting and rolling processing industry	0.64	0.64	1	drs
24	Non-ferrous metal smelting and rolling processing industry	0.744	0.795	1	drs
25	Fabricated Metal Products	0.594	0.822	1	drs
26	General equipment manufacturing	0.56	0.934	1	drs
27	Special equipment manufacturing industry	0.451	0.929	1	drs
28	Transportation Equipment Manufacturing	0.503	0.966	1	drs
29	Electrical machinery and equipment manufacturing	1	1	1	-
30	Communications equipment, computers and other	0.688	0.823	1	drs
31	Instrumentation and culture, office	0.462	1	0	irs
32	Electricity, heat production and supply industry	0.325	0.673	1	drs
33	Gas production and supply	0.176	1	0	irs
34	Water production and supply industry	0.158	1	0	irs

Compare and analyze the stage 1 result and stage 3 result of the four major categories of industriy industrial sectors can obtain the result shown in Table 5.

Table 5. Efficiency Values and After Adjustment of Four Major Industrial Sectors

	TE		PTE		SE	
	Before	After	Before	After	Before	After
Mining industry	0.5144	0.8114	0.6726	0.9374	0.76	0.858
Light Industry	0.4326	0.6195	0.6596	0.8834	0.663	0.706
Heavy industry	0.2895	0.5416	0.491625	0.85631	0.584	0.739
Electricity, gas and water industries	0.1676	0.2263	0.614	0.891	0.402	0.371

The above table showed that the pure technical efficiency of four major industries were above 0.8, it means that various industries have high technology and management level on the aspect of energy utilization, but their efficiency value have not yet reached technological frontier and still have room to improve. From the table, we know that the value of four major industrial sectors has changed drastically after adjustment using Tobit regression model. Except the scale efficiency of electricity, gas and water industry has decreased after adjustment, the efficiency value of other industrial sectors is all increased, it means that external environment variables has a great influence on industrial energy efficiency, consider the impact of the external environment variables is necessary.

Compare Table 1 and Table 4 we know that industry number which in the efficient frontier has risen from 2 to 4, efficiency values in various industries have also risen, and there is no decreasing scale industries. These show that China's industrial energy efficiency have a lot of space to enhance,each industry should continue to increase the investment of element and expand the scale of industrial actively. After adjustment, TE and PTE of the electricity, gas and water industry are increased, only the scale efficiency value is decreased,it means that scale efficiency is the factor which constraints its electrical energy efficiency reached the frontier.

5. Conclusion and Recommendation

This paper analyzes China's industrial electrical energy efficiency in 2011 using the optimized DEA model, the conclusions are summarized as follows: (1) The four external environmental variables this paper introduced affect the electrical energy efficiency significantly, the electrical energy utilization efficiency values of China's industry has changed sigenificantly before and after adjustment. This conclusion confirms the necessity that considering the external environment variables. (2) The energy efficiency values were increased after considering the external environmental factors, pure technical efficiency changes particularly evident, it indicats that most industry have high level in technology and management. (3) Although the technical efficiency value is increased, it has not yet reached the efficiency frontier. Therefore, all the industries, especially electricity, gas and water industry and other monopoly industries also has much room to improve.

Based on the above analysis, the corresponding recommendations are as follows: fisrstly, improving the scale of industrial energy utilization to achieve the optimum scale. Nowadays, many small and medium enterprises only concerned the production efficiency in the early development stage, they pay little attention to the electrical energy efficiency.So this companies should concerned the optimal use of electrical energy from the early stage. Large enterprises should make full use of their scale advantage to guide and promote small and medium enterprises to achieve the optimal economic. Secondly, using various means to eliminate monopolies as soon as possible. High monopoly industry is not conducive to strengthen the competition of industries itself. China needs to accelerate the speed and increase the intensity to "break the monopoly and promote competition". Because of the monopoly of some state-owned enterprises and high-monopoly industry, the inner of industry is less competitive, it caused the industry to improve their industrial scale and electric energy management not so actively, some high monopolied enterprise have low efficiency. Thirdly, government should allocate the technology funding for various industries rationally, reduce the blind investment on capital and take efforts to improve the technical efficiency, only do these can the electrical energy be fully and effectively utilized in various industries.

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