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A comparative study on grid resource utilization rate between China Southern Power Grid and National Grid Plc of UK

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Abstract

Grid resource utilization rate plays a key role in power grid operation. Although the proportion of population and the area in China Southern Power Grid (CSG) and National Grid Plc of UK (NG) are nearly, grid resources utilization of CSG is lower than that of NG. In this paper, the utilization of human resources and equipment resources of CSG and NG have been reviewed. It is discovered that there is a large gap between these two companies. The results show that the utilization in CSG is about 20% to 50% of that in NG. And it is estimated that if the equipment resources utilization of CSG increases to the level of NG in 2012, the coal consumption and thus CO_2 emissions would be reduced by 17 million tons and 21 million tons, respectively. As China is a developing country and Britain is a mature developed country, it is to some extent reasonable that grid resources utilization of CSG is lower than that of NG. The benefits of improving equipment resources utilization are illustrated in detail, which provided the reference for developing the grid resource utilization in China.

Keywords: Electrical equipment, Human resources, Power grid enterprises, Energy saving

1 Introduction

According to the statistics released by National Bureau of Statistics of China, the total coal consumption in China had an increase of 130%, from 1.81 billion to 4.16 billion tons from 2003 to 2014 [1, 2]. It is acknowledged that exhaust gas produced by the combustion of fossil fuels contributes to greenhouse gas (GHG) emissions and threatens human living environment [3]. The CO_2 emissions in China were 8.24 billion tons in 2010 and rose to 10 billion tons in 2013, which were more than the total emissions of the EU and the US [4]. Moreover, in terms of the scale of power system and GHG emissions, China ranks first in the world [5]. Therefore, reducing energy consumption and GHG emitted from power system in China will make a significant contribution to the sustainability of global energy and environment.

Although the number of employees of NG showed a reduction of 15.2% from 28,208 in 2009 to 24,274 in 2015 [6], its scale of power system retained relatively

stable and the performance of power system increased during that time. This, to some extent, was due to the increased human resources utilization.

The UK is a representative industrialized country. Its fixed assets investments, installed capacity and electricity sales are stable, while the number of employees is low, indicating the high human resources utilization. The asset management level of NG also ranks as top player. The total coal consumption of NG was 40.4 million tons in 2003 and 60.7 million tons in 2013, and this increase (50%) was far lower than that in China during the same period [7, 8]. The methods and experience of NG are of great significance for management and construction of power grid in China. CSG ranked the 113th among the Fortune 500 companies in 2015. It is serving five southern provinces, including Guangdong, Guangxi, Yunnan, Guizhou and Hainan. The power supply area and population of CSG are 1 million km^2 and 230 million, respectively. Its maximum load and electricity consumption in 2015 were 142.0 GW and 962.8 Tera Watt Hour (TWh), respectively [9]. In contrast, the power supply area and population of NG are 0.25 million km^2 and 63 million, respectively, and its maximum load and

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electricity consumption in 2015 were 52.3 GW and 302.7 TWh, respectively [10, 11].

The load increase rate of China is informed as higher than that of the UK. CSG of China is at the stage of industrialization development to some extent [12], with a large quantity of factories, especially high energy-consumption enterprises. Because the UK is in the post industrialization stage, its most manufacturing industries have experienced transformation. Gross Domestic Product (GDP) of China in 2015 ranked second in the world and took the first place in the developing countries, so the comparison could indicate the gap about the power grid enterprises between China and a developed and mature society from which China will benefit in the development of its power industry.

In order to develop operation efficiency and cut cost of power grid, some latest researches on strategies for improving equipment resource utilization and thus reducing carbon emission have been made in different perspectives. In [13], a study on the factors influencing best utilization rate from the aspects of network structure and connection mode of line is presented. In [14], presents a day-ahead optimal energy management strategy for economic operation of industrial microgrids with high-penetration renewables under both isolated and grid-connected operation modes. A method of asset management to select a transformer based on loss of life calculation according to the fundamental heat transfer laws to is presented in [15]. Likewise, in [16–18], it respectively proposes the use of a customized integrated data management system, Internet of things, and information and analytical system to improve life cycle management of power transformers.

This paper makes a comparative review of business performance of power grid enterprises in China and UK based on the perspective of investment, resulting in the final summary of constructive strategies and actions for narrowing the gap between these two power grids. The benefits of energy conservation and emission reduction by improving equipment resources utilization in CSG are also assessed.

2 Comparison in NG and CSG

To weigh the level of economic development of these two regions, GDP/GRP (Gross Regional Product) per capita of UK and CSG has been listed and calculated respectively [19]. Besides, the comparison of household electricity consumption per capita has also been made. According to Table 1, GRP/GDP per capita of CSG is about 13%~ 14% of NG, and the GRP of GSPG is almost 50% of the GDP of UK [20]. The calculation obtained from Table 1 shows that the household electricity consumption per capita of China is nearly 70% of that in the UK [11, 21], which is narrower apparently in terms of the gap about GDP/GRP per capita.

According to the data in [22, 23], it's apparent that the difference between these two regions in the energy source used for electricity generation lies in coal and gas power generation (Table 2), which is influenced by the energy-resource structure fundamentally. By the end of 2014, coal reserves in the UK and China had been 228 Million Tons of Oil Equivalent (Mtoe) and 62,200 Mtoe respectively, and reserve-production ratio 20% and 30% respectively [24]. As two gas-imported countries, the gas power generation accounts for a larger proportion of 30% in NG than that of 2.45% in CSG. With gas recognized as a clean energy, gas power generation unit installed capacity requires less investment, only about two-thirds of the coal-fired power plant investment internationally, and requires fewer personnel that is generally 2% of the coal-fired power plant, and has significant advantages in pollution emissions. For example, the CO and CO_2 emission of a 500 MW coal-fired power plant is 2.37 times that of the gas turbine power plant with the same capacity [25].

As can be seen, in terms of power system scale, operation condition, economic development level and the energy source used for electricity generation, NG and CSG are comparative. Besides, the population and the area of NG are nearly in the same proportion to that of CSG. Therefore, it is reasonable to compare CSG and NG to analyze the utilization potential of improving human

Table 1 GDP/GRP per capita and household electricity consumption per capita of CSG and NG

	Year	GDP/GRP per capita (USD)	Household electricity consumption per capita(kWh)
NG (United Kingdom)	2012	41,294	5452
	2013	42,295	5407
	2014	46,278	5595
	2015	43,733	5989
CSG (China)	2012	5554	3676
	2013	6092	3936
	2014	6813	4078
	2015	6831	3851

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Table 2 Energy source used for electricity generation in NG and CSG

	NG			CSG		
Year	2012	2013	2014	2012	2013	2014
Coal	40%	36%	30%	74.46%	74.09%	70.5%
Gas	28%	27%	30%	2.32%	2.26%	2.45%
Nuclear	19%	20%	19%	1.97%	2.07%	2.37%
Renewables	11.3%	14.9%	19.1%	19.29%	19.34%	22.18%
Other Fuels	2.3%	2.4%	2.6%	1.96%	2.24%	2.5%

resources and equipment resources in China, to provide reference for China.

3 Human resources utilization

3.1 Power supply area per employee

The power supply area, population and electricity consumption of CSG are about 4 times, 3.6 times, and 3 times as many as those of NG, respectively. Therefore, the scale of power supply of CSG is 3 to 4 times as many as that of NG. As shown in Table 1, the number of employees in CSG was 12.8 times and 12.5 times as many as that of NG in 2014 and 2015 respectively [26], resulting in that the power supply area per employee of CSG was much less than that of NG [6, 27]. The power supply population per employee and power supply area per employee of NG were about 3.5 times and 3 times than those of CSG respectively according to the Table 3.

It can be seen that NG can serve more consumers and a larger area per staff member. Compared with NG, the automation level of CSG is lower, resulting in large numbers of employees. Moreover, gas distribution is operated in NG, but not in CSG, and employees involved in this operation are also included in the number shown in the Table 3. This demonstrates that NG is more automated with higher efficiency.

3.2 Electricity sales per employee

Table 4 shows the annual electricity sales and revenue of CSG and NG from 2010 to 2015 [6, 11, 27]. As can be seen from this table, the electricity sales of CSG are more than 2 times than those of NG every year. In respect of revenue, CSG shows a growing tendency, with an increase of 27.3% from 2010 to 2015, while the

revenue and electricity sales of NG maintain stable from 2010 to 2015. According to Tables 3 and 4, it can be calculated that the electricity sales per employee and revenue per employee of NG are about 5 times and 4 times as many as those of CSG, respectively. And given that the number of employees of NG includes those who operate gas distribution, its electricity marketing efficiency is higher and benefits are much greater than CSG.

3.3 Labor costs of CSG and NG

As can be seen from Table 5, the labor costs of CSG were very close to those of NG from 2011 to 2012 [6, 26, 28, 29]. Although the number of employees in CSG was about 12.5 times as large as that of NG in 2013, the wages of employees in CSG are far lower than in NG, thus the labor costs of CSG are close to NG. Even though human resource utilization of CSG is lower than in NG, labor costs will not be an excessive burden on CSG.

However, with the increase of labor costs in China, it will be necessary for CSG to reduce the number of employees and increase the labor productivity. Unit labor cost, which is the ratio of average labor cost and labor productivity, reflects the cost advantage of an industry and a country. Based on the comparison of the number of employees in CSG and NG, it is discovered that there is a great potential for reduction in the unit labor cost of CSG.

4 Equipment resources utilization

4.1 Investments of fixed assets

The investments of fixed assets in CSG are huge every year. Figure 1 demonstrates fixed assets investments in CSG and NG from 2010 to 2015. As shown in the figure, the fixed assets investments of CSG experienced a declining trend, and its annual investment from 2010 to 2015 was about 12.76 billion USD [26, 30]. By contrast, the investments of NG were relatively stable, with an annual investment of about 2.03 billion USD [31]. Higher utilization of equipment resources can help to make full use of existing electrical equipment, to reduce power investments.

Table 3 Power supply area of CSG and NG in 2013–2015

		Employee number	Power Supply Population per Employee	Power Supply Area per Employee (km^2)
2013	CSG	316,000	728	3.16
	NG	25,224	2498	10
2014	CSG	305,000	754	3.28
	NG	23,909	2635	10.55
2015	CSG	303,000	759	3.3
	NG	24,274	2596	10.39

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Table 4 Electricity sales of CSG and NG

Year	Electricity Sales (GWh)		Revenue (billion USD)	
	CSG	NG	CSG	NG
2010	602,700	319,919	54.589	120.39
2011	666,700	308,033	56.037	120.8
2012	701,000	308,408	61.916	120.05
2013	743,300	306,748	66.199	120.82
2014	785,900	291,101	69.980	121.47
2015	782,200	289,337	69.160	122.71

4.2 Equipment utilization

4.2.1 The index of equipment utilization

The whole life cycle process is a design theory that considers all aspects of the life course of the product in the design phase, and comprehensively plans and optimizes all the related factors in the design phase of the product [32, 33]. Life cycle assessment is a process to evaluate the input, output and potential environmental, energy and economic impacts of a product's life cycle [34–36].

Generally, load rate is used as an index to evaluate the utilization of equipment in distribution network. Load rate which is equal to the ratio of maximum load to capacity of equipment can only evaluate a fixed period of equipment utilization. Burden rate and load rate can evaluate the utilization efficiency of supply-side and demand-side respectively, and life expectancy rate can reflect actual service time. When considering the entire life cycle, the evaluating indicator for equipment utilization efficiency need to be changed [37]. In this paper, the definition of load rate has been improved, and the equipment utilization is defined as life cycle load rate, which is as follow:

$$\eta = \frac{\sum_{i=1}^{n} \eta_i}{y_n} \times \frac{y_n}{y_d} \tag{1}$$

where η is life cycle load rate, n is the number of actual service year of equipment, η_i is the load rate of equipment in the i year, y_n is actual service life of equipment, and y_d is design life of equipment, $\sum_{i=1}^{n} \eta_i$ is the sum of load rate of equipment during the whole life, y_n/y_d is the
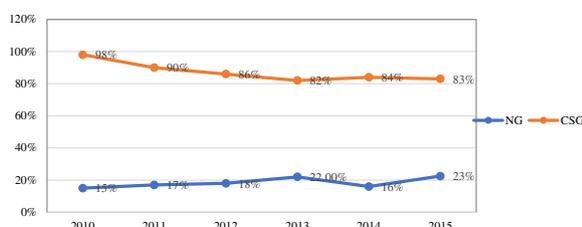
Fig. 1 Fixed assets investments of CSG and NG

life expectancy rate. Compared with load rate, life cycle load rate considers the actual life of the equipment, and can evaluate the equipment utilization during its whole life, which is more comprehensive.

According to the evaluation index of equipment utilization in PAS-55 Optimal Management of physical assets, the net asset salvage value, which has been used as an evaluation index in this paper, can evaluate the equipment utilization in terms of economy. In this paper, life cycle load rate and net asset salvage value are used as two indexes to measure the equipment utilization.

It can be seen from the equation that the sum of load rate of equipment during the whole life can be improved when the actual service life of equipment is improved, which results in improvement of life cycle load rate. Net asset salvage value can evaluate whether the equipment is fully utilized in terms of economy. Improving the life cycle load rate and actual service life of equipment can help to reduce net asset salvage value.

4.2.2 The comparative analysis of equipment utilization

The installed capacity of CSG was about 2.67 as much as that of NG in 2013 [27, 38]. However, the electricity generation of CSG was just about 2.55 times as much as that of NG. There was a gap of about 5% in electricity generation. There are a lot factors that make electricity generation fewer than installed capacity, such as some equipment failing to work as planned, a lower capacity factor and equipment maintenance.

System load factor is the average hourly quantity of electricity available during the year. When other conditions are the same, the higher the load factor is, the higher the equipment resources utilization is. Therefore, the load factor can reflect the equipment utilization to some degree.

Table 6 shows the load factor of CSG and NG. As can be seen from the table, the system load factor of NG was about 65% in 2009, which increased to 71% in 2013 [27]. In 2009 and 2010, the system load factor of CSG was about 62% and 68%, respectively [39]. In 2011 and 2014, the system load factor of CSG and NG at the same value. In general, these load factors seem similar. The system load factor of CSG was lower than that of NG in 2009 and 2013.

Generally, load rate refers to the ratio of maximum load to capacity, which is one of the indicators to measure equipment utilization, and higher load rate means

Table 5 Labor costs of CSG and NG (billion USD)

	2011	2012	2013	2014	2015
CSG	11.968	12.204	–	–	–
NG	12.249	12.246	12.285	12.268	12.514

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Table 6 Load factor of CSG and NG

Year	System Load Factor	
	CSG	NG
2009	62%	65%
2010	68%	65%
2011	67%	67%
2012	68%	66%
2013	70%	71%
2014	67%	67%

higher equipment utilization. The load rates of medium-voltage lines of the five provinces of CSG in 2012 are demonstrated in Fig. 2. The load rates of these five provinces are low, among which Hainan is the highest with 45.1% and Yunnan the lowest with only 32.6%. The average load rate of medium-voltage lines of CSG is 40.5%. And in 2012, the load rates of medium-voltage lines of NG have been estimated to 64.3% [27]. The average load rate of medium-voltage equipment of CSG is lower than NG, which is about two thirds of NG.

PAS-55 Optimal Management of physical assets was a Publicly Available Specification published by the British Standards Institution. This standard for fixed assets management is internationally accepted at present. In this standard, the actual service life and net asset salvage value rate of equipment are important measurement to assess assets utilization. The net asset salvage value rate equals the ratio of net value when scrapping to the original value of the asset.

Table 7 shows the actual service life of some electrical equipment in CSG and NG [40, 41]. As shown in the table, the actual service life of electrical equipment in CSG is lower than in NG. Specifically, the actual service life of distribution transformers, electrical cables and switchgear of NG are about 2.9 times, 2 times and 1.7 times as those of CSG.

The figure below demonstrates net asset salvage value rate of NG and CSG during 2010 and 2012. As indicated, the net asset salvage value rate of NG is about 5%, which has reached the rejection standard of international
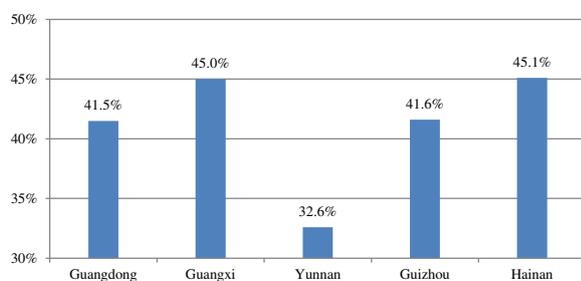
Fig. 2 Load rates of medium-voltage lines of CSG in 2012

advanced assets management. The net asset salvage value rate of electrical equipment scrapped most in CSG was at a high level of about 19%. The high net asset value means that the equipment has not been fully utilized, and thus the utilization is low.

It could be inferred that there are some reasons for shorter actual service life of some electrical equipment and higher net asset salvage value rate in CSG when compared with NG. (1) The capacity planning of some electrical equipment in CSG is inadequate. These pieces of equipment cannot meet the requirement of load growth, and consequently they are replaced before being used for enough time. (2) Equipment maintenance is not timely. Sometimes, when failures happen, the causes could not be diagnosed accurately. As a result, the equipment cannot be maintained in time, and problems of early retirement and short life will appear. (3) The manufacturing process is not rigorous enough, resulting in short actual service life.

The equipment utilization of some developed countries is between 30% and 50%, and the line loss rate is about 6–10% [42]. According to China Southern Power Grid Corporation, the utilization of some electrical equipment of CSG was about 17%, and the line loss rate reduced from 10% in 2010 to 6.72% in 2015 [43]. The wide gap between CSG and UK in equipment utilization can be seen in Table 8.

The annual fixed assets investment of CSG is about 3.4 to 6.2 times as much as NG. It can be seen from Table 7 that the actual service life of some electrical equipment in NG is about 1.7 to 2.9 times as much as CSG, and Fig. 3 demonstrates that the net asset salvage value rate of CSG is about 3.8 times as much as NG. In terms of these assets management indicators, the asset utilization of NG is about 1.7 to 3.8 times as much as CSG. As the average of 1.7 and 3.8 is 2.75, the asset utilization of NG is about 2.75 times as much as CSG. According to Table 8, the equipment resource utilization of NG is about 3 times as much as CSG.

According to the comparison of utilization of human resources and equipment resources in CSG and NG, the gap of human resources utilization between CSG and NG is larger. The short actual service life of electrical equipment means the frequent replacement of electrical equipment. Replacing the ageing assets of CSG needs a large number of labors, which is one of the reasons for greater labor requirement of the CSG. What's more, unlike the stable electricity demand of NG, the electricity demand in southern China is growing rapidly, which is also an important reason for the increasing labor intensity.

However, because wages are lower in China than the UK, the labor costs may not be an excessive burden on CSG even though there are more employees compared

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Table 7 Actual service life of some electrical equipment

Grids	Distribution Transformers (years)	Electrical Cables (years)	Switchgear (years)
CSG	19	20	24
NG	55	40	40

to production. This is part of the social condition of China and cannot be changed without social consequences. It is certainly good for southern China to adopt the best international practices to manage the assets of power grid, but rapid growth of electricity demand brings a significant challenge.

5 Benefits of improving equipment resource utilization

In 2012, electricity generated by coal in China was about 3784.93 TWh, i.e. about 325.5 Mtoe [44], and the coal consumption of electricity generation was about 1785.31 million tons (1249.7 Mtoe) [45]. The efficiency of electricity generated by coal can be calculated as follow:

$$K_1 = \frac{M_e}{M_c} = \frac{325.5Mtoe}{1249.7Mtoe} = 26\% \tag{2}$$

where K_1 is the efficiency of electricity generated by coal, M_e is the electricity generated by coal, and M_c is the coal consumption of electricity generation.

In 2012, electricity generated by coal in NG was about 143 TWh, i.e. about 12.3 Mtoe, and the coal consumption of electricity generation was about 55 million tons (38.5 Mtoe) [27]. Then the efficiency of electricity generated by coal is 31.9% by calculation.

In 2012, the total electricity consumption of electrical machinery and equipment manufacturing in China was about 5.276 Mtoe [45], and the industrial sale value was about 5328.7 billion RMB [46]. Power equipment manufacturing was a part of the electrical machinery and equipment manufacturing. The industrial sale value of power equipment manufacturing was 6945.9 billion USD [47], and thus the electricity consumption of power equipment manufacturing is estimated at 4.743 Mtoe. The equipment resources utilization of CSG is about one third of NG. It means that, to achieve the same electricity, NG merely needs one third of CSG's consumption of power equipment manufacturing. If the equipment resources utilization of CSG increases to the

Table 8 Equipment utilization of UK and CSG in 2010

Country	Equipment Utilization (%)	Line Loss Rate (%)
UK	50.9	8.0
CSG	17	10

level of NG, the reduced electricity consumption (ΔE) could be estimated as:

$$\Delta E = E_e \times (1-U) = 4.743Mtoe \times \left(1-\frac{1}{3}\right) = 3.162Mtoe \tag{3}$$

where ΔE is the reduced electricity consumption when the equipment resources utilization of CSG increases to the level of NG, E_e is the electricity consumption of power equipment manufacturing, and U is the ratio of equipment resources utilization of CSG to NG.

The reduced coal consumption (C_m) could be estimated as:

$$C_m = \frac{\Delta E}{K_1} = \frac{3.162Mtoe}{26\%} = 12 \ Mtoe \tag{4}$$

where C_m is the reduced coal consumption when the equipment resources utilization of CSG increases to the level of NG, ΔE is the reduced electricity consumption, and K_1 is the efficiency of electricity generated by coal.

The electricity consumption of 3.162 Mtoe is equivalent to 36.8 TWh, and 12 Mtoe is equivalent to 17 million tons of coal. Each 1 kWh in CSG produces 572 g of CO_2 [3, 30]. Higher utilization will reduce CO_2 emissions and the reduction of CO_2 emissions (ΔCO_2) could be estimate as:

$$\begin{aligned}\Delta CO_2 &= R_e \times C_{kWh} = 36.8 \times 0.572 \\ &= 21 \ million \ tons\end{aligned} \tag{5}$$

where ΔCO_2 is the reduced CO_2 emissions, R_e is the reduced electricity when the equipment resources utilization of CSG increases to the level of NG, and C_{kWh} is the CO_2 emissions for producing each 1 kWh in CSG.

According to the target of energy conservation and emissions reduction in CSG's twelfth five-year plan, standard coal consumption and CO_2 could be reduced by 100 million tons and 300 million tons during 2010 to 2015, respectively, which equals a reduction of about 20 million tons of coal and 60 million tons CO_2 per year [48]. If the 2012 figures are sustained for these 5 years, and the equipment resources utilization of CSG increases
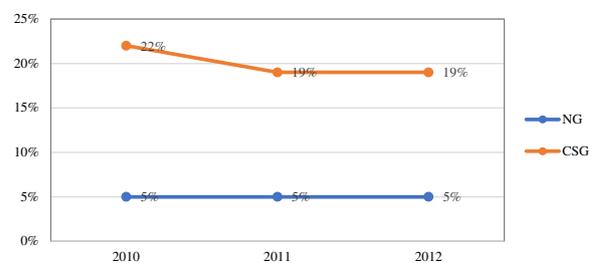
Fig. 3 Net asset salvage value rate of CSG and NG in 2010–2012

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to the level of NG, CSG will contribute to the 85% reduction of standard coal and 35% reduction of CO_2.

According to the estimation, if the equipment resource utilization of CSG increases to the level of NG, CSG will reduce coal consumption by 17 million tons and CO_2 emissions by 21 million tons in 2012. According to the target of energy conservation and emission reduction in China's twelfth five-year plan, standard coal consumption could be reduced by 670 million tons during 2010 to 2015, which equals a reduction of about 134 million tons per year [49]. Assuming that 2012 figures are sustained for these 5 years, and the equipment resources utilization of CSG increases to the level of NG, CSG will contribute to 12.7% reduction of the target.

6 Conclusions

In this paper, the grid resource utilization of CSG and NG experiences comparatively analysis, and the following conclusions can be drawn.

(1). The power supply area and power supply population of CSG are about 3 to 4 times as many as NG.

(2). The power supply area per employee and power supply population per employee of CSG are about one third of NG. The electricity sales per employee and revenue per employee of CSG are only about 20% to 25% of NG. Therefore, the human resource utilization of CSG is much lower than NG. However, the labor costs of CSG are close to NG, so the large number of employees will not be an excessive burden on CSG.

(3). According to the comparison of equipment resource utilization, the actual service life of some electrical equipment in CSG is about 20% to 50% of NG, and the utilization of some equipment resources is about 33% of NG. Therefore, the equipment resource utilization of CSG is lower than that of NG.

The huge potential for improving the resource utilization of CSG is discovered. It is estimated that if the equipment resource utilization of CSG increases to the level of NG, CSG could reduce coal consumption by 17 million tons and CO_2 emissions by 21 million tons in 2012. Obviously, the benefits of energy conservation and emission reduction brought by improvement of grid resource utilization are significant.

CSG is one of the two biggest power grid enterprises in China, whose resource utilization level is representative among China's power grid enterprises. Improving resource utilization can reduce investment in power system, boost the performance of power system, and promote energy conservation and emission reduction. Thus, improving the efficiency of resource utilization should be the key measure for China's power grid industry to achieve energy conservation and emission reduction.

Abbreviations
CSG: China Southern Power Grid; GDP: Gross Domestic Product; GHG: Greenhouse Gas; GRP: Gross Regional Product; Mtoe: Million Tons of Oil Equivalent; NG: National Grid Plc of UK; TWh: Tera Watt Hour

Availability of data and materials
Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Authors' contributions
LZ conceived the idea. DZ, WW and CL participated in the design of the study and performed the statistical analysis. MZ and HY conceived of the study, and participated in its design and coordination. DZ, MZ, HY, CL, GL, FL and MC helped to draft the manuscript. All authors wrote the manuscript. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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