Quantitative Analysis on the Electrification Process of China

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Abstract. The electrification of energy production and consumption has become a strategic choice of global energy transition, since electricity can be transformed from a massive renewable energy efficiently, and also be helpful to boost the overall level of energy efficiency. In this paper, it presents the promotion of the electrification to the energy transition, and analyses the basic conditions of China's continuous upgrading of the electrification level. Based on the international comparison, the trend of the future global electrification process is identified, and the strategic path of China's electrification is proposed through the 3E energy consumption prediction model and the energy and electricity optimization planning model. It is of great significance to provide a decision support that accelerating energy transition and development of electrification in China thoroughly and efficiently.

1. Introduction
In the background of the global combat to climate change, low carbon development using clean energy has become a strategic choice of energy transition all around the world. In consideration of China’s special national conditions, the large-scale development and utilization of wind energy and solar energy, expansion of scale and scope of electric energy, and improvement of energy use efficiency are of significance to the energy transition. Therefore, continuously upgrading electrification level will be a trend and the key of China's energy transition [1].

In this paper, we analyze the promotion function of the electrification to the energy transition from the dimensions of low-carbon, clean, efficient and intelligent, and identify the trend of the global electrification in both sides of the energy production and consumption. Then, we study and design the roadmap of China's electrification process based on the 3E energy consumption prediction model and the energy optimization planning model. Finally, we present the significant role of the power system in the China’s electrification process and its development trend in the future. The conclusions are of great importance to provide a decision support that accelerating energy transition and development of electrification in China thoroughly and efficiently.

2. Comparison analysis on the electrification level of different countries
Since Edison invented the electricity in 1879, electricity began to enter the human society. In the next hundred years, the electric industry in many countries has developed continuously rapidly, becoming an important force driving economic growth.

2.1. The role of electrification in driving this energy transition
The core features of this new round of energy transition are cleanliness, low-carbon, efficiency and intelligence, which could be achieved mainly relies on large-scale development of renewable energy (RE) and improvement of energy efficiency. Considering almost all the RE have to be transformed
into electricity to be used, electrification must plays significant supporting roles in turning energy system to be clean, low-carbon, efficient and intelligent.

Electrification is an effective way to energy low-carbon transition. Wind and solar are mostly converted into electric power for utilization with no carbon emission, and replacing coal, oil and other fossil energy with electric power in the end-use sector can also reduce carbon emissions.

Electrification is a key step in energy clean transition. Improvement of the generation ratio of clean energy and substitution of electric energy for pulverized coal can reduce emissions of air pollutants effectively. Also, advanced thermal power pollutant emission control technology can realize desulfurization, denitrification and dust removal in a centralized and efficient way.

Electrification is an important means of energy efficient transition. The level of electrification can effectively reduce energy consumption, through the econometric cointegration analysis model, the average level of electrification of China increased by 1% in 1990-2015, and the energy consumption of unit GDP decreased by 3.6%, as in [2].

Electrification is the inevitable choice for energy intelligent transition. Nowadays, the needs of the energy consumption are more and more diversity and intelligent. Electricity can meet those needs with the characteristics suchas flexible, controllable and variable by combining with advanced sensing, communication, internet and other technologies.

2.2. Comparison analysis of the electrification process in different countries

There are usually two types of indicators to measure the level of electrification development, the index from the energy supply side is the share of power generation in total primary energy consumption (TPED); the index from the energy consume side is the share of electricity in total final consumption (TFC). In this paper, we do the comparison analysis of the electrification process with two kinds of countries, one are the United States, Britain, Japan, Germany, France and other developed countries, the other are China, Russia, India, Brazil, South Africa (which also known as BRICS) [3-5].

The result of the comparison from the energy supply side shows that, the level of electrification on energy supply side is relatively high in developed countries, remaining at around 35% [6], with the highest in France (46.5% in 2014); but the electrification level on energy supply side has increased faster in the BRICS, reaching around 25% to 30%, with the highest in China, reaching 39.1% in 2014.

The causes of the phenomenon above are the differences of resources endowment and technology state, extensive utilization of coal, hydro and nuclear power in primary energy composition has promoted the rapid improvement of electrification level such as China, Brazil and France. In recent years, the development speed of power generation in these major countries has slowed down due to the increasing constraints of resource and environment, also the stabilization of total energy demand.

The result of the comparison from the energy supply side shows that, the developed countries have a higher level of electrification, with OECD countries reaching 24% in 2014, which France (2014, 27.7%) and Japan (2014, 26.8%) were the highest, the United States (2014, 21.2%), UK (2014, 23.2%) and other natural gas utilization is lower than the significant national level. Electrification level in
energy consume side is generally low in emerging economies, with the BRICS 2014 level of 18.4%, with the exception of China (2014, 23.2%) and South Africa (2014, 22.8%) exceeding 20%, while the remaining countries are lower.

2.3. Trend identification of the global electrification process in the future

Furthermore, there’re still strong growth drivers of power demand because developing countries need to accomplish their industrialization and information age being a main world development trend. Considering the energy supply will be cleaner and lower-carbon, and the energy use will be more efficient and intelligent, the future electrification development will be not only a continuation and enhancement of the past, but also an upgrading and quality change. In energy primary consumption side, high proportion of clean energy development and utilization will promote a new round of electrification level quickly climbed to 40% in 2030. On final consumption side, many new types of power utilization are in the field of continuous expansion, which promote the deep substitution from fossil energy to clean electricity, and will trigger share of electricity in TFC to break 30% round 2040.

3. Research on the Roadmap of the China’s electrification

As the largest developing country in the world and a major energy producer and consumer country dominated by coal, China will face many difficulties and obstacles in this round of energy transformation, such as resource endowments, environmental protection and technological bottlenecks. In particular, China's economic development has entered a “New Normal Stage”, the energy demand has slowed down, and the “Supply Side Reform” has been in-depth promotion, thus we design a roadmap of the electrification based on the 3E energy consumption prediction model and the energy and electricity optimization planning model to support the energy strategic transformation of China.

3.1. Methodology

In the energy consumption side, the 3E energy consumption prediction model is used to forecast the medium and long-term energy and power demand, which is applied to meet the constraint objectives of total volume control, pollution emission and efficiency enhancement (as shown in Fig.4). The trend extrapolation, energy price comparison and econometric simulation optimization algorithms are used to forecast and analyse energy supply and demand, including primary energy, terminal energy, energy for conversion and consumption (such as power generation).

In the energy supply side, the energy and electricity optimization planning model is used to work out the optimal supplcation solution of energy and power, which include the layout and cross-district power flow of various types of power supply with the objective of the lowest system supply cost. Certainly, all the modelling boundary conditions are constrained by the strategic goal presented by national energy policy as shown in Table 1.
3.2. Roadmap of Green Electrification in the energy supply side

In the energy supply side, it needs to promote the "Green Electrification" through the vigorous development of clean energy, gradually realize the incremental substitution of fossil energy and stock substitution, and steadily improve the level of energy supply side electrification.

In 2020-2030, it mainly complete the "Green Electrification" of the incremental energy consumption. From the energy perspective, the incremental consumption will basically be supplied by non-fossil energy and natural gas, and non-fossil energy is the most important incremental alternative source. From the electricity perspective, non-fossil energy generation will account for more than 50% of the additional electricity and become the main alternative power supply, in which the wind and solar power account more than 50%. The share of power generation in TPED will exceed 66% in 2030.

In 2030-2050, on the basis of completing the incremental partial cleaning substitution, gradually realize the clean substitution of the stock part, and finally realize the "Green Electrification". From an energy supply perspective, the non-fossil energy supply is more than 50% in 2050, which will become the dominant source. Among them, the new energy generation (wind+solar), hydro and nuclear power, as well as the non-fossil energy with non-power utilization are about 6:3:1. From a power supply perspective, the electricity generated by non-fossil energy accounted for more than 70% in 2050,
becoming an absolute dominant power source. Among them, the electricity generated by wind and solar, hydro and nuclear are 5:3:2. The share of power generation in TPED will exceed 66% in 2050.

3.3. Roadmap of Extensive Electrification in the end-use energy consume side
In the end-use energy consumption side, it needs to promote the "Extensive Electrification" through expanding the breadth and depth of the use of electricity, which means replacing the fossil fuels such as coal, oil or gas with electricity with the order that industry sector first, then transportation, commercial and residential sectors later.

In 2020-2030, electricity consumption will increase 550 million tons of standard coal (tce), oil and gas consumption will increase 550 million tce, coal consumption will decrease 360 million tce, drop 27%. By 2030, the shares of electricity in TFC will exceed 30% which means the electricity will surpass coal and become the dominant energy in the end-use energy consumption. The industrial sector is still the main driver of China's electrification level, contributing about 40% to electricity growth, and 25%, 17% and 10% respectively for residential, transportation and commercial sectors.

In 2030-2050, electricity consumption will increase 370 million tce, gas increase 180 million tce, oil consumption decrease 220 million tce, and coal consumption decrease 360 million tce and reach 620 million tce. In 2050, the shares of electricity in TFC will exceed 40%. The electrification of industrial sector will decline, and residential, transportation and commercial sectors will become the main drivers of the increase in electrification level, contributing 52%, 42% and 39% respectively.

4. Future power grid to support the electrification development
With the development of the "Green Electrification" and “Extensive Electrification”, a large number of the new energy, electric-electronic components and diversified load will be integrated into the power grid, which will change the traditional operation characteristics of the system and bring in enormous challenges [7, 8]. Thus it is necessary to promote the deep utilization of the modern technology such as Big Data, Cloud Computing, Mobile Internet and etc.in the energy and power
industry, optimize the security and stability control capability of large power grids and enhance the
friendly interaction among the power source, grid and load.

By improving the intelligent level of the power grid, supporting the coordinated development of
different voltage-level grids, to achieve an optimal allocation and large-scale utilization of the clean
energy. By 2030, the East Central region (including Guangdong, Guangxi) is expected to be input
420GW power, including 70% electricity are generated by the clean energy. While the transmission
network guarantees a wide range of power flow, the distribution networks and microgrids are more
active, intelligent and self-healing, which can meet all kinds of need of the users.

5. Conclusions
Electrification plays a significant supporting role in driving this energy transition to be clean, low-
carbon, efficient and intelligent. The future global electrification development will be not only a
continuation and enhancement of the past, but also an upgrading and quality change with the share of
electricity in TFC 40% in 2030, and the share of electricity in TFC to break 30% round 2040.

The electrification process of China is focused on the "Green Electrification" in the energy supply
side and "Extensive Electrification" in the end-use side. For the "Green Electrification", it mainly
complete the clean substitution of the incremental portion of energy demand by 2030, then gradually
realize the clean substitution of the stock part by 2050, the share of power generation in TPED will
exceed 54% in 2030 and 66% in 2050 respectively. For the " Extensive Electrification", it mainly
complete the electrical substitution in the industry sector by 2030, then complete the electrical
substitution in the transportation, commercial and residential sectors by 2050, the shares of electricity
in TFC will exceed 30% in 2030 and 40% in 2050 respectively.

The power grid is the most significant infrastructure to carry on the electrification process of China.
To improve the intelligent level of the system, it is necessary to promote the deep integration of more
modern information technology and artificial intelligence technology into the energy technology.

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