Research on the Domain and Potential for Further Electrification of Rural Domestic Energy Consumption

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Abstract. As energy production and the consumption revolution continues to deepen in the 21st century, the world is entering a new phase of electrification. On the supply side, there are now more and more clean energy sources of electricity such as wind and solar that are being developed and utilized. On the consumption side, electrical energy is continuously replacing fossil fuels. As electric engines, electric cooking and electric heating become more common, electricity will increasingly displace coal and oil. Currently, energy consumption levels are low in rural China, especially in the domestic sector, constraining rural-urban integration and development as well as improvement in the energy consumption of rural regions. Electrification is an effective way to make rural energy consumption cleaner and less carbon-intensive. It can significantly reduce pollution and emissions, thus improving the quality of life and the environment. The present paper discusses the main applications of electrification in rural energy consumption. As rural-urban integration continues to develop, rural energy consumption levels will gradually converge with urban energy consumption levels. The present paper proposes areas where there is potential to increase electrification in rural domestic energy consumption, providing a reference for improving rural domestic energy consumption, bearing significance for energy transformation and mitigation of rural environmental pollution.

1. Introduction

Recent years have seen great increases in energy security in rural China. Remarkable achievements have been made in the adjustment of energy structure, but the commoditization and optimization of energy is still significantly lower in rural regions than in the cities. Traditional biofuels and low-quality coal are still widely used. In particular, many rural households in farming provinces continue to burn straw and firewood. Low levels of rural energy consumption and low levels of electrification have led to constraints on the rapid integration of urban and rural development and the upgrading of energy consumption in rural areas, creating environmental pollution in rural regions.

Source 1 explores the relationship between economic activities and changes in electrical energy, obtaining a model for optimizing electrical energy that can adjust the supply structure of electricity. Sources 2 and 3 introduce the development process, organization and management structure of electrification in American farming regions, providing some lessons for the electrification of China’s villages. Source 4 discusses how Japan supported the construction of electric vehicle charging stations and taxed fossil fuels in order to promote electric vehicles. Source 5 conducted a technical and economic analysis of four main types of electric heat pumps that are replacing coal-fired boilers in rural areas of Beijing, Tianjin and Hebei. Source 6 constructed a model to study the potential for
electricity to replace traditional fuel sources and environmental efficiency, studying the potential for electrical energy to replace traditional energy sources using data from rural regions across 26 Chinese provinces. Source 7 explores the feasibility of replacing traditional fuel sources with electricity at the end-consumption point and the possible obstacles thereof. Source 8 proposes that clean coal technology should be developed further, allowing electricity thus generated to replace “dispersed coal burning”. These sources have discussed the main ways by which electricity can replace traditional fuel sources as well as its economic aspects, proposing policies that can promote electrification. However, they have not conducted in-depth analysis on rural domestic energy consumption and the key areas where electricity can replace traditional energy sources as well as the potential thereof.

The present paper first explores the main fields where electrification of rural energy consumption structure can be carried out, before going on to discuss the convergence of rural and urban energy consumption levels as rural-urban integration continues. Using national statistics, the present paper estimates the potential for electrification in rural domestic energy consumption in 2020, bearing significance for energy transformation and reduction of environmental pollution in rural regions.

2. Main Areas for Electrification in Rural Energy Consumption

As rural living standards improve, the number of household electrical appliances have significantly increased. Two-wheeled and three-wheeled light electrical vehicles are already in common use throughout rural regions. There is still great space for improving electrification levels in rural villages. The current structure of rural domestic energy consumption, as well as China’s current level of technology (in terms of substituting electricity for traditional sources), suggests that the main ways by which electricity can replace traditional energy sources in rural villages mainly consist of household electrification (electric cooking equipment, electric kettles), electric heating/cooling and light electric vehicles, among which electrification of the household and electric heating/cooling can allow electricity to replace natural gas and coal. The use of light electric vehicles can allow electricity to replace gasoline.

2.1. Electrification of the Household

Although electric household cooking equipment and electric water heaters are not very economical at the moment, their advantages (such as convenience and safety) mean that there is potential for further market expansion. The main types of electric cookers that can replace coal/gas/firewood stoves are induction cookers and electric stoves (which apply direct heat). The main types of electric water heating devices that can replace coal/gas heaters and provide residents with hot water are volumetric electric water heaters, tankless electric water heaters and electric chip heaters. Household cooking equipment and electric water heaters are thermally efficient, low-polluting, clean, convenient and safe. However, they are not as economical as coal and natural gas. These appliances have the potential to become more widespread in future, through increased government policy support and improvements in technology.

2.2. Electric Heating/Cooling

Comprehensive assessment of the technical and economic characteristics of various electric heating/cooling technologies, technology that can be widely applied in rural villages include stand-alone air conditioners (which can also provide heating). There are many forms of electric heating/cooling, including electric boilers, carbon crystal heating pads, electric heating cables, electric heating films, stand-alone air conditioners and heat pumps. Electric boilers incur high operating costs, which limit their use to large cities that have strict environmental codes. Carbon crystal heating pads require large upfront investments and are used only in limited quantities in schools. Electric heating cables and electric heating films are concentrated in some cities which lack access to central heating and some upper-class gated communities due to their high costs. Stand-alone air conditioners are used mainly south of the Yangtze, and not often used in the harsh winters of the north. Geothermal heat pumps (also known as ground source heat pumps) are used more widely. They absorb heat collected in the ground during the winter and use that energy to heat rooms. In the summers, they use the relatively cooler ground as a heat sink to lower condensing temperatures and increasing cooling efficiency.
2.3. Low-Speed Light Electric Vehicles

Rural residents often use two-wheel/three-wheel light electric vehicles to travel, which creates great potential for electrification. Apart from household appliances and cooking, electricity can also replace gasoline. As light electric vehicles are comfortable and charge quickly, many residents in various regions have already chosen to replace their bicycles with light electric vehicles. Currently, two-wheel/three-wheel light electric vehicles are already widely used in rural villages. As the construction of charging piles/stations speeds up, the rate at which electric cars replace traditional cars will also increase.

3. Potential for Electrification in Rural Domestic Energy Consumption

There are three main aspects to the electrification of domestic energy consumption in rural villages: (1) main domestic energy consumption; (2) other domestic energy consumption; (3) clean (non-polluting) heating. Main domestic energy consumption refers to the main durable consumer goods in rural villages as tabulated in the China Statistical Yearbook. Other domestic energy consumption refers to the remainder after deducting main domestic energy consumption from total domestic energy consumption (per Yearbook figures). Clean heating refers to electric heating during winter in northern China.

3.1. Main Domestic Energy Consumption

According to the China Statistical Yearbook (2018), durable consumer appliances for every 100 urban/rural resident households at the end of the year are as shown in Tables 1 and 2 (where the number of electric cookers, high-pressure cookers, induction cookers and lightbulbs are estimated according to 2015 figures in Research Report on Energy Consumption of Chinese Households). It can be seen that the number of durable electrical appliances (accounting for main domestic energy consumption) are increasing each year. Apart from light electric vehicles and mobile phones, urban residents have more of each type of electrical appliance. Using light electric vehicles and air conditioning in rural regions as examples, growth in recent years is as shown in Figure 1. In the urban-rural integration process, rural residents will come to use greater numbers of electrical appliances, eventually reaching urban standards.

| Indicator             | 2013 | 2014 | 2015 | 2016 | 2017 |
|-----------------------|------|------|------|------|------|
| Light Electric Vehicle| 39.0 | 42.5 | 45.8 | 49.7 | 53.1 |
| Washing Machine       | 88.4 | 90.7 | 92.3 | 94.2 | 95.7 |
| Refrigerator          | 89.2 | 91.7 | 94.0 | 96.4 | 98.0 |
| Microwave Oven        | 50.6 | 52.6 | 53.8 | 55.3 | 56.9 |
| Color Television      | 118.6| 122.0| 122.3| 122.3| 123.8|
| Air Conditioner       | 102.2| 107.4| 114.6| 123.7| 128.6|
| Water Heater          | 80.3 | 83.0 | 85.6 | 88.7 | 90.7 |
| Kitchen Hood          | 66.1 | 68.2 | 69.2 | 71.5 | 73.7 |
| Mobile Phone          | 206.1| 216.6| 223.8| 231.4| 235.4|
| Computer              | 71.5 | 76.2 | 78.5 | 80.0 | 80.8 |
**Table 2. Number of Durable Electrical Appliances Owned per 100 Rural Households at the end of the Year**

| Indicator               | 2013    | 2014    | 2015    | 2016    | 2017    |
|-------------------------|---------|---------|---------|---------|---------|
| Light Electric Vehicle  | 40.3    | 45.4    | 50.1    | 57.7    | 61.1    |
| Washing Machine         | 71.2    | 74.8    | 78.8    | 84.0    | 86.3    |
| Refrigerator            | 72.9    | 77.6    | 82.6    | 89.5    | 91.7    |
| Microwave Oven          | 14.1    | 14.7    | 15.0    | 16.1    | 17.3    |
| Colour Television       | 112.9   | 115.6   | 116.9   | 118.8   | 120.0   |
| Air Conditioner         | 29.8    | 34.2    | 38.8    | 47.6    | 52.6    |
| Water Heater            | 43.6    | 48.2    | 52.5    | 59.7    | 62.5    |
| Kitchen Hood            | 12.4    | 13.9    | 15.3    | 18.4    | 20.4    |
| Mobile Phone            | 199.5   | 215.0   | 226.1   | 240.7   | 246.1   |
| Computer                | 20.0    | 23.5    | 25.7    | 27.9    | 29.2    |
| Electric Cooker         | /       | /       | 60.8    | 65.1    | 69.6    |
| High-Pressure Cooker    | /       | /       | 11.8    | 12.6    | 13.5    |
| Induction Cooker        | /       | /       | 24.1    | 25.8    | 27.6    |
| Light Bulb              | /       | /       | 600     | 642.0   | 686.9   |

**Figure 1. Number of Light Electric Vehicles and Air Conditioners (per 100 households)**

The power (in watts) and yearly operating duration for main electrical appliances are as shown in Table 3, assuming main electrical appliance figures for rural households in 2020 will reach 2017 levels for urban residents (apart from light electric vehicles).

Annual electricity consumption by main electrical appliances = power of each appliance × annual operating duration × number of appliances per 100 households × number of rural households. It can be calculated that main domestic electricity consumption in rural villages will reach 354.1 billion kWh, an increase of 127.7 kWh.
Table 3. Typical Parameters for Domestic Electrical Appliances

| Appliance             | Power (W) | Annual Operating Duration (Hour) | Remarks                                           |
|-----------------------|-----------|---------------------------------|--------------------------------------------------|
| Light Electric Vehicle| 200       | 500                             | Based on 10 hours of charging per week            |
| Washing Machine       | 300       | 100                             | Based on 2 hours of use per week                  |
| Refrigerator          | 100       | 1800                            | Based on 10 hours of use per day during winter and summer |
| Microwave Oven        | 1000      | 180                             | Based on 0.5 hours of use per day                 |
| Color Television      | 100       | 1000                            | Based on 3 hours of use per day                   |
| Air Conditioner       | 1000      | 270                             | Based on 3 hours of use per day in summer and winter |
| Water Heater          | 1200      | 180                             | Based on 2 hours of use per day in summer and winter |
| Kitchen Hood          | 150       | 360                             | Based on 1 hour of use per day                    |
| Mobile Phone          | 5         | 1000                            | Based on charging duration of 3 hours per day     |
| Computer              | 200       | 1800                            | Based on 5 hours of use per day                   |
| Electric Cooker       | 500       | 360                             | Based on 1 hour of use per day                    |
| High-Pressure Cooker  | 1000      | 360                             | Based on 1 hour of use per day                    |
| Induction Cooker      | 2000      | 360                             | Based on 1 hour of use per day                    |
| Light Bulb            | 30        | 1800                            | Based on 5 hours of use per day                   |

3.2. Other Domestic Electricity Consumption

According to China Energy Statistical Yearbook (2018), rural domestic electricity consumption was 410.975 billion kWh. Based on the parameters for main electric appliances and the average number of domestic electrical appliances owned by every 100 rural households in 2017, it can be determined that rural main domestic electricity consumption was 223.755 billion kWh in 2017, implying that other rural domestic electricity consumption was 410.975 billion – 223.755 billion = 187.22 billion kWh. Assuming an annual growth rate of 7%, it can be estimated that other rural domestic electricity consumption in 2020 will be around 229.4 billion kWh.

3.3. Clean-Energy Heating

According to the Clean Winter Heating Plan for Northern China (2017 – 2021), winter heating is provided in 400 million km² of northern China. Combining such factors as the heating load characteristics of the covered area, environmental regulations, electrical energy resources, and grid capacity, electrical heating should be developed according to local conditions. By 2021, heating provision will cover 1.5 billion km² (1 billion km² in urban areas; 500 million km² in rural regions). Electric heating will increase electricity consumption by 1.1 billion kWh, meaning that rural electricity consumption will increase by approximately 36.7 billion kWh due to electric heating.

Considering the additional energy to be consumed by new electrical appliances, other rural domestic electricity consumption and additional energy to be consumed for clean winter heating, rural domestic energy consumption will increase by approximately 206.5 billion kWh to a total of 617.5 billion kWh, as summarized in Table 4.
Table 4. Projections for Rural Domestic Electricity Consumption in 2020

| Item                              | Amount (billion kWh) |
|-----------------------------------|----------------------|
| Main Domestic Electric Appliances | 351.4                |
| Electric Heating                  | 36.7                 |
| Other Domestic Electric Appliances| 229.4                |
| Total                             | 617.5                |

4. Conclusion

In recent years, energy supplies in rural China have become more abundant and secure. Adjustments to the energy structure have yielded significant results. However, when compared to urban regions, energy use in China’s rural villages have caused serious environmental problems, especially because energy sources that supply electricity for domestic use suffer from the drawbacks of low efficiency and high energy consumption levels. As rural incomes increase and electrification technology improves and becomes more widespread, there is great potential for increasing electrification in the rural domestic electricity sector. The present paper has analyzed the main areas where there is potential for greater electrification of rural energy consumption. In combination with statistical data and assuming the urban-rural integration trend continues, the present paper proposes that the potential for further electrification of rural domestic energy consumption bears significance for improving energy consumption in China’s rural villages.

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