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A comparative analysis of rural electrification in policy, technology and finance in the world

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Affidavit

I, **JIANG XING, BA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "A COMPARATIVE ANALYSIS OF RURAL ELECTRIFICATION IN POLICY, TECHNOLOGY AND FINANCE IN THE WORLD", 64 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

For decades, countries around the world have made all efforts to achieve the access to electricity. This study focus on why the varied success of rural electrification is caused, what the effects of different measures are, and how the policy, technology and finance factors promote the rural electrification programme. First of all, to understand how the successful implementation of rural electrification will affect a country, a comprehensive analysis on human development, economy, and ecology and environment is conducted. Further, technical approaches used to improve access to electricity are discussed. Besides, the rural electrification practice of some typical countries is studied to discover the common point of successful implementation of rural electrification programme. It is found that four aspects, including institutional, laws and regulation, funding and market level, should be integrated to promote the rural electrification development. The choice of technical approaches can be diversified, but there must be sufficient and stable policies and funds to cooperate with the implementation of technical approaches.

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List of abbreviations

AC	Alternating Current
AD	Anaerobic Digestion
AREP	Accelerated Rural Electrification Program
ARI	Acute Respiratory Infections
CERTS	Consortium for Electric Reliability Technology Solutions
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
COE	Cost of Energy
DC	Direct Current
DDG	Decentralized Distributed Generation
DDUGJY	Deendayal Upadhyaya Gram Jyoti Yojana
DISCOMs	State Power Distribution Companies
ESMAP	Energy Sector Management Assistance Programme
ESS	Energy Storage System
GDP	Gross Domestic Product
HES	Hybrid Energy System
HOMER	Hybrid Optimization Model for Electric Renewables
IEA	International Energy Agency
KJP	Kutir Jyoti Program
KNES	Kenya National Electrification Strategy
KPLC	Kenya Power and Lighting Company
kV	Kilovolt
LCOE	Levelized Cost of Electricity
MNES	Ministry for Non-Conventional Energy Sources
MNP	Minimum Needs Program
NABARD	National Bank for Agriculture and Rural Development
NPBD	National Project on Biogas Development
NPIC	National Programme on Improved Chulha

OECD	Organization for Economic Cooperation and Development
PFC	Power Finance Corporation
PM	Particle Matter
PMGY	Pradhan Mantri Gramodaya Yojana
PV	Photovoltaic
REA	Rural Electrification Authority
REC	Rural Electrification Company
REDB	Rural Electricity Distribution Backbone
REF	Rural Electrification Fund
REST	Rural Electricity Supply Technology Mission
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
RIDF	Rural Infrastructure Development Fund
SDGs	Sustainable Development Goals
SHS	Solar Home System
ST&D	Sub-Transmission & Distribution
TWh	Terawatt hour
UNPS	Uganda National Panel Survey
VEI	Village Electrification Infrastructure
VRB	Vanadium Redox Battery

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1 Introduction

1.1 State of the art

Energy, as the essential requirement of human life, has played a fundamental role in social and economic development. Within all types of energy, electricity is irreplaceable because of its unique characters from other energy sources. The discovery and application of electric power have brought considerable changes to human society, and the development of industrialization and informatization is inseparable from support by electric power. For the last decades, all efforts have been made to accelerate access to electricity around the world. The electricity access had been raised from 73% in 2000 to 89% in 2018. As shown in Figure 1, in the period from 2010 to 2018, most access-deficit countries have made progress on the access growth rate, but there are some countries that facing a challenge of slow growth (International Energy Agency et al., 2020).

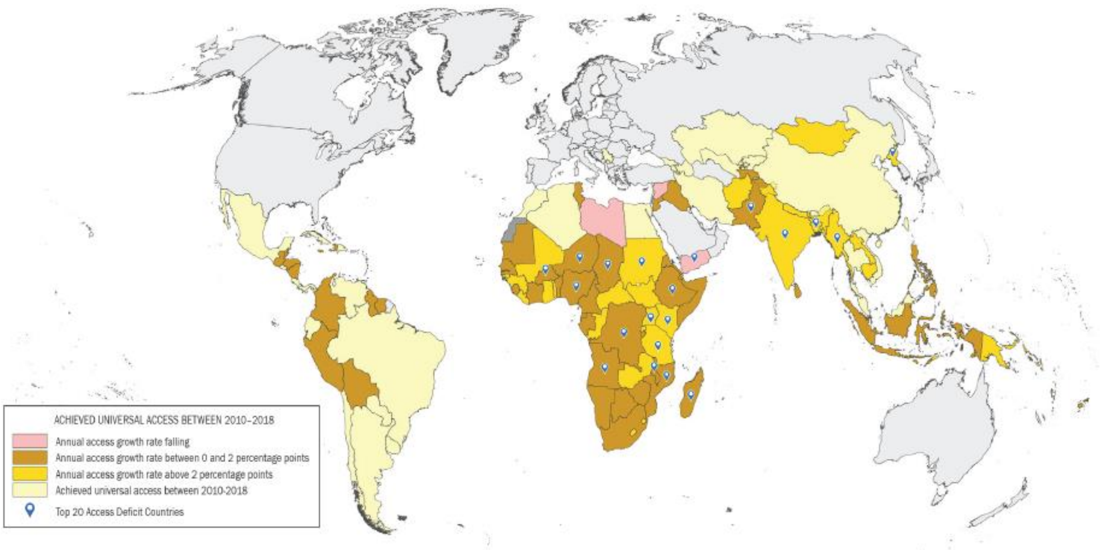

Figure 1: Annual increase in access to electricity rate in access-deficit countries, 2010-2018

In the progress that has been made, the developing countries have made plenty of contributions. Through three phases of rural electrification in China, the electrification rate has reached more than 99% during the period from 1949 to 2011(Bie and Lin 2015). One of the other countries that made distinguished achievements is India. In 2000, the proportion of the population with access to electricity was only 43%; however, after the implementation of ambitious projects by the government, this rate has climbed to 95% (International Energy Agency (IEA), 2017).

Even though there are still 860 million people around the world in 2018 that do not have access to electricity, of which 600 million are distributed in sub-Saharan Africa (IEA, 2019). According to Target 7.1 of Sustainable Development Goals (SDG), universal access to affordable, reliable and modern energy services should be ensured. In the face of enormous power demand, most of the newly formed power generation capacity is still in urban areas because of the high population density, low transmission and distribution costs, and technical, economic and political reasons for investment. Compared with urban areas, sparsely populated, remote areas far from the power grid, and low electricity consumption, especially remote rural areas with scattered residences, have less priority than urban areas. Besides, not only the access to energy but also promoting the proportion of renewable energy in the total energy supply shall be considered as a goal. Typically, there are two different approaches to access to electricity, on-gird and off-grid. Each approach has its advantages and shortages, but the best is always the most appropriate (Kaundinya, Balachandra, and Ravindranath 2009).

Considering that the population who lacks energy access, almost lives in rural areas, decentralized energy system is one of the effective and affordable solutions for them. By comparing existing approaches that have been adopted for rural electrification, this study focuses on how the differences of rural electrification are caused and what can we do for the rural electrification even the development. This paper will concentrate on the analysis of different aspects of promoting energy access, e.g., technology, finance, policy, etc., and propose recommendations for countries that are facing the same problems.

The technical approaches mentioned above have been used to provide power to the populations for gaining access to electricity. However, different countries or regions within one country made their choices based on their natural endowment and social structure.

In China, due to the centralized social organization, the government can utilize the accumulated massive social wealth to form a ‘big push on the rural electrification. Peng and Pan (2006, p83) state that “[t]he main driving force of rural electrification in China is a top-down one that relates to national macroeconomic and strategic concerns.” Relying on the strong institutional and abundant natural endowment, the Chinese government achieved the goal by investing in numerous as well as large-scale power plants and the extension of power grid. However, since this ‘top-down’ approach is unique, it is difficult for other countries to learn from, especially the countries in sub-Saharan Africa.

For most other countries, the grid connection does help to improve access to electricity. However, a decentralized energy system is adopted because of the lack of grid access, which is under restrictions of geography, financial barrier, technical barrier or even political barrier.

Under the precondition of off-grid, different power generation technologies are adopted to meet electricity demand, including wind turbine, solar photovoltaics (PV), diesel generator, biomass direct combustion power generation, biomass gasification power generation, biogas power generation with anaerobic digestion and their combinations.

Biomass-based power generation technology is widely used in many countries for its easy-to-access and renewable fuels. Mohammed et al. (2013) presents an overview of the potential of agricultural biomass-based resources for decentralized energy in rural areas of Ghana, in which either biomass direct combustion, biomass gasification or biogas obtained from an aerobic digestion are introduced to be a better option for decentralized energy system. In the case study of Suberu Mohammed et al. (2020), corn residue, as one of the biomass residues, is recommended to be used in gasifier system for electricity generation. Silva Herran and Nakata (2012) introduced an optimization energy model for decentralized energy systems, and this model utilize agricultural waste and forest biomass, leading to a reduction of supply cost by 30% and CO_2 emission by 15%.

Notwithstanding the biomass-based power generation has its benefits, Flores, Furubayashi, and Nakata (2016) argued that the transportation cost of fuel must be considered since the levelized cost of electricity (LCOE) will drop along with the increase of installed capacity. In their research, different options for rural electrification in a developing country is analyzed. From their findings, the optimal LCOE of off-grid electrification scheme is USD 0.81/kWh, which is much higher than that of grid-connected scheme. However, this result is estimated based on that solar PV for the off-grid case and wind turbines for the grid-connected cases. Besides, "[d]ue to the limitation of solar and wind resources of some area, off-grid scheme is not always applicable".

In order to improve the applicability of wind turbine and solar PV in the decentralized energy system, the hybrid system is employed. Hybrid energy systems are defined as the integration of several types of energy generation equipment such as generators, storage systems, and renewable energy sources.

In early stage, the configuration of hybrid system involves wind turbine and diesel generators. Since 1990s, solar PV-diesel combination, solar PV-wind turbine combination and solar PV-wind turbine-diesel combination became a common choice (Borges Neto et al. 2010; Ajlan, Tan, and Abdilahi 2017). Apart from the typical hybrid energy system, new type of hybrid energy system has more diverse alternatives for the energy source, e.g., biomass-based power generation, battery etc. And this benefits from the technical innovation on the bioenergy and energy storage. For example, a hybrid power system consisting of solar PV, wind turbine and biogas engine is proposed to supply the electricity demand of a village in Kenya (Sigarchian et al. 2015). And in Benin (Odou, Bhandari, and Adamou 2020) and Ethiopia (Brenna et al. 2016), the hybrid system all involves the battery system to balance the gap between consumption peak and generation peak.

Castellanos et al. (2015) introduced a more complicated hybrid system which contains solar PV, Vanadium redox battery (VRB), DC-AC converter and Combined Heat and Power (CHP) generator fueled by biogas generated in anaerobic digestion (AD). The system "had many benefits compared with the other scenarios where only one energy source was available".

1.2 Research question

This study focus on why the varied success of rural electrification is caused, what the effects of different measures are, and how the policy, technology and finance factors promote the rural electrification programme.

In the next chapter, some aspects of human development, economy, ecology and environment will be analyzed to demonstrate the impacts of rural electrification. After that, this research will try to summary the technical approaches adopted for rural electrification. Through the comparison of different technical approaches, the technical characteristics of each will be discussed and what role these technical features can play in rural electrification will be revealed. In the fourth chapter, some typical countries will be selected to explore why rural electrification in some countries or in one country for a certain period are successful while others meet limited success. c

2 Impact of rural electrification

The influence of rural electrification is multi-level and comprehensive. These influences can be divided into direct influence and indirect influence according to the scope of influence. In addition, it can also be divided into the impact on human development, the impact on the social economy, and the impact on the ecological environment according to the field of impact. These influences are closely related to each other. The increase in the rate of rural electrification will firstly exert a positive influence on households. This impact is embodied in the improvement of the quality of life of each family member, including the improvement of children's education level, the improvement of health level, and the accumulation of family wealth. These improvements are built on the improvement of public service levels. In addition to promoting human development, rural electrification can also bring benefits to the economic development of society. Modern society pays more attention to sustainable development, focusing on not putting too much pressure on the environment while the economy is being developed. We can't look at this kind of improvement in each field alone. In fact, the interaction between various fields is far beyond our expectations. For example, with the improvement of public health and education, the improvement of people’s quality of life is conducive to providing a better labor force for economic development, and in the long run, the level of labor will continue to accumulate and upgrade, which will provide enormous, qualified labor force for the development of all sectors, driving the development of economy. On the other hand, the election in rural area will bring new opportunities for industrial and commercial development to the local area, catalyze the establishment of a few related companies and enable these companies to maintain long-term development. By employing labor, the dividends of this development can be brought to every household to raise their life quality. The environmental benefits are not direct, but through the access of renewable energy, the pollution generated by traditional fossil energy is greatly replaced, and it can indeed make a huge contribution to the improvement of local environmental quality. So as to better attract business investment and promote people's health. In the following sections, the specific impact on human development, economy and environment will be discussed.

2.1 Human development

In the following section, the impact on human development by rural electrification will be analyzed for three different aspects, namely the quality of education, health, household welfare.

2.1.1 Education

The most direct case of the impact of electrification on education is that the access to electricity can enable schools or families to extend the time of education, thereby improving students' learning effects. Not only that, but the electrification of schools can also allow teachers to use computers and electronic products to improve the quality of teaching. It promotes the stability of the teaching staff as well as it can also attract more children to school.

Buyinza and Kapeller (2018) studied the impact of electrification on educational outcomes in Uganda households by analyzing the education history of school-age population (children aged from 6 to 18). Through reviewing the information collected by Uganda National Panel Survey (UNPS), the authors find out that under the electrified condition the enrolment rate of children is higher, and the dropout rate is lower. The results suggested that although there are other factors that could affect the educational outcomes in terms of enrolment and dropout rate, the impact of electrification on household education is materially strong and positive. More interestingly, the author found that this effect is much stronger in girls that boys. Besides, there are more case studies from other regions demonstrating the positive effect of rural electrification on education, e.g. Peru form Latin America (Aguirre 2017), Bhutan from Asia (Kumar and Rauniyar, 2018).

2.1.2 Health

In addition to rural electrification having a great impact on education, another important impact on human development is health issues. Like the impact on education, the impact on health is various.

From the perspective of household, rural electrification has greatly improved indoor air quality. This is mainly because it reduces the chance of family members being exposed to polluted air by replacing traditional fuels for indoor lighting or heating. Kerosene or candles used in indoor lighting can release harmful gases as well as fine particles when burning. Traditional fuels, such as biomass residues or animal manure, will produce a large amount of smoke, sulfur- and nitrogen- containing compounds when burned, which will increase the probability of family members suffering from respiratory diseases, tuberculosis, asthma, and even cancer. Barron and Torero (2014) sampled some households in Northern El Salvador, measured the concentration of indoor PM2.5. They found that the PM2.5 concentration of household with electrification is 67% lower than the ones without electrification. Furthermore, Barron and Torero (2017) found that the acute respiratory infections (ARI) in children under age of 6 is significantly reduced. It's worth pointing out here that the improvement in air quality is only due to the replacement of kerosene for illumination. The use of traditional cooking methods have not changed significantly. Karakara and Osabuohien (2020) found in their study that only after the wealth of the family increased, they would switch from dirty fuels (e.g., wood, charcoal) to clean fuels (e.g., electricity, LPG) for lighting and cooking. And this energy transition in fuel type starts with lighting and then followed with cooking. Therefore, for poor families, the effect of electrification on improving indoor air quality is mainly brought about by the change in lighting methods, rather than the change in cooking methods.

Another contribution of electrification to family health factors is to facilitate the popularization of household appliances (such as radio, television, and the Internet). An important result of the expansion of such information access channels is to increase people's access to health knowledge. The more health knowledge the people get, the healthier behaviour they will be, and eventually change the health outcomes.

From the perspective of health facilities, Javadi et al. (2020) explored the relationship between electrification for health facility and the service availability and readiness in Uganda and Ghana by examining the effect of implementation after the solar electrification project. The result demonstrates that the service availability and readiness is improved, because of the enhanced availability of medical equipment depending on electricity such as autoclaves, centrifuges, microscopes and vaccine refrigerators. Except for the infrastructure enhancement, the availability, motivation, retention and attitudes of medical practitioners is also improved by the implementation of electrification. As a result, residents also showed their increased satisfaction on health facilities in Uganda and Ghana following electrification. The electrification can help the local health facilities to overcome the obstacles in providing medical services and strengthen the health system.

2.1.3 Household welfare

Chakravorty, Pelli, and Ural Marchand (2014) studied how electrification in India affects household income, especially the specific effect of the quality of power supply. Research shows that the non-agricultural household income of rural users who were connected to the power grid between 1994 and 2005 was about 9% higher than that of the same type of household that was not connected to the power grid. In particular, it should be noted that the increase in income brought about by the improvement of power supply quality is more than that of simply connecting to the grid.

In fact, the positive effect of electrification on household income is the result of many factors. The first channel is the improvement of the education level of family members. With the improvement of education outcome, family members will not only have more opportunities to be employed, but also have the opportunity to engage in higher-paying jobs. This will help them switch from traditional agriculture to non-agricultural-related work. Moreover, the increase of information channels, such as the popularization of radio and television, will help them obtain more recruitment information. Another channel is that as health levels improve, medical expenditures will decrease, which is conducive to the accumulation of family wealth.

2.2 Economy

Energy poverty and economic poverty interact with each other. Poverty reduction depends on accelerating its industrialization process, but industrialization needs modern energy to drive. Without modern energy, it is impossible to develop productivity. Energy poverty leads to low productivity, which is the main source of economic poverty.

Generally speaking, access to electricity in rural areas has a positive role in promoting local economic development. This is because the education, health and other factors discussed above can promote an important input in economic development, that is, the promotion of human resources. With the accumulation of human capital, as the most basic unit of social economy, the firms directly enjoy the benefits of rural electrification. On the other hand, the enterprises themselves also need access to electricity to maintain their operations during the reproduction process. The above two points can improve the production efficiency of enterprises and contribute to economic development.

But if we study carefully, we will find that the contribution of electricity access to economic development needs to be considered in conjunction with the level of social development. Yeager et al. (2012) noted in their research that in some countries with relatively slow economic development, compared with labor and capital, energy plays a less important role in promoting economic development. Most of these low-income economies are dominated by agriculture, and the access to electricity does not greatly promote traditional agriculture. These economies are more faced with unreliable energy supply and lack of infrastructure.

Unreliable power services have a negative impact on the company's output. Faced with this negative impact, the measures taken by companies of different sizes are also different. Large companies have the strength to use self-generation to make up for the losses caused by power shortages, while small and medium-sized companies are facing greater pressure. Specifically, large companies can reduce pressure by enjoying more favorable electricity prices or public utility services, while small and medium-sized enterprises cannot reduce high electricity prices through the above measures. Faced with this negative impact, small and medium-sized enterprises are more often using outsourcing of energy-intensive inputs. Fisher-Vanden, Mansur, and Wang (2015) show that Chinese manufacturing companies usually outsource production to companies in regions with reliable power supplies to cope with power outages. Continued interruption will limit the expansion of industry and service industries to a very low level, which will have a negative effect on labor demand and the employment situation. The end result may be that the company relocates to other regions or ceases business for this reason. Providing reliable electricity has the potential to promote the growth of the industrial sector by increasing business access and the survival of existing companies. In addition, unreliable power supply will also affect the business environment and hinder investors' willingness to enter the market.

2.3 Ecology and Environment

Regarding the impact on ecology and environment, one view is that changes in lifestyle, such as switching from using kerosene or wood to using electricity for lighting and heating, will reduce greenhouse gas emissions and deforestation. da Silveira Bezerra et al. (2017) mentioned in the study that after the implementation of an electrification programme in Brazil, the consumption of fossil energy in the household energy consumption structure has indeed fallen sharply due to the substitution effect of electricity. However, the reduction of fossil fuel consumption in the household does not necessarily lead to the reduction of greenhouse gas emissions. We need to consider the GHG emissions that may be generated during the process of electricity generation. In the early stages of rural electrification, diesel generators were often used as a shortcut for electricity generation. In this case, the view on the benefits of climate change is not necessarily valid. Ilskog and Kjellström (2008) found in seven rural electrification areas in Eastern and Southern Africa through field surveys that two cases were powered by diesel generators, and the annual CO_2 emissions per capita were 400kg, which is relatively low even in OECD countries. However, the data does not represent the overall situation due to the lack of detailed accounting process and insufficient sample richness.

In addition, the impact on the ecosystem is also open to discussion. This involves the wood used by the family in traditional cooking. There is no necessary connection between rural electrification and the family abandoning the use of wood as cooking fuel, and the resulting protection of ecosystems, especially forests, cannot form a strong evidence relationship. According to the Household Budget Survey published by Tanzania National Bureau of Statistics (2019), in 2017-2018, although about 29% of households are connected to electricity, the main energy sources for cooking are firewood and charcoal, and households using electricity for cooking accounted for only 2.1%.

Regarding the impact of land use, da Silveira Bezerra et al. (2017) found that on the one hand, the popularization of irrigation pumps due to electrification has increased the efficiency of agricultural production, on the contrary, it has caused severe threats to local forest protection. This is because the development of agriculture has allowed more forests to be reclaimed into agricultural land. But on the other hand, because of the development of agriculture, the original graziery that poses more threats to the environment has been transformed into agriculture. Therefore, the impact due to land use is not very clear.

3 Technology utilized in rural electrification

In the previous rural electrification programme, various power generation technologies have been used to increase the ratio of access to electricity in the region, but from the perspective of the approach of access to electricity, it can be divided into extension of the grid, or off-grid approach, including stand-alone system and microgrid system. This section will carry out a comprehensive comparative analysis of these approaches.

3.1 Grid-extension

The extension of the power grid is to connect power to users (such as households, commercial users, or industrial enterprises) by continuously improving the coverage of the power grid and setting up transmission lines. Electricity comes from various types of power plants connected to the grid, such as thermal power plants, nuclear power plants, hydropower plants, wind farms, photovoltaic power plants, and so on. These power sources tend to be more inclined to areas with dense power users in site selection, and thus are farther away from rural areas. Therefore, the problem that needs to be solved by the grid extension to tackle the rural electrification is the laying of the power grid. Although the grid extension method, once implemented smoothly, will bring a stable power supply to rural areas, it will face many obstacles during the implementation process, especially in the process of solving the electrification of rural areas.

The first obstacle to face is the economic cost. The cost here includes two factors, one is the construction cost, and the other is the operating cost. On the one hand, due to the need for long-distance transmission and minimizing losses, transmission lines need to adopt higher voltage levels, which will increase the cost of transmission lines, corresponding transformer equipment as well as labor costs. In addition to the distance factor, complex terrain will also increase the cost of construction. According to the paper published by Energy Sector Management Assistance Programme (ESMAP) of World Bank, the typical per-kilometer cost of middle voltage transmission lines for grid extension to rural areas range from US $8,000 to US $10,000 (World Bank, 2000). This number may be lower in developing countries, but it may still reach about US$5,000 per kilometer. Faced with such a high construction cost, this also explains why under normal circumstances, the construction of power grids is carried out by enterprises under government. On the other hand, the method of improving rural electrification through grid extension also faces high operation and maintenance costs. Although the operation and maintenance costs will vary due to different labor costs, transmission & distribution losses caused by long-distance transmission will greatly increase the operation and maintenance costs of transmission. Regardless of construction costs or operation and maintenance costs, in addition to partial government subsidies, in order to maintain the financial viability of the project, the costs will eventually be transferred to users. Therefore, before making an investment decision, the project implementer will try to understand the relevant information of the access area to determine whether the project is feasible. This information includes the number of households and industrial or commercial users in the area (determining the number of end users and the capacity level), the distance between the area and the nearest grid access point (determining the length of the transmission line and the voltage level), and the distribution density of users (determines the scale of the distribution system). Generally speaking, the smaller the number of users, the lower the density, and the longer the distance, the lower the feasibility of using grid extension.

In addition to economic barriers, other barriers include technical barriers and institutional barriers. For example, the lack of sufficient technical personnel to maintain the built transmission lines will seriously affect the stability of the grid operation. Relevant government departments lack experience in the planning of power grid lines, which will cause adverse environmental and social impacts after the project is completed. However, by comparing with other methods to be introduced below, we can find that such obstacles are not unique to the approach of grid extension, and other approaches will also encounter similar problems.

3.2 Off-grid solutions

Except for on-grid approach, off-grid solution for rural electrification can also be adopted, where the grid extension can not be implemented due to the barriers mentioned in section 3.1. In many countries, stand-alone energy systems are used to provide electrification solutions in areas that cannot be covered by the grid. Subsequently, based on the stand-alone energy system, people considered integrating different power generation technologies as energy sources, and proposed a hybrid energy system. With the continuous development of power transmission technology, the scale benefits of interconnection have become increasingly significant. People have begun to connect various distributed systems and operate on the grid. In order to fully tap the value and benefits that distributed energy brings to the grid and users, scholars have proposed microgrid.

3.2.1 Stand-alone energy system

Different from other renewable energy power generation technologies, solar photovoltaic power generation has a natural advantage in the availability of energy, so it is taken as the preference in the early technical application of stand-alone energy system. The most typical stand-alone energy system using solar PV is the Solar Home System (SHS). Therefore, this section mainly introduces the composition, characteristics and applications of SHS. A Solar Home System consists of PV module, battery, charge controllers, DC/AC inverter and miscellaneous cables and switches (Urmee, Harries, and Holtorf, 2016).

PV module or arrays are used to convert the solar radiation into electrical energy. The charge controller works as the control unit to make sure the battery is charged and discharged under normal conditions. Battery, as the storage system of SHS, ensure the stable power supply. And DC/AC inverter is necessary when there is AC appliances connecting to the system.

The photoelectric conversion efficiency is an important indicator of solar panel, which refers to the ratio of the maximum output power of the panel when exposed to light to the power P_{in} of the incident light irradiated on the panel, expressed by the symbol η. The photoelectric conversion efficiency of a solar panel is an important parameter to measure the quality and technical level of the panel. It is related to the panel structure, junction characteristics, material properties, operating temperature, radiation damage from radioactive particles, and environmental changes. Calculations show that under the clean air condition, the upper limit value of the theoretical photoelectric conversion rate of the current silicon solar panel is about 33%; the photoelectric conversion rate of the current commercial monocrystalline silicon solar panel is generally 16% to 20 %, the photoelectric conversion rate of current commercial polysilicon solar panels is generally 15% to 18%. Before the breakthrough of new materials, the photoelectric conversion rate will not change much.

Another important component is the storage system. For SHS, battery systems are usually used in practice. An ideal battery system usually has the following characteristics: low cost, high system efficiency, low capacity loss, easy maintenance, and long lifetime. Low cost is very important for battery storage systems, which determines whether household in remote areas can afford. System efficiency determines whether the battery can make the best use of the power generated by the solar panel. The capacity loss and lifetime directly determine the service time of the battery and indirectly affect the operation and maintenance costs. In addition, it is also necessary to consider the impact of batteries on the environment during manufacturing, operation, and decommissioning (e.g., life cycle assessment). The current mainstream battery used in SHS is Lead-acid batteries because of its cheap initial cost. In addition, more and more literature mention that the use of Lithium-ion batteries has more superior performance than Lead-acid batteries. Zubi et al. (2020) concluded that Lithium-ion battery is more favorable than Lead-acid battery for SHS in many aspects, including light and compact layout, outstanding performance, reliable operation and long cycle life.

Household power consumption and usage habits greatly determine the size of the solar panel and the capacity of the battery storage system. On the one hand, due to the characteristics of the solar power generation system, that is, electricity can only be generated during the day to charge the battery; on the other hand, the peak of household electricity consumption is often at night, and the battery needs to be discharged. Therefore, SHS generally performs a charge and discharge cycle every day. Moreover, if the daytime weather is not suitable for solar panels to generate electricity and cannot provide sufficient charging power to the battery, the household can only face the power shortage. Sizing of solar home systems is very important in the process of carrying out the project. In the design stage, if more consideration is given to the user experience, the size of the solar panel and the capacity of the battery storage system will be selected with a certain margin, but on the other hand, if the affordability of the household is considered, the initial investment need to be controlled within a certain tolerable range. However, this will also hinder users' willingness to purchase new household appliances and limit the possibility of households to increase electricity consumption. Monyei, Adewumi, and Jenkins (2018) discussed the energy justice problem in the off-grid electrification process in South Africa, and proposed adopting the hybrid generation scheme to eliminate this possible dilemma, increase the user's acceptance of the rural electrification project, and ultimately improve electricity access rate.

Another issue that needs attention in deploying SHS is maintenance, and this is also a key factor in the success of the SHS business model. For many users, the difficulties they face include the technical difficulty of repairs that require professional personnel to complete. The huge repair costs will force some users to abandon repairs when the system fails. In this regard, suppliers can take a series of measures to reduce maintenance costs and improve rapid response to maintenance needs, such as increasing the number of local professional and technical personnel and formulating regular maintenance plans. In SHS, battery maintenance is a core issue. Not only is the battery the most expensive component of the entire system, but also the maintenance and recycling of a large number of lead-acid batteries after use are important to the environment and sustainable development. If not handled properly, it will cause negative effects on the local environment.

Hybrid energy system (HES) was introduced to make up for the shortcomings of SHS, especially the intermittent nature of solar PV. In addition, the system efficiency and the total amount of energy supply have a greater improvement than SHS. As illustrated in Figure 2, Hybrid energy system is composed of two or more energy sources (Sahoo, 2021). The choice of these two energy sources is diversified. It can all use renewable energy, or it can be a combination of renewable energy and traditional fossil fuel energy. For example, the more common combination method is photovoltaic power generation and wind power generation. In addition, it can also be used in combination with small hydropower, biomass power generation, and geothermal energy. Even in many cases, diesel generators are used as an energy source. Similar to SHS, Hybrid energy system also needs to be equipped with an energy storage system to comprehensively manage energy output. But for HES, there are many options, like pumped hydro storage, compressed air energy storage, fly-wheel, batteries, fuel-cell and super capacitor. More components mean more complex systems, so a management system is needed to comprehensively manage the generation, storage, and distribution of electricity.

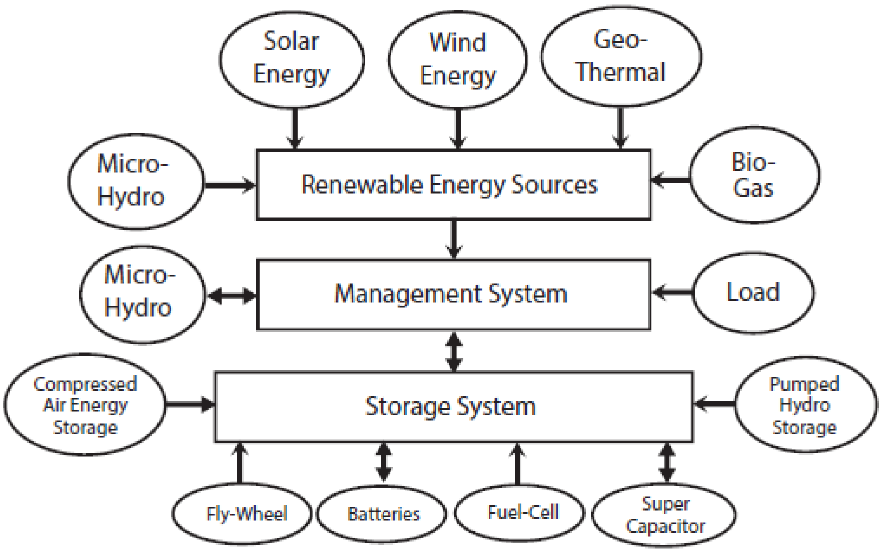

Figure 2: Hybrid renewable energy system

The purpose of this combination is mainly to form a stable and continuous power supply. Take the hybrid solar PV and wind energy system as an example, typically, the output of photovoltaic power generation is mainly during the day, while the output of wind power is mainly distributed at night. When the two are used as energy sources alone, it is difficult to meet the continuous and stable power demand of users. When the two are combined into a hybrid energy system, they form a kind of complementarity, which not only improves the reliability and stability of the system, but also spare the scale of the energy storage system, and the cost of power generation is reduced. In addition to the most common hybrid solar PV and wind energy systems, small hydropower systems are often included in HES as an energy source. The research of Mostofi and Shayeghi (2012) shows that, thanks to the lower cost than photovoltaic panels and wind turbines, incorporating with small hydroelectric power to the hybrid solar-wind system can reduce the cost of energy (COE) from USD 0.284/kWh to USD 0.261/kWh. Due to the limitation of natural resources, not all regions can have hydropower resources for development. Moreover, because the basic principle of hydroelectric power generation is to use the height of the water head, the height of the water head determines the scale and cost of the power generation equipment. Although the research of Ultra-low-head hydroelectric technology has attracted more and more attention, it is difficult to reduce costs before large-scale commercial popularization. Therefore, the popularization of hybrid energy system with micro hydropower has many limiting factors, and its generalizability is limited.

It should be noted here that in the early practical applications, a large number of projects used traditional energy as one of the energy sources and combined with renewable energy (such as photovoltaics) to form a hybrid energy system. Among them, the most commonly used technology is diesel power generation. Due to the availability of fuel, diesel power generation systems can usually make up for the shortfalls of photovoltaic power generation in terms of continuity and power supply. Therefore, in practical applications, diesel power generation systems are used as a backup power source. Although compared to HES, which is composed entirely of renewable energy (e.g., hybrid solar-wind system), hybrid solar-diesel system has certain deficiencies in environmental protection, especially greenhouse gas emissions, but under the premise of sufficient fuel, this system is indeed a technical solution that can guarantee the power supply all day long. But the biggest disadvantage of this system is also determined by its advantages. In remote areas, the cost of obtaining a continuous supply of diesel is much higher than expected. As the price of diesel increases, the COE of the project will also increase, causing difficulties for users' electrification.

However, with the addition of more energy sources, the complexity of HES also increases. If the system cannot be reasonably optimized, a series of design problems such as over-sizing are likely to occur, thereby increasing the risk of system failure. At present, a lot of software has been developed for the design, optimization and technical economic analysis of HES. These software contain some algorithms and models to simulate the HES to be used, thereby improving energy efficiency and minimizing levelized cost of energy. Sinha and Chandel (2014) conducted a review and comparative analysis of 19 Hybrid Energy System optimization software, and compared some of the software in combination with specific cases. They found that Hybrid Optimization Model for Electric Renewables (HOMER), developed by the US National Renewable Energy Laboratory is widely used in the optimization of HES, for its 'maximum combination of renewable energy systems and performs optimization and sensitivity analysis which makes it easier and faster to evaluate the many possible system configurations'.

3.2.2 Microgrid system

Since entering the 21st century, research on multi-energy complementary integrated systems containing renewable energy has shown an exponential upward trend. Microgrid technology is gradually taking shape under such a demand background. Its ideas were first described and summarized by the Consortium for Electric Reliability Technology Solutions (CERTS) in 1999 and a more complete definition was proposed in 2002 (Lasseter et al. 2002). Microgrid is considered to be an effective technical means to promote the friendly integration of distributed energy into the grid, and one of the solutions for multi-energy complementary integration and optimization.

The microgrid essentially changes the topology of the single power flow of the traditional distribution network, dividing the distributed power, energy storage, and load connected at the distribution network level into a small unit for coordinated planning, design, operation control, and protection. It can meet the energy needs of different regions from big cities to remote villages.

Although the microgrid is also a form of decentralized power supply, it is by no means a simple recurrence of the isolated system in the early development of the power system. Microgrid uses a large number of advanced modern power technologies, such as fast power electronic switches and advanced converter technology, efficient new power resources and diversified energy storage devices, etc., which the original isolated system does not have at all. In addition, the microgrid and the large power grid are an organic integration, which can be flexibly connected or disconnected, and its intelligence and flexibility are far above the original isolated system.

The microgrid has the following characteristics, as summarized by the European Smart Grids Vision (European Commission and Directorate General for Research, 2007):

1) Flexibility: While adapting to the changes and challenges of the future power grid, it can meet the diverse power needs of users.

2) Accessibility: All users can access the power grid, especially to promote the use of renewable, efficient and clean energy by users.

3) Reliability: Improve the reliability and safety of power supply to meet the power demand in the digital age.

4) Economics: Through technological innovation, effective energy management, orderly market competition and related policies, the economic benefits of the power grid will be improved.

Compared with hybrid energy system, microgrid has greater advantages in the following aspects.

1) Control system.

From the structural analysis of the microgrid, it can be seen that such a flexible operation mode and high-quality power supply service of the microgrid are inseparable from a complete stability and control system. The control problem is also a difficult problem in the research of microgrid. One of the basic technical difficulties is that there are too many micro uncontrolled power sources in the microgrid (Hartono, Budiyanto, and Setiabudy, 2013). It is difficult to require a central control point to respond quickly to the entire system and perform corresponding control. Often, once a control element in the system fails or the software fails, the entire system may be paralyzed. Therefore, microgrid control should be able to autonomously react to events in the grid based on local information. For example, for voltage drops, faults, power outages, etc., generators should use local information to automatically switch to independent operation instead of traditional approach that is dispatching by central grid.

2) Protection

The protection problems of microgrid are very different from traditional protection. Typical performances are as follows: bidirectional flow of power flow; under two working conditions of grid-connected operation and independent operation, the short-circuit current of the microgrid is different and the difference is tremendous (Brearley and Prabu, 2017). Therefore, how to respond to internal faults in the microgrid under both independent and grid-connected operating conditions, and quickly sense large grid faults in the grid-connected situation, while ensuring the selectivity, rapidity, sensitivity and reliability of protection is the key to microgrid protection.

3) Energy storage system (ESS)

Energy storage technology, as an important functional unit of the microgrid, can effectively solve the negative impact of the high proportion of renewable energy applications on the grid. It can not only be used to reduce or eliminate the mismatch between power generation and demand, but also to solve demand forecasting. The uncertainty of the power grid is of great significance to the safe operation of the microgrid, and it also provides the necessary means for shifting peaks and filling valleys, and has great application space in the microgrid. Microgrid can adopt more forms of energy storage technology, mainly including chemical energy storage (such as hydrogen storage, methane storage), electrochemical energy storage (such as flow battery, lead-acid battery, lithium ion battery), and mechanical energy storage (such as Pumped water energy storage, compressed air energy storage, flywheel energy storage), electromagnetic energy storage (such as super capacitor, superconducting magnetic energy storage), and heat storage (such as molten salt heat storage, heat storage oil), etc. (Sahoo 2021).

The microgrid is affected by the randomness, intermittentness, and uncertainty of renewable energy in the system. The system usually needs to cut off the connection with the grid when the system fails. All above will inevitably lead to the demand for reasonable planning and integrated utilization of the energy storage system and renewable energy sources to achieve the purpose of improving the reliability of the power supply of the system. The functions that the energy storage system contributes to the operation of the microgrid include (Rohit and Rangnekar, 2017):

1) Maintain the stable operation of the microgrid. When there are power quality problems or a grid failure caused by the intermittent energy source in the microgrid, the energy storage device can provide users with short-term backup energy to match the predicted output value, so that the intermittent energy source can be used as a dispatchable energy source;

2) Participate in frequency regulation. Ensure that the energy output and demand of the microgrid reach a balance;

3) Participate in load shifting. When the total output of distributed energy in the microgrid is greater than the load demand, the energy storage system can store the surplus energy to avoid energy waste; when the total output of the distributed energy in the microgrid is less than the load demand, the energy storage system can release the stored energy, eliminate or reduce the energy shortage, improve the power supply capacity of the microgrid, and play the role of system peak regulation.

In addition, the optimal configuration of the energy storage system, especially the scale design, also has an important impact on the construction investment and long-term operation of the microgrid system. A reasonable energy storage size design can effectively improve the operating cost of the microgrid system.

3.3 Summary

At present, the gradual completion of rural electrification through the expansion of the power grid is still the mainstream technical route. However, in many areas, because the villages that require electrification are too remote, the existing technical means are difficult to overcome the geographical difficulties, or the investment in the project cost is not proportional to the social, economic and environmental benefits, which makes it difficult to achieve full coverage of electrification by only relying on grid extension. This requires off-grid solution as an effective supplement. Generally speaking, the investment costs of various technical routes used in rural electrification projects have different characteristics. For off-grid, especially standalone system, the increase in the number of users will not affect the average investment cost, that is, for each additional household, the increased investment is fixed. But for grid extension, even microgrid, the increase in the number of users reflects the effect of diminishing marginal costs. In other words, for unelectrified users in a region, under the condition that the number of users is increasing, the overall cost of adopting the stand-alone system (e.g., SHS) is at a certain point higher than the overall cost of grid extension.

Although from a technical point of view, microgrid is more flexible than grid extension, more reliable and more accessible than SHS, the popularization of microgrid still requires the further development of various technologies, such as energy storage and control systems.

A point that needs to be specifically put forward here is that a technical approach is only a tool used by people. Although the technologies are different and have their own strengths and weaknesses, it is more important to select the appropriate technical approach according to the actual situation. In addition, the same technical method is very effective in some countries, but it is difficult to succeed in other countries. This is because in addition to the technical route, there are other key factors that can affect the success of rural electrification. This is what we will discuss in the next chapter, which is the impact from policy and financing.

4 Path to Rural Electrification: Gains and losses in rural electrification

In this chapter, we will select a few typical countries, review their specific situations in the process of rural electrification, and analyze them. There are two purposes for this. One is to summarize the convergence of policies in different countries by looking for common factors or elements; the other is to try to discover the different types of policies adopted by the same country in different periods and the effects of these policies.

The first country we selected is China. China's development results are obvious to all. Since the 1980s, China's GDP growth rate has been maintained at about 10%. Economic development cannot be separated from the support of energy, and the popularization of electricity has always played an important role.

The second typical country is India. As an emerging economy, India has also made a qualitative leap in economic development during the past 20 years. Especially since entering the new century, India has achieved success in increasing its access to electricity rate from about 60% to more than 90% in less than 20 years.

Currently, the countries facing huge challenges in rural electrification are mainly concentrated in sub-Saharan Africa. Kenya, as a leading country in the region's economy, has also achieved impressive results in rural electrification. The study of Kenya will help provide useful references for other countries in the same region.

Some basic information about the three selected countries is listed in Table 1 below (World Bank, 2021). We can see that no matter geographical location, population, land area or degree of economic development, these three countries all have certain heterogeneity. By comparing these three different countries, it is more conducive to extract the same characteristics of different countries in the seeking rural electrification process.

Table 1 Basic information of China, India and Kenya in 2019

Country	China	India	Kenya
Location	East-Asia	South-Asia	Sub-Saharan Africa
Population (Billion)	1.398	1.366	0.053

Surface area (aq. km)	9,600,013	3,287,259	580,370
GDP per capita (current USD)	10,216.63	2,099.60	1,816.55
Access to electricity (% of population)	100%	97.82%	69.70%
Access to electricity, urban (% of urban population)	100%	100%	90.80%
Access to electricity, rural (% of rural population)	100%	96.67%	61.69%

(Data source: World Bank)

Through reviewing the open data from World Bank, Figure 3 is drawn to show the variation of population access to electricity of total, urban and rural area in the three typical countries for the last two decades (World Bank, 2021). Combined with the specific analysis in this chapter, we can better understand the specific policies, gains and losses of these three countries at different periods in the process of universal electrification.

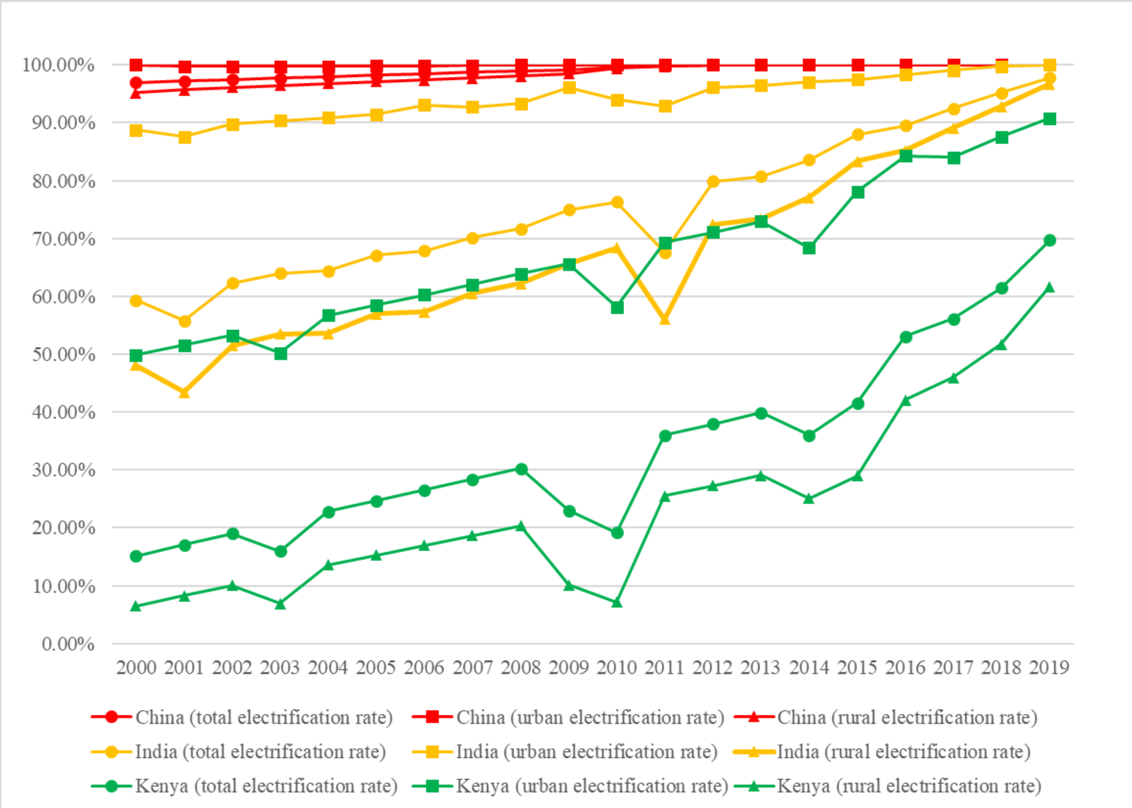

Figure 3 Percentage of total, urban and rural population access to electricity in China, India and Kenya, 2000-2019

(Data source: World Bank)

4.1 China

The evolution of rural electrification in China has mainly gone through five stages. The main purpose is to use electricity extensively in agriculture and rural economic sectors, as well as rural residents' production and life. On the one hand to solve the problem at the source, that is, to continuously expand power production, on the other hand, to strengthen the construction of rural power grids, and to continuously increase the coverage of the distribution network, and to better coordinate and solve various problems in rural electrification by formulating and improving the rural power institutions. Since the Chinese government began to pay attention to the improvement of rural electrification in the early days, grid extension has been regarded as the main technical route.

Regarding the different stages of the development of rural electrification in China, many researchers have their own understandings (Bhattacharyya and Ohiare 2012) (Wu 2020) (Ding, Qin, and Shi 2018), after combining these arguments, I would like to divide the development process of China's rural electrification into the following stages with my understanding.

The first stage was from 1949 to 1978, and the main result was to lay a solid foundation for the subsequent rapid development. In the early days of the founding of the People's Republic of China, rural electricity mainly used local energy in rural areas, and farmers built small hydropower stations, mainly used for lighting, agricultural irrigation, and simple processing of agricultural and sideline products (such as grain mills). During this period, the management of rural electric power lacked a unified department, but was handed over to various local governments, and the operation was in a state of decentralization. In 1958, the Ministry of Agriculture convened the National Rural Hydropower Conference and proposed to select 5 counties and 100 communes in a province as pilot projects to implement preliminary rural electrification construction, and continue to develop (Peng and Pan, 2006). Nearly ten years after the founding of New China, investment in rural power was mainly raised by local governments. After that, the central government put forward the national economic development policy of "agriculture-based and industry-led". The construction of electric drainage and irrigation stations to solve agricultural electricity demand became an important measure to develop agriculture and increase grain and cotton production. In 1963, the central government approved the establishment of the Rural Electrification Bureau by the then Ministry of Water Resources and Electric Power (Luo and Guo 2013). The power supply of the state grid company began to extend from the suburbs of large cities to commodity grain production areas. Rural power supply focused on commodity grain and cotton production, utilizing electricity from power grids as the main source to supply electricity to the drainage and irrigation center. The power grid and rural small power stations (mainly small hydropower stations) developed simultaneously. In 1978, the country's rural electricity consumption reached 27.5 TWh, accounting for 13.3% of the country's total electricity consumption (Peng and Pan, 2006). These is progress on rural electrification, but the progress is slow.

The second stage is from 1978 to 1987. The characteristic of this period is that electrification is slowly getting on the right track. After the Third Plenary Session of the Eleventh Central Committee of the Communist Party of China, China has moved towards a development track centered on economic construction, and rural electrification construction has become increasingly important. The central government's focus on rural power development is to systematically implement rural electrification. In 1983, the State Council approved the establishment of 100 rural electrification counties, and the central government provided 100 million Yuan in support each year (Peng and Pan, 2006). At this stage, electricity management stations were established at the town and village levels, and rural electrification was expanded from counties to towns and villages. At the end of 1987, the annual electricity consumption in rural areas reached 65.9 TWh (National Bureau of Statistics of People's Republic of China, 1988).

The third stage was from 1988 to 1997. During this decade, rural electrification developed rapidly. At this stage, the gradual liberalization and decentralization of energy policies allowed local investment to enter the emerging power generation market, which accelerated the development of electrification in rural areas. The state-owned power sector has implemented some measures to achieve rural electrification, starting with towns around the county seat, and then expanding to remote areas. The county government, like other investors, began to build its own power generation and distribution facilities to supply electricity to local users. In 1991, the State Council approved the construction of the second batch of 200 rural hydropower primary electrification counties, and decided to arrange 200 million Yuan of financial investment every year (Luo and Guo 2013). The central government guaranteed the need for rural hydropower primary electrification construction in terms of funds. In 1992, due to the country's lack of electricity, the rural, agricultural and peasant's daily use of electricity could not be guaranteed. The state promptly proposed "Ensure seasonal electricity consumption for agricultural production, and ensure that farmers' living lighting electricity for a few hours at night." In 1994, the state proposed the "Eight-Seven Poverty Alleviation Plan" (it will take 7 years to solve the problem of poverty alleviation of 80 million poor people). According to the overall deployment of the State Council, the power system proposed the "Poverty alleviation and common prosperity program through improving electricity accessibility" (Luo and Guo 2013). Within 7 years, 28 counties without electricity will be eliminated, and 95% of rural households in the country will have access to electricity. In areas with more developed rural economy, efforts will be made to increase the level of electricity consumption and better meet the requirements of rural economic development. More than one year after the project was implemented, 24 provinces (cities, autonomous regions) have realized "village electricity" in administrative villages, and solved the electricity problem of nearly 60 million farmers. Shandong Province took the lead in realizing household electricity in the country. At the end of 1997, the area where rural households had electricity reached 95.9%, and the proportion of rural electricity consumption in the country's total electricity consumption rose to 33%. At the same time, the rural power management system has been gradually strengthened and improved, and a six-level management system with the country, large regions (such as North China and East China), provinces, cities, counties, and townships as the main framework has been formed throughout the country. Before June 1998, there were about 2,400 power supply companies in counties across the country, of which 760 companies were directly managed by the central power department and directly supplied power; 1,040 companies were owned by local governments and were supplied by batches of provincial power companies; the remaining 600 This enterprise is a local self-built, self-managed, self-supplied, small hydropower-based power supply enterprise. The investment and construction of rural electrification at this stage are mainly local construction, and the policy goal is to solve the problem of electricity consumption by households without electricity and rural electricity supply.

The fourth stage is from 1998 to 2002, rural electrification has been further developed. In May 1998, in order to cope with the Asian financial crisis, expand domestic demand, and stimulate economic growth, the State Council decided to increase six infrastructures (agriculture, forestry and water conservancy, transportation and communication, urban infrastructure, urban and rural power grid construction and transformation, centrally-owned grain reserve, economic Applicable housing) investment, rural power grid construction and transformation projects are one of them (Luo and Guo 2013). In October 1998, the State Council issued a new document to drive the rural electricity institutional reforming, aiming to realize the unique tariff under the same power grid no matter it is located in urban or rural areas (Peng and Pan, 2006). In the financing source of the rural power grid renovation project, 20 % will be raised by the national debt issued by the central government; 80 % will be solved by bank loans (Niez 2010). The central enterprises as the main body of loans, repay the principal and interest by adding two cents to the electricity tariff. In order to adapt to the transition from subsistence to well-off in rural areas, the rural electrification county construction policy has played a positive role in promoting. The State Council agreed that the two power grid companies are responsible for organizing and implementing the construction of electrified counties in their power supply areas. By the end of 1998, 500 electrified counties were built in the power supply areas of the large power grids, which strongly promoted the development of rural power industry. From August 1998 to 2002, China carried out two phases of transformation of rural power grids, which constituted the core and focus of rural electrification during this period. Since then, the main source of funds for China’s rural power grid construction has completely changed the situation of relying on local investment. National policy support and loans from power grid companies have become the main channels. This has basically solved the long-term problem of insufficient funding for rural power grid development and marked the rural A major strategic change in the power development model.

In 2003, in order to improve the operating conditions of the county power grid, enhance the power supply capacity and reliability of the county power grid, and better meet the needs of the increase in power consumption in the county, the state issued a fixed asset investment plan for the construction and transformation of the county power grid. The National Development and Reform Commission issued a notice on fixed assets investment plan for county level power grid construction and renovation project, which greatly solve the problem of the shortage of funds for the construction and renovation of urban and rural power grids, and indicate the source of these funds. At the end of 2004, in order to solve the problem of insufficient coverage of rural power grid transformation in the central and western regions, the state started the improvement project of the western rural power grid, which was expanded to the central region in 2006. In 2010, the first document of the central government proposed that “we must promptly implement a new round of rural power grid renovation and upgrading projects to improve the reliability and power supply capacity of rural power grids”.

With the changes in the rural economic situation and rural policies, the rural power development policy environment has also changed. The rural power development policy gradually adapts to the former's changes from not adapting to the former. Taking the "rural power grid transformation, rural electricity institutional reform, and same tariff for urban and rural area" achieved in 1998 as a watershed, rural power investment entities, funding sources, development policy objectives and measures have undergone qualitative changes, from building a new countryside to urban and rural coordinated development, rural power development policies are changing towards breaking the urban-rural dual structure and achieving coordinated development.

Before 1998, the development of rural power grids mainly obtained funding from subsidies and other electricity surcharges. With the introduction of a new goal in 1983, namely the establishment of 100 rural electrification counties, a series of policy recommendations were put forward. On 1/2 of China's land area, within 2/3 of the counties, with a population of nearly 800 million, and the foundation for the development and utilization of local resources in the rural areas, the central government provides policy support in terms of loans and taxes. Entities are organized with counties as units, and the principle of "utilize revenue from the sale of electricity to reinvested in power infrastructure construction" is adopted to develop rural electrification. Electricity consumption at and below the county level nationwide increased from 24.2 TWh in 1978 to 459.9 TWh in 1998. In 20 years, rural electricity consumption has increased by 19 times.

Rural power is a product of a dual structure, and its development is deeply imprinted by the planning system. Unlike urban power grids that are invested and constructed by the government, rural power grids (also include power supply construction, such as small thermal power, small hydropower, etc. in some places) are invested and constructed by farmers and rural collective economic organizations self-raised funds. During this period, China's rural power grid development was characterized by self-construction, self-management, and self-use. The main sources of rural grid construction funding were contributed partly by farmers, partly by collective economic organizations, and partly by the central government (water conservancy departments, power departments). There is a lack of financing channels and reliable sources such as banks for rural grid construction, and there is no unified plan for grid development.

After 1998, the state has implemented new policies and measures, and established a rural power development mechanism that relies on the central government's capital construction investment and power grid companies' investment. The main policy measures for rural power development mainly include:

1) Rural power grid fund loan repayment policy. In order to solve the problem of repayment of principal and interest of rural power grid loan funds, the source of capital

will be solved by adding a price increase (0.02 Yuan per kWh) to the sales price of electricity. For the subsequent implementation of the rural power grid improvement project in the central and western regions, and the rural power grid construction project in areas without electricity access, the state stipulates that the rural power grid loan repayment policy can be continued.

2) The policy of transferring investment from loan to financial appropriations. The capital invested in China's first and second phases of rural power grid construction and renovation projects is jointly borne by the central and local governments and invested in the form of discounted loans. In order to support the development of rural power grids in the western region, the central government has decided to change part of the central and local loan in the western region to financial appropriations, which has greatly improved the funding situation of power grid companies.

3) Low-voltage maintenance fee policy for rural power grids. Historically, China's rural low-voltage power assets are composed of state-owned assets, collective assets, and households' assets. The maintenance costs incurred are proportionally borne separately by power supply companies, local power management stations, and asset owners. In order to solve the normal maintenance of low-voltage power grid assets and personnel salaries by power supply companies, the central government has issued policies that require the maintenance fees of rural low-voltage power grids to be charged from the local low-voltage sales price. Changes in maintenance costs have effectively ensured the maintenance and normal operation of rural power grids. The above series of policies have solved the problem of insufficient funds that have plagued the development of rural power grids for a long time, and have provided a solid foundation for the transformation of rural power grid development models.

Since the reform and opening up of China, the level of rural electrification has been increasing. In particular, the new round of rural power grid transformation and upgrading programme has been successfully implemented since the "13th Five-Year Plan". While improving the power supply capacity of rural power grids, it has also improved the development of local agriculture and released rural electricity demand. The level of rural electric power equipment and the electrification of agricultural production in rural areas have also been continuously improved. In some areas, the energy transformation in the fields of catering, accommodation, and transportation have also been promoted, which greatly reducing the use of traditional fossil fuels as coal and diesel, and reducing emissions.

Although rural electrification in China has strongly promoted the rapid development of the rural economy, markedly improved the living standards of rural residents and contributed to battle against poverty, there is still a big gap between the overall level of rural electrification and the urban electrification, and some problems still need to be solved.

The first problem that needs to be solved is the lack of overall planning at the national level. At present, there are still gaps in the guiding policies and documents for rural electrification at the national level. Rural electrification is a systematic project involving the participation of the whole society, which requires overall consideration of rural economic and social development at the national strategic level. For example, part of the rural electrification construction process did not closely cooperate with the implementation of the local new rural construction and rural revitalization strategies, resulting in the failure of the rural power grid site selection plan to be integrated with the long-term planning of the new rural area, and blind investment for the purpose of completing tasks and disorderly construction.

The second problem is the unbalanced and insufficient development of the rural network. The development of China's rural power grid is still relatively lagging, especially the rural power grids in the central and western regions have many shortcomings, poor power supply reliability, and lack of power supply capacity. However, rural development has increasingly higher requirements for power supply capacity and quality. During the "13th Five-Year Plan" period, the State Grid Corporation of China plans to invest 635.4 billion Yuan in rural power grids, and there is a large funding gap.

The third is the large scale of investment in rural power grid projects, less new electricity, high operating costs and low economic benefits. With the in-depth promotion of the rural revitalization strategy, the development of new industries, new formats, and new models such as rural energy revolution, clean heating, e-commerce, etc. has accelerated, and the requirements for power supply capacity and power supply reliability have become higher and higher. The task of speeding up the transformation and development of rural power grid remains very difficult. The input and output levels of rural power grids in the central and western regions are far lower than those in the eastern regions, and the sustainable development of the power grid cannot be maintained only by the existing transmission and distribution prices and sales of electricity. For example, some "coal-to-electricity" areas have far higher requirements on the power supply capacity per household than the average level of rural power grids, and the upgrading of supporting power grids is imminent.

The fourth is the lack of a long-term mechanism for sustainable development of rural electrification. When the universal power service mechanism is in urgent need of improvement, power grid companies have undertaken a large number of rural power grid construction tasks with obvious social welfare and public welfare characteristics, such as power supply for pumped wells, power supply for villages, etc. The construction investment is large, the operation and maintenance cost are high, and the cost of operation and maintenance is high. The income is low, and there is still a large investment demand in the future, which will have a greater impact on the operation of the power grid, and it is also not conducive to the overall development of rural electrification in China.

4.2 India

Since India's independence, successive governments have been working hard to improve the degree of rural electrification. As in other countries, the main goals of rural electrification in the early stage are two: one is to provide electricity to rural household users to improve their quality of life; the other is to provide sufficient power guarantee for agricultural production (such as irrigation systems), and as much as possible to increase agricultural production. During the early first three five-year plans, although specific goals were set for rural access to the grid, the final results failed to achieve the goal. During the subsequent Fourth Five-Year Plan period, the government proposed a target-based approach of rural electrification, focusing on powering irrigation pumps for agricultural production and powering villages with more than 5,000 people. It is worth mentioning that in 1969, REC (Rural Electrification Company) was established, aiming at financing rural electrification schemes and the promotion of rural electricity co-operatives, focusing on solving the problem of funding sources in rural electrification. With the continuous development of the company, its functions have become more and more diversified, including the issuance of special bonds, the management of government funding, the provision of project consultation, and project development. In the 1980s, Sixth and Seventh Five Year Plan periods, a series of rural energy plans were introduced, such as the National Programme on Improved Chulha (NPIC) dedicated to the promotion of improved cooking devices and the National Project on Biogas Development (NPBD), which popularized family type biogas plants. Entering the 90s, Ministry for Non-Conventional Energy Sources (MNES) was formally established in 1992, and rural electrification entered a new era of development. The rural power development under the responsibility of REC and MNES is accompanied by the formulation and implementation of a series of schemes, gradually increasing the rural electrification rate.

In India's rural electrification plan, the launch of the 'Rajiv Gandhi Grameen Vidyutikaran Yojana' (RGGVY) in 2005 can be used as a watershed. Before and after that, there is a big difference in rural power development.

Prior to 2005, the rural electrification related plans were in a relatively dispersed state, lacking an overall plan, the focus of each plan was different, there was no mutual connection in the implementation, and the actual implementation effect was different (Samanta, 2015).

Pradhan Mantri Gramodaya Yojana (PMGY)

PMGY was started in 2000 and is coordinated and supervised by the Rural Development Division of the Planning Commission. The main content is based on additional financial assistance to provide funds for the construction of basic infrastructures in rural areas such as medical care, education, drinking water, and electrification. The source of funding is 90% of bank loans and 10% of government grants, totaling INR16 billion. However, since electrification is only one of the uses of funds, and local governments can flexibly adjust the proportions of various parts, the funds allocated to electrification in the specific implementation are not clear.

Kutir Jyoti Program (KJP)

KJP was launched in 1988 to provide lighting facilities (60W) for Below Poverty Line (BPL) households. It plans to provide 6 million households with a one-time fee including wiring at a rate of about 400,000 households per year during 15 years. The plan was included in the "Accelerated Electrification of one lakh villages and one crore Households" plan in 2004, and was finally included in RGGVY.

Minimum Needs Program (MNP)

MNP is a loan assistance program that plans to provide 100% loans to those states whose rural electrification rate is less than 65% to solve the last mile problem. The plan was terminated in 2005.

Accelerated Rural Electrification Program (AREP)

For local governments and power facilities involving rural electrification projects that obtain loans from Rural Electrification Corporation (REC), Power Finance Corporation (PFC) and from NABARD under the Rural Infrastructure Development Fund (RIDF), AREP can provide an interest subsidy of 4 for them %.

Rural Electricity Supply Technology Mission (REST)

REST was initiated in 2002, focusing on rural electrification projects utilizing local renewable energy sources and decentralized technologies. It has now been incorporated into RGGVY.

The Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) scheme was launched in February 2005 by the Ministry of Power. The scheme not only included the existing plans, but also proposed a quite ambitious target, setting up the following objectives: 1) 100% electrification of all villages and habitations in the country; 2) Electricity access to all households; 3) Free of cost electricity connection to BPL (Below Poverty Line) households. Under the RGGVY, projects would be financed for provision of the following systems: 1) A Rural Electricity Distribution Backbone (REDB) with 33/11 kV (or 66/11 kV) sub-station of adequate capacity in every block where none exists; 2) Village Electrification Infrastructure (VEI) with provision of distribution transformer of appropriate capacity in villages/habitations; and 3) Decentralized Distributed Generation (DDG) systems based on conventional sources where grid supply is not feasible or cost-effective (Niez 2010). The proposal of RGGVY marks a huge change in the route of rural electrification in India. The most important sign is the introduction of Decentralized Distributed Generation systems. In the past practice of rural electrification, it is difficult to completely cover all villages and families by relying on grid extension alone. For many reasons, areas where the power grid cannot be extended, and areas where even if it can be extended but will face huge costs, cannot get access to electricity. As an effective supplement, Decentralized Distributed Generation can greatly make up for this deficiency. The DDG system here is defined as stand-alone systems power by renewable energy sources or conventional sources. In actual project implementation, a variety of renewable energy technologies are applied, including generators based on biofuels and biomass gasification, solar photovoltaic, wind power, small hydropower plant and their hybrid systems. It is worth mentioning that although diesel generators are also included in DDG, they are usually used as backup power sources to minimize possible environmental pollution.

Through the implementation of RGGVY, rural electrification has made great progress and has brought various benefits to the rural areas of India. First of all, 96% of the villages that were previously not connected to electricity have been electrified, and 77% of households below the poverty line have received free electricity access. Secondly, with the access to electricity, the use of various household appliances (including lighting, electric fans, TVs, and mobile phones) has also begun to spread, improving the quality of life of the people. In addition, due to the large-scale installation of street lights, the safety of rural areas has been guaranteed, and crimes such as attacks by wild animals and robberies have also been improved. In particular, children can have more time to learn, and they can gain more knowledge through the popularization of electronic products.

In December 2014, Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) was launched to subsume RGGVY, in response to the problems found during the implementation of RGGVY and further promoting the rural electrification development.

Components of DDUGJY include (Ministry of Power, 2014):

1) Separation of agriculture and non-agriculture feeders facilitating judicious rostering of supply to agricultural & non-agricultural consumers in the rural areas;

2) Strengthening and augmentation of sub-transmission & distribution (ST&D) infrastructure in rural areas, including metering at distribution transformers, feeders and consumers end;

3) Rural electrification for completion of the targets laid down under RGGVY for 12th and 13th Plans by subsuming RGGVY in DDUGJY and carrying forward the approved outlay for RGGVY to DDUGJY.

First of all, as the successor of RGGVY, one of the main tasks of DDUGJY is to continue rural electrification to ensure the smooth realization of the goal of electrification in every village. In addition, on the basis of the implementation of RGGVY, the quality and reliability of power supply will be further improved, and the basic lighting power consumption will be improved to better guarantee the household power consumption. This requires the upgrading of the existing rural power grids, especially the upgrade of the distribution system. In addition, due to the limitation of power supply capacity, it is currently unable to fully meet all rural power needs. Therefore, an important goal of DDUGJY is to distinguish between agricultural users and non-agricultural users. This is to ensure that agricultural users are given priority to supply power and protect agriculture for the improvement of farmers' quality of life and the development of agricultural production.

In addition, Pradhan Mantri Sahaj Bijli Har Ghar Yojana - "Saubhagya" is a scheme to ensure electrification of all willing households in the country in rural as well as urban areas. The objective of the 'Saubhagya' is to provide energy access to all by last mile connectivity and electricity connections to all remaining un-electrified households in rural as well as urban areas to achieve universal household electrification in the country (Ministry of Power, 2017).

Since RGGVY, the rural electrification scheme in India all have some common characteristics. Rural Electrification Corporation Limited (REC) is assigned as the nodal agency for implementation of the schemes and the funding mechanism is quite clear compared to the formal schemes.

As the Nodal Agency for operationalization and implementation of the scheme, REC is responsible for all matters of rural electrification projects and enjoys great authorization, including release of guidance, appraisal of project reports, grant management, quality monitoring etc. The biggest advantage of this is that the management of the project from the pre-planning to the post-implementation monitoring can maintain consistency, and there will be no increase in management costs due to changes in the management institute, and will not lead to increasing time costs due to multi-departmental management.

Both DDUGJY and Saubhagya have formulated detailed funding mechanisms, which are conducive to providing guarantee for the funds needed in the project implementation process. Specifically, the fund raising is done by all parties including the government. Other fund sources include the state power distribution companies (DISCOMs) and bank loans.

4.3 Kenya

The early rural electrification programme progress in Kenya is relatively slow, although related work has started since the 1960s. In 1967, East African Power and Lighting Company, which is the predecessor of Kenya Power and Lighting Company (KPLC), began to draw a certain percentage of annual sales to invest in rural electrification (de Gouvello, 2006). This is also a common situation in the early stages of various countries, not only lacking a designated organization, but also investing very little money. In 1973, with the support of Sweden, the Kenyan government formed the Rural Electrification Fund (REF) to provide funds for the rural electrification program. Subsequently, KPLC was appointed as the management function of the rural electrification scheme (de Gouvello, 2006). However, due to the lack of relevant technical level, management ability and sufficient financial support, the progress of rural electrification in a long period of time was not as expected. Moreover, because KPLC is mainly responsible for the electricity distribution business, the country's overall systemic rural electrification planning ability is insufficient, making it only within the scope of its main business (that is, through the grid extension approach) to increase the energy access rate. However, as we analyzed in Chapter 3, due to technical and economic constraints, relying on grid extension alone can achieve full coverage.

In addition to the institutional level issue, another issue that hinders the rapid deployment of the rural electrification project comes from the funding level. The financial pressure comes from two aspects, one is investment, and the other is operation and maintenance costs. From the 1970s to the beginning of the 21st century, Kenya’s sources of funds for rural electrification were mainly REF and grants from foreign governments (de Gouvello, 2006). Due to policy-oriented reasons, the proportion of revenue from electricity sales accounted for the entire proportion of funding sources is small. The result of this situation is that the progress of rural electricity expansion is determined entirely by the amount of external funds. When more external financial support is obtained, the project may advance faster, but once the external donors are reduced, the rural electrification project will be difficult to continue to expand. On the other hand, due to high operation and maintenance costs, it cannot be covered by electricity prices, which further reduces the funds that could be used for investment projects.

The Rural Electrification Authority (REA) was established in 2006 for purposes of enhancing rural electrification in Kenya. This can be regarded as an important landmark event in the reform of the Kenya electricity sector. The management function of REF was transferred from the previous KPLC to REA, which straightened out the relationship between funding management and helped to give greater play to the role of REF in the rural electrification project. Not only that, the establishment of REA helps Kenya have more exploration in the technical route of rural electrification, and off-grid project is also valued as a new solution in addition to grid extension.

In 2008, the Kenyan government launched Kenya Vision 2030, planning to promote reforms and development on the three pillars of economic, social and political, aiming to make Kenya a "newly industrializing, middle-income country providing a high quality of life to all its citizens by" 2030 in a clean and secure environment (Government of the Republic of Kenya, 2007). Economic development is closely related to the upgrading of power energy structure. The most important thing is the achievement of universal access to electricity, and on this basis, the quality of electricity supply is continuously improved. Initially, universal access to electricity was planned to be reached in 2030. However, in 2013, the Kenyan government decided to speed up this process and moved the deadline to 2022. Then in 2014, the Kenya National Electrification Strategy (KNES) was developed by the government to deal with the existing challenges and possible risks. KNES includes a series of measures to solve the problems that have plagued Kenya's rural electrification implementation for many years, and hopes to remove obstacles on the road to universal access to electricity (World Bank, 2019).

Under the framework of Kenya National Electrification Strategy, a series of disruptive measures were used to increase the electricity access rate. These measures worked together and achieved great results. According to the data of Kenya Power and Lighting Company (KPLC), from 2009 to 2016, the annual growth rate of new users maintained an average rate of 22%, and the total number of users far exceeded the total number of users in the past 30 years (World Bank, 2019). In addition to the increase in connected users, the Kenyan government also pays attention to the improvement of power generation capacity, and pays attention to the proportion of renewable energy in the new generation capacity while increasing the capacity. They build and operate various types of renewable energy power plants by introducing private investors, including geothermal power plants, small hydropower plants, wind power plants, and photovoltaic power plants. The role of the increase in power generation capacity for the increase in electricity access is reflected in not only improving the power shortage problem that has existed for a long time, but also providing protection for the increase in power demand that may occur in the future.

The increase in access to electricity in Kenya in recent years has benefited from the following measures taken at the technical, policy and financial levels (World Bank, 2019).

At the technical level, in addition to grid extension, more diverse technical routes are adopted. The diversification of technical routes has reduced the cost of the implementation of the rural electrification project and further increased the success rate of the project's implementation. Specifically, the existing power transmission and distribution network is expanded on the basis of the 15km limit, and within the limit, the grid extension method is adopted to connect these users to the power grid to provide them with stable power supply; outside the limit, use the microgrid solution. In addition, for areas that have been connected to the existing power grid, the grid densification and intensification method is used to enable users who have not been connected to the power grid to have the opportunity to access, making the coverage of the power grid denser. On the basis of the above two different schemes, standalone solar home systems are used to further supplement the areas without power coverage. The method of overall planning of these different technical routes is completed by the creative geospatial planning platform. The original intention of the Geospatial planning platform was to collect information (including satellite imagery, census data, etc.) to comprehensively analyze different technical route choices in different regions, and to provide suggestions to decision-making departments.

At the institutional level, Kenya has established an institutional structure with a clear division of labor. As the lead institution for energy policy development and planning, the Ministry of Energy is responsible for the overall policy control. In addition, in the field of rural electrification, the Rural Electrification Authority is mainly responsible for specific project implementation, fund management, and provides development plans and related suggestions to the government. In addition, on the power generation side and the supply side, there are dedicated companies responsible for the production, transmission and distribution, and sales of electricity. The clear division of labor allows each participant to know their respective scope of authority, avoiding management confusion.

At the financial level, in addition to continuing to expand REF's investment to promote grid expansion, densification and intensification, Kenya actively introduces private investors to participate in the construction of micro-grid and Solar Home Systems. This helps to use social capital to accelerate the advancement of rural electrification projects. In order to broaden investment channels, the country has begun reforms to change the power sector and allow private capital to develop power to make up for the lack of state funds. The participation of private capital in Africa's power development has made substantial progress. With the increase in private investment, the number of rural electrification projects is also increasing, and the electricity access rate is also increasing. This model also provides a reference for other countries, especially countries in sub-Saharan Africa. When a country lacks sufficient state-owned funds, in addition to trying to obtain assistance from foreign governments or international organizations, mobilizing private capital is a very important solution.

4.4 Summary

On the road of chasing full rural electrification, different countries have different institutional structures and implement different policies, but by comparing we can find the common points among them. These common points can be understood as the key to the successful implementation of the rural electrification project. Because changes in these key aspects will have an impact on whether the project can achieve the expected results. They include the institutional level, the legal and regulatory level, the funding level, and the market level.

4.3.1 Institutional level

Institute is a reflection of political choice. Institutional role in rural electrification is to provide a solid guarantee for the implementation of policies and funds. A stable and dedicated institution is specifically manifested in the organization that is specifically responsible for promoting rural electrification, and the establishment of special funds to support the development of rural electrification. The agencies can ensure that the relevant national policies are accurately implemented and continue to play a role, forming specific standards and guidance. Special funds can ensure that funds prepared for rural electrification will not be used for other purposes. Thus, suggestion is given that the rural electrification programme should be carried out by designated agency and grant adequate authorization.

4.3.2 Laws and regulations level

The establishment of relevant laws and regulations can also escort the smooth implementation of the rural electrification project. The specific performance is to achieve clear property rights in the implementation of the rural electrification project. Legal property rights are the reflection, recognition and protection of economic relations. Because the final development of rural electrification is to form a market-oriented operation mechanism, and a clear definition of property rights, including ownership, usufruct, etc., can allow the market to maintain an efficient and stable operation, which is more conducive to the implementation of subsequent projects.

4.3.3 Funding level

The implementation of rural electrification projects requires a lot of funds to support. Generally, it is difficult for other entities except the government to have such strength to promote the implementation of the project. Without the government's solid support for related plans and financial support, it is difficult for the rural electrification project to achieve the expected results. Long-term strategic planning and financial resources are necessary conditions for a successful rural electrification project. We can see this in the examples of China and India. For example, the reason why RGGVY failed to complete during the Tenth Five-Year Plan period as planned and was delayed to the Eleventh Five-Year Plan was largely due to the lack of sufficient financial support and the slow progress of the project. In China, it is also because the problem of the source of funds for the construction of the power grid has been solved, that the grid extension can be carried out.

4.3.4 Market level

As mentioned in 4.3.2, the final development of rural electrification is to form a market-oriented operation mechanism. To build a solid rural electricity market, it is necessary to maintain the vitality of the market, and through correct policy guidance, attract more market entities, including private investors, to participate, instead of just staying in a situation dominated by state-owned assets. Capital has the instinct to chase profits, so how to ensure that investors get the sustainable income they deserve is an important issue. India has given a good answer to this point, and China is also trying to introduce private investors in the promotion of stand-alone systems. On the other hand, the electricity market is also inseparable from a stable customer base, namely consumers. The investor's income comes from consumers (households and companies). The ability to obtain sustainable profits through power supply will help the electrification project to be implemented smoothly. However, the establishment of electricity prices also needs to consider the affordability of consumers. Therefore, for the continued stability of the market, it is urgent to consider the income of investors and the acceptance of consumers. Policy makers need to consider comprehensively to formulate market rules.

5 Conclusion

At present, all countries are striving to achieve "universal access to an affordable, modern, and reliable energy service" under the guidance of SDG7. However, in the actual process, it is often found that there is a certain gap between the result and the expectation. Some countries have encountered many difficulties in the process of implementing rural electrification.

This master thesis analyzing the various aspects of the impact of rural electrification, exploring the technologies used in the process of rural electrification, the policies implemented, and funding measures. This research is expected to answer why some countries have achieved worse than expected results in the process of implementing rural electrification projects, and what aspects should be paid attention to for successful rural electrification projects.

Chapter 2 discussed the impact of rural electrification. This kind of impact is multifaceted. This study analyzes the impact of the successful implementation of the rural electrification project from the three aspects of human development, economy, and ecology and environment. This kind of impact is multifaceted. This study analyzes the impact of the successful implementation of the rural electrification project from the three aspects of human development, economy, and ecology and environment. Through research, it is found that children can have more learning time after electrification, so their academic performance has been significantly improved. In addition, rural electrification has a positive impact on household health. On the one hand, electric lighting directly replaces traditional kerosene lamp lighting, which greatly improves indoor air. On the other hand, with the popularity of household appliances, people have wider channels for obtaining health information. Not only that, rural electrification also helps the construction and improvement of the rural medical system, which can provide people with better and timely medical services. With the improvement of the education and health of family members, the income of the family also increases. Rural electrification also plays an important role in promoting social and economic development. Because human development provides sufficient labor for economic development, and companies will not affect daily production due to power shortages, the overall social economy can develop healthily and sustainably. Unlike the previous two aspects, the ecological and environmental aspects are more complicated. Due to the more complex connections between the natural environment and the ecosystem, it cannot be simply assumed that household after electrification will definitely have a positive impact on the environment.

Chapter 3 analyzes and compares the main technical approaches used to improve access to electricity. As the most important and first thought of the technical route, grid extension does have its own advantages, but it is difficult to be adopted in the case of solving the electricity access of the rural area. This situation is particularly evident in some areas that is difficult to access from a technical level or not feasible from economical level. Therefore, many off-grid solutions have been proposed to make up for the deficiencies of grid extension. One of them is the stand-alone energy system represented by the Solar home system. Although SHS is widely used because of its simplicity and low cost, it also has certain limitations. The most important thing is that the capacity of the system is difficult to support the growing and continuous electricity demand of the family. This leads to the Hybrid Energy System, which greatly complements the shortcomings of SHS due to a single energy source, and can provide households with a larger capacity and more sustainable power supply. The emergence of Microgrid has triggered new technological innovations. It has unparalleled advantages in flexibility, accessibility and reliability, and can play a greater role in rural electrification.

In Chapter 4, the rural electrification process of some typical countries is studied. The main purpose is to find out what needs to be paid attention to during the implementation of the rural electrification project. Through comparison and comprehensive analysis, we found that a successful implementation of rural electrification programme should attract enough attention in the following four aspects, institutional, laws and regulation, funding and market level. Considering the situation of a specific country, when formulating a rural electrification plan, there must be an overall consideration of these four aspects. If any aspect is lacking, it may cause the program to fail to achieve the expected effect. The experience of China, India and Kenya proves that having a designated organization to uniformly manage the rural electrification project can help improve efficiency and avoid management gaps. The joint efforts of all parties involved in the management and execution of the project, and having an entity responsible for the overall planning can better carry out the project well and quickly. At the national level, this work needs to be highly valued, and related laws and regulations are needed to ensure the implementation of the project. Not only will the focus of economic development be shifted to rural electrification from a macro perspective, but also specific systems must be introduced to protect the rights and interests of investors, so as to provide support for the establishment of the market and the maintenance of a virtuous circle. Different from the aforementioned policy-level problems, one of the biggest problems that currently plague most countries to increase access rate is the lack of funds, which is difficult to solve through the country's own adjustments in the short term. In the long run, each country must gradually improve and enrich its own financing channels to maintain economic development and the continuous improvement of rural electrification; in the short run, these countries may need financial assistance from external channels to help themselves overcome the problem of funding shortage. Therefore, these countries can seek more international financial support through active international cooperation. Kenya is a good example in this regard. Through cooperation between North and South countries, a certain amount of start-up funds can be obtained. Stimulating rural electrification development through market-oriented operation means can break the situation of relying solely on government funds or external assistance to solve the problem of access to electricity. The introduction of more types of investors will help to mobilize market flexibility, which can not only attract more funds into the market, but also reduce investment costs through market competition to achieve the greatest benefit to users in the rural area.

Generally, rural electrification is a complex system project with a long-time span. When formulating relevant plans, each country or region must first take into account the geographical conditions and natural resource endowments of the region, and make specific plans and measures after fully understanding the basic situation of the region. No matter what kind of technology, policy, or even funding channels is adopted, there is no uniform and fixed model. Policy makers in various countries must not only ensure the stability of the policy, but also constantly adjust to respond to new changes in specific implementation, and finally find the path of rural electrification that is most effective for the local area.

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