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Considerations for decision-making on distributed power generation in rural areas

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HIGHLIGHTS

- Considerations include technical and non-technical factors for energy decisions.
- Coal and renewable power are compared based on cost and availability of resources.
- Key factors for renewable power generation are capacity shortage and availability of resources.
- Rural China case study evaluates the viability of distributed wind or solar power relative to coal.

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ABSTRACT

Energy resources for rural electrification are variable and widely dispersed, such that a solution for one region might not be appropriate for another. This study evaluates the feasibility of renewable energy technologies, centralized grid extension and local coal-fired power for rural areas that currently do not have sufficient access to electricity. The renewable power generation options considered are solar photovoltaic and wind power, with battery storage or fossil fuel generator backup. New local coal-fired power, as well as extension of the grid from an existing centralized power system, are considered to compare the impacts of scale and traditional approaches to power generation. A case study for a rural area in Northwestern China demonstrates the complexity of energy decision-making when faced with low peak demands and non-ideal renewable resource availability. Economic factors, including cost of electricity generation, breakeven grid extension distance, capacity shortage fraction (the ratio of the annual capacity shortage to the annual electric load) and land use are evaluated.

1. Introduction

Approximately 1.3 billion people worldwide lack access to electricity, 84% of whom live in rural areas of developing countries (International Energy Agency (IEA), 2011). China, like many developing countries, is paving the way for industrialization by building centralized grids to electrify major population centers. However, this approach to electrification is not always amenable to rural areas, especially in remote areas. Extension of the centralized grid to remote or underdeveloped areas is often not practical due to geographic isolation, limited electricity demand or economic constraints. Furthermore, installation of a new grid can be slow, and even if one exists, load shedding can result in unreliable power for lower-priority regions on the grid.

Distributed generation (DG) systems, ranging from a few kilowatts to tens of megawatts, produce power locally with the goal of providing energy to the nearby populace. Grid losses, which are intrinsic to centralized power generation, are minimized since the DG system is typically located near the demand. The implementation of DG systems in areas without electricity can benefit from job creation and increased standard of living. When a reliable energy resource is located near the service area, off-grid DG can produce reliable power that is independent of the grid and has reduced environmental impacts (Lovins et al., 2002). Distributed generation systems can also be connected to the grid with options to sell power to the grid during times of surplus. However, the primary function of the grid-connected DG system is to provide power to the local community.

In the past when establishing the power infrastructure, industrialized countries relied on fossil fuels, primarily coal, to bring reliable power to manufacturing and population centers. With the threat of resource constraints and climate change, industrialized countries have since begun implementing renewable energy in a

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grid-connected manner. Developing countries, on the other hand, can approach industrialization with a mixed portfolio of energy options, often without the established fossil-fuel infrastructure, particularly the centralized grid. Diverse energy portfolios with both renewable and fossil fuel technologies can also help meet regulations on energy and the environment.

Renewable DG has been considered not only to increase generation capacity, but also to electrify regions that otherwise have little or no access to electricity (El Fadl et al., 1997; Nässén et al., 2002; Karki et al., 2008). Lower emissions are another reason for renewable DG. Wind, mini-hydro, and wood-fired grid-connected DG power plants in Sri Lanka have reported reduced emissions with only marginal cost-increases compared to large hydropower and coal-fired power plants due to reductions in transmission and distribution losses (Wijayatunga et al., 2004). Bangladesh, which has abundant renewable resources, utilized DG to provide power for the 60% of the population that presently does not have access to electricity (Chowdhury et al., 2012). Renewable DG can be more naturally utilized to meet the energy demands of local rural populations, but as economies expand and industrialize, the electricity demands increase, as does the need for highly reliable power.

Coal power plants have traditionally been used to provide low-cost and reliable electricity. They are heavily utilized in countries like China, India and the U.S., where there are abundant coal reserves and a large demand for electricity. Coal-generated electricity has a significant economic advantage over wind and solar at large scale, but at smaller scales the cost of electricity increases and the complexity of the power plant can tax the skills of the local community. To better understand the tradeoffs at smaller scale, distributed generation of both fossil fuel and renewable energy should be considered to optimize the utilization of resources and minimize costs and environmental impact.

Many studies of renewable DG do not include a comparison of local small-scale coal or grid extension. In this work, technical, economic, and environmental factors are used to compare three options for power generation in rural areas: renewable DG power systems, coal-fired DG power systems and connection to the centralized grid. Challenges and opportunities will be discussed for each option. Wind and solar photovoltaic (PV) power with battery or diesel generator backup are compared to coal-fired power to understand the fundamental issues associated with DG and how they are influenced by scale.

To further demonstrate the applicability of these options, a case study for a rural area in northwestern China will also be discussed. Burqin County, Xinjiang Province, China is characteristic of rural areas without access to electricity, in that the choice for power generation is not easily identified. The discussion of issues surrounding power options for an area like Burqin County will elucidate the potential technical, economic, and environmental challenges for electrification when considering distribution generation sources.

2. Power generation in rural China

Over the past 20 years, China has reached a 98% electricity access for all major cities and has connected millions of rural residents to provincial and national grids. Ethnic populations in Xinjiang, Tibet, Sichuan, and Qinghai account for 84% of the nearly 4 million people in western China that do not have access to electricity (Luo and Guo, 2013). Distributed generation projects have the potential to greatly impact the local economies and livelihoods of people in these areas. However, the choice of DG technology can vary greatly from region to region, and an all-encompassing technology does not exist.

2.1. *Case study for Xinjiang province, China*

The northwest region of China is home to 40% of the country′s coal reserves, which are largely unutilized. However, Xinjiang is located at least 3000 km away from the east coast centers of demand, leading to transportation challenges (World Coal Association, 2011). China has begun work on an intercontinental railroad to address these challenges, which would drive a shift in the coal production base from the east coast to the north and northwest. Xinjiang is also the largest producer of oil and natural gas in the country. Consequently, an expansion of power capacity will be needed throughout the province if a shift in population occurs due to the economic opportunities afforded by these vast resources. The fossil fuel resources are currently being prioritized for the east coast where the major population and manufacturing centers are located (U.S. Energy Information Administration (EIA), 2012).

One of the authors, MLH, visited Burqin County, Altay Prefecture, Xinjiang Province to assess the current energy situation and needs. Burqin County needs to expand existing capacity due to the growing population. The hydropower plants have historically operated below capacity due to droughts in the area (Zhang et al., 2012). Electricity from a local grid network is available, but many of the coal plants that supply this power are small ($<$100 MW), and are in jeopardy of being shut down due to their low efficiency and high emissions (U.S. Energy Information Administration (EIA), 2012).

Discussions with local community members and leaders formulated the community input. Burqin County is a rural community with people living and working in the central city and nomadic herders living semi-permanently on the outskirts. A large percentage of the population works in the farming and animal husbandry industries. Burqin County is located at a latitude of 47°50′N and a longitude of 88°8′E, has an annual average wind speed of 4.5 m/s and an average solar radiation of 4.5 kW h/m^2/day. The population of 67,700 lives in 19,500 households (China Statistics Press, 2007) with an average household electricity demand of 586 kW h/yr (Burqin News, 2008) and a current peak demand of 3 MW. The peak demand times are in the early morning and early evening before sunset. The current cost of electricity for the residents of Xinjiang is approximately CNY ¥0.4/kW h (equivalent to USD $0.06/kW h) (Tang, 2009), which is subsidized by the Chinese government (Lam, 2004). The combination of low electrical demand and non-ideal renewable resources makes the addition of new power generation a challenge, not just for Burqin, for many other rural areas around the world.

Burqin County is located 686 km north of the capital city, Urumqi, where the provincial grid is centered. Unless the provincial grid is expanded beyond its current boundaries, there will be significant portions of the province that will not be connected to the grid. Thus, new DG technologies could be valuable to these communities. The semi-nomadic herders that live nearby have access to portable household-sized ($\sim$10 kW) solar PV and hybrid solar PV/wind systems that are used to power small electronics and lights. These have been made accessible through funding from non-governmental organizations (NGOs) and the local government. The herders are not allowed to connect to the local grid. Consideration of DG systems would allow Burqin County to increase electricity capacity and to include the herders' energy needs, while utilizing low emission and/or renewable energy.

3. Methods for economic analysis

The approach to rural electrification varies from one location to another, depending on demand, availability of resources, environmental concerns and the financial means of the community. The challenges