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A decision support assessment of cogeneration plant for a community energy system in Korea

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HIGHLIGHTS

- We case-studied cogeneration plants for a residential complex in Korea.
- We estimated the annual 8760-hourly demands for electricity, heating, and cooling.
- We simulated the operation of CHP and estimated the fuel and electricity costs.
- We found payback periods that were shorter than two years for well-planned systems.
- A progressive electricity tariff plays a key role in the economic merits.

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ABSTRACT

We have undertaken a case study of a Combined Heat and Power (CHP) plant applied to a mixture of buildings comprising residential premises, offices, hospitals, stores, and schools in Korea. We proposed five *Plans* for grouping buildings in the complex and estimated the annual 8760-hourly demands for electricity, cooling, heating, and hot water. For each *Plan*, we built about ten *Scenarios* for system construction. Then, we simulated the operation of the system to find the fuel consumption, electricity purchase, and heat recovery. Applying the local rates to the amounts of fuel and electricity, we estimated the operating costs. Combining the operating cost with the initial cost associated with the purchase and construction of the system, we calculated the payback periods for the *scenarios*. We found that the payback period can be as short as two years for smartly grouped buildings with a generator capacity of around 50% of the peak electricity demand. A progressive electricity rate that applies only to residential premises currently plays a key role in the economic merits. We recommend extending a sound progressive system to other types of building in Korea to promote distributed power production and enhance energy saving practices in general.

1. Introduction

Even though 37% of its electricity requirement is produced by nuclear power plants, Korea still imports 97% of the total energy supply of 236 million TOE (Lee et al., 2009a, b). As of 2007, energy consumption by residential, public, and commercial buildings accounted for 27.8% of the total energy consumed (KEMCO, 2009). Most experts in Korea agree that Korea has great potential for savings in the building energy sector. In addition to this large room for improvement, there is another good reason for Korea to be particularly interested in a district energy system based on cogeneration. The mainstream form of residence is densely populated apartment complexes. Tens of high-rise (10 to 30 stories) buildings accommodating tens to hundreds of houses comprise a complex along with convenience-providing buildings such as schools, hospitals, and offices. This type of arrangement facilitates the centralization of energy supplying devices and the efficient management of control systems. In this study, our team analyzes a candidate apartment complex in Yanju Koup, located 30 km north of Seoul, and tries to provide basic information that is necessary for the decision processes for adopting cogeneration systems in a Community Energy System (CES).

Cogeneration has been one of the popular subjects in energy research due to its proven effectiveness and documented success

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cases. Confining our attention to only the economic and policy nature of cogeneration by excluding technological research, we still can find many authors from various parts of the world with interesting technologies. Madlener and Bachhiesl (2007) studied socio-economic drivers of large urban biomass cogeneration in Austria. Szklo et al. (2004) and Soares et al. (2001) investigated incentive policies and economic potential for natural gas based cogeneration in Brazil. Lund et al. (2000) proposed implementation of cogeneration in Estonian energy systems. Ramai (1980) performed an economic analysis for a district heating system in France. Purohit and Michaelowa (2007) studied CDM potential of bagasse cogeneration in India. Wolpert (1996) reported CHP activities in Japan, and Bonilla et al. (2003) modeled the adoption of industrial cogeneration in the same country using surveyed data, which is a similar technique to the one we used in our study. In Korea Kwon and Yun (2005) estimated market value for thermal energy of cogeneration and, Kwon et al. (2003) quantitatively scoped the economics for cogeneration systems in South Korea.

The research topics that are closely related to our work have been studied by many researchers. The key concepts include: load estimation (Steenhof, 2006), optimal design (Wickart and Madlener, 2007), impact of factors like tax reform (Platt and Welch, 1989; Leth-Petersen and Togeby, 2001), economics and merits (Dobbs, 1982; Chicco et al., 2007), feed-in-tariff (Uran and Krajcar, 2009a, 2009b), data analysis (Eric et al., 1982) and the deregulation effects of electricity market on district heating prices (Linden and Peltola-Ojala, 2010). We can also find comparisons (Amundsen et al., 2010), models (Mavrotas et al., 2007; Marchand et al., 1983; Saros, 1984), and case studies (Iacobescu and Badescu, 2011) and demand-models for technology diffusion (Faber et al., 2010).

If we focus more on electricity generation, we are basically studying microgrids. Zerriffi et al. (2007) characterized five failure modes for the integrated system and compared the performance of centralized to distributed generation systems under various levels of stress including conflict-induced stress. They found that distributed generation is significantly more reliable than centralized systems and when whole-economy costs are considered they are also more economical. Hatziargyriou et al. (2007) summarized ongoing R&D and demonstration projects on microgrids, and Venkataramanan and Marnay (2008) discussed the potential role of microgrids in power supply expansion. Two Ph.D. dissertations were published from Carnegie Mellon University: Zerriffi (2004) evaluated centralized versus distributed system architectures and King (2006) discussed the considerable potential for improving the value of DERs (Distributed Energy Resources) provided by the micro-grid architecture built on conventional continuous-use DER applications by aggregating and interconnecting small groups of customers to a local grid.

Important concepts and issues raised in this paper have been dealt with at length in published papers by other authors. Siddiqui et al. (2005) discussed the effects of carbon tax on microgrid CHP, and Marnay et al. (2008) studied optimal technology selection and operation of commercial-building microgrids. Our research includes a CES composed of up to 17 different types of buildings as a result of our own building energy models (Chung and Park, 2009).

Our paper is primarily concerned with the effective energy utilization in an oil-importing country by recovering waste heat and accompanying benefits achieved by distributed power generation. In a recent symposium (Jeju, 2011) a broad range of issues were discussed and a large amount of information exchanged centering around microgrids. Emerging concepts such as smart renewables, data center infrastructure, remote application and emerging regions were key topics among experts from all over the world.

For our simulation we followed similar methods to Marnay et al. (2008) and King and Morgan (2007). The main differences being that we used our own load models developed through separate research (Chung and Park, 2009) and we based our calculation on the real-world market catalogs. The current local utility price systems are applied for the cost operation estimation. Similar to the study by Marnay et al. (2008), our study is providing tools for optimal technology selection and estimating the effects of such deployments. We are trying to demonstrate how separate unit operations can be assembled in a systematic way and modern computational applications developed. Specifically, we will demonstrate how building loads can be estimated through a statistical treatment of building characteristics through a nationwide survey and sampling. The procedures on how the key decision variables for the economic and technological optimization are structured and processed are expected to be of interest to researchers in similar fields. The methodology we are providing through this study can be potentially applied in other countries provided there is a sufficient amount of underlying data available. The planning of a CES is demanding as it requires a long chain of tasks each of which requires different specialties ranging from engineering and technology to economy and policy. When a cogeneration system is applied to a community, it should be individually customized to the local environment to make it fully realize its potential. The environment includes customers (buildings and residents), markets (components, services, and utility companies), policies (taxation, incentives for particular technologies, etc). Due to this multi-disciplinary nature, an integrated approach to the entire design process of cogeneration is highly desirable with centralized knowledge management.

A structured algorithm will be ideal for our problem. However, a large and diverse body of information is associated with the problem including, the individual building description, building composition of the community, local climate, energy consumption culture for only energy consumption prediction. When we include the devices, we need market information, technical specifications, and device to device compatibility among many other factors. The calculation is further complicated when we impose prices associated with fuel and electricity consumption. The only reasonable option is to use a simulation that is preferably based on real-world data.

Our final goal is to estimate the initial and operating costs of a cogeneration system that is proposed for a specific complex. We cannot avoid certain kinds of technological or stochastic analysis to properly address the whole problem. The difficulty is that the costs that we seek depend on many factors (technological, stochastic, and socio-economic). Some examples are provided below.

- The manner in which the buildings are grouped. This will determine the load demand patterns.
- The kinds of equipment and devices that are employed.
- The means by which the equipment and devices serve to meet the energy demand.
- The kinds of tariffs that are imposed on energy consumption (gas and electricity).
- The initial costs for the equipment/devices and construction.

First, the energy demands for a group of buildings must be properly estimated. This is not an easy task because buildings consume different amounts regarding electricity, heating, cooling, and hot water depending on their business type, location, size, etc. We need a way to systematically account for the building loads. The next step is to select the equipment and devices of the cogeneration system: engines, refrigerators, boilers, cooling towers, and other accessory components. The markets for