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ScienceDirect

Energy Procedia 136 (2017) 342–348

Energy Procedia

www.elsevier.com/locate/procedia

4th International Conference on Energy and Environment Research, ICEER 2017, 17-20 July 2017, Porto, Portugal

# An optimization model for design and analysis of a renewable energy supply system to the sustainable rural community

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**Abstract**

The goal of this paper is to present a new optimization framework for design and analysis of a stand-alone energy supply system to rural communities using 100% renewable energy sources (RES). In achieving this goal, we first propose a technology superstructure for energy supply. The superstructure starts from different types of RES which are easily available in rural communities, including solar, wind, organic waste, and lignocellulose biomass. The RESs are processed in multiple technologies to meet energy demands of a rural community (chemical, thermal and electric powers). Using the model we identify the optimal system configuration and practical operational strategies.


Peer-review under responsibility of the scientific committee of the 4th International Conference on Energy and Environment Research.

*Keywords:* MILP; optimization; renewable energy resource; rural communities; superstructure

## 1. Introduction

Recently, global concerns about environmental issues such as climate change, particle materials emission, and global warming by greenhouse gas (GHG) has been increasing. Accordingly, many technical improvements and economic policies to mitigate such environmental problems have been implemented world widely. According to the Kyoto Protocol, the total amount of greenhouse gases (GHG) emitted in developed countries must be reduced by an

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1876-6102 
Peer-review under responsibility of the scientific committee of the 4th International Conference on Energy and Environment Research.
10.1016/j.egypro.2017.10.285

average of 5% below the 1990 levels [1]. In addition, since 2015, the Paris Agreement has extended the greenhouse emissions reduction obligation limited to some developed countries to 195 countries [2]. Korea also has an obligation to contribute to the reduction of GHG emissions, thereby aims to decrease GHG emissions by 37% in 2030 compared to the 2012 [3] and with the introduction of renewable fuel standard (RFS) [4].

Furthermore, the energy system of Korea is very vulnerable due to its low energy security. Korea's dependence on imported energy is nearly 95.8% of its total energy supply; in particular fossil fuels account for about 85% of the total energy consumption [3]. The fossil fuel-oriented energy structure of Korea will aggravate the energy security due to severe imbalance of energy supply and demand, and energy price instability by the depletion of global fossil fuel reserves [5]. Therefore, the transition to a renewable energy resource (RES)-based energy production has been recognized as one of the most attractive solutions to address the environmental issues. In addition the RES-based energy system can bring together sustainable benefits due to its features of diversity and even-distribution of resources compared to conventional sources. Recently, Won et al. developed a superstructure-based optimization model to design and operate RES-based hydrogen supply system [6]. Kim and co-workers also developed an optimization-based approach that determines the optimal design of a renewable energy network including production, storage, and transportation [7,8].

In particular, the RES-based energy system can bring about huge impacts, when it is implemented in rural communities, such as agriculture and livestock sectors. For example rural communities of Korea have high biomass potential about 19% of the total biomass potential of Korea [9]. And most of organic wastes such as manure, food waste, sludge, and lignocellulosic biomass are not currently properly utilized as an energy sources, even though they are already used as an important sources in other energy industries [4]. Thus, the establishment of the RES-based energy supply system for a rural community is expected not only to contribute to the sustainable development of the local community but also to support a policy of the renewable energy production with improving the energy security in Korea.

Therefore, the purpose of this study is to develop a new design and analysis framework of the RES-based energy supply system for the rural community, which consists of various renewable resources, a number of energy technologies, and different types of energy demands. To achieve this goal, a technology superstructure for the energy system is generated. We then develop a new optimization model using a mixed-integer linear programming (MILP) technique to identify system configuration and economic performance.

**Nomenclature**

*Index*

| | |
|---|---|
| $i$ | set of resources |
| $j$ | set of technologies |
| $k$ | set of energies |
| $t$ | set of time period |

*Variable*

| | |
|---|---|
| $P_{jkt}$ | amount of energy $k$ produced in technology $j$ during time period $t$ |
| $N_{jk}$ | number of technology $j$ for producing energy $k$ |
| $R_{it}$ | amount of resource $i$ used for producing energy during time period $t$ |
| $D_{kt}$ | amount of energy $k$ toward to the final energy demand ( $\varepsilon_{kt}$ ) during time period $t$ |
| $S_{jkt}$ | amount of stored energy $k$ in technology $j$ during time period $t$ |
| $E_{kt}^{ex}$ | amount of excess energy $k$ during time period $t$ |

*Parameter*

| | |
|---|---|
| $\delta_j$ | unit capital cost of technology $j$ |
| $\rho$ | unit cost of energy activity |
| $\xi_{jk}$ | unit energy consumption of technology $j$ for producing energy $k$ |
| $\psi_j$ | unit $CO_2$ emission rate of technology $j$ |
| $\eta_{jk}$ | conversion efficiency of technology $j$ for producing energy $k$ |
| $\theta_{jk}$ | maximum capacity of technology $j$ to for producing energy $k$ |
| $\omega_{it}$ | available amount of resource $i$ during time period $t$ |