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Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors

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ABSTRACT

The horticulture and stockbreeding sectors are the highest energy consumers in the Korean agriculture industry. Reducing this consumption would be useful given that non-renewable resources account for 70.3% of the source of this energy. We apply the fuzzy analytic hierarchy process with the benefits, opportunities, costs, and risks (BOCR) approach to select an optimal heating facility for the horticulture and stockbreeding sectors in Korea. We set 11 factors based on the BOCR approach and evaluate six heating options that use either fossil fuels or renewable energy (oil-fired boiler, coal-fired boiler, electricity heater, geothermal heat pump, aero-thermal heat pump, and wood pallet-fired boiler). From the energy and agricultural experts' perspectives, the geothermal heat pump is selected as the most appropriate heating source. While it requires the highest initial investment cost of all the options, the geothermal heat pump earned high scores on most other factors. Moreover, the aero-thermal heat pump and the wood pallet-fired boiler, which run on renewable energy, also scored relatively well. However, the oil-fired boiler, which currently has the predominant share of heating facilities in these sectors, ranked the lowest. The results show that the Korean government's energy policies regarding the agriculture industry have resulted in a distorted resource allocation. Thus, it would be prudent to phase out the tax exemption on petroleum products and discounts on electricity provided to this industry.

Contents

1. Introduction

The final energy consumption of the Korean agriculture, forestry, and fishery industries increased 1.7 times from 1,813,000 TOE to 3,082,000 TOE between 1990 and 2011 [1]. The growth rate was relatively low when compared with the combined average growth rate of all industries, which increased by 3.5 times during the same period. However, horticulture and stockbreeding are energy-intensive sectors and consume a greater share of energy than do labor-intensive sectors. This can be attributed to the restructuring of the agriculture, forestry, and fishery industries since the 1990s. Furthermore, the dependence on energy in these industries has increased, as has the intensity of energy use in each industry (see Table 1).

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Table 1
Changes in energy consumption and energy intensity of floriculture sector in Korea.

Year	1995	2007
Energy consumption (kTOE)	67	514
Proportion of agricultural energy consumption (%)	9.2	32.2
Energy intensity of floriculture sector (kTOE/million Won)	0.274	0.653
Energy intensity of vegetable sector (kTOE/million Won)	0.022	0.105

Table 2
Current status of heating equipment for floriculture and stockbreeding in Korea.

Equipment	Number of farms	Ratio (%)
Oil-fired boiler	213	71.00
Coal-fired boiler	8	2.67
Electricity heater	73	24.33
Geothermal heat pump	2	0.67
Aero-thermal heat pump	0	0.0
Wood pallet-fired boiler	2	0.67
Others	2	0.67
Total	300	100.00

Table 3
Energy share of agricultural sectors.

Sectors	Consumption (TOE)	Share (%)
Farmland	1,399,072	45.4
Flowers	425,782	30.4
Stockbreeding	261,995	8.5
Forestry and fishery	1,069,172	34.7
Services for agriculture	350,782	11.4

As of 2011, the agriculture, forestry, and fishery industries were found to depend heavily on oil, with petroleum products accounting for 70.3% of the source of the industries' energy [1]. In particular, oil-fired boilers accounted for 71.0% of heating applications used in the horticulture and stockbreeding industries, while the share of renewable resources was very low at 1.34% (see Table 2). This is because farmers believe conventional heating facilities are easier to use and that their operating costs are relatively low. The result is a significant gap between the needs of farmers and policymakers. However, the heavy dependence on oil and the high oil prices that have prevailed in recent years have decreased the profitability of farms. In addition, electricity consumption has increased substantially in the agriculture, forestry, and fishery industries. Here, the ratio of electricity to total energy mix jumped from 6.9% in the 1990s to 29.5% in 2011. This trend is mirrored in the choice of heating facilities by horticulture and stockbreeding businesses, in which the use of electricity heaters has increased rapidly.

This changing pattern of energy consumption in the agriculture industry, and especially in the horticulture and stockbreeding sector, is attributable to government policies. As an economic incentive to farmers, the Korean government grants tax exemptions on petroleum products used in the agriculture industry. The consumption of tax-free petroleum products stood at 1,761,000 kL in 2012, which means that the agriculture industry received tax breaks worth 1.04 trillion KRW. The Korean government also grants farmers discounts on electricity. For instance, horticulture and stockbreeding farmers pay 38.4–39.1 KRW/kWh for electricity, which is only one-half to one-third of the rates paid by other industries, such as the manufacturing industry. In particular, the price of electricity has been controlled, while the prices of energy sources such as oil, gas, and coal have increased [2].

For farmers, the easiest way to make a profit is to use the cheapest source of energy. However, it is necessary that the government encourage the optimal use of energy sources by considering the economic feasibility, environmental concerns, and industrial ripple effects at a national level. Previous government policies for the agriculture industry focused on providing economic support and, accordingly, the government granted tax exemptions on petroleum products and price cuts on electricity, which were the industry's two main energy sources. However, it is crucial to investigate whether such policies resulted in distorted resource allocations. Renewable energy has recently shown substantial improvement in terms of economic feasibility and offers more advantages, such as reduced social costs, than do conventional energy sources.

In light of this, the Korean government recently operated a subsidy program for the dissemination of renewable sources to the agricultural sector. However, the share of renewable energy is still too low, owing to the high initial investment cost and its relatively low technological credibility. Therefore, examine suitable decision criteria to use when selecting a heating facility for the horticulture and stockbreeding sector. Then, we determine the optimal heating facility from a social viewpoint using the fuzzy analytic hierarchy process (AHP). To conduct the fuzzy AHP analysis, we set 11 factors based on the benefits, opportunities, costs, and risks (BOCR) approach, and evaluate six heating options: the oil-fired boiler, the coal-fired boiler, the electricity heater, the geothermal heat pump, the aero-thermal heat pump, and the wood pallet-fired boiler.

The remainder of this paper is organized as follows. Section 2 introduces the fuzzy AHP and the BOCR method used in this study. Section 3 selects the hierarchy and presents a set of selected criteria and factors. The analytical results are explained in Section 4, and Section 5 presents a summary and implications of our research.

2. Fuzzy AHP and BOCR approach

2.1. Fuzzy AHP

We apply a fuzzy AHP with the BOCR approach to select optimal heating options for the horticulture and stockbreeding sectors, which consume a high share of energy within the agriculture industry (see Table 3). The BOCR approach can consider negative priorities in decision making, and the fuzzy AHP method can capture the vagueness of answers in a crisp AHP [3].

We employ the AHP, generally used in decision-making research for policy issues, in an optimal energy source selection problem. The fuzzy AHP and crisp AHP have been applied to decision making. Yi et al. [4], Sánchez-Lozano et al. [5], and Uyan [6] used the crisp AHP, while Lee et al. [7], Heo et al. [8], and Lee et al. [9] applied the fuzzy AHP.

The AHP proposed by Saaty [10] is based on crisp appraisal. However, because all human preferences have a degree of uncertainty, it is difficult to derive a precise judgment in the real world. In addition, as Heo et al. [3] mention, decision makers prefer to use familiar language expressions than numbers when assessing criteria or alternatives. Thus, the fuzzy AHP, which effectively represents human perceptions and uncertainty, has been applied by various researchers.

Chang's approach [11] to the fuzzy AHP is the most popular of the various AHP methods concerning fuzziness [12–16]. Chang used triangular fuzzy numbers (TFNs) for a pairwise comparison and proposed the extent analysis method (EAM) for the synthetic extent values of the comparisons. In our study, following Heo et al. [3], a modified method of Chang's approach is used, incorporating the arguments of Zhu et al. [17] and Wang and Elhag [18].