A Study on the Electricity Savings by Reinforcing Energy Efficiency Standards for Refrigerators in Korea

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Abstract: - Due to rapid economic growth in the past and the ambient temperature increase by greenhouse effect, the usage of residential cooling electrical appliances, especially air conditioners and refrigerators, for the last decades has increased dramatically in Korea. Like other developing countries, recently Korea has experienced a dramatic increase in the number of refrigerators. Additionally, Korean family has some special type of refrigerator for the traditional food, Kimchi, which must be conserved always in the cool and fresh condition. So the diffusion of this refrigerator has been increased rapidly. In order to reduce its energy consumption, the authorities forced to implement energy efficiency standards for principal appliances, including refrigerator. This paper proposes an estimation method for the amount of potential energy cost/profit saved in the residential sector by reinforcing energy efficiency standards for refrigerators. The demand energy reduction by this standard reinforcing can result in fewer new power plants being built and reductions in generation cost and emissions of carbon dioxide. The calculations were based on the Bass' diffusion model, statistical and economic analysis, and can be applied to the estimation for the amount of incentive.

Key-Words: - Refrigerator, Energy Efficiency Standards, Statistical and Economical Analysis

1 Introduction

With the improvement of standard of living and temperature increase by greenhouse effect, the usage of residential cooling electrical appliances, especially refrigerators, for the last decades has increased drastically in Korea. In order to reduce its energy consumption, the authorities forced to implement energy efficiency standards and labels for principal appliances, including refrigerators.

Standards are a set of procedures and regulations that prescribe the energy performance of manufactured products, sometimes prohibiting less energy-efficient ones than the minimum standard [1,4,7,11]. Energy efficiency standards can be either mandatory or voluntary. A mandatory energy efficiency standard is generally the most effective means of rapidly improving the energy efficiency of appliances.

Energy-efficiency improvement is generally considered as one of the important options to reduce greenhouse gas emissions, improve the security of energy supply, and more general, to attain a sustainable energy. Many countries have introduced energy efficiency standards with very successful result which other country can learn the experienced system [2,3,5,8,11].

This paper proposes an estimation method for the amount of potential energy cost/profit saved in the residential sector by reinforcing energy efficiency standards for refrigerators. The demand energy reduction by reinforcing standards can result in fewer new power plants being built and reductions in generation cost and emissions of carbon dioxide. The calculations were based on statistical and economic analysis, and can be applied to the estimation for the amount of incentive.

T.M.I. Mahlia presents papers for analyzing potential energy savings of refrigerators and air conditioners in his own country [6,7,9]. However these papers have some mistakes in calculations and data collection and calculate cost/energy savings with respect to the base case. And yearly number of distributed refrigerators is represented by estimated quadratic function; therefore it does not represent saturation process in distribution

This paper attempts to predict the potential energy and cost savings through reinforcing energy efficiency standards for refrigerators in Korea. The calculations were based on the Bass' diffusion model [10] in the refrigerator ownership data. The diffusion model is known as a good representation method on the natural distribution process of products.

The study found that the energy efficiency standards for refrigerators would save a large amount of cost. This analyzing method can be applied to a proper estimation for the amount of incentive costs to penetrate high efficient appliances.

2 Energy and Cost Savings Analysis

In this paper, an analysis on the energy and cost savings is proposed by the statistical and economic analysis method. Firstly, based on the historical data, annual cumulative numbers of diffused refrigerators are estimated by using the Bass' diffusion model.

$$TCN_i = m\int_i^{i+1} \frac{p(p+q)^2 e^{(p+q)t}}{(p+q\cdot e^{-(p+q)t})^2}\,dt \qquad (1)$$

TCN_i : total cumulative number of refrigerator in year i
m : potential maximum number of refrigerator
p : coefficient of innovation
q : coefficient of imitation

The new diffusion of refrigerator in year i can be calculated by the subtraction of cumulative numbers.

$$ND_i = TCN_i - TCN_{i-1} \qquad (2)$$

ND_i : New diffusion number of refrigerator in year i

However, in this estimation the life span of refrigerator should be considered. Therefore the number of new and replaced refrigerator in year i is as follows:

$$NR_i = ND_i + NR_{i-L} \qquad (3)$$

L : Life span of refrigerator
NR_i : The number of new and replaced refrigerator in year i

The capacity of targeting high efficient refrigerator is calculated by the product of efficiency rate and the base case capacity. The number of targeting high efficient refrigerator is estimated by the product of penetration rate and NR_i.

$$HCAB_i = CAP_B \cdot ER_i \qquad (4)$$
$$NHNR_i = NR_i \cdot PR_i \qquad (5)$$

CAP_B : Average capacity(Watt) of refrigerator in base case
ER_i : Efficiency rate in year i
$HCAP_i$: The capacity of high efficient refrigerator in year i
PR_i : Penetration rate in year i
$NHNR_i$: The number of high efficient refrigerator in year i

Consuming energy (kWh) of diffused refrigerators is are calculated by the product of the number of refrigerators, capacity (Watt) and the average consumption hours.

$$CAP_i = CAP_B + (1\text{-}NEI\cdot(B\text{-}i)) \qquad (6)$$
$$CENR_i = (NR_i - NHNR_i)\cdot CAP_i\cdot UHD\cdot UD + NHNR_i\cdot CAP_B\cdot(1\text{-}ER_i)\cdot UHD\cdot UD \qquad (7)$$
$$TCE_i = TCE_{i-1} + CNER_i - CNER_{i-L} \qquad (8)$$

CAP_i : Capacity(Watt) of refrigerators produced in year i
NEI : Natural efficiency improvement by technological development(%)
$CENR_i$: Consuming energy of new and replaced refrigerators in year i
UHD : Using time (hour) per day
UD : Using day per year
TCE_i : Total cumulative consuming energy in year i

The saved energy results in cost savings in generators, such as nuclear-typed generators in the Korea case. Benefits from the generation cost saving are as follows:

$$CSG_i = MCG_i \cdot (TCE_i - TCENH_i) \qquad (9)$$

MCG_i : Marginal cost of nuclear-typed generators (won/kWh)
$TCENH_i$: Total cumulative consuming energy in year i not using policy of penetrating high efficient refrigerators
CSG_i : Cost saving in the generation in year i

However, when penetrating high efficient appliances, like refrigerators, we should consider the additional cost in the manufacturing.

$$AC_i = AMC_i \cdot (TCE_i - TCENH_i) \quad (10)$$

AC_i : Additional total cost in manufacturing high efficient refrigerator
AMC_i : Additional marginal cost in manufacturing high efficient refrigerator

The total benefits from the penetration of high efficient refrigerators are calculated by subtracting the cost from the benefit simply.

$$TB_i = CSG_i - AC_i \quad (11)$$

3 Case Study

The proposed analysis is applied to the following test system. The base case is chosen to be a year 2005. The Bass' diffusion model is developed based on the statistical data. Coefficients of innovation and imitation are estimated by the least-square method and trial and errors. The maximum potential number of refrigerator is assumed to be the following estimation method. The maximum population number is about 60,000,000. The ownership of refrigerators per a family is assumed to be 1.02. The number of family member is about three. Therefore, maximum potential number of refrigerator is 20,400,000 = (60,000,000/3*1.02). From the year 1965 to 2040, estimated TCN is shown in Figure 1.

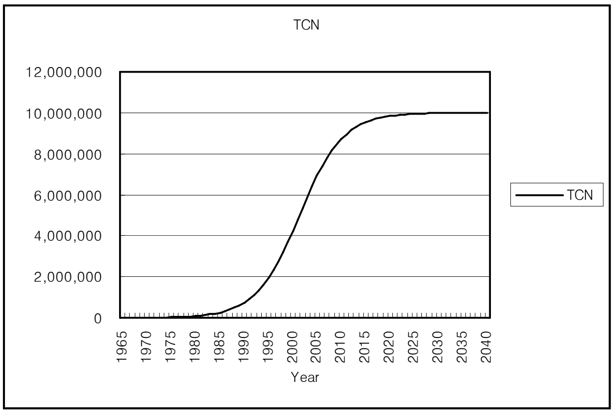

Fig. 1 Total cumulative number of refrigerator in year i estimated by Bass' diffusion model based on statistical data

The calculated analysis data are summarized in the Table 1. The base case capacity is estimated as 2,676kW. The penetration rate is assumed to be 30% in the beginning year, and its value is increased by 1% every year. The life span of refrigerators is about 15 years. The efficiency rate is chosen as 15%.

Table 1 Calculated analysis data - diffusion

Year	TCN	NR	PR (%)	NHNR	CAP (W)
2006	7,381,514	627,774	30	188,332	2,649
2007	7,789,571	609,824	31	191,367	2,623
2008	8,149,934	617,314	32	195,144	2,596
2009	8,463,102	607,568	33	200,498	2,570
2010	8,731,479	612,330	34	208,192	2,545
2011	8,958,732	623,031	35	218,061	2,519
2012	9,149,218	638,945	36	230,020	2,494
2013	9,307,533	657,870	37	243,412	2,469
2014	9,438,182	676,948	38	257,240	2,444
2015	9,545,372	693,147	39	270,327	2,420
2016	9,632,894	703,814	40	281,525	2,396
2017	9,704,077	707,205	41	289,954	2,372
2018	9,761,789	702,856	42	295,199	2,348
2019	9,808,457	691,684	43	297,424	2,325

Table 2 Calculated analysis data - energy

Year	CENR (GWh)	TCE (GWh)	TCENH (GWh)
2006	1,290	16,735	16,792
2007	1,257	17,475	17,586
2008	1,232	18,097	18,259
2009	1,217	18,601	18,811
2010	1,217	18,993	19,249
2011	1,228	19,282	19,581
2012	1,250	19,479	19,819
2013	1,277	19,594	19,973
2014	1,305	19,642	20,055
2015	1,327	19,633	20,079
2016	1,338	19,581	20,054
2017	1,336	19,496	19,992
2018	1,319	19,388	19,902
2019	1,290	19,266	19,792

The marginal cost of nuclear-typed generators is about 14.4 won/kWh. The additional marginal cost in manufacturing high efficient refrigerator is very hard to determine. It should be studied more intensively. In this paper it is assumed to be 10 won/kWh.

Table 3 Calculated analysis data - cost

Year	CSG (Bi.Won)	AC (Bi.Won)	TB (Bi.Won)
2006	91	57	34
2007	178	111	67
2008	259	162	97
2009	336	210	126
2010	409	256	153
2011	478	299	179
2012	544	340	204
2013	605	378	227
2014	662	414	248
2015	713	445	267
2016	757	473	284
2017	794	496	298
2018	822	514	308
2019	841	526	315

The graphs of saved energy and cost are illustrated in the following figures.

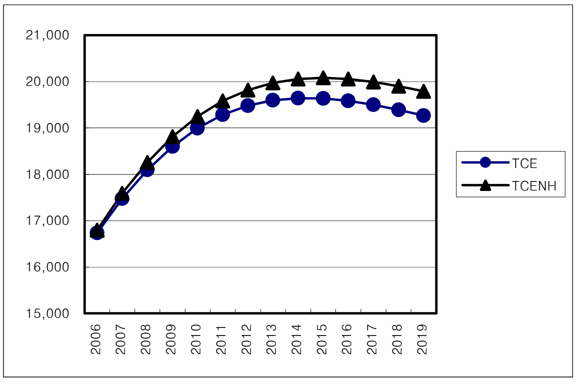

Fig. 2 Total cumulative consuming energy with and without high efficient refrigerators

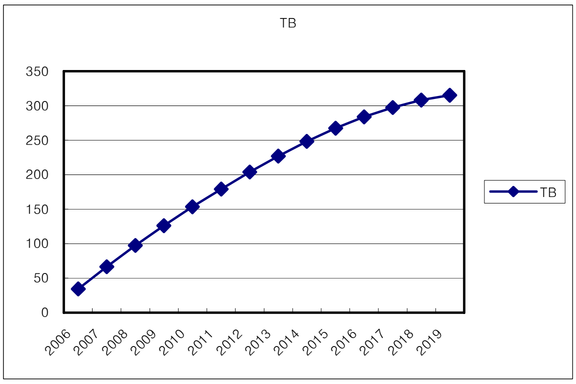

Fig. 3 Total benefit from the penetration of high efficient refrigerators

4 Conclusion

This paper presented the method for the estimations of the potential energy and cost savings through reinforcing energy efficiency standards for refrigerators in Korea. The calculations were based on the Bass' diffusion model in the refrigerator ownership data. The results show that the energy efficiency standards for refrigerators would save a large amount of cost. This analyzing method can be applied to the proper estimation for the amount of incentive costs to penetrate high efficient appliances.

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