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Marginal Abatement Cost of CO_2 Mitigation Options for the Residential Sector in Korea*

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This paper is to address the potentials of GHG (greenhouse gas) emission reductions with energy-efficient technologies for estimating the marginal abatement cost (MAC) curve. In this paper, the Asia integrate model (AIM)/Enduse model was applied to estimate the abatement costs for the residential sector in Korea. Under the business-as-usual (BAU) scenario, energy services for the residential sector in Korea will increase, resulting in significant CO_2 emissions in 2050. Under a GHG emission reduction scenario, it is found that most of GHG reduction in the residential sector could be feasible with reasonable abatement costs. The positive value of MAC provides the direction for implementing energy efficient technology to foster innovation.

JEL Classification: Q47, Q54, Q55, Q58
Keyword: bottom-up model, CO_2 mitigation, climate change, marginal abatement cost (MAC) curve, GHG emission reduction

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1. INTRODUCTION

Countries across the globe adopted an historic international climate agreement at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP21) in Paris in December 2015. Republic of Korea submitted its Intended Nationally Determined Contribution (INDC) to the UNFCCC, aiming at an economy-wide target to reduce its greenhouse gas (GHG) emissions by 37% below business-as-usual (BAU) emissions of 850.6 $MtCO_2$-eq. by 2030. The Korean government allocates GHG emission reduction targets to every sectors, including industrial sector. These specific targets of GHG emissions will accelerate the Korean energy supply and demand systems to low-carbon systems.

At the final stage of energy consumption in end-use sectors, buildings are the largest energy consumers, which accounts for over one-third of global, thus they are largely responsible for carbon dioxide emissions (IEA, 2013). The energy consumptions in the residential sector in Korea do not take large shares, compared with other sectors. However, it is expected that the energy consumptions in this sector will increase as lifestyles are changed due to the income effect, climate change, and others factors in the long term. In order to achieve the INDC target in Korea, it is important to examine the potentials of energy savings in this sector, leading the GHG emission reductions with associated cost of GHG emission reduction for specific energy saving technologies.

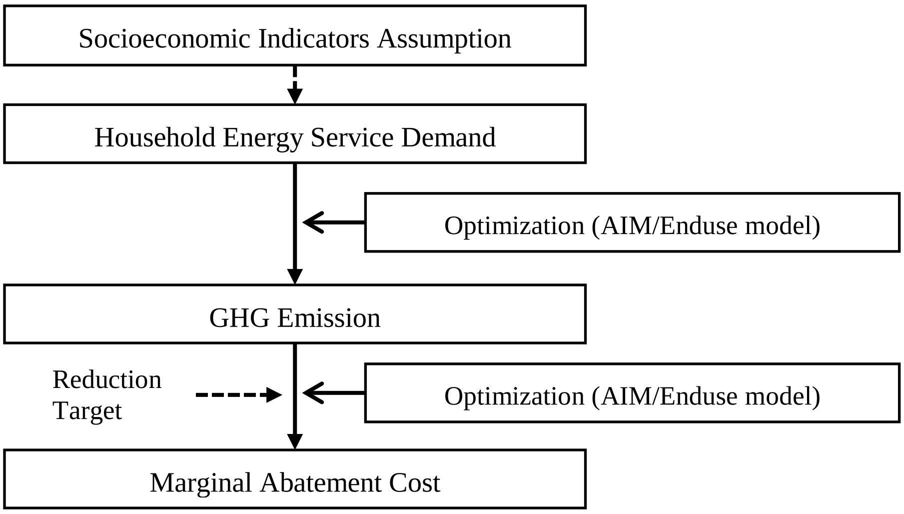
Several studies have analyzed residential buildings' energy consumptions and CO_2 emissions. Some have discussed energy consumption patterns in the residential sectors, using empirical data (Papachristos, 2015; Diaz-Rainey and Ashton, 2015; Galvin, 2014; Hart and Dear, 2004), whereas others have focused on the correlation between household expenditure and energy consumption (Büchs *et al*., 2013; Chitnis and Hunt, 2012; Dai *et al*., 2012; Rosas-Flores *et al*., 2011). Also, there have been studies focused on the available technologies to reduce CO_2 emissions. For example, Thailand's reduction of CO_2 emissions measures related to the marginal abatement cost in the long term was investigated (Kamphol *et al*., 2014). The technology options and advanced technology for the future was the primary concern since there would not much influences than technology development and its application to reduce GHG emissions (Xing *et al*., 2015; Akashi *et al*., 2010; 2012).

There still are few studies to analyze CO_2 emissions and their reduction potentials for the case of Korean residential sector. In this paper, the GHG emission reduction potentials of more energy efficient technologies for the residential sector are estimated. This paper focused on energy service demands of residential sector and their implication of the reduction of CO_2 emissions and a cost-effectiveness assessment of low-carbon technologies to achieve CO_2 emissions reduction targets by applying AIM (Asia-Pacific integrated model)/Enduse, which is a bottom-up optimization model.

2. METHODOLOGY

Figure 1 shows the flow of the modeling framework of AIM/Enduse.

Figure 1 Modeling Framework



There are three steps. First step is to make the assumptions on key socioeconomic indicators that are used in the model for the future. Secondly, it is to estimate household energy service demand to see how much GHG emission occurs by using optimization of AIM/Enduse model. Lastly, the MAC curve is estimated to show the expected amount of reduction with specific technology options for the residential sector.

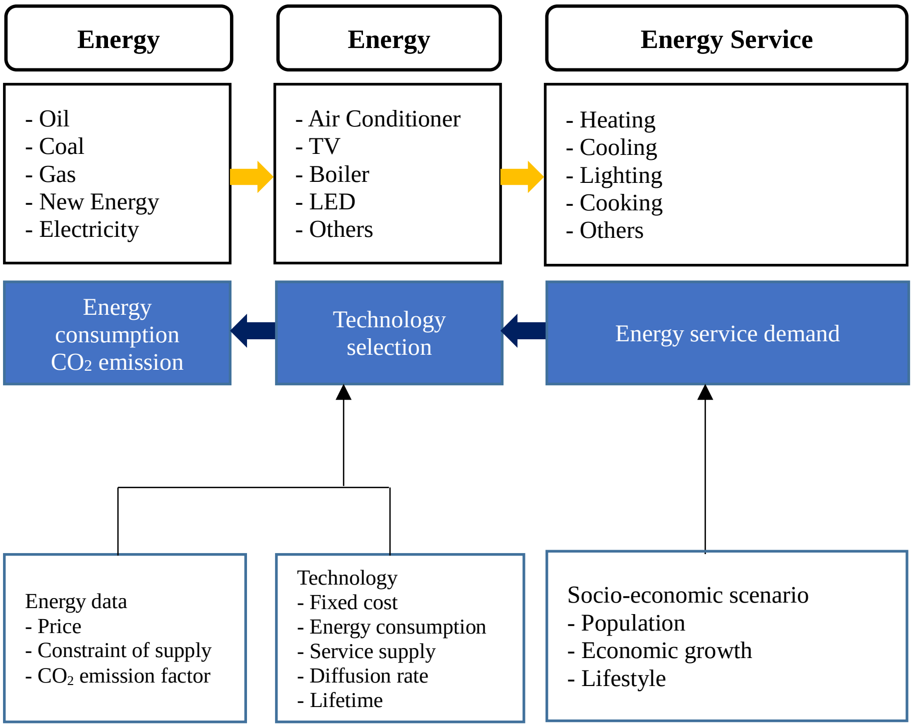
2.1. AIM/Enduse Model

AIM/Enduse is a bottom-up optimization framework to select a proper technology for policy analysis on mitigating GHG emissions and controlling local air pollution. It simulates economic energy flow with the supply of primary energy and materials by the supply and conversion of secondary energy and materials, to satisfy energy services (Hanaoka *et al*., 2015). Figure 2 shows the structure of the AIM/Enduse Model. 'Energy technology' provides a useful service for energy consumption. 'Energy service' refers to a measurable need that must be satisfied. As an example, the air conditioner is an energy technology and the space cooling is an energy service in residential sector. The energy service unit varies with the type of service.

The energy-service demands in this model are scenarios based or results from other models. The combination of technologies is calculated to satisfy service demands. And then, the consuming energy is calculated from the specific energy consumption of each technology and the combination of technologies. Finally, the CO_2 emissions are calculated from the energy consumption and the emission factors.

The AIM/Enduse model has an energy service system linked to the information about service technology. The system is composed of final energy services, external energy, internal services/energy and service technologies. Final service in the residential sector are from outside of the energy system such as lighting, cooling, heating and cooking. The demands of the final services are based on socio-economic information. A service technology provides several energy services. Selecting service technologies

Figure 2 Structure of AIM/Enduse Model

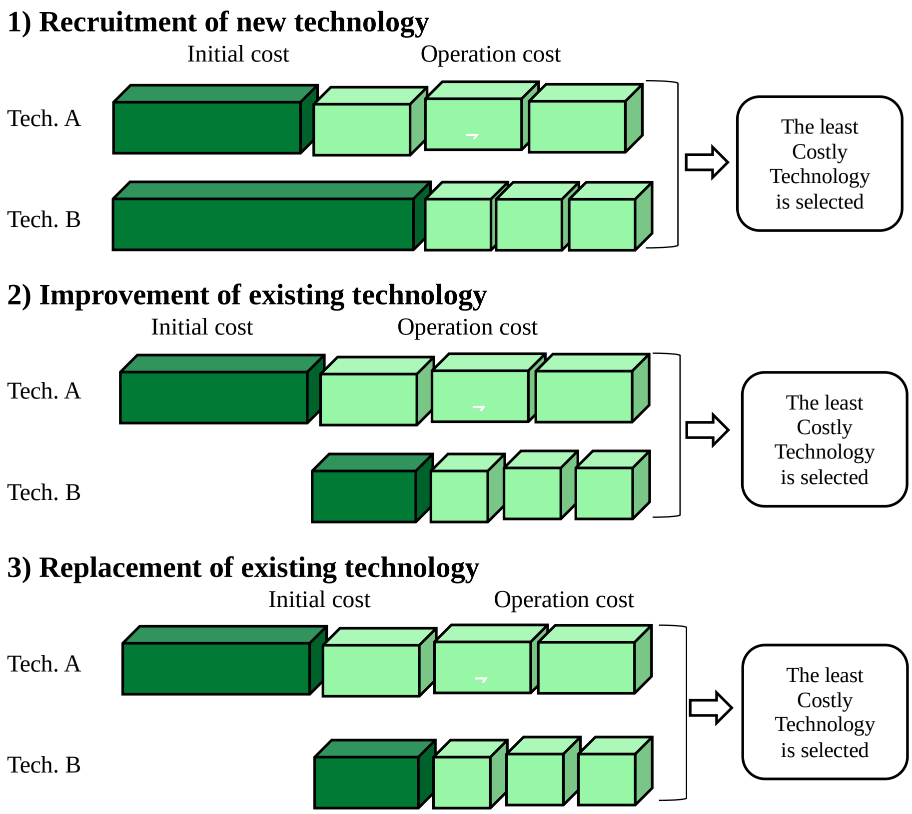


Source: T. Hanaoka *et al.* (2015).

is the most important factor in the bottom-up model like AIM/Enduse (Kainuma *et al.*, 2000).

The AIM/Enduse model combines energy technologies to minimize the total cost of annual energy services which has some limits, such as energy availability and the maximum share of the diffusion of a specific technology. It is logical to select a cost-efficient one to provide services to minimize the total cost of energy services. Three types of cohort could be considered simultaneously in the AIM/Enduse model: (1) Application of new technology at the end of life time of the old technology service or when there is an increase in energy service demand. (2) Improvement of an existing technology. (3) Replacement of an existing technology while it still in service (see figure 3). In the first type of cohort, the least costly technology is selected, which

Figure 3 Logic of Technology Selection



Source: T. Hanaoka *et al*. (2015).

includes energy and maintenance cost. In the second type, by comparing the total cost and the 3-year running cost before improvement, improvements are accepted. In the case of the last cohort, the 3-year running cost of the working technology and the total cost are compared (T. Hanaoka *et al*., 2015).

2.2. Socio-Economic Assumptions

In order to estimate future service demands, it is important to make some assumptions on the growth rate of population and that of GDP. In this paper, the rates of population growth and GDP growth based on the SSP scenario developed by IIASA and OECD are used to keep the consistency with similar studies for other countries with common SSP storylines. According to the SSP2 scenario, the total population of Korea is projected to increase up to 2030, and to decrease from 49.4 million people in 2030 to 48.8 million people in 2050. The gross domestic product (GDP) in SSP2 will grow by 3.2% from 2010 to 2030, and by 2.6% from 2031 to 2050 annually according to OECD outlook.

2.3. CO_2 Emission Scenarios

Two emission scenarios are considered to project the future estimation. (1) Business as usual scenario (BAU) is included as a consequence of technological progress in the future. (2) Reduction scenario (RD), which is 30% reduction of CO_2 emissions in 2050 compared to BAU level is anticipated with CO_2 mitigation options. In the BAU scenario, energy efficient technologies are allowed to use in the future market. However, it should be used under a condition to minimize the total system cost and the effects of 'no regret' mitigation options. In the RD scenario, CO_2 emissions in the residential sector are set to decrease, compared with those of BAU scenario. The emissions cap refers to the reduction target by 2030 announced by the Korean government (IEA, 2012). The RD penetration rate of efficient technologies must reach a higher level than BAU to meet the emission cap. Table 1 summarizes the definitions of the two scenarios.

Table 1 Scenario Definitions

Scenario	Abbreviation	Definition
Business as Usual	BAU	Autonomous energy efficiency improvements are included to some extent as a consequence of technological progress
		No emissions cap, no emissions tax
Reduction	RD	Emissions cap: 30% reduction compared to the BAU level in the target year
		Efficient technologies are introduced into the market in order to meet the pre-set emissions cap

2.4. Marginal Abatement Cost (MAC)

Policy makers seek to find affordable policy and measures to reduce CO_2 emissions. Marginal abatement cost (MAC) curves have been used to represent the economic and technological feasibility of CO_2 mitigation options and technologies. A MAC curve indicates the marginal cost (the cost of the last unit) of emission abatement for varying amounts of emission reduction (F. Kesicki, 2011). The MAC curves are based on the individual assessment of abatement measures, such as an assessment of the cost, emission reduction potential, and ranking of the measures according to their costs (F. Kesicki, 2011). The marginal abatement is easily calculated using equation (1):

$$MAC_{j,t} = \left(C_{j,t} - C_{i,t}\right) / \left(E_{i,t} - E_{j,t}\right). \quad (1)$$

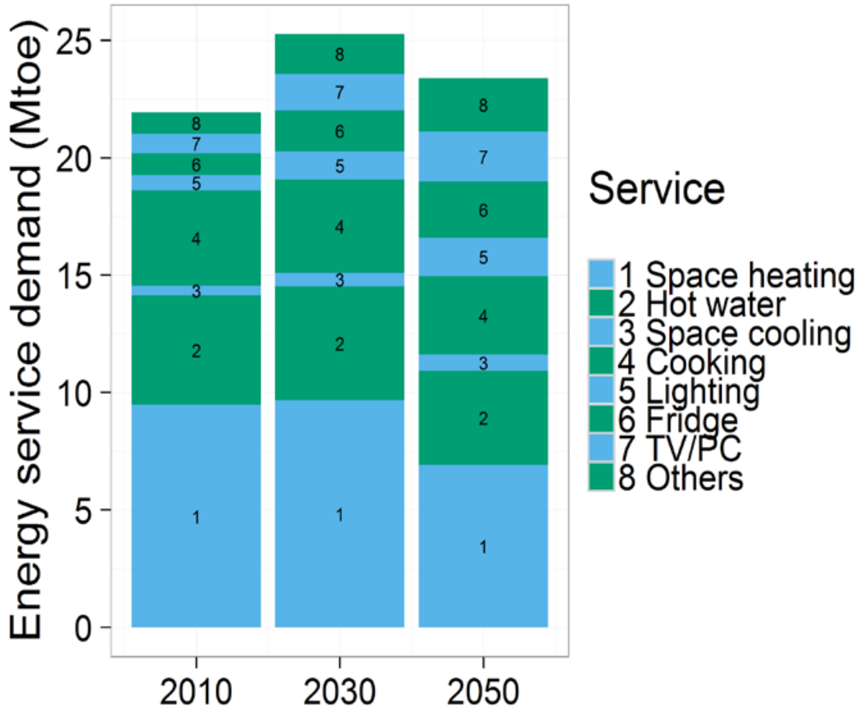
The MAC is defined at time t for technology j, which is a substitute technology to i. $E_{i,t}$ is the CO_2 emission of technology i in BAU scenario and $E_{j,t}$ is the CO_2 emission of the substitute technology j in low carbon scenario. $C_{i,t}$ is the net present value (NPV) of technology i, associated with $E_{i,t}$ and $C_{j,t}$ is the NPV of technology j, associated with $E_{j,t}$. Afterwards, MAC curve for each low carbon measure (*y*-axis) with associated CO_2 reduction potential (*x*-axis) is in numerical order from lowest to highest marginal abatement cost, to complete the MAC curve.

3. RESULTS AND DISCUSSION

3.1. Energy Service Demand

According to the AIM/Enduse, final energy service demand does not grow significantly up to 2050, which is predominantly due to population decline (see figure 4). Energy service demand in the residential sector increases to 1.15 times in 2030 and 1.08 times in 2050. It is also shown that energy service

Figure 4 Energy-Service Demand in the Residential Sector

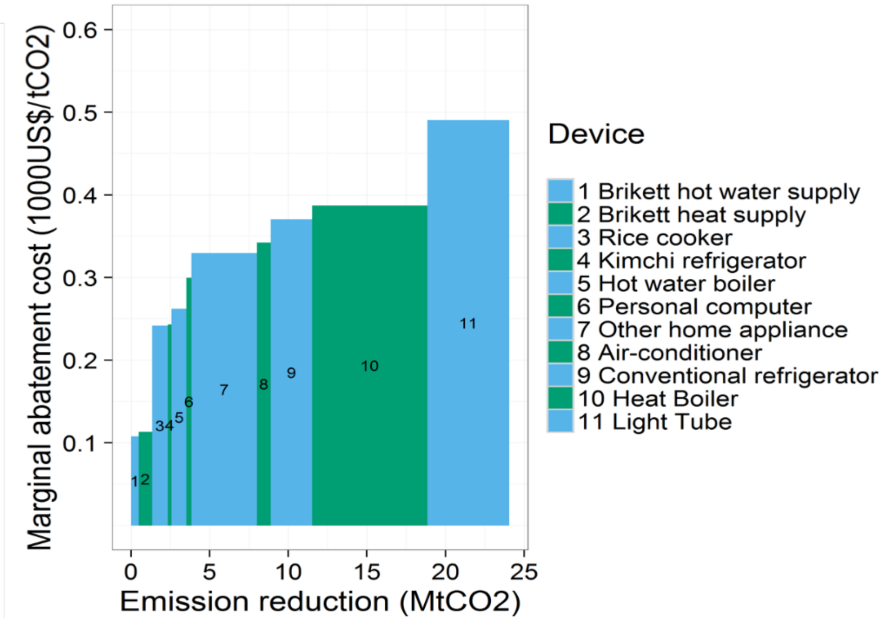


demand for heating and hot water is decreasing due to the temperature increase by climate change. On the other hand, cooling service demand appears to be increasing slightly. Other services using electricity are expected to increase their service demand because of higher income level and more home appliances. Energy demand for cooking is assumed to be decreasing as the people's life patterns are changed to less cooking at home.

3.2. RD Scenario and MAC

According to the BAU scenario, GHG emissions in the residential sector will peak, and emit 76 $MtCO_2$-eq. in 2030. After 2030, GHG emissions will decrease to 72 $MtCO_2$-eq. due to the decline of population. The RD (30% reduction from BAU in 2050) scenario, on the other hand, shows a positive

Figure 5 MAC Curve for the Korean Residential Sector in 2050



MAC curve which requires a cost of implementing high-efficiency energy devices. The 30% reduction scenario shows that GHG emissions could be reduced by 21 $MtCO_2$-eq. in 2050 compared to the BAU in the entire residential sector, and it would cost in the range of 100 to 500 dollars in US per ton of CO_2-eq. Based on the optimal technology selection, the advanced brisket boiler technologies would be the most beneficial mitigation option with low MAC values, as shown in figure 5.

However, the amount of reduction contribution is small because of energy supply infrastructure system: most of households use town-gas for heating and hot-water. Energy saving from implementing high efficient (town-gas) heat boiler would contribute to the largest CO_2 emission reduction of 7.3 $MtCO_2$-eq. The MAC curve tells us that the substitute for tube type LED is highest due to the current price. Since the price of LED light tends to decrease, if the price goes down in the future, LED light could be a competitive option for GHS emissions reduction in the residential sector. Despite the fact that reduction potential of an air-conditioner is low, it still is important because its usage proliferates during the summer peak time and it affects the stability of the entire power system. With the current structure of electricity price system for the residential sector, which has six phases of a progressive rate, the usage of the air-conditioner is restricted due to the high cost, but if the power charging system changes, this could have an impact on the limited usage. Increasing efficiency of air-conditioner usage will become a major factor if the climate change of global warming continues. Refrigerators and other home appliances have a high reduction potential in the residential sector.

4. CONCLUSIONS AND POLICY IMPLICATION

In this paper, GHG emission, its reduction and MAC for the residential sector in Korea is examined with AIM/Enduse model. The BAU scenario was used as a reference case, and its technology mix is assumed to be the same for the whole period of time up to 2050. In the BAU scenario, energy service in the residential sector will increase to 23 million ton of oil equivalent (MTOE) in 2050, resulting in substantial CO_2 emissions of 72 $MtCO_2$-eq. in 2050. In a 30% reduction scenario, 24 $MtCO_2$-eq. of CO_2 emission reduction is expected with adoption of high energy efficient devices and technologies in 2050.

The implicit marginal abatement cost of technologies demonstrated how much marginal abatement costs vary for different services. The positive values of MAC indicate necessary information for the implementation of deployment policies and research policies to foster innovation. The range of reasonable and positive value for MAC is the most attractive to the implementation of market-based policies and the resulting level of abatement or carbon price. In this MAC analysis, the advanced technologies such as heating and lighting would have substantial reduction potential with a competitive cost. Reduction potential on air-conditioner is very slight. However, if global warming continues and the stability of the power system due to the peak demand of air-conditioner from the residential sector are considered, it is quite necessary to develop policies to promote high energy-efficient devices and home appliances for the residential sector.

Based on the results, the numbers in the range of 100\$/tCO_2-eq. to 500\$/tCO_2-eq. are required to meet the 30% reduction target. Numbers between –200\$/tCO_2-eq. and 500\$/tCO_2-eq. are the most reasonable for Korea residential sector (Chung *et al*., 2015). For the case of Toronto, Canada, MAC curve has a range of –600\$/tCO_2-eq. to 2,400\$/tCO_2-eq. by sectors in 2050 (Ibrahim and Kennedy, 2016). Our results show relatively high values of MAC compared to those from two studies. But, the range of 100\$/tCO_2-eq. to 500\$/tCO_2-eq. is reasonable because 'no regret' case is already applied in our BAU scenario. In order to meet the GHG emission targets, it is necessary for a society to agree on such targets, since we have to bear the additional social cost as follows: according to our analysis, approximately 8.8 billion dollars, in other words, 170\$ per person, are needed in the entire residential sector to meet the reduction target. It is a significant cost when we compare it to the total budget of government. In 2017, South Korea invested 468 dollars per capita for social overhead capital (SOC).

Obviously, uncertainty remains in further studies. However, uncertainty could be examined if sensitivity analyses are applied to inputs such as technology costs, energy prices, GHG intensity of electricity, adoption rates and market penetration of technology, existing infrastructure stock and existing implementation of measures, and discount rate. The methodology for marginal abatement cost curves has developed to be able to apply to the residential sector in Korea and it made them available to consider more energy efficient devices. In the policy perspective, the government should implement incentive policies for the residential sector to achieve the target of GHG reduction.

MAC curve analysis needs to be updated and improved by adding more technology options with various GHG mitigation policy measures, modifying socio economic assumptions, and revising abatement potentials based on the rates of technological diffusion and market penetration.

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