Dissertation for the Degree of
Master of Landscape Architecture

Estimation of Energy Consumption and Greenhouse Gas Emissions Considering Aging and Climate Change in the Residential Sector, 2010-2050

고령화 특성과 기후변화를 반영한 가정 부문 에너지 사용량 및 온실가스 배출량 변화 예측, 2010-2050

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Abstract

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The impacts of climate change are a global concern. Rising temperatures are of particular importance, and expected to continue to increase over time. To counter this phenomenon, many nations are aiming to reduce greenhouse gas (GHG) emissions through energy demand management. This key set of policies call upon energy consumption and GHG emissions estimates to combat rising temperatures. Demographic factors such as socio-economic status and age, as well as climate change, are important components of accurate estimations in this regard. The aging demographic is especially noteworthy, because of its prominence worldwide. South Korea is the fastest aging country in the world, and can thus provide a look at the most dramatic aging scenario. Therefore, this study estimates energy consumption and GHG emissions in the residential sector of South Korea through both climate change and demographic characteristics.

This study examines four scenarios from 2010 as the base year, and 2050 as the target year setting four scenarios. The first scenario considers a change in socio-economic elements: GDP and population, the second scenario includes socio-economic elements in scenario 1 plus climate change. The third scenario further adds aging characteristics such as the length of time spent at home and income of the elderly in addition to scenario 2 taking climate change and socio-economic change. Lastly, scenario 4 includes the components of scenario 3 and introduces energy reduction policies. The methodology for evaluating each scenario follows three steps: 1) determining socio-economic factors, climate change factors, and aging factors; 2) estimating energy service demand using an estimation formula; and 3) estimating energy consumption and GHG emissions using an adapted AIM/end-use model.

Results show that energy consumption increase from 21.9 Million Tons of Oil Equivalent (MTOE) in 2010 to 26.02 MTOE in scenario 1, 25.05 MTOE in scenario 2, and 29.91 MTOE in scenario 3 in 2050. GHG emissions also increase 68.88 Million Tons of CO_2 Equivalent (MT CO_2 eq.) in 2010 to 106.38 MT CO_2 eq. in scenario 1, 104.36 MT CO_2 eq. in scenario 2, and 122.18 MT CO_2 eq. in scenario 3 in 2050. This growth is caused by an aging population who stays at home longer and thus increases heating energy use, and an increase in cooling energy demand due to rising temperatures. However, the addition of energy reduction policies in scenario 4 considerably reduced energy consumption and GHG emissions, 23.37 MTOE and 86.44 MT CO eq. in scenario 4 in 2050. In conclusion, this study is useful in preparing energy demand management and establishing and attaining GHG emissions reduction goals.

Keyword: AIM/end-use model, Heating degree days and Cooling degree days, Energy service demand, RCP scenarios, Socio-economic change

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1. Introduction

1.1. Background

The impacts of climate change can be observed across the globe, particularly with the increase in emissions of CO_2 the most influential greenhouse gas (GHG) (IPCC, 2013). Thus, climate change and its impacts are expected to continue to increase.

Rising temperatures and abnormal weather conditions are representative of climate change. According to Representative Concentration Pathways (RCP) scenarios, temperatures simulated by the RCP 4.5 scenario will rise 2.8℃, and as simulated by the RCP 8.5 scenario will rise 4.8℃ by the end of the 21^{st} century (2070−2099). In particular, rising temperatures in South Korea have been reported as reaching a level twice that of the global average increase in temperature (Korea Meteorological Administration, 2014).

The impacts of rising temperatures will affect energy consumption and cause ecosystem changes as well (Lim et al., 2013; Wilbanks et al., 2008). Energy demand management is a key policy in meeting a target maximum increase of 2℃ and in establishing countermeasures required in an energy master plan (IPCC, 2013).

Climate change is not the only factor affecting energy consumption. Demographic factors are potential key drivers of energy consumption (Chen, 2014; Dietz and Rosa, 1997; Garau, Lecca, and Mandras, 2013; York, 2007), in any estimation of energy consumption and GHG emissions (Dalton et al., 2008).

An aging population manifest a noticeable demographic change. South Korea is the world's fastest aging nation (Kim and Park, 2014) and energy use and consumption patterns expected to change accordingly. Therefore, it is necessary to reflect the aging population in estimations of future energy use and GHG emissions to improve their accuracy(O'Neill et al., 2010, 2012; Shi, 2003; Tonn and Eisenberg, 2007).

There have been several studies on the impacts of aging on energy consumption and GHG emissions. Won (2012) analyzed the impacts focused on electricity demand, while Kim and Park (2014) studied the effects of aging on energy use and CO_2 emissions through household consumption. However, the former reflected only electricity demand and the latter considered household consumption to the exclusion of other factors.

More studies on aging and energy consumption have been conducted internationally than in Korea. Yamasaki and Tominaga (1997) investigated the effects of aging on energy consumption in the residential sector, and looked for a correlation between the two. Dalton et al., (2008) studied the effects of aging on future GHG emissions in the United States using the Population–Environment–Technology (PET) model. Kronenberg (2009) analyzed the impacts of demographic changes in Germany on energy use and GHG emissions. Many literature reviews have established that aging affects energy consumption and GHG emissions.

1.2. Research objectives

Numerous nations have attempted to reduce GHG emissions to ameliorate the impacts of climate change, and all these country have reported their intended nationally determined contributions (INDC) according to the establishment of a new climate regime. South Korea aims to reduce 2030 GHG emissions by 37% from business as usual (BAU) levels. Emissions from the residential sector account for 11.9% of the total emissions in the country in 2010. In addition, the residential sector has many potential avenues of emission reduction such as lifestyle changes, and renewable energy policies; the residential sector thus plays an important role in meeting the reduction target.

As such, an accurate estimation of GHG emissions is necessary to set a realistic reduction target. Current INDC GHG BAU emissions from the residential sector have been estimated without considering climate change and demographic factors, although the emissions are in fact affected by various factors. Therefore, this study estimated energy consumption and GHG emissions from the residential sector considering climate change and aging characteristics. This research will be useful in the preparation of energy demand management policies and the establishment of attainable GHG emission reduction goals.

2. Literature Review

2.1. Greenhouse Gas Emissions and INDC

Climate change has been intensifying, so a number of negative effects are observed. GHG emissions are identified as the main cause of climate change, thus lots of countries efforts to reduce GHG emissions.

However, comments on GHG emissions reduction has sparked disagreement between developed and developing countries. Countries compromised their opinions, so each countries decided to submit a GHG reduction target, 'Intended Nationally Determined Contributions' (INDC) in new climate regime negotiation(International Energy Agency, 2007). South Korea also submitted a GHG emissions target by 37 percent from BAU levels.

GHG emissions of South Korea in 2010 is 657.1 MTOE, and it is more than twice in 1990, 241.5 MTOE. GHG emissions in 2012 ranked eighth in the world (National Greenhouse Gas Inventory Report of Korea, 2014), it showed a tendency to increase steadily. Therefore, South Korea need a systematic and specific plan to cut GHG emissions.

The government announced 'National GHG emissions reduction roadmap for 2020' before announcing INDC(Interagency Ministry, 2014). The government established a step by step reduction target for each sectors, and reduction rate in the infrastructure sector including residential is the second highest rates accounted for 26.9 percent by the transport sector. That is, the residential sector has a huge potential reduction in GHG emissions.

2.2. Climate Change and Energy Consumption

Heating and cooling service are the most sensitive service to the climate change for estimation energy consumption in residential sector. Because heating and cooling service include heating degree days (HDD) and cooling degree days (CDD) as variables for estimation energy service demand. HDD and CDD are an quantitative index to reflect energy demand for heating and cooling buildings, and lots of researchers use this to estimate the effects of climate change in energy demand (Matzarakis and Balafoutis, 2004; Christenson et al., 2006; Lee et al., 2014).

Various studies were conducted to estimate heating and cooling degree days at home and abroad. Calculation formula based on the base temperature and daily, monthly, and annual temperature is a little bit different depending on each method, but basic form is similar. (Mourshed, 2012) suggested four kinds calculation formula in study.

First, 'Hourly method' is calculated using base temperature and hourly outdoor air temperature. This method is the most accurate method mathematically, but it is necessary hourly temperature data. HDD_d is heating degree days, CDD_d is cooling degree days, T_b is the base temperature, and T_i is hourly mean outdoor air temperature (Equation 1, 2).

$$HDD_d = \frac{\sum_{i=1}^{24}(T_b - T_i)^+}{24} \quad \text{Equation 1}$$

$$CDD_d = \frac{\sum_{i=1}^{24}(T_i - T_b)^+}{24} \quad \text{Equation 2}$$

Second method is ASHRAE formula. This method uses base temperature and daily mean outdoor temperature. T_b is the base temperature, T_d is daily mean outdoor air temperature, T_{max} is daily maximum outdoor air temperature, and T_{min} is daily minimum outdoor air temperature (Equation 3, 4, 5).

$$\boldsymbol{HDD_d = (T_b - T_d)^+} \quad \text{Equation 3}$$

$$\boldsymbol{CDD_d = (T_d - T_b)^+} \quad \text{Equation 4}$$

$$\boldsymbol{T_d = \frac{(T_{max} + T_{min})}{2}} \qquad \text{Equation 5}$$

Third method is the UKMO formula. The UKMO formula uses the base temperature, maximum and minimum temperature. HDD and CDD is estimated by scenarios based on relationships between the base temperature and diurnal temperature variation (Equation 6, 7).

$$\boldsymbol{HDD_d = \begin{cases} T_b - 0.5(T_{max} + T_{min}), & T_{max} \le T_b; \\ 0.5(T_b - T_{min}) - 0.25(T_{max} - T_b), & T_{min} < T_b; and\ (T_{max} - T_b) < (T_b - T_{min}); \\ 0.25(T_b - T_{min}), & T_{max} > T_b; and\ (T_{max} - T_b) > (T_b - T_{min}); \\ 0, & T_{min} \ge T_b. \end{cases}}$$

Equation 6

$$\boldsymbol{CDD_d = \begin{cases} 0.5(T_{max} + T_{min}) - T_b, & T_{min} \ge T_b; \\ 0.5(T_{max} - T_b) - 0.25(T_b - T_{min}), & T_{max} > T_b; and\ (T_{max} - T_b) > (T_b - T_{min}); \\ 0.25(T_{max} - T_b), & T_{max} < T_b; and\ (T_{max} - T_b) < (T_b - T_{min}); \\ 0, & T_{min} \le T_b. \end{cases}}$$

Equation 7

The last method is Schoenau−Kehrig monthly mean temperature method. This method was developed by Schoenau and Kehrig, and is one of the generally adopted methods. It uses the base temperature, monthly mean temperature, and the number of days in the month. N is the number of days in the month, Z_b is the difference between base temperature and monthly mean temperature divided S_d, which is standard deviation of the daily mean temperature (Equation 8, 9, 10, 11).

$$HDD_m = NS_d[Z_b F(Z_b) + \mathrm{f}(Z_b)] \qquad \text{Equation 8}$$

$$Z_b = \frac{(T_b - T_m)}{S_d} \qquad \text{Equation 9}$$

$$CDD_m = NS_d[Z_b F(Z_b) + \mathrm{f}(Z_b)] \qquad \text{Equation 10}$$

$$Z_b = \frac{(T_m - T_b)}{S_d} \qquad \text{Equation 11}$$

Function f is the Gaussian probability density function, and function F is the equivalent cumulative normal probability function (Equation 12, 13).

$$\mathrm{f(Z)} = \frac{1}{2\pi}\exp\left(\frac{-Z^2}{2}\right) \qquad \text{Equation 12}$$

$$\mathrm{F(Z)} = \int_{-\infty}^{Z} f(z)dz \qquad \text{Equation 13}$$

The domestic studies were reviewed to determine what the climatic conditions of the domestic is suitable besides four kinds of formulas. Seo (2013) estimated HDD and CDD by city. This study suggested four formulas; hourly method, official method of the United Kingdom, official method of the United States and Germany, and the basic formula. This paper used the basic formula, and θ_b is the base temperature, and θ_o is daily mean outdoor air temperature (Equation 14, 15).

$$H_d = \sum_{i=1}^{N}(\theta_b - \theta_o)^+ \qquad \text{Equation 14}$$

$$C_d = \sum_{i=1}^{N}(\theta_o - \theta_b)^+ \qquad \text{Equation 15}$$

In the result of this study, errors were obtained between hourly method and other three formulas, and the basic formula showed the lowest error compared to others. Lee et al., (2014) also used the same formula to estimate the future HDD and CDD change using climate change scenario.

2.3. Aging and Energy Consumption

Aging in demographic change is considered serious social problems in South Korea as well as around the world. So numerous nations have conducted studies to discover a link between aging characteristics and energy consumption and GHG emissions and estimated considering it.

Yamasaki and Tominaga (1997) had conducted to determine eight aging factors that affected energy demand in residential sector in Japan, and predicted the future energy consumption. This study estimated energy use in 2010 compared to it in 1995. In consequence, elderly household uses more energy than no aging households and energy demand in residential grow by 47 percent.

Dalton et al. (2008) studied aging and CO_2 emissions in the United States. This study considered change of age structure based on the cohort study and estimated energy consumption and CO_2 emissions in 2010 to in2100 through the Population–Environment–Technology (PET) model. As a results, wages, capital, and labor decreased due to aging, and concluded that CO_2 emissions in 2100 were down.

Kronenberg (2009) researched the effects of demographic change on energy use and GHG emissions in Germany. This study predicted demand through an environmental input–output (EIO) model using consumption expenditure of households by commodity group. Consequently, energy demand for heating increased and for transporting decreased in aging households.

Hamza and Gilroy (2011) estimated energy consumption due to aging and suggested the reduction method on fuel poverty in the United Kingdom. People over 65 spent 85 percent of their time at home, but a third of them did not use enough energy because of poverty. However, this study suggested that energy consumption will increase in the future because import growth and efficiency improvement of energy will mitigate fuel poverty.

In the domestic studies, Won (2012) researched the impacts of aging on energy consumption in residential using electric power cost, income, and aging. This study analyzed the long and short-term effects, as a results, suggested that aging reduce demand for electricity.

Kim and Park (2014) considered the effects of aging on consumption expenditure of households and estimated change of energy use and CO_2 emissions through change of consumption structure from 2010 to 2035. In conclusion, energy use and CO_2 emissions was on the rise due to aging.

The results of studies are different. Because they analyzed different scope of the study. Won (2012) included only electricity, but Kim and Park (2014) included energy use about house and transport for households. However, they are consistent about same scope. For example, aging population use more energy for heating.

2.4. Synthesis

Accurate BAU estimation is required to keep the international commitments according to establishment of new climate system and submission of INDC. The measure of meeting a goal, Korea's INDC was organized based on 2020 reducing target, exact estimation is need to meet a reduction target through considering numerous factors in estimation GHG emissions. Residential sector of many sectors which emit GHG emissions has great reduction potential, and can reflect climate change, morphological feature, and socio-economic factors change in substance(Liddle & Lung, 2010; Menz & Welsch, 2010, 2012). Therefore, this study examined that how each factors effect energy use in residential sector through literature reviews.

First, it is reasonable to estimate the energy consumption and GHG emissions considering climate change because lots of countries discuss new climate system to overcome pasture climate change measure and prepare new climate change system. Thus, this study searched estimation formula of HDD and CDD including climate change factors through literature reviews.

Second, aging was investigated at the impact on energy use. There are lots of papers about the effect of aging on energy consumption at home and abroad, but they are not suitable for domestic state, and also suggest conflicting results by papers because of circumstances and conditions of countries. Meanwhile, in domestic research, accurate estimation of energy consumption and GHG emissions is not enough. They just considered electricity demand or expenditure structure. In addition, the elderly of South Korea use little energy than other age group unlike overseas because there are lots of low-income seniors. Therefore, the research which estimates accurately energy consumption and GHG emissions is needed to fit the national situation, and consider circumstance and policy of South Korea.

3. Methodology

3.1. Scope of the Study

This study focused on energy end-use for the residential sector of South Korea, using 2010 as the base year and 2050 as the target year for emission reduction. The Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report suggested that Asia cut GHG emissions by 30-50% from 2010 to 2050, and set 2050 and 2100 as mid-term and long-term targets. The reduction of GHG emissions is a key measure for energy management and mid/long-term prospects could be linked to the national energy system planning; thus, this study set 2050 as the target year to attain realistic prospects. This study considered climate change, demographic change, and aging on energy consumption and GHG emissions.

3.2. Database for the study

The research considered two scenarios; shared socio-economic pathways (SSP) are used for socio-economic factors, and representative concentration pathways (RCP) scenarios are used for climate change factors. The International Institute for Applied Systems Analysis (IIASA) combined national socio-economic change, policy, and technology to forecast future socio-economic change. Statistics Korea also forecasted future population based on births, deaths, and other factors. Lastly, the IPCC determined GHG concentrations by the amount of radiation affecting the atmosphere as caused by human activities.

3.3. Method

3.3.1. Research flow

Figure 1 shows the flow of this research. This study aimed to estimate energy service demand considering an aging population and climate change factors, and subsequently energy consumption and GHG emissions through the AIM/end−use model. Aging and climate change factors were reflected in the energy service demand estimation stage. The basic structure of energy service demand is composed of activity (A), structure (S), and intensity (I), and intensity includes aging and climate change factors. Lastly, energy service demand was estimated using the factors.

Energy consumption and GHG emissions were estimated using the AIM/end−use model, which estimated emissions using calculated energy service demand. In this study, the model was suitable for the residential sector in South Korea, as it considered impacts of energy service demand, the introduction of technology, and emission reduction policies on estimations of energy consumption. Next, GHG emissions were estimated using energy consumption and emissions factors. Finally, the results were verified based on real data.

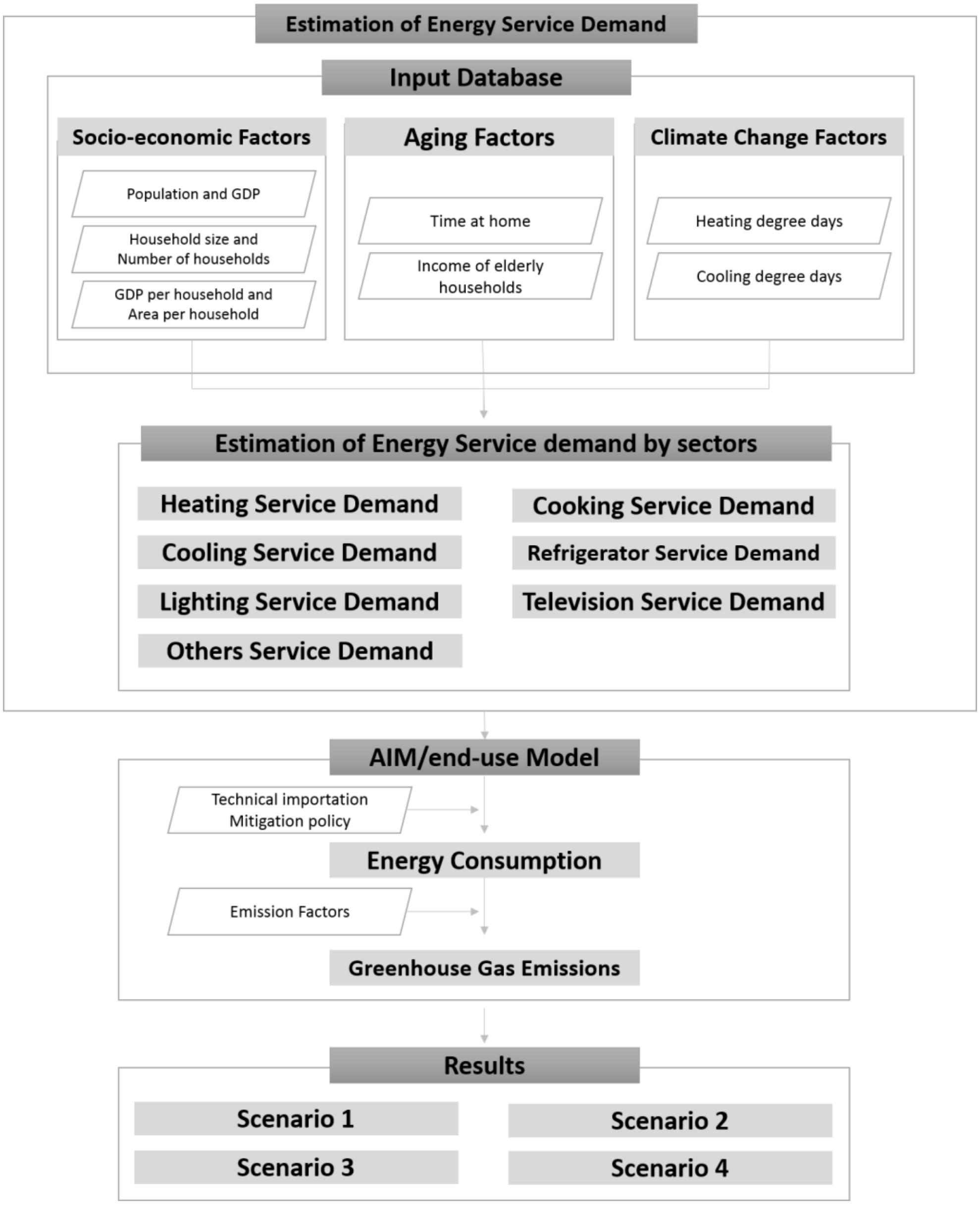

Fig. 1. Research flow

3.3.2. Energy service demand estimation

3.3.2.1. Base structure of energy service demand

Energy service demand is different from energy demand. Energy demand is just the amount of energy that is required, while energy service demand is reflecting device efficiency on energy consumption.

Energy service flow in the residential sector entails energy, devices, and services. Devices used in the residential sector include such characteristics as energy consumption, service output, lifetime, and installation charge. Efficiency means the ratio between energy input and output.

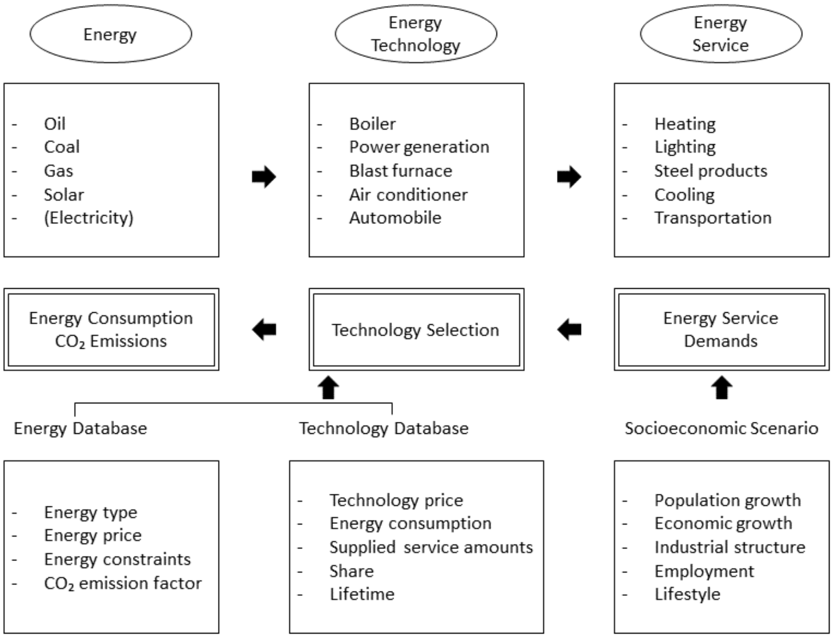

Fig. 2. The structure of AIM/end−use model
(National Institute for Environmental Studies, 2006)

Figure 2 represents the structure of the AIM/end−use model. Energy technology means a device providing a useful energy service. Energy service is a visible or abstract concept to measure output from devices such as heating, lighting, and cooling. Energy service demand refers to a quantified demand produced by the service, and the service output from devices meets the service demand. Energy service demand in the model is determined on the basis of the scenarios or simulation results from different models (National Institute for Environmental Studies, 2006)

Schipper and Meyers (1992) suggested the formula of energy service demand for the residential sector.

$$\mathbf{ESD} = \sum(\boldsymbol{A} \times \boldsymbol{S} \times \boldsymbol{I}) \qquad \text{Equation 16}$$

Energy service demand is estimated using three factors: A is activity, S is structure, and I is intensity. While the estimation formula will differ by service, each formula has a fundamental structure as in equation 16 (Schipper and Meyers, 1992), in which A means the number of households, S means areas or times needing the services, and I means heating degree days (HDD), cooling degree days (CDD), efficiency of devices, insulation levels, distribution rate of home appliances and so on (Isaac and van Vuuren, 2009).

This study included the following seven services: heating, cooling, lighting, cooking, refrigeration, television, and other appliances. It estimated the energy service demand required for these services to obtain energy consumption, and estimated energy demand based on energy service demand.

Table 1. Service demand variables of the residential sector (per household)

Service	Activity	Structure	Intensity
Heating	·Number of household	·Area per household ·Time at home	·Heating degree days ·Income of elderly households
Cooling	·Number of household	·Area per household ·Time at home	·Cooling degree days ·GDP per household ·Income of elderly households
Lighting	·Number of household	·Area per household ·Time at home	
Cooking	·Household size		·GDP per household
Refrigerator TV	·Household size	·Size	·Penetration rate
Others			·GDP per household ·Income of elderly households

Estimation formulas differ based on the service (Table 1). When considering heating and cooling, A includes the number of households, S contains the area per household and length of time spent at home, and I means HDD, CDD, GDP per household, and income of the aging population used for heating and cooling services. When considering lighting, A means the number of households, S includes the area per household, and I contains the GDP per household used for lighting service. When considering cooking, A means household size, and I includes GDP per household used for cooking service. When looking at refrigerators and televisions, A means household size, S includes the size of appliances, and I contains the penetration rate used for refrigeration and television service.

When looking at other appliances, I means GDP per household, and the income of the aging population used for other appliance services.

The study regarded the length of time spent at home and income of the aging population were used for aging characteristics, and HDD and CDD were used for climate change factors.

3.3.2.2. Reflecting socio−economic factors

(1) Population and GDP

Population scenarios were created using Statistics Korea’s future prediction data because the scope of this research was limited to South Korea. Scenarios were classified into three scenarios: low, BAU, and high, according to the combined birth rate, life expectancy, and international migration.

GDP figures were used in the modified SSP scenario based on IIASA. Predictions were made by combining socio−economic change, policy, and technology. However, SSP scenarios were estimated using SSP scenario populations; therefore, this study revised GDP figures using Statistics Korea’s population data. The resulting scenarios were also classified into three scenarios, low, BAU, and high, according to policy, lifestyle, and environmental awareness levels.

Estimation of GHG emissions is important to keep international commitments and to reflect local characteristic, so it is necessary to use the international scenario and to modify using Korea local database.

(2) Household size and the number of households

Household size estimations were based on forecasted household sizes from 2010–2035 from Statistics Korea (Table 2).

Table 2. Foundation stat of household size (five year period)

Year	2010	2015	2020	2025	2030	2035
Household size	2.71	2.55	2.42	2.32	2.24	2.17

This study formulated Equation 17 by time series analysis to forecast future household size, and predicted household size by 2050. In Equation 17, H means household size and t means time. A coefficient of the model was statistically significant (p value 0.00 < 0.05), had stationarity, and the reversibility of a coefficient was ｜−0.876｜ < 1, which also satisfied validity conditions. The suitability of this model was confirmed using Ljung−Box verification. The significance probability was greater than 5% by 0.583; thus, the hypothesis was not rejected that the residual amount was white noise. Therefore, the model was deemed suitable. The number of households was estimated using predicted household size.

$$\begin{aligned} \boldsymbol{H_t} &= \mathbf{-1.335 \times [\{\boldsymbol{x}(\boldsymbol{t}-1) - \boldsymbol{x}(\boldsymbol{t}-2)\} - 0.001]} \\ &\mathbf{-0.876 \times [\{x(t-2) - x(t-3)\} - 0.001} \\ &\mathbf{+\boldsymbol{u}(\boldsymbol{t}) + 0.382 \times \boldsymbol{u}(\boldsymbol{t}-1) + 0.001} \end{aligned} \quad \text{Equation 17}$$

(3) GDP per household and floor space area per household

This study estimated GDP and floor space area per household using the predicted number of households. GDP per household was estimated using IIASA's GDP and forecasted the number of household from this study. This study did not use a fixed household size because the forecasted household sizes changed with an increase in single−person households, for example. Thus, the floor space area per household was calculated after determining the floor space area per capita, and derived by multiplying with the household size. The floor space area per capita was estimated by regression analysis using area data from the period 1990−2010 and GDP (C. Lee & Park, 2009) (Table 3).

Table 3. Foundation stat of floor space area per person (five year period)

Year	**1990**	**1995**	**2000**	**2005**	**2010**
Area/person(m^2)	13.2	15.6	17.9	21.3	24.5

The floor space area per capita was estimated by Equation18, and the R square value had a significance of 0.999. GDP is usually acted as a proxy variable on behalf of the income, the income has a close connection with the housing area (Jung, 2012; C. Lee and Park, 2009; Lee et al., 2007). The highest area per capita was applied so as not to exceed the average area per capita of other developed countries.

$$\mathbf{Area\ per\ capita} = \mathbf{45} \div (\mathbf{1} + \mathbf{4.886092} \times \mathbf{exp}(-\mathbf{0.0000795} \times \mathbf{GDP\ per\ capita})) \qquad \text{Equation 18}$$

(4) Device

The status of appliance distribution is important in estimating energy service demand from the residential sector; therefore, this study referred to the household appliance penetration rate and power consumption behavior survey conducted by Korea Power Exchange (2012).

Table 4 lists the appliances used in the study. Heating devices were boilers and electric heaters, and boilers were divided by energy source. Insulation level was classified according to the presence and degree of heating equipment, and the only cooling equipment considered was an air conditioner. Lighting devices included incandescent lamps, fluorescent lamps, and light emitting diodes (LEDs). Finally, television, refrigerator, and other appliances are considered three types: old, conventional, and efficient type. The coefficient for performance includes such concepts as energy efficiency, which is the output value for a unit value of input energy, and share means the occupied ratio by the equipment in a given year.

Table 4. Device information

Service	Device	Energy Source	Coefficient for performance	Share (2010)
Heating	Coal boiler	Coal	0.7	1%
	Kerosene boiler	Kerosene	0.8	19%
	Condensing boiler(LNG)	LNG	0.9	6%
	LNG boiler	LNG	0.8	37%
	Heat boiler	Heat	1	6%
	LPG boiler	LPG	0.8	9%
	Air conditioner, old type	Electricity	3.3	20%
	Air conditioner, conventional type	Electricity	5	
	Air conditioner, efficient type	Electricity	5	
	Air conditioner, best available technology	Electricity	5	
	Biomass boiler	Biomass	0.7	2%
	Insulation level 1 (without insulation)		1.0	40%
	Insulation level 2		2	60%
	Insulation level 3		2	
	Insulation level 4		3.3	
	Insulation level 5		3.3	
Cooling	Air conditioner, old type	Electricity	3.3	100%
	Air conditioner, conventional type	Electricity	3.3	
	Air conditioner, efficient type	Electricity	5	
	Air conditioner, best available technology	Electricity	5	
Lighting	Incandescent lamp	Electricity	1.0	8%
	Compact fluorescent lamp	Electricity	5	
	Compact fluorescent lamp, efficient type	Electricity	5	
	Fluorescent lamp	Electricity	5	92%
	Fluorescent lamp, efficient type	Electricity	5	
	LED	Electricity	20	

3.3.2.3. Reflecting aging factors

(1) Length of time spent at home

Time spent at home was derived from a lifestyle survey conducted by Statistics Korea. First, the average time spent at home by age was calculated, and the average time spent at home in 2010–2050 was estimated by multiplying the age ratio (Equation 19).

$$\textbf{Time at home} = \sum_{teen}^{old}(\boldsymbol{age\ ratio} \times \boldsymbol{average\ time\ at\ home})$$

Equation 19

(2) Income of the elderly

This study analyzed relationship between income of the elderly and energy consumption before forecasting them. In the results, the income of the elderly in Korea was lower than other age groups (Table 5).

Table 5. Income of the elderly households (2010)

	Income (Won)
20s	2,112,700
30s	3,459,740
40s	3,790,003
50s	3,458,066
Over 60s	1,529,954

However, the wealthy aging population also use lots of energy than the poor, so if the elderly's income increase, energy consumption would be increased. Figure 3 shows flow of income of the elderly. Income of the elderly was analyzed based on household survey data from Statistics Korea. Only households including the elderly were selected and analyzed to determine the relationship between energy consumption and income of the elderly. Energy consumption per household was replaced by the cost of fuel in expenditure item, and the average energy consumption by income of the elderly was estimated using household expenditure and energy use per household. Next, the future income of the aging population was determined using domestic GDP predictions and the income of the elderly and GDPs of numerous countries. Average energy consumption was calculated using the future income of the elderly.

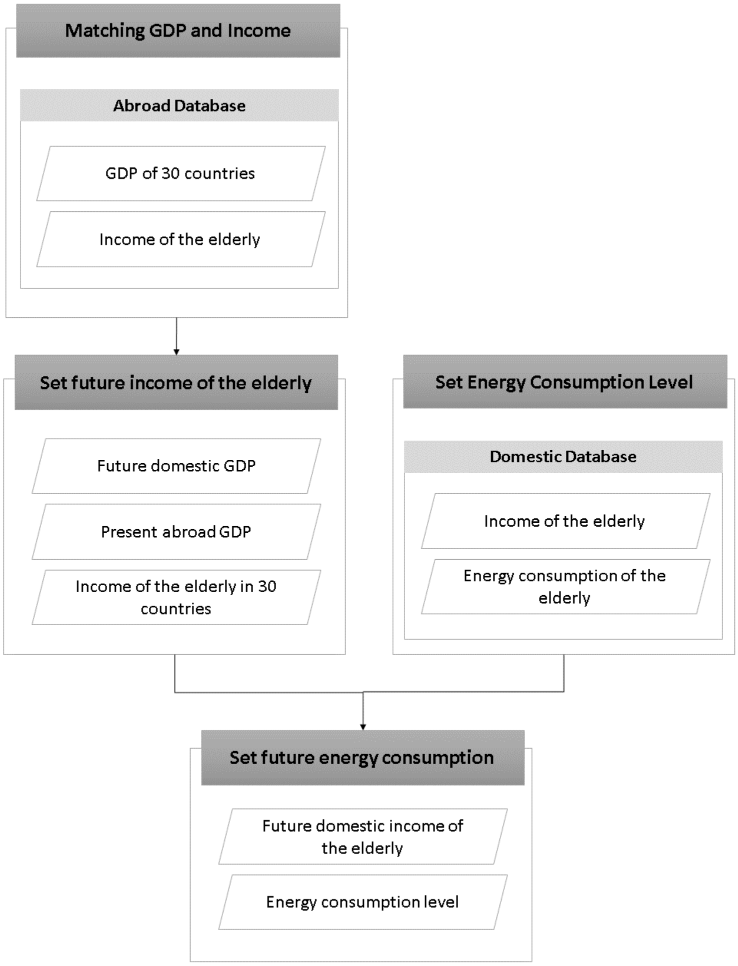

Fig. 3. Flow of income of the elderly

3.3.2.4. Reflecting climate change factors

(1) Heating degree days and cooling degree days

Heating degree days (HDD) and cooling degree days (CDD) are the sum of the temperature difference between the base temperature and the outdoor air temperature for a given time period. When the outdoor air temperature is lower than the base temperature, heating is required, and when the outdoor air temperature is higher than the base temperature, cooling is required (Lee et al., 2014). The base temperature implies a temperature that does not require the operation of heating or cooling systems to maintain comfort levels (Hekkenberg et al., 2009).

This study estimated future HDD and CDD. In the literature review, the hourly method supplies the most accurate equation, however, it requires temperature data from multiple regions by time. However, climate change scenarios do not provide temperature data by time, so this equation was not found to be suitable. Equation 20 and 21 have the lowest error as compared to the hourly method in the literature review, so this study employed these equations (Lee et al., 2014; Seo, 2013). θ_b means daily mean outdoor air temperature and θ_o means the base temperature and N is the number of days during given period.

$$\mathbf{H_d} = \sum_{i=1}^{N}(\theta_b - \theta_o)^+ \qquad \text{Equation 20}$$

$$\mathbf{C_d} = \sum_{i=1}^{N}(\theta_o - \theta_b)^+ \qquad \text{Equation 21}$$

HDD and CDD are determined by varied climate characteristics in South Korea, and are thus estimated by region (Seo, 2013). However, the base temperature of HDD and CDD is not officially defined, so many researches use different base temperatures. Thus, this study used widely used base temperatures, which are 18℃ in heating and 24℃ in cooling.

In this study, the average degree days were estimated by region after calculating the degree days for each grid area based on RCP scenarios. Next, national HDD and CDD were derived using the average degree days by region and population−weighted data. The future HDD and CDD did not consider population change, and used the 10−year mean data because climate variables exhibit large variations.

Air conditioning was used in the calculation of cooling energy service demand. The prediction of air conditioning demand is dependent on many factors, including economic, social, and climatic conditions (Sailor and Pavlova, 2003). Therefore, cooling energy service demand is predicted by Equation 22 to estimate demand and McNeil and Letschert, (2008) suggested Equation 22.

$$\mathbf{Saturation} = \mathbf{Availability}(\mathbf{Income}) \times \mathbf{ClimateMaximum}(\mathbf{CDD})$$

Equation 22

3.3.2.5. Synthesis of variables

Table 6 shows the comprehensive variables which are used in this study.

Table 6. Variables

	Variables		Database	References	Analysis method
Socio-economic	Population		Population scenarios	Statistics Korea	
	GDP		SSP scenarios	IIASA	
	Household size	2010~2035	Household Projections for Korea:2010~2035	Statistics Korea	
		2036~2050	Household Projections for Korea:2010~2035	Statistics Korea	Time series analysis
	The number of households		·Population scenarios ·Household size (2010~2050)	Statistics Korea	Population/ Household size
	GDP per household		·SSP scenarios ·Household size	IIASA Statistics Korea	GDP/Number of households
	Floor space area per capita		Floor space area per capita (1990~2010)	Korea Institute for Health and Social Affairs	Regression analysis
	Floor space area per household		·Floor space area per capita ·Household size	Korea Institute for Health and Social Affairs	Floor space area per capita x Household size
	Device		2011 Household appliances penetration rate and power consumption behavior survey	Korea Power Exchange	
Aging	The length of time spent at home		Lifestyle survey	Statistics Korea	
	Time spent at home per age		·Time spent at home ·Age ratio	Statistics Korea	Age ratio x average time at home
	Income of the elderly		Household survey data	Statistics Korea	
	Relation with Energy consumption and Income		·Income of the old ·Energy expenditure of the old	Statistics Korea OECD	Regression analysis
Climate change	Heating degree days & Cooling degree days		RCP scenarios	Korea Meteorological Administration	Estimation formula

3.3.3. Estimation of energy consumption and greenhouse gas emissions

3.3.3.1. AIM/end-use model

The model that was adapted to fit Korea's residential sector was used to forecast energy consumption and GHG emissions based on the AIM/end-use model. The AIM/end-use model was developed by the National Institute for Environmental Studies (NIES) in Japan. It estimated energy consumption and GHG emissions through selecting a technology in national energy, economic, and environmental system.

Many models estimate energy consumption and GHG emissions, but the AIM/end-use model can consider not only climate change, but also the introduction of new technology, energy price variations, policy changes, and other future economic changes. Thus, the model was used in this study.

Selecting technology in the AIM/end-use model is achieved through a linear optimization model that minimizes system costs under some constraints, including satisfying service demand, energy and material supply, and other systems in the model. System costs include initial costs, technology operating costs, energy costs, taxes and subsidies. The AIM/end-use model can calculate a number of years simultaneously, and analyze different scenarios such as policy responses (Hibino et al., 2003).

3.3.4. Reduction policy

This study considered GHG emissions reduction policies based on estimations of energy consumption through the AIM/end-use model. Table 7 lists relevant reduction policies from this model.

Table 7. Greenhouse gas emissions reduction policy

Sector	Policy	References
Heating	Vacuum Insulation Panels	Low Carbon Economy System Strategy - regional low-carbon economy system development
	Reinforced Insulation	Green Buildings Act compositions - Energy-saving Design Criteria in Apartment Housing
	Reinforced Insulation	National Greenhouse Gas Reduction Roadmap
	Condensing boiler	National Greenhouse Gas Reduction Roadmap
Cooling	High-efficiency air-conditional	Low Carbon Economy System Strategy - regional low-carbon economy system development
Lighting	High-efficiency Lighting	Low Carbon Economy System Strategy - regional low-carbon economy system development
	LED	National Greenhouse Gas Reduction Roadmap
Others	High-efficiency Appliances	National building energy conservation policy evaluation system policy effectiveness analysis models and methodologies to build
	High-efficiency Appliances	Low Carbon Economy System Strategy - regional low-carbon economy system development
	Efficiency Improvement	National Greenhouse Gas Reduction Roadmap

3.3.4.1. Scenario setting

This study estimated energy consumption and GHG emissions using four scenarios (Table 8). Scenario 1 reflected the effects of socio-economic change. Population and GDP scenario are classified as low, BAU, and high, so scenario 1 can identified the effects by each level.

Then, scenario 2 reflected the effects of climate change considering different climate change scenarios. RCP 8.5 scenario are used for climate change scenario and climate in 2010 are also used to identify the effects of climate change. Population and GDP scenario which are classified as three levels are used in scenario 2.

Scenario 3 included the impacts of an aging population on scenario 2. The length of time spent at home and the income of the elderly are used for the aging characteristics.

Lastly, scenario 4 included a reduction of the policy by adding reduction policies. This scenario considered all of factors such as socio−economic, climate change, aging and policy.

Table 8. Scenarios used in the research

Scenarios	Independent variables	Control variables
Scenario 1	·Population, GDP (Low, BAU, High) ·Climate in 2010	·Climate change ·Aging characteristics ·Reduction policy
Scenario 2	·Climate change scenarios (2010. RCP 8.5) ·Population, GDP (Low, BAU, High)	·Aging characteristics ·Reduction policy
Scenario 3	·Climate change scenarios (2010, RCP 8.5) ·Aging characteristics (Time at home, Income) ·Population, GDP (Low, BAU, High)	·Reduction policy
Scenario 4	·Climate change scenarios (2010, RCP 8.5) ·Aging characteristics (Time at home, Income) ·Reduction policy ·Population, GDP (Low, BAU, High)	-

4. Results and Discussions

4.1. Results of building variables

4.1.1. Reflecting aging characteristics

4.1.1.1. The length of time spent per day at home

The length of time spent per day at home by each age group was recorded following a lifestyle survey conducted by Statistics Korea. Table 9 shows that aging population tend to increase the length of time spent at home. Specifically, people over 60 spend more time at home than the ones in other age groups.

Table 9. Average time at home by age groups

Age	10s	20s	30s	40s	50s	Over 60s
Average time at home (min/day)	860.13	870.02	902.69	857.27	894.92	1055.23

Table 10. Age ratio in 2010 and 2050 (BAU)

Age	10s	20s	30s	40s	50s	Over 60s
2010	13%	14%	16%	17%	14%	17%
2050	7%	9%	9%	10%	14%	59%

Figure 4 shows that time at home increases from 2010 to 2050 in all the three scenarios. This is because age ratio and numbers of the elderly increase (Table 10) and older people spend more time at home. Time at home is higher in the low scenario in comparison to the high scenario in socio−economic scenario, as a low population growth attributed to low birth rate in low scenario results in increase in the ratio of the elderly.

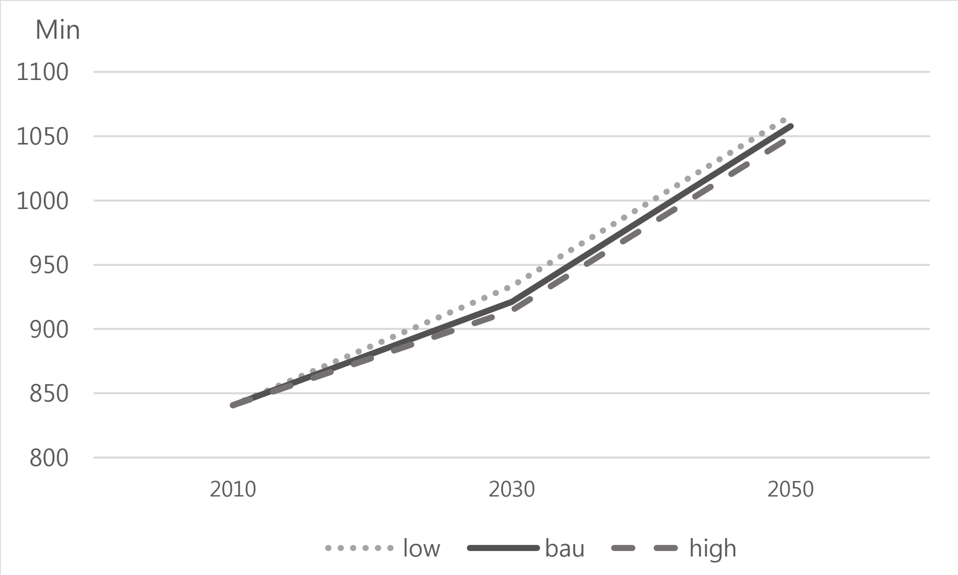

Fig. 4. Time at home (person/day)

4.1.1.2. Energy consumption according to income of the elderly

This study projects income change of the elderly using GDP and income data of the elderly from other countries. This information will be used to identify changes in energy consumption with change in income of the elderly in South Korea. Table 11 shows changes in average energy consumption based on income change of the elderly. As can be seen energy consumption increases along with income of the aging from 2010 to 2050. As there is little difference in socio-economic scenarios, these values are used for substitution in estimation formulas in this study.

Table 11. Energy consumption ratio considering the household incomes of the elderly (Compared to 2010)

	Low	BAU	High
2010	1	1	1
2030	1.042535	1.042535	1.042535
2050	1.042535	1.042535	1.055522

4.1.2. Reflecting climate change factors

4.1.2.1. Heating degree days and cooling degree days

Figure 4 shows HDD projections from 2010 to 2050 in South Korea. HDD tends to decrease generally. HDD is 2,683 degree days in base year 2010 and decreases slightly to 2,594 degree days in 2030. HDD decreases drastically to 2,471 degree days in 2050, probably because of reduction in heating usage due to rising temperatures attributed to climate change.

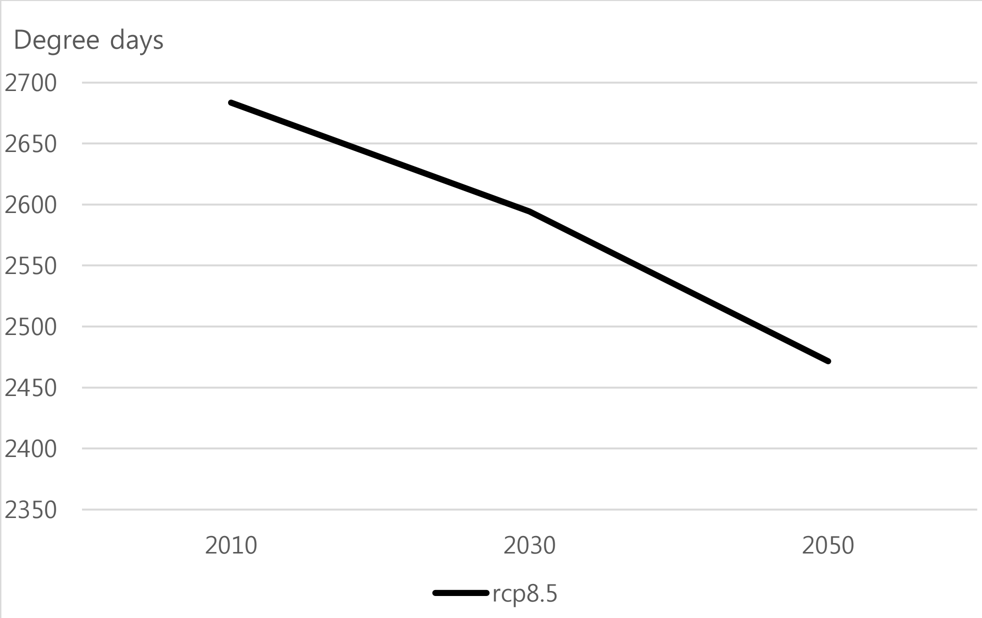

Fig. 5. Heating degree days in RCP 8.5 scenario

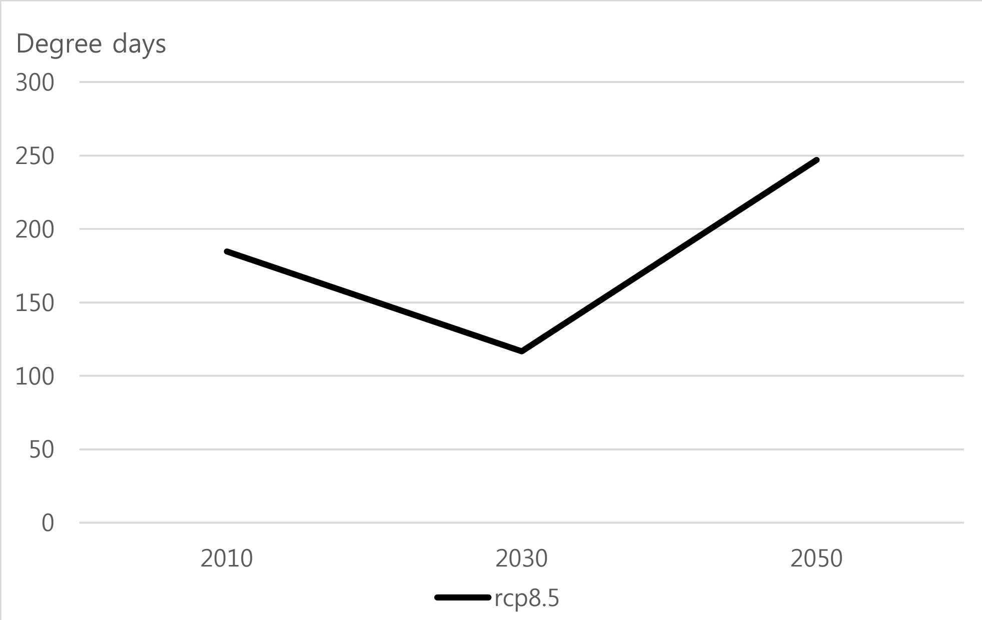

Fig. 6. Cooling degree days in RCP 8.5 scenario

However, CDD tends to increase generally (Figure 5). CDD is 184 degree days in the base year 2010 and decreases to 116 degree days in 2030, but increases after 2030. It increases continually and exceeds the base year's value in 2050. This is attributed to climate change that has a greater effect in the long−term.

4.2. Estimation of Energy Service Demand

BAU scenarios in population and GDP scenario were used only to focus on the role of individual sets of factors during the study on energy service demand.

Figure 7 shows that energy service demand generally tends to increase in all scenarios. Scenario 1 includes only socio−economic change such as population and GDP and it increases up to 57.35 MTOE in 2050. Scenario 2 includes socio−economic change and climate change and it increases up to 56.07 MTOE in 2050, but decreases 1.3 MTOE compared to scenario 1 in 2050.

Energy service demand of scenario 3 representing aging characteristics, climate change, and socio-economic change is about 69.52 MTOE in 2050. It needs more demand than scenario 1 and 2 without considering aging factors, 57.35 and 56.07 MTOE.

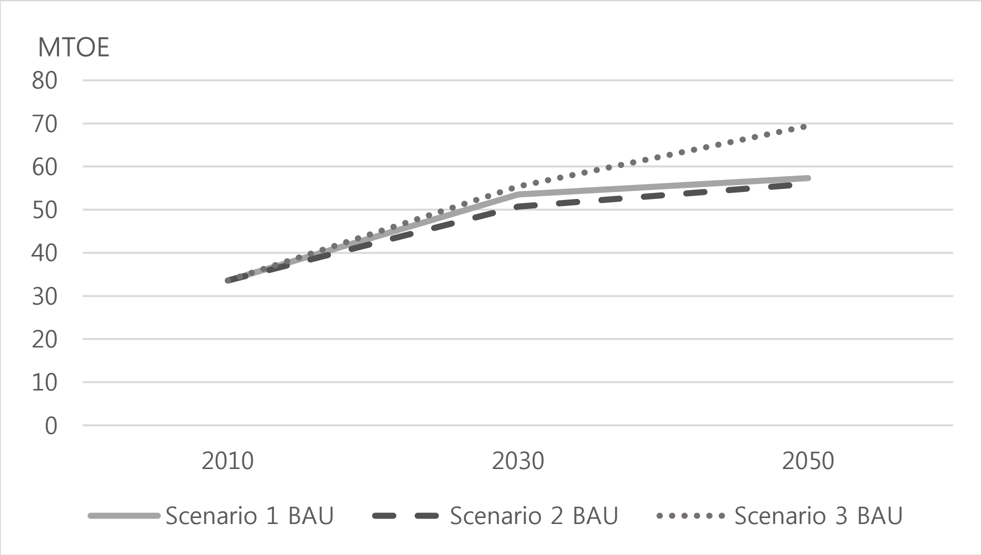

Fig. 7. Energy service demand in BAU scenario

Figure 8 shows change in heating energy service demand to focus on effects of climate change. Heating energy service demand is about 21.63 MTOE in 2010 and accounts for over 60 percent of residential energy service demand. This graph shows two scenarios. First is a heating energy service demand in maintaining climate in 2010 from 2010 to 2050. Second included climate change scenario, RCP 8.5 scenario. RCP 8.5 scenario need less demand than climate in 2010 because of the rising temperatures.

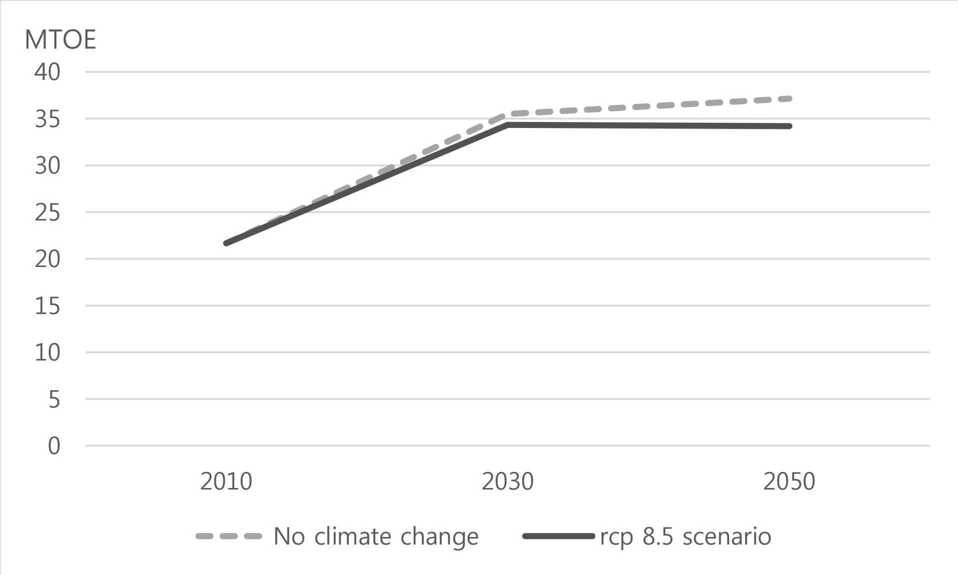

Fig. 8. Heating energy service demand

Figure 9 shows effects of climate change on cooling energy service demand. Demand is about 2.80 MTOE in 2010, and it increased by 307 percent up to 8.58 MTOE in the RCP 8.5 scenario in 2050. Although this is a smaller value compared to the heating energy service demand, the growth rate is greater than heating energy service demand. This means cooling service demand will increase in the future. The trend is similar to heating energy service demand up to 2030, but cooling energy service demand increases drastically after 2030 due to rising temperatures unlike heating energy service demand that little increases up to 2050.

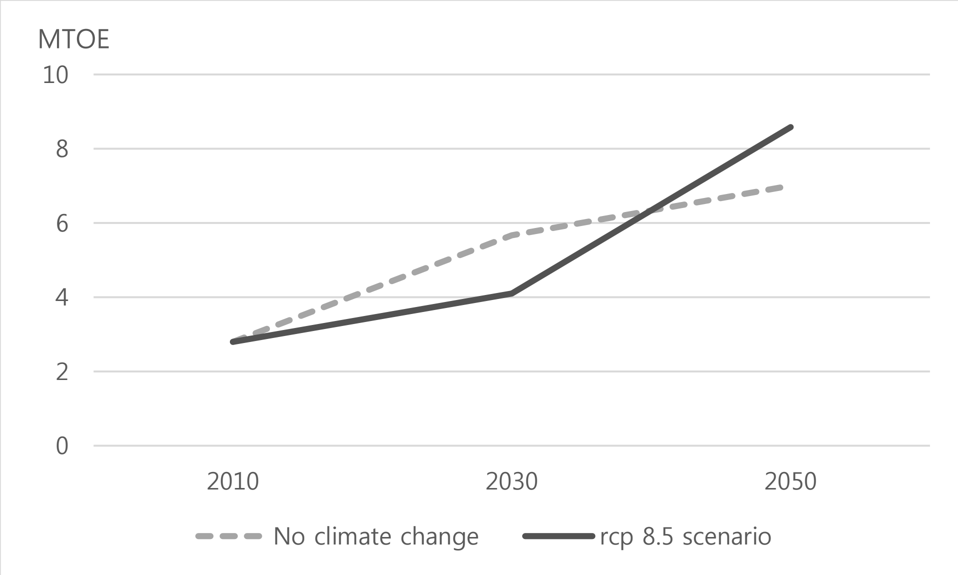

Fig. 9. Cooling energy service demand

4.3. Energy Consumption and Greenhouse Gas Emissions

Four scenarios were set and energy consumption and GHG emissions were estimated for each scenario. The results without scenario 1 considered socio−economic effects will discuss results of BAU in socio−economic scenarios only in order to focus on the roles of specific factors. Complete results are presented in the appendix.

4.3.1. Scenario 1 _ socio−economic effects

Figure 10 shows energy consumption taking socio−economic factors into consideration. This scenario uses 2010 climate information to identify socio−economic effects. According to the results, population growth and economic development cause increasing energy consumption from 2010 to 2050 and the high scenario uses more energy than the low scenario. Energy consumption is about 21.90 MTOE in 2010, and increased to about 26.02 MTOE in 2050 in the BAU scenario, and to about 30.94 MTOE in 2050 in the high scenario. However, energy consumption in the low scenario increases slightly to 21.93 MTOE as population decreases considerably and the GDP growth is slow.

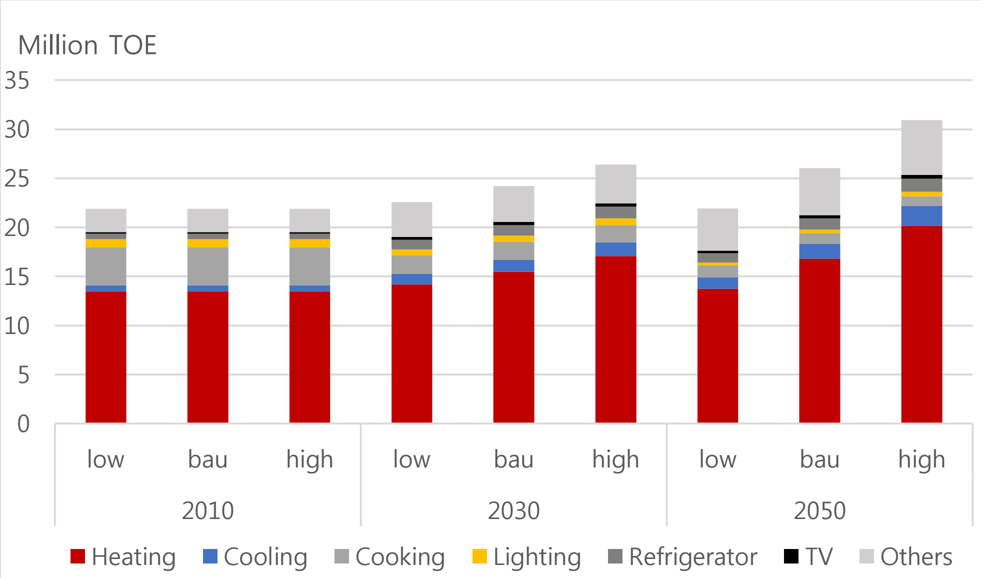

Fig. 10. Energy consumption in scenario 1 (Total)

GHG emissions also show a similar trend to the pattern of energy consumption (Figure 11). In the BAU scenario GHG emissions is about 68.88 MT CO_2 eq. in 2010 and 89.73 MT CO_2 eq. in 2050. BAU emits 20.85 MT CO_2 eq. GHG more than the high scenario. More GHGs are emitted from the low to the high scenario, and growth rate of emissions appears to be higher. This is probably because the demand for cooling serviced and the use of other appliances increases, and consequently, electric sources that constitute high emission factors increase.

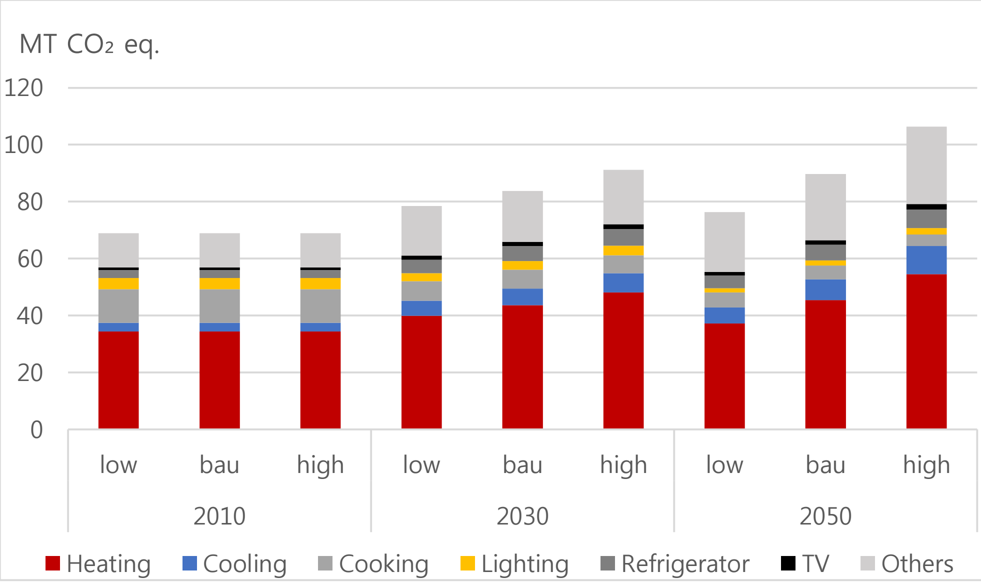

Fig. 11. Greenhouse gas emissions in scenario 1 (Total)

4.3.2. Scenario 2 _ climate change effects

4.3.1. section shows energy consumption and GHG emissions according to socio−economic change. Scenario 2 estimates energy consumption and GHG emissions under the influence of climate change in addition to factors considered in scenario 1.

Figure 12 shows energy consumption under the influence of climate change factors. This scenario uses RCP 8.5 climate change scenario, and discusses results of the BAU scenario only to identify climate change effects. This section focus on heating and cooling services as heating and cooling services, through HDD and CDD, reflect climate change factors. In results of the heating service, energy consumption increases from 2010 to 2050. Energy consumption is about 21.90 MTOE in 2010, and increased to about 25.05 MTOE in 2050 in the BAU scenario. Although climate change causes rising temperatures, heating energy consumption increases as use of boilers is predominant in housing culture in South Korea.

In this context, cooling energy consumption also increases from 2010 to 2050. Cooling energy consumption in 2010 is 0.61 MTOE and increases more than three times to 1.86 MTOE in 2050 because climate change effects are greater in 2050. In addition, climate change seems to affect growth rates of heating and cooling energy consumption levels. Heating uses more energy than cooling in absolute amounts, but the growth rate of cooling is more than heating. Cooling increased by 316 percent in 2050 compared to 2010, while heating increased by 115 percent in 2050. This means cooling energy consumption increase more than heating in the future. Moreover, cooling use electricity for energy source, so we consider these growth to establish electrical grid.

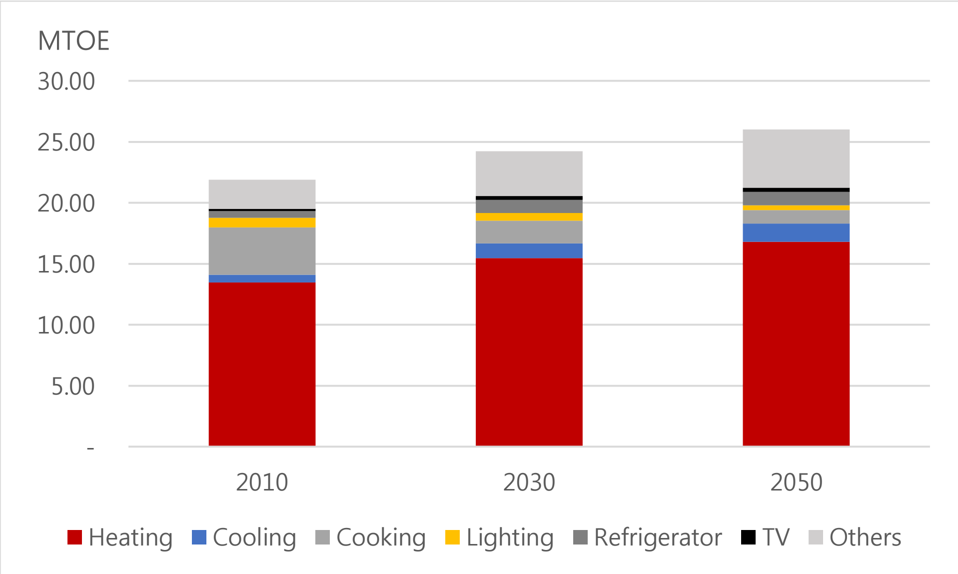

Fig. 12. Energy consumption in scenario 2 (Total)

Figure 13 shows GHG emissions in scenario 2. It shows a similar trend with energy consumption. The proportion of the heating service reduces and proportion of cooling increases. Essential household appliances such as refrigerators emit more GHG because the number of households increases due to reduction in household sizes. However, emissions of the cooking sector decreases significantly as frequency of cooking at home decreases due to improved standards of living.

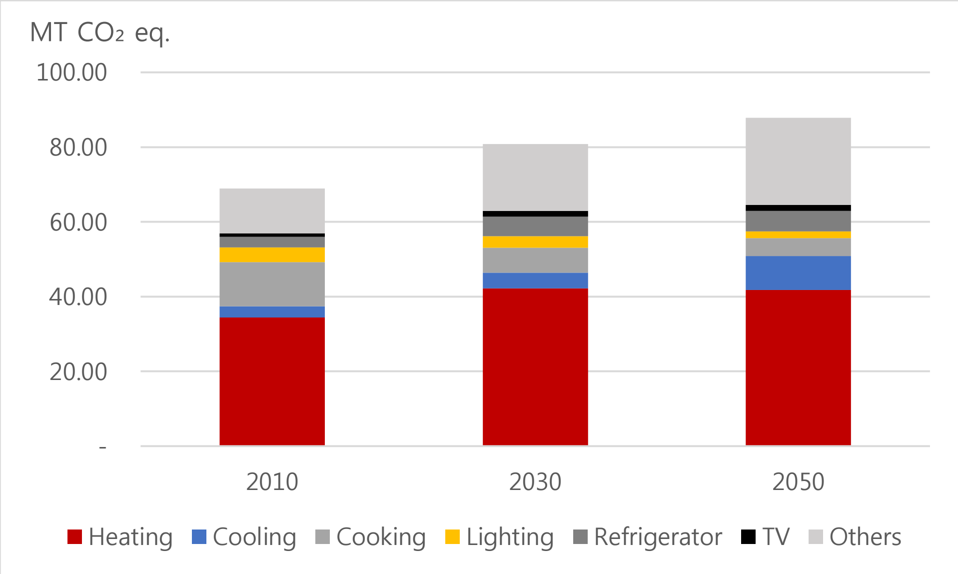

Fig. 13. Greenhouse gas emissions in scenario 2 (Total)

4.3.3. Scenario 3 _ aging effects

Figure 14 shows energy consumption levels taking aging factors into consideration.

Scenario 3 includes aging effects in addition to factors considered in scenario 2. This section will discuss results of the BAU scenario in socio-economic scenario only in order to focus on aging effects. Results show increases in energy consumption from 2010 to 2050. Energy consumption of heating and cooling services increases considerably in scenario 3 in comparison to scenario 2 as energy service demand for health care sector increases due to increasing income of the elderly. In addition, energy consumption of other appliances increases from 4.79 MTOE in scenario 2 to 4.99 MTOE in scenario 3. This is because energy service demand for the appliances associated with wellbeing also increases due to growing incomes.

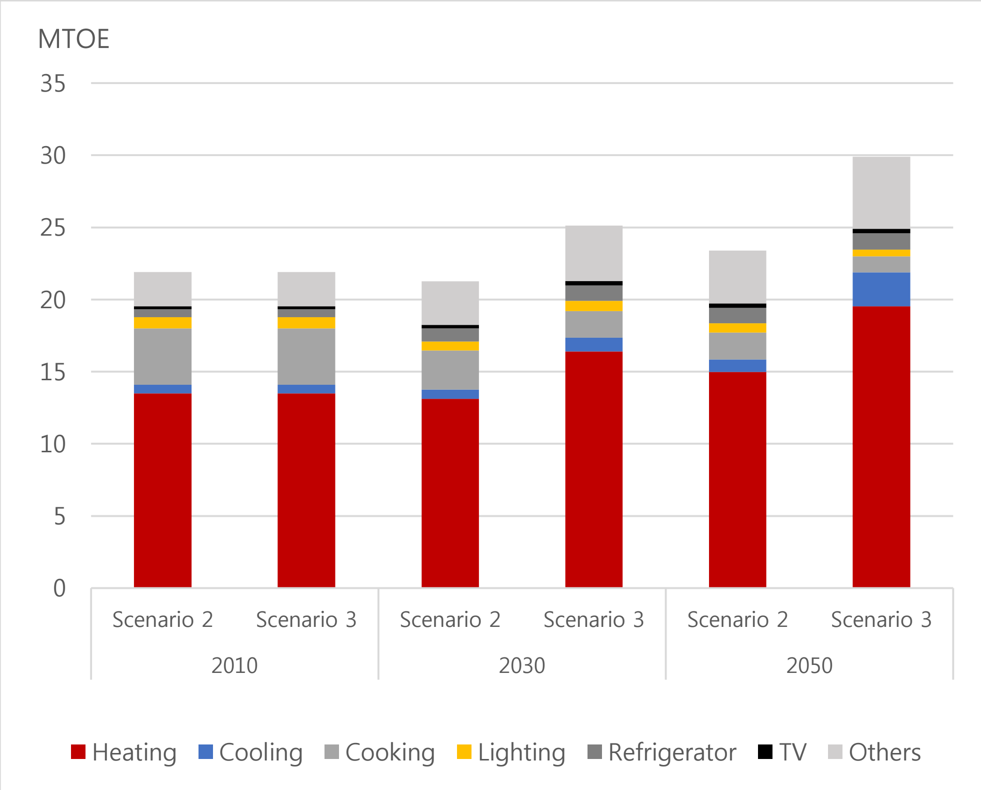

Fig. 14. Energy consumption in scenario 2, 3 (Total)

Figure 15 shows GHG emissions under scenario 3. The tendency is similar to energy consumption and scenario 3 emits more GHG than scenario 2. Aging factors appear to influence heating, cooling, lighting services, and other appliances. GHG emissions in heating, cooling, and lighting services increase due to the rise in the length of time spent at home and use of other appliances. GHG emissions also increase because services that use electricity as an energy sources increase. Therefore, as aging progresses in the future, more GHG emissions can be expected.

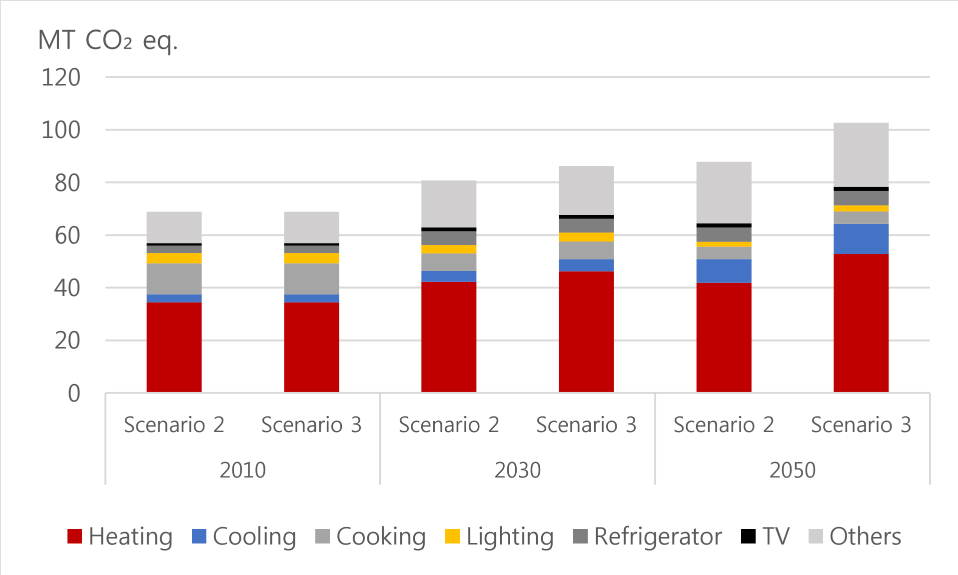

Fig. 15. Greenhouse gas emissions in scenario 2, 3 (Total)

4.3.4. Scenario 4 _ reduction policy effects

Figure 16 shows the results of scenario 3 and scenario 4 that are projected by adding reduction policies to factors included in scenario 3. The effect of reduction policies appear from 2020. These policies have the greatest impact on heating services. Heating energy consumption in scenario 4 decreases 6.20 MTOE to 19.54 MTOE in the year 2010 and finally to a value of 13.34 MTOE in 2050. In addition, energy consumption of other sectors decreases because of use of high-efficiency equipment. Specifically, heating energy reduces considerably due to expansion in supply of condensing boilers and strengthening of insulation levels. Energy consumption by the lighting sector also reduces because of the popularization of LEDs. Energy consumption by residential sector in 2010 is 21.90 MTOE and 23.4 MTOE in 2050. This means that energy consumption is reduced considerably when energy policies are introduced.

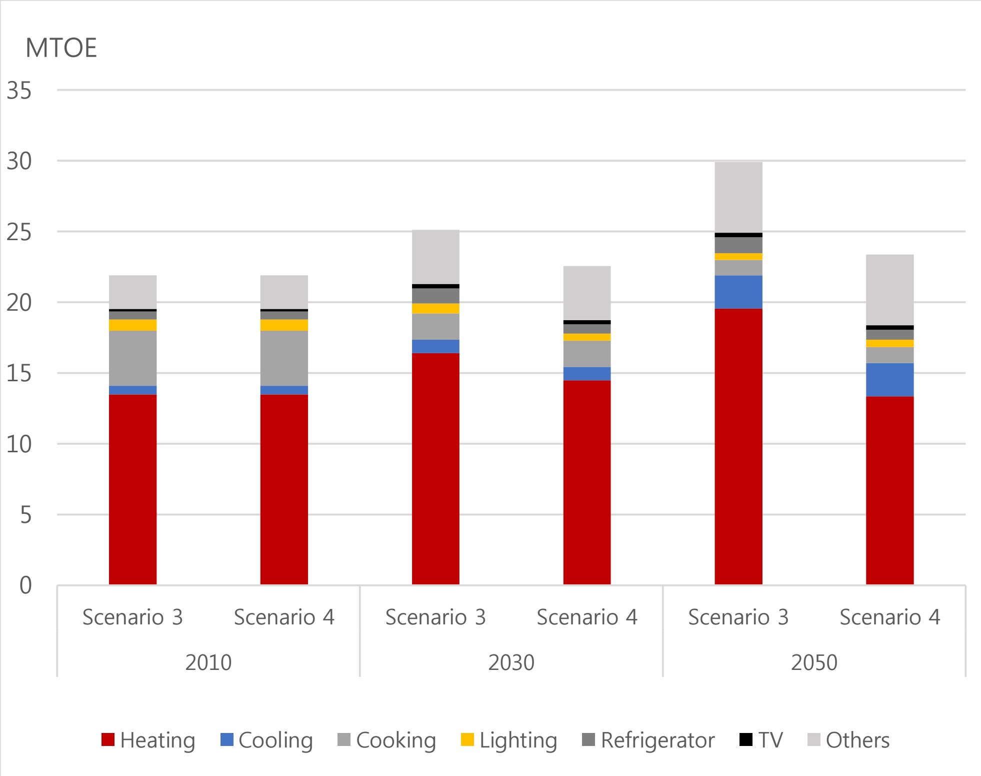

Fig. 16. Energy consumption in scenarios 3 and 4 (Total)

4.4. Synthesis of Scenarios

In this study, the impact of different factors on energy consumption and GHG emissions (Table 12) has been observed using four scenarios.

Table 12. Information of four scenarios

	Climate change	Aging	Reduction policies
Scenario 1	X	X	X
Scenario 2	O	X	X
Scenario 3	O	O	X
Scenario 4	O	O	O

Figure 17 shows the comprehensive results of four scenarios. As energy consumption and GHG emissions show similar tendencies, this section discusses GHG emissions only.

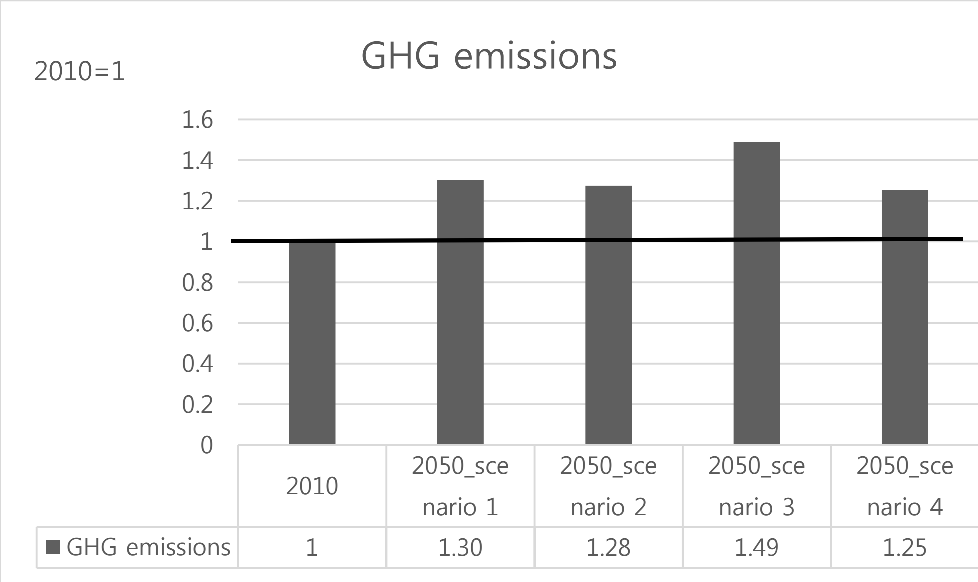

Fig. 17. GHG emissions changes in four scenarios (Total)

The first bar in the graph represents GHG emissions for scenario 1 in 2010, Subsequent bars in the graph represent figures for 2050 under each scenario. The second bar represents scenario 1 in 2050 and shows increased GHG emissions because of population growth and rising GDP. In particular, rising GDP means improved standards of living, consequently energy consumption for heating, cooling, and other appliances increases considerably while energy use for cooking reduces. In the results, GHG emissions also increase.

The third bar in the graph represents GHG emissions under scenario 2 in 2050, which reflects climate change scenario. GHG emissions are reduced compared to scenario 1 because energy demand from heating and cooling sector changes. Heating GHG emissions decreases and cooling GHG emissions increases because of rise in temperatures attributed to climate change. Total GHG emissions in residential sector decrease as heating accounts for a large part of the residential sector emissions and its reduction rate is substantial.

Fourth bar in the graph represents GHG emissions in 2050 under scenario 3, which considers aging characteristics. It increases to about 50 percent point compared to the base year 2010. In particular, heating and cooling sectors use a lot of energy because of increase in elderly staying longer at the homes. Other appliances sector use more energy because use of appliances for health care and wellbeing increases due to increasing income of the elderly. In the results, GHG emissions also increased. This means that South Korea will use more energy and emit more GHG depending on the progression of aging and climate change. Moreover, aging will be an important factor to manage energy demand.

Finally, last bar in the graph represents GHG emissions in 2050 under scenario 4 reflecting the influence of reduction policies. GHG emissions in heating sector decrease the most following implementation of reduction policies. Heating reduces considerably because of supply of high−efficiency boilers and strengthening of insulation levels. In addition, other sectors also reduce GHG emissions due to high−efficiency equipment.

5. Conclusion

This study set scenarios to look at the impact of different factors on energy consumption levels and GHG emissions and forecasts the results of each scenario. First scenario considered change in socio-economic factors and concludes that people will use more energy and emit more GHG because of population growth and rising GDP. Second scenario reflected effects of climate change and concludes that total energy consumption and GHG emissions reduce in comparison to scenario 1 as the heating sector that comprises the highest percentage of the residential sector, decreases considerably due to rising temperatures. Third scenario considered effects of aging characteristics, such as the length of time spent at home and income of the elderly, and sees an increase in energy consumption and GHG emissions in different sectors because of the rising ratio and income of the elderly. Lastly, scenario 4 reflects effects of reduction policies. It reduces energy consumption and GHG emissions significantly, despite roles of aging, climate change, and socio-economic changes. This means that energy consumption and GHG emissions can be reduced if countries tried, although there are numerous factors that can increase energy consumption and GHG emissions.

The finding of this study is that climate change reduces total energy consumption and GHG emissions in the residential sector. In addition, this study also finds that aging increases energy consumption and GHG emissions. Increase in energy service demand means the future residential energy service demand will also increase as aging advances. Moreover, aging factors will augment energy consumption because the future older age groups will live financially stable lifestyle and current young generations who are familiar with electronic appliances and equipment will age in the future.

This research required extensive data to predict different factors as the object of this study is estimation of future energy consumption and GHG emissions considering different factors. However, data currently available is limited. For example, forecasts for the number of households were also available only up to 2030 and this study included work on predicting figures until 2050. Nonetheless, this study was performed with efforts to reduce errors as much as possible, within the given limits, and to establish the data necessary to estimate energy service demand.

This study can predict the future of energy consumption and GHG emissions of the residential sector considering different factors such as socio−economic, climate change, aging characteristics, and reduction policies. This study reflect some factors that can influence aging and related lifestyle patterns, but further studies are needed to consider more factors and identify quantitative amounts of the factors. Nevertheless, the results are helpful in predicting energy demand in the future with progressing aging and climate change, and can reduce energy waste by better estimation of reserve power. Finally, this study will be useful in designing policies for implementing measures in energy demand management and meeting targets to reduce GHG emissions.

6. References

Agency, I. E. (2007). Energy and Climate Change Study. *World Energy Outlook Special Briefing for COP21*. http://doi.org/10.1038/479267b

Chen, B. S. (2014). Determinants Demographic Use of Household Energy in the United States. *Population Council*, *28*(2002), 53–88.

Dalton, M., O'Neill, B., Prskawetz, A., Jiang, L., & Pitkin, J. (2008). Population aging and future carbon emissions in the United States. *Energy Economics*, *30*(2), 642–675. http://doi.org/10.1016/j.eneco.2006.07.002

Dietz, T., & Rosa, E. a. (1997). Effects of population and affluence on CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America*, *94*(1), 175–179. http://doi.org/10.1073/pnas.94.1.175

Exchange, K. P. (2012). 2011 Household appliances penetration rate and power consumption behavior survey, 22–52. http://doi.org/10.1007/s13398-014-0173-7.2

Garau, G., Lecca, P., & Mandras, G. (2013). The impact of population ageing on energy use: Evidence from Italy. *Economic Modelling*, *35*, 970–980. http://doi.org/10.1016/j.econmod.2013.09.006

Hamza, N., & Gilroy, R. (2011). The challenge to UK energy policy: An ageing population perspective on energy saving measures and consumption. *Energy Policy*, *39*(2), 782–789. http://doi.org/10.1016/j.enpol.2010.10.052

Hekkenberg, M., Moll, H. C., & Uiterkamp, a. J. M. S. (2009). Dynamic temperature dependence patterns in future energy demand models in the context of climate change. *Energy*, *34*(11), 1797–1806. http://doi.org/10.1016/j.energy.2009.07.037

Hibino, G., Pandey, R., Matsuoka, Y., & Kainuma, M. (2003). A Guide to AIM / Enduse Model. *Climate Policy Assessment*, 247–398.

IPCC. (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http://doi.org/10.1017/CBO9781107415324

Isaac, M., & van Vuuren, D. P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy*, *37*(2), 507–521. http://doi.org/10.1016/j.enpol.2008.09.051

Jung, E. (2012). Housing Welfare Situation and Policy Direction. *Real Estate Market Trends*, *1*(part 3), 93–107.

Kim, D., & Park, S. (2014). The Impact of Population Aging on Energy Use and Carbon Emissions in Korea. *Journal of Environmental Policy*, *13*(2), 99–129.

Kronenberg, T. (2009). The impact of demographic change on energy use and greenhouse gas emissions in Germany. *Ecological Economics*, *68*(10), 2637–2645. http://doi.org/10.1016/j.ecolecon.2009.04.016

Lee, C., & Park, J. (2009). An Estimation Model of Long-Term Housing Demand Considering Hosuehold Types. *Korea Planners Association*, *10*, 149–161.

Lee, K., Baek, H.-J., & Cho, C. (2014). Future Projection of Changes in Cooling and Heating Degree Days in Korea. *KU Climate Research Institute*, *9(1)*, 1–13.

Liddle, B., & Lung, S. (2010). Age-structure, urbanization, and climate change in developed countries: revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Population and Environment*, *31*(5), 317–343. http://doi.org/10.1007/s11111-010-0101-5

Lim, H.-J., Jung, S.-K., & Won, D.-H. (2013). An Analysis of the Impact of Global Warming on Residential Energy Consumption: Focused on the Case of Electricity Consumption. *Korean Energy Economic Review*, *12*(2), 33–58.

McNeil, M., & Letschert, V. (2008). Future air conditioning energy consumption in developing countries and what can be done about it: the potential of efficiency in the residential sector. *Lawrence Berkeley National …*. Retrieved from http://escholarship.org/uc/item/64f9r6wr.pdf

Menz, T., & Welsch, H. (2010). Population aging and environmental preferences in OECD countries: The case of air pollution. *Ecological Economics*, *69*(12), 2582–2589. http://doi.org/10.1016/j.ecolecon.2010.08.002

Menz, T., & Welsch, H. (2012). Population aging and carbon emissions in OECD countries: Accounting for life-cycle and cohort effects. *Energy Economics*, *34*(3), 842–849. http://doi.org/10.1016/j.eneco.2011.07.016

Ministry, I. (2014). National GHG emissions reduction roadmap, 1–64.

Mourshed, M. (2012). Relationship between annual mean temperature and degree-days. *Energy and Buildings*, *54*, 418–425. http://doi.org/10.1016/j.enbuild.2012.07.024

National Greenhouse Gas Inventory Report of Korea. (2014). *Greenhouse Gas Inventory and Research Center of Korea*, (1), 1–401. http://doi.org/10.1007/s13398-014-0173-7.2

National Institute for Environmental Studies. (2006). AIM Enduse Model Manual, (November).

O'Neill, B. C., Dalton, M., Fuchs, R., Jiang, L., Pachauri, S., & Zigova, K. (2010). Global demographic trends and future carbon emissions. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(41), 17521–17526. http://doi.org/10.1073/pnas.1004581107

O'Neill, B. C., Liddle, B., Jiang, L., Smith, K. R., Pachauri, S., Dalton, M., & Fuchs, R. (2012). Demographic change and carbon dioxide emissions. *The Lancet*, *380*(9837), 157–164. http://doi.org/10.1016/S0140-6736(12)60958-1

Sailor, D. J., & Pavlova, a. a. (2003). Air conditioning market saturation and long-term response of residential cooling energy demand to climate change. *Energy*, *28*(9), 941–951. http://doi.org/10.1016/S0360-5442(03)00033-1

Seo, D.-H. (2013). A Study on Heating and Cooling Degree-Days Calculation Methods for South Korean Cities. *The Korean Solar Energy Society*, *33*(2), 198–201.

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions , 1975 - 1996: evidence from pooled cross-country data. *Ecological Economics*, *44*, 29–42. http://doi.org/10.1016/S0921-8009(02)00223-9

Tonn, B., & Eisenberg, J. (2007). The aging US population and residential energy demand. *Energy Policy*, *35*(1), 743–745. http://doi.org/10.1016/j.enpol.2005.12.011

Wilbanks, T. J., Bhatt, V., Bilello, D. E., Bull, S. R., Ekmann, J., Horak, W. C., … Scott, M. J. (2008). Effects of Climate Change on Energy Production and Use in the United States, (February).

Won, D.-H. (2012). The impact of an aging analysis of energy consumption in the residential sector. *Environmental and Resource Economics Review*, *21*(2), 341~369.

Yamasaki, E., & Tominaga, N. (1997). Evolution of an aging society and effect on residential energy demand. *Energy Policy*, *25*(11), 903–912. http://doi.org/10.1016/S0301-4215(97)00040-2

York, R. (2007). Demographic trends and energy consumption in European Union Nations, 1960-2025. *Social Science Research*, *36*(3), 855–872. http://doi.org/10.1016/j.ssresearch.2006.06.007

7. Appendix

Table 7－ 1. Energy consumption in scenario 1 (MTOE)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
Low	2010	13.48	0.61	3.90	0.79	0.55	0.19	2.38	21.90
	2030	14.20	1.07	1.90	0.58	0.98	0.28	3.58	22.59
	2050	13.76	1.15	1.21	0.31	0.92	0.26	4.32	21.93
BAU	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
	2030	15.48	1.20	0.64	0.64	1.07	0.31	3.67	24.22
	2050	16.80	1.51	0.38	0.38	1.12	0.32	4.79	26.02
High	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
	2030	17.08	1.38	0.71	0.71	1.19	0.34	3.92	26.38
	2050	20.17	2.03	0.45	0.45	1.35	0.39	5.59	30.94

Table 7－ 2. GHG emissions in scenario 1 (MT CO_2 eq.)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
Low	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	39.94	5.23	6.84	2.84	4.77	1.38	17.41	78.41
	2050	37.15	5.62	5.30	1.50	4.47	1.29	21.03	76.35
BAU	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	43.58	5.83	6.66	3.11	5.23	1.51	17.88	83.80
	2050	45.37	7.37	4.77	1.83	5.47	1.58	23.34	89.73
High	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	48.16	6.74	6.22	3.45	5.80	1.68	19.10	91.14
	2050	54.50	9.90	4.07	2.20	6.58	1.90	27.24	106.38

Table 7− 3. Energy consumption in scenario 2 (MTOE)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
Low	2010	13.48	0.61	3.90	0.79	0.55	0.19	2.38	21.90
	2030	13.75	0.77	1.90	0.58	0.98	0.28	3.58	21.85
	2050	12.68	1.42	1.21	0.31	0.92	0.26	4.32	21.12
BAU	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
	2030	14.99	0.86	1.86	0.64	1.07	0.31	3.67	23.40
	2050	15.48	1.86	1.10	0.38	1.12	0.32	4.79	25.05
High	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
	2030	16.54	1.00	1.75	0.71	1.19	0.34	3.92	25.46
	2050	18.59	2.49	0.96	0.45	1.35	0.39	5.59	29.82

Table 7− 4. GHG emissions in scenario 2 (MT CO_2 eq.)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
Low	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	38.67	3.77	6.84	2.84	4.77	1.38	17.41	75.68
	2050	34.24	6.90	5.30	1.50	4.47	1.29	21.03	74.73
BAU	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	42.19	4.21	6.66	3.11	5.23	1.51	17.88	80.78
	2050	41.81	9.05	4.77	1.83	5.47	1.58	23.34	87.85
High	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	46.62	4.86	6.22	3.45	5.80	1.68	19.10	87.72
	2050	50.22	12.15	4.07	2.20	6.58	1.90	27.24	104.36

Table 7− 5. Energy consumption in scenario 3 (MTOE)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
	2010	13.48	0.61	3.90	0.79	0.55	0.19	2.38	21.90
Low	2030	15.22	0.86	1.90	0.65	0.98	0.28	3.73	23.63
	2050	16.13	1.81	1.21	0.39	0.92	0.26	4.50	25.22
	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
BAU	2030	16.40	0.95	1.86	0.70	1.07	0.31	3.83	25.12
	2050	19.54	2.35	1.10	0.47	1.12	0.32	4.99	29.91
	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
High	2030	18.00	1.09	1.75	0.77	1.19	0.34	4.09	27.24
	2050	23.27	3.13	0.96	0.56	1.35	0.39	5.90	35.56

Table 7− 6. GHG emissions in scenario 3 (MT CO_2 eq.)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
Low	2030	42.86	4.21	6.84	3.15	4.77	1.38	18.16	81.37
	2050	43.56	8.81	5.30	1.90	4.47	1.29	21.93	87.25
	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
BAU	2030	46.21	4.63	6.66	3.41	5.23	1.51	18.64	86.28
	2050	52.80	11.46	4.77	2.30	5.47	1.58	24.33	102.70
	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
High	2030	50.77	5.32	6.22	3.75	5.80	1.68	19.91	93.44
	2050	62.89	15.24	4.07	2.75	6.58	1.90	28.75	122.18

Table 7– 7. Energy consumption in scenario 4 (MTOE)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
Low	2010	13.48	0.61	3.90	0.79	0.55	0.19	2.38	21.90
	2030	13.39	0.87	1.90	0.44	0.61	0.27	3.73	21.22
	2050	11.00	1.81	1.26	0.43	0.57	0.25	4.50	19.83
BAU	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
	2030	14.48	0.96	1.86	0.48	0.67	0.30	3.83	22.57
	2050	13.34	2.35	1.14	0.53	0.70	0.31	4.99	23.37
High	2010	13.48	0.61	0.79	0.79	0.55	0.19	2.38	21.90
	2030	15.95	1.10	1.75	0.53	0.74	0.33	4.09	24.49
	2050	15.91	3.13	0.97	0.63	0.84	0.37	5.90	27.76

Table 7– 8. GHG emissions in scenario 4 (MT CO_2 eq.)

	Year	HT	CL	CK	LT	RF	TV	OT	Total
Low	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	36.21	4.25	6.81	2.17	2.98	1.32	18.16	71.90
	2050	31.72	8.82	5.17	2.11	2.79	1.23	21.93	73.77
BAU	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	39.16	4.68	6.63	2.34	3.27	1.44	18.64	76.16
	2050	38.50	11.47	4.66	2.56	3.42	1.51	24.33	86.44
High	2010	34.37	3.07	11.78	3.96	2.79	0.94	11.97	68.88
	2030	43.15	5.36	6.20	2.58	3.63	1.60	19.91	82.43
	2050	45.91	15.26	4.00	3.05	4.11	1.81	28.75	102.89

국문초록

고령화 특성과 기후변화를 반영한 가정 부문 에너지 사용량 및 온실가스 배출량 변화 예측, 2010-2050

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전 세계적으로, 기온상승과 같은 기후변화가 심화되고 있으며, 이에 대응하기 위해 많은 국가들은 온실가스 배출량 감축을 목표로 하고 있다. 에너지 수요 관리는 감축 목표를 위한 핵심 정책으로 여겨지고 있으며, 이를 위해서는 기후변화를 고려한 에너지 사용량 및 온실가스 배출량 예측이 필요하다. 정확한 예측을 위해 기후변화뿐 아니라 인구학적 요소 또한 고려해야 할 중요한 요소 중 하나이다. 고령화는 전세계적으로 진행되고 있으며, 한국은 세계에서 가장 빠르게 고령화가 진행되고 있는 국가이므로 인구학적 변화 중 고령화는 주목할 만한 요소이다. 따라서 본 연구에서는 정확한 에너지 수요 관리 및 배출량 감축 목표를 위해 기후변화와 고령화 특성을 반영하여 대한민국, 가정 부문의 에너지 사용량 및 온실가스 배출량을 산정하고자 한다.

본 연구는 2010 년을 기준연도로 2050 년을 목표연도로 설정하였다. 본 연구에서는 네 가지 시나리오를 설정하여 진행하였다. 첫 번째 시나리오는 GDP, 인구와 같은 사회경제적 요소의 변화를 반영하였으며, 두 번째 시나리오는 시나리오 1 의 사회경제적 요소에 기후변화

요인까지 반영하였다. 세 번째 시나리오는 사회경제적 변화와 기후변화를 포함하는 시나리오 2 에 고령화 요소까지 함께 포함하였으며, 네 번째 시나리오는 시나리오 3 에 에너지 감축 정책을 포함하였다. 본 연구는 세 단계 과정을 통해 에너지 사용량 및 온실가스 배출량을 산정하였다. 첫 번째로 사회경제적 요소, 기후변화 요소, 고령화 요소에 대해 정의하고 정보를 수집하였다. 두 번째로 산정식을 사용하여 에너지 서비스 수요를 산정하였다. 마지막으로 AIM/end-use 모델을 사용하여 에너지 사용량과 온실가스 배출량을 산정하였다.

연구 결과, 미래의 에너지 사용량과 온실가스 배출량은 점진적으로 증가하는 것으로 나타났다. 2010 년의 에너지 사용량은 21.9 MTOE 에서 2050 년에 각각 시나리오 1 에서는 26.02 MTOE, 시나리오 2 에서는 25.05 MTOE, 시나리오 3 에서는 29.91 MTOE 로 증가하였다. 또한 온실가스 배출량 역시 2010 년에는 68.88 MT CO_2 eq.에서 2050 년에는 각각 시나리오 1, 2, 3, 순으로 106.38, 104.36, 122.18 MT CO_2 eq.로 증가하였다. 이는 고령화 측면에서는 재택시간의 증가와 이로 인한 난방 에너지 사용의 증가 등으로 인한 것으로 보이며, 기후변화 측면에서는 기온상승의 영향으로 인한 냉방에너지 수요의 증가 등으로 인한 것으로 보인다. 그러나 에너지 감축 정책을 반영한 시나리오 4 에서는 2050 년에 에너지 사용량과 온실가스 배출량이 각각 23.37 MTOE, 86.44 MT CO_2 eq.로 상당히 줄어드는 모습을 보였다. 결론적으로, 본 연구는 에너지 수요관리를 위한 대책 마련 및 온실가스 배출량 감축 목표 달성에 있어서 정책 지원 자료로 활용될 수 있을 것이다.

키워드: AIM/end-use 모델, 냉난방도일, 에너지 서비스 수요, RCP 시나리오, 사회경제적 변화

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