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Japan's Residential Energy Demand Outlook to 2030 Considering Energy Efficiency Standards "Top-Runner Approach"[1]

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ABSTRACT

As one of the measures to achieve the reduction in greenhouse gas emissions agreed to in the "Kyoto Protocol," an institutional scheme for determining energy efficiency standards for energy-consuming appliances, called the "Top-Runner Approach," was developed by the Japanese government. Its goal is to strengthen the legal underpinnings of various energy conservation measures. Particularly in Japan's residential sector, where energy demand has grown vigorously so far, this efficiency standard is expected to play a key role in mitigating both energy demand growth and the associated CO_2 emissions. This paper presents an outlook of Japan's residential energy demand, developed by a stochastic econometric model for the purpose of analyzing the impacts of the Japan's energy efficiency standards, as well as the future stochastic behavior of income growth, demography, energy prices, and climate on the future energy demand growth to 2030. In this analysis, we attempt to explicitly take into consideration more than 30 kinds of electricity uses, heating, cooling and hot water appliances in order to comprehensively capture the progress of energy efficiency in residential energy end-use equipment. Since electricity demand, is projected to exhibit astonishing growth in Japan's residential sector due to universal increasing ownership of electric and other appliances, it is important to implement an elaborate efficiency standards policy for these appliances.

BACKGROUND

To promote highly energy efficient appliances and vehicles, Japan's revised energy conservation law, enacted in April 1999, makes it obligatory for manufacturers and importers to ensure that their products satisfy energy efficiency standards. The government has established the *Top-Runner Approach*, under which efficiency standards are pegged equivalent to the most energy efficient product commercially available in a given appliance category. Each manufacturer and importer must ensure that the weighted average efficiency of all units shipped within that category meets the standard by the target year.

Japan's residential energy demand has grown vigorously, so this efficiency standard is expected to play a key role in mitigating both energy demand growth and the associated CO_2 emissions. This paper explores Japan's residential energy demand outlook to 2030, and analyzes the impact of the energy efficiency standards.

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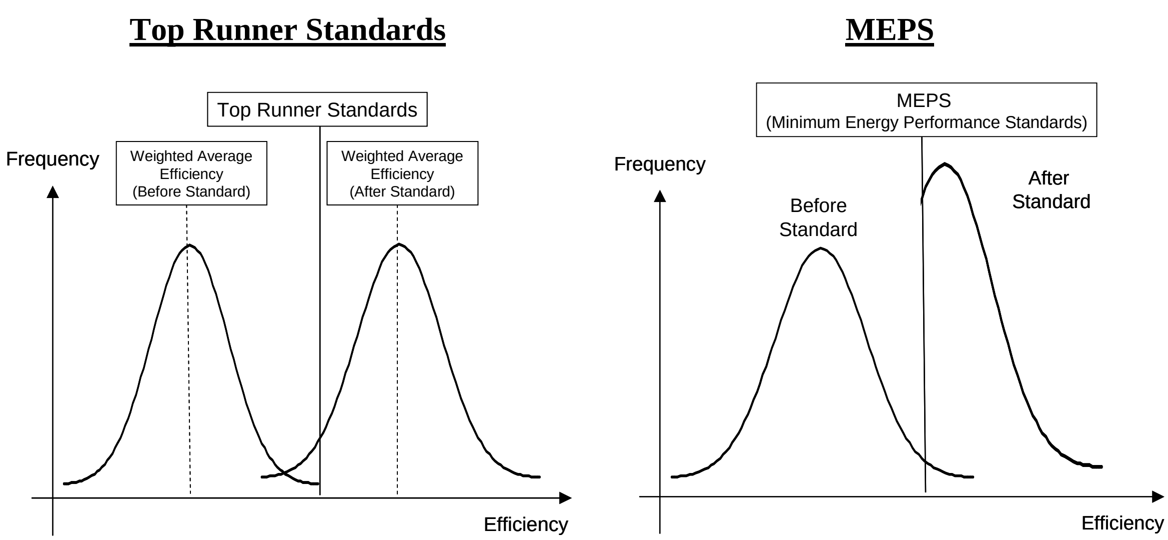
"TOP-RUNNER APPROACH"

Figure 1 shows how the efficiency distributions of new appliances might appear under a Top Runner approach versus a Minimum Efficiency Performance Standard (MEPS) as applied in the United States. The Top Runner standard pulls the whole distribution of efficiencies to higher levels, whereas an MEPS cuts off the left tail of distribution and truncated distribution will emerge as shown. Top Runner Standards are thus different from the concept of MEPS which prescribes minimum efficiencies (or maximum energy consumption) that manufacturers must achieve in each product.

The Top Runner specifies target products based on a policy to include widely used appliances that consume considerable amount of energy. The range of target products is being gradually extended, see Table 1. Table 2 describes the Top Runner standards for major appliances in household sector.

Figure 1. Schematic View of "Top Runner Standards" and MEPS



Actual target standard values are established for many classifications within each product category depending on sizes and functions. The target fiscal years by which the target standard value must be achieved are selected considering future technological development and the development of products, both are usually in the range of 4 to 8 years.

Table 1. Products covered by Top Runner Standards

Listed in 1999	Air Conditioners, Florescent Lights, Video Cassette Recorders, CRT TV Sets, Copying

	Machines, Computers, Magnetic Disk Units and Electric Refrigerators/Freezers
Additionally Listed in 2003	Space Heaters, Gas Cooking Appliances, Gas Water Heaters, Oil Water Heaters, Electric Toilet Seats, Vending Machines and Transformers
Additionally Listed in 2006	Electric Rice Cookers, DVD Recorders, Microwave Ovens and Routers TV sets: not only CRT type but LCD and PDP type

In the target fiscal year, compliance with the target is evaluated on the basis of a weighted average efficiency of shipments of each product category by each manufacturer and importer. In Top Runner Standards, the measurement method primarily uses JIS (Japan Industrial Standards).

Table 2. Top Runner Standards for Major Appliances in Household Sector

	Current Target			After the Target Year to 2030
	Unit	Target Year	Energy Saving Effects	
Refrigerators	kWh/year	FY2010*	-21% compared with FY2005	Improving toward the most energy efficient product commercially available now
CRT TV Sets	kWh/year	FY2003	-16.6% compared with FY1997	Improving toward the most energy efficient product commercially available now
LCD, PDP TV sets	kWh/year	FY2008	-15.3% compared with FY2004	Improving toward the most energy efficient product commercially available now
Air Conditioners	COP	Refrigeration Year 2007**	-63% (cooling-cum-heating type), -14% (cooling type) compared with Refrigeration Year 1997	Improving toward the most energy efficient product commercially available now
	APF***	Refrigeration Year 2010	-22.4% compared with FY2005	
Florescent Lights	lm/W	FY2005	-16.6% compared with FY1997	Improving toward the most energy efficient product commercially available now
Gas Water Heaters	Thermal efficiency	FY2006	-4.1% compared with FY2000	Keeping the target
Oil Water Heaters	Thermal efficiency	FY2006	-3.5% compared with FY2000	Keeping the target
Microwave Ovens	kWh/year	FY2008	-8.5% compared with FY2004	Improving toward the most energy efficient product commercially available now
DVD Recorders	kWh/year	FY2008	-22.0% compared with FY2004	Improving toward the most energy efficient product commercially available now
Electric Toilet Seats	kWh/year	FY2012	-9.7% compared with FY2006	Improving toward the most energy efficient product commercially available now
Rice Cookers	kWh/year	FY2008	-11.1% compared with FY2003	Improving toward the most energy efficient product commercially available now

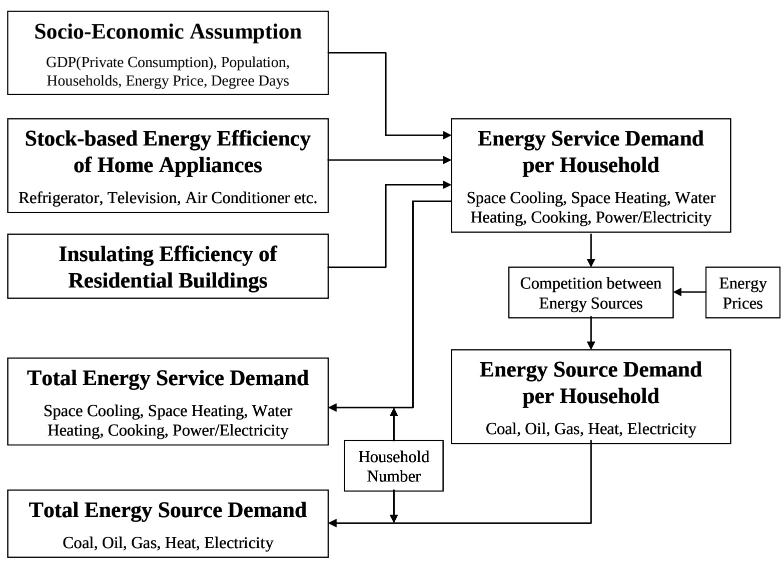
* Japan's fiscal year begins April 1st.
** For some categories of air conditioners, the target year is designated as refrigeration year 2004.
*** Annual performance factor (APF) is cooling or heating capacity divided by annual electricity consumption measured on specific condition. The methodology to calculate this value is described in JISC 9612 (2005), Appendix 3.

Modelling Framework

Figure 2 illustrates the modelling structure. Numerous indicators such as economic growth, crude oil price, population, number of households, and degree-days are assumed exogenous variables with statistical distributions that follow specific probability functions as explained later. Based on these assumptions, the first step is to calculate energy service demand in each category, e.g., space cooling, space heating, water heating, cooking and plug load, on the basis of the economic activity and energy efficiency indicators.

Then energy source demand is determined by energy price indicators, taking into consideration competition among energy sources. Economic activity indicators mainly determine the energy service demand while prices determine the energy source. In both energy service demand and energy source demand, a causal relationship is modeled by an econometric equation. Based on this econometric modeling, we assume future uncertainty in exogenous variables such as macroeconomic indicators, energy prices, demographic factors and the energy efficiency of household appliances through Monte Carlo simulation as explained in a later section, which allows us to analyze future uncertainty of residential energy demand to 2030.

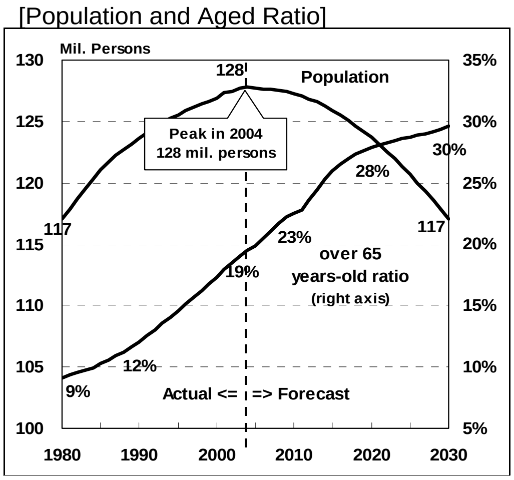
Figure 2. Evaluation Flow Diagram

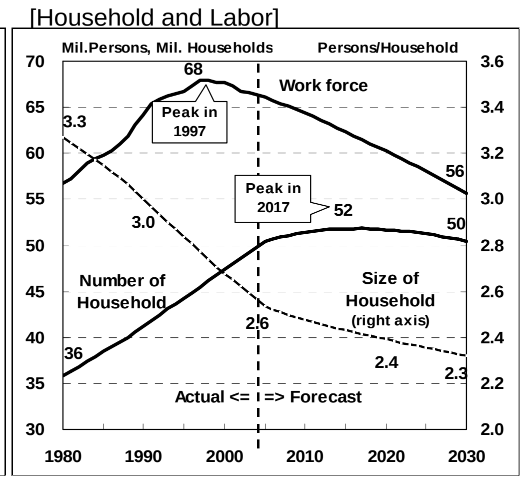


Demography

Japan's population, an important factor in predicting residential energy demand as well as future economic and social structure, peaked in 2004 and is declining. At the same time, the aging of society is progressing at a speed unparalleled elsewhere in the world; 30% of the population will be over 65 years old in 2030. Along with the progress of population decrease and an aging society, the labor force will also decrease. In addition, the number of households will peak around 2017, after which the decrease in the number of persons in each family will accelerate.

Figure 3. Prospects for the Population Structure





We assume in our analysis that for the period up to 2030, the Japanese economy will show moderate growth with annual real GDP growth of around 1.5% in spite of a decreasing population and aging society. The oil price, which has been continuously increasing in recent years, is assumed to show sluggish growth by 2010 due to factors such as increased production in non-OPEC countries, followed by a moderate rise in price. It is assumed that the supply will be tight in the international oil market, and oil price reaches \$45 (nominal price of \$75) per bbl in 2030.

Appliance Energy Efficiency

In order to develop energy efficiency outlook to 2030, we assume that the stipulated improvements in energy efficiency will take place in the years up to the target year, and in subsequent years, energy-saving efforts will continue at a moderate pace as explained in Table 2.

For predicting energy demand, we calculate stock-based energy efficiency of each appliance according to following equation.

$$EFI.S_s = \frac{\sum_{t \le s} X_{t,s} * EFI.X_t}{S_s}, \quad S_s = \sum_{t \le s} X_{t,s}, \quad X_{t,s} = X_{ini,t} * \exp(-\alpha (s-t)^{\beta})$$

s: year, *t*: model year, S_s: Total stock of in-service appliances in year *s*, $X_{t,s}$: In-service appliances of model year *t* in year *s*, $X_{ini,t}$: Shipments of appliance in year *t*, $EFI.S_s$: Efficiency of total stock in-service in year *s*, $EFI.X_t$: Efficiency in appliances of model year *t*

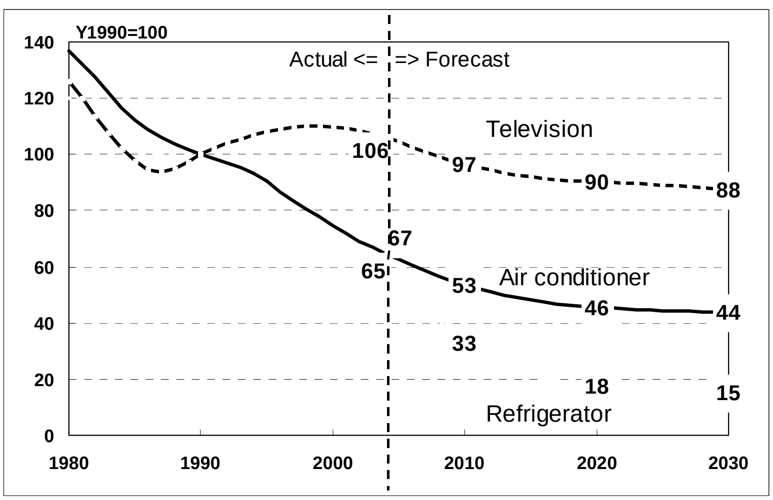
We calculate total in-service stock of equipment by integrating historical shipments data starting from a specific year. The start year depends on the historical data available for the product. As units are added to the in-service stock, some of the older ones retire and exit the stock. The retired fraction is determined by a retirement probability function described as a Weibull distribution function. Considering this stock turnover behavior of each appliance, we identify stock based energy efficiency of each appliance. In order to develop energy demand projections, we calculate the stock-based efficiencies of more than 30 kinds of appliances, shown in Table 3.

Table 3. Energy Efficiency Value Considered in This Analysis

Space cooling Appliance	Air conditioner, Electric fun
Space heating Appliance	Kerosene heater, Kerosene fun heater, Air Conditioner, Electric Fan heater, Electric carpet
Water heating appliance	Oil water heater, Gas water heater, LPG water heater
Electric Appliance	Hot Water Lavatory Seat, Refrigerator (<300L, >300L), Dishwasher, Clothes washer, Clothes Dryer, Futon(Bed) Dryer, Vacuum Cleaner, Lighting, CRT TV(<29 inch, >29 inch), LCD TV(<29 inch, >29 inch), PDP TV, VTR, DVD Player, Video Camera, Stereo, CD Player, PC, Telephone, Facsimile, Other Electric Appliance

Figure 4 shows the future trajectory of stock-based efficiency of major household appliance. The stock-based energy efficiency of home appliance improves due to the Top-Runner Standards, together with the replacement of lower efficiency appliance.

Figure 4. Stock-Based Energy Efficiency of Major Household Appliances



On the basis of this stock-based energy efficiency determination for each appliance, we then build up an energy efficiency index for each energy service for the purpose of forecasting energy demand using the econometric equation, as explained later. We first aggregate the estimated stock-based energy efficiency of each appliance based on a weighted average by energy consuming share of each appliance in each energy service, eventually developing an energy efficiency index for each energy service in the following equation.

$$Energy\ Efficiency\ Index_i = \Sigma_{j \in Si} (EnergyEfficiency_{i,j})*EnergyShare_{i,j}$$

i = space cooling, space heating, water heating, cooking, plug load
j = index of energy consuming appliance
S_i : Group of appliances supplying energy service *i*
$EnergyEfficiency_{i,j}$: Stock-based Energy Efficiency of appliance *i* in energy service *j*
$EnergyShare_{i,j}$: Energy consuming share of appliance *i* in energy service *j*

Insulating Efficiency of Residential Buildings

The previous heat-insulating "1992 standards" of residential buildings have been replaced by the latest, stricter standard, the "1999 Standards" which are generally equivalent to those adopted by Western countries. While the assessment criteria used focus mostly on heating, the newly adopted standards include space cooling efficiency as well.

However, unlike the Top Runner Standards which are mandatory for household appliances, these standards are non-binding. The goal is to have at least 50% of newly constructed buildings comply with the standards starting in FY2008. Efficiency of residences on a stock basis improves slowly because residences have long life spans and the 1999 standards are not mandatory. In this analysis, efficiency index of insulation is assumed to improve reflecting on these building efficiency standards to 2030.

Figure 5. Standard Coefficient of Heat Loss for Residences

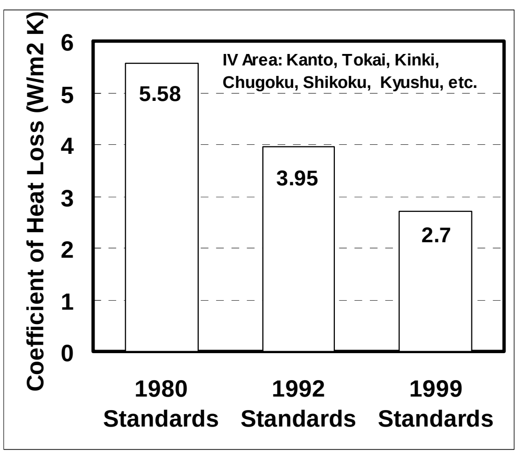
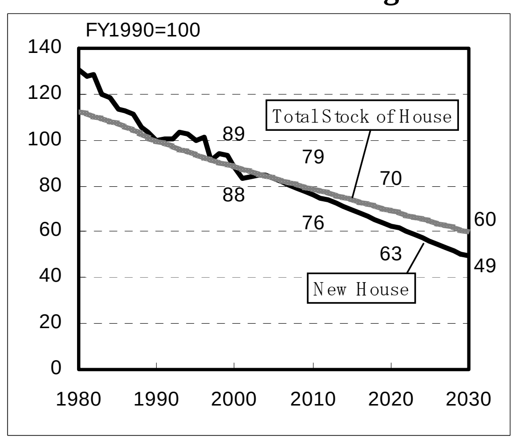


Figure 6. Heat Insulating Index for Residential Building



Econometric Equation

In our modeling framework, as explained in Figure 2, the module which calculates energy service demand per household plays a central role in determining energy demand to 2030. In order to forecast energy service demand based on energy efficiency index, we harness the following conceptual equation.

$$\text{Energy Service (Lighting, Refrigeration etc.)} = \text{Energy Demand} / \text{Energy Efficiency}$$

Improving energy efficiency means that "Energy Efficiency" in the above equation takes lower value. Assuming energy demand remains constant, if energy efficiency improves by double (value is half of current level), then energy service (which households can consume) will also double. On the basis of this formulation, we attempt to determine the energy service demand using an econometric equation. The core conceptual econometric formulation is mathematically expressed as follows.

$$Energy\ Service_i \,/\, Energy\ Efficiency\ Index_i = f\,(Income,\ Energy\ Efficiency\ Index_i{*}Energy\ Price,\ldots)$$

i = space cooling, space heating, water heating, cooking, plug load

The energy efficiency index, the second item in the right hand side function in the above equation, shows the *rebound effect* (energy efficiency improvement induces energy service demand increasing). This effect is modeled by improving energy efficiency or a decreasing price effect on energy demand. For example, the econometric equation that calculates space heating demand is formulated as follows.

$$LOG\left(\frac{Heating_t}{EFIA_t * EFII_t}\right) = A + \alpha * LOG\left(\frac{CP00_t}{HSE_t}\right) + \beta * LOG\left(EFIA_t * EFII_t * \frac{Price_t}{CPI_t}\right) + \gamma * WARMDD_t$$

Variables:

t: year, $Heating_t$: Heating demand per household (kcal/household), $EFIA_t$: Energy Efficiency Index of Heating Appliance, $EFII_t$: Energy Efficiency Index of Insulation, $CP00_t$: Final Consumption Expenditure (10 bil. yen 2000 prices), $Price_t$: Nominal Energy Price in Heating (Yen/1,000kcal), CPI_t: Consumer Price Index, $WARMDD_t$: Warm Degree Days (Degree Days), HSE_t: Number of Household

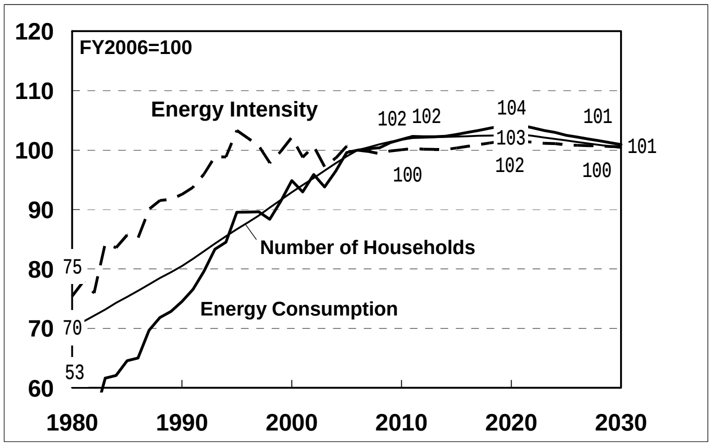
Estimation for Space Heating Demand from 1980 to 2005

A	α	β	Γ	R^2
4.00488 (9.52)	+1.16296 (3.71)	-0.523780 (-4.39)	0.000793 (6.28)	0.91

Calculation Results

This section describes the residential energy outlook in Japan to 2030. Figure 7 illustrates residential energy demand trend in Japan to 2030. Energy demand to 2030 is predicted by the average of 300 trial runs performed by Monte Carlo simulation with statistical distribution of the exogenous variable.

Figure 7. Residential Energy Demand to 2030 (300 Trial Runs, Average Value)



* Energy demand calculated in this analysis stands for final energy demand (onsite consumption), excluding such factors as generation losses.

In the past several decades, residential energy demand had increased reflecting a gradual increase of household and household appliance penetration. However, basically due to the decrease in the number of households and improvement in energy intensity (energy consumption per household) attributable to energy efficiency standards, total residential energy consumption is projected to exhibit sluggish growth and a decreasing trend after around 2020.

Due to the increasing saturation of appliances, new appliances, the pursuit of amenity and the progressive aging of population, the utility of energy consumption will continue to increase, contributing to increased energy demand. On the other hand, the efficiency of appliances will continue to improve thanks to the effectiveness of the Top Runner Standards and the extensive use of high-efficiency appliances, offsetting most of the increase in energy consumption resulting from a higher utility. Decreasing number of households will jointly contribute to the sluggish growth of energy demand.

Figure 8 describes residential energy demand by energy service and by energy source to 2030. By energy source, the demand for electricity grows due to the following factors: the increased number of electric appliances in each household; the market appearance of new electric appliances such as next-generation DVD recorders; and the use of air conditioners over a longer period of the year and longer hours of the day. With air conditioners becoming more efficient and electric water heaters and IH (Induction Heating) appliances attracting more consumers, there will be a shift in demand to electricity, which is more convenient and safer than other energy sources. Thus, electricity will be the only energy source for which the demand increases in residential sector; electricity will acquire a share of nearly 55% by 2030 from 44% in 2006. In electricity demand, its usage in plug load and space heating will expand to 2030. In service demand, the share of plug load is forecast to increase from 35% in 2006 to 42% in 2030.

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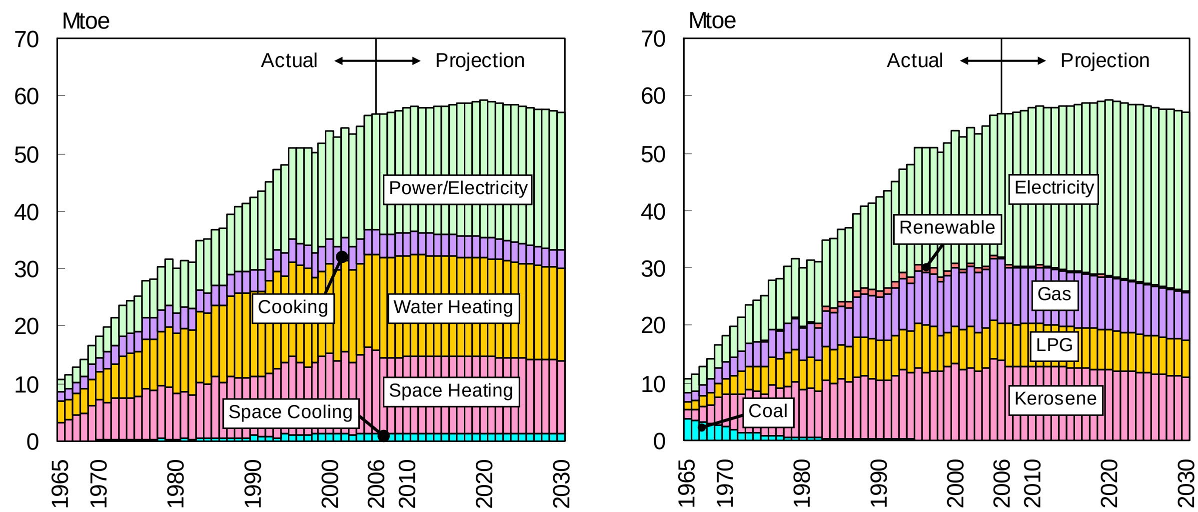
Figure 8. Final Energy Demand in Japanese Residential Sector by Energy Service and Energy Source to 2030 (300 Trial Runs, Average Value)

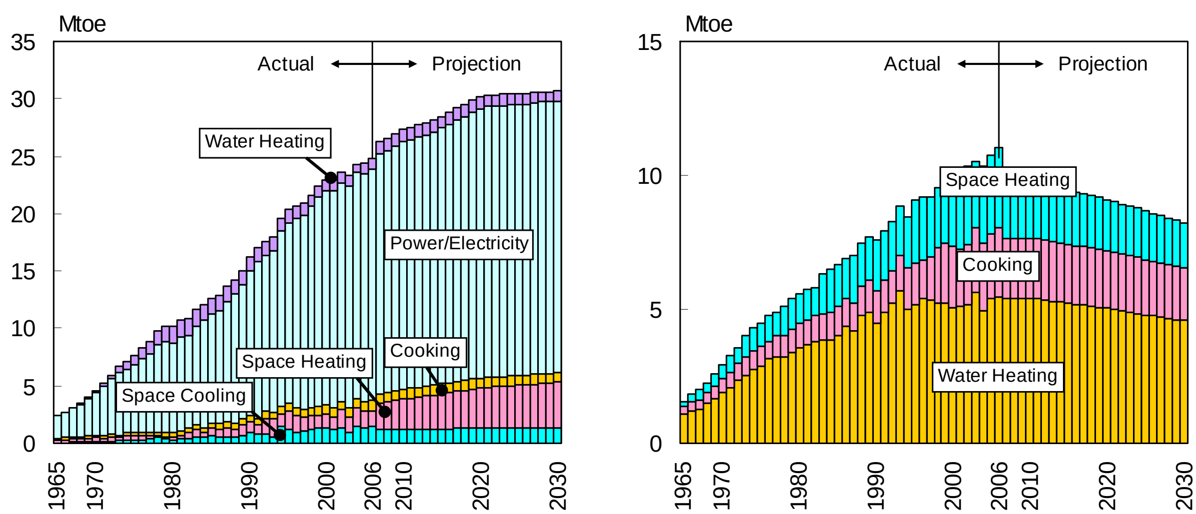
By Energy Service | **By Energy Source**



* "Mtoe" is million ton of oil equivalent
** "Power/Electricity" stands principally for plug load on a final energy demand basis, excluding generation losses.

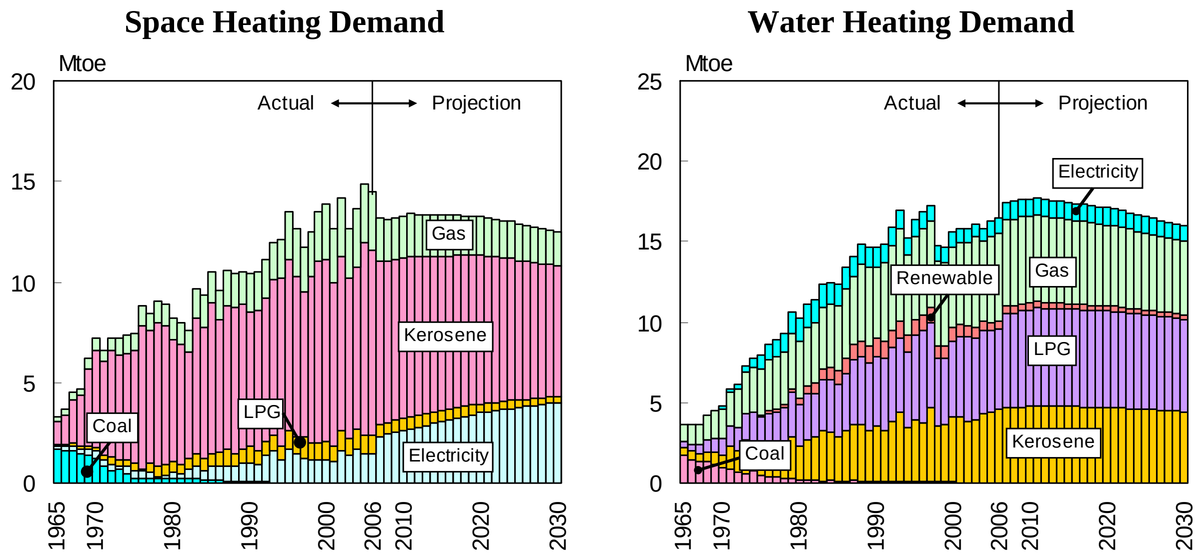
Figure 9. Electricity and Natural Gas Demand in Japanese Residential Sector by Energy Service to 2030 (300 Trial Runs, Average Value)

Electricity Demand | **Natural Gas Demand**



* "Mtoe" is million ton of oil equivalent
** "Power/Electricity" stands principally for plug load on a final energy demand basis, excluding generation losses.

Figure 10. Space Heating and Water Heating Demand in Japanese Residential Sector by Energy Source to 2030 in (300 Trial Runs, Average Value)



* "Mtoe" is million ton of oil equivalent

Considerable increases in demand for kerosene, LPG, and utility gas are unlikely because utilization of these fuels for water heating and cooking will decrease with improved appliance efficiencies, and also because a shift to electric appliances is expected, particularly for space heating. The demand for kerosene, in particular, will decline. The demand for kerosene in 2030 will be as low as two-thirds of the present level. In space heating demand, the share of kerosene will decline from 63% in 2006 to 52% in 2030, while electricity will grow from 10% in 2006 to 32% in 2030.

Monte Carlo Simulation

In our analysis, we assume future uncertainty in the macroeconomic indicators energy price, demographics, and energy efficiency of household appliances. Although A.Yanagisawa et al (2006) developed a residential energy demand forecast for 2030, the uncertainty of socio-economic factors is not explicitly considered. In order to take this uncertainty into account, uniform probability distributions for these factors are adopted, which assumes a uniform probability between the maximum and minimum achievable values of each exogenous parameter. For example, the annual GDP growth rate is postulated at a reference growth of 0.95% per annum from 2010 to 2020. A uniform likelihood is assumed for the interval between –0.05% (=0.95%-1%) minimum and 1.95% (=0.95%+1%) maximum achievable values. Table 4 shows the asummed probability distribution of exogenous variables.

Table 4. Assumption about Probability of Random Variables

Random Variables	Probability Distribution Function
GDP - Annual Growth Rate	Uniform Distribution (Max:Reference+1%, Min:Reference-1%)
CPI - Annual Growth Rate	Uniform Distribution (Max:Reference+1%, Min:Reference-1%)
Energy Price - Annual Growth Rate	Uniform Distribution (Max:Reference+1%, Min:Reference-1%)
Household - Annual Growth Rate	Uniform Distribution (Max:Reference+1%, Min:Reference-1%)
Degree Days	Uniform Distribution (Max:Past Maximum, Min:Past Minimum)
Energy Efficiency of Appliance	Uniform Distribution (Max:Reference+10%, Min:Reference-10%)

The next step is to start the Monte Carlo simulation, where value from each distribution of specific assumption is randomly picked up and residential energy demand is recalculated many times, each time using a different combination of values for the GDP growth, energy price and energy efficiency etc. In order to conduct the Monte Carlo simulation on the basis of the econometric model as explained before, we adopt the Analytica™ platform developed by Lumina Decision Systems, Inc. which is designed for risk analysis in various fields.

Figure 11. Total Residential Energy Demand by Cumulative Probability to 2030

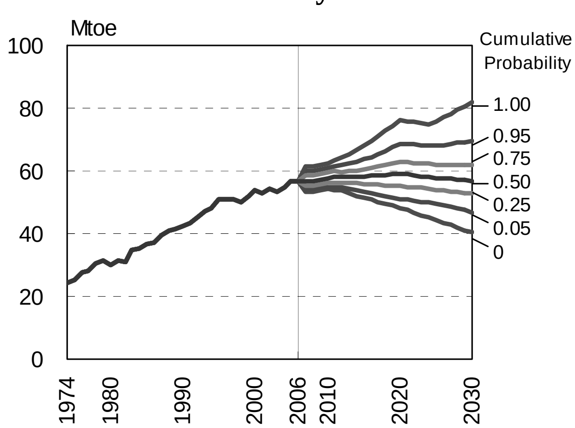
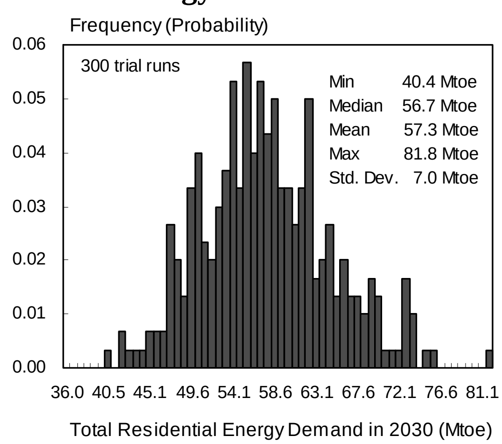


Figure 12. Frequency Chart of Total Residential Energy Demand in 2030



* Energy demand calculated in this analysis stands for final energy demand (onsite consumption), excluding such factors as generation losses.

After 300 trial runs, there will be 300 estimations of residential energy demand and summary statistics of the output can be derived. Figure 11 illustrates total residential energy demand by cumulative probability to 2030 and Figure 12 is the frequency chart of total residential energy demand in 2030. The frequency distribution shows the degree of uncertainty in the total residential energy demand, namely the range of simulated 300 values for total residential energy demand and how often they occur. Though average value of residential energy demand in 2030 is 57 Mtoe, possible residential energy demand in 2030 is statistically distributed from 47 Mtoe to 69 Mtoe in the range of cumulative probability distribution from 5% to 95%. Thus, careful energy policy decision making is required in order to tackle the energy security and global warming problem in an effective manner.

Conclusions

This paper explores Japan's residential energy demand outlook and develops a stochastic econometric model for analyzing the impact of the Japan's energy efficiency standards, as well as the future stochastic behavior of income growth, demography, energy price and climate, on residential energy demand growth to 2030. Since electricity demand is projected to exhibit astonishing growth in Japan's residential sector due to the increasing household saturation of electric and other appliances, it is important to implement more elaborate efficiency standard policies for these appliances. In addition, total residential energy demand in 2030 remains uncertain considering the future uncertainty of the economy, demography and energy prices, which implies that careful energy policy analysis is required to comprehensively tackle the energy security and global warming problems.

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