Residential Energy Demand Modeling Based on Multi-Economy Data

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Abstract

Residential energy consumption plays an important role in the structure of final energy consumption. Residential energy demand models not only explain the behavior of residential energy demand, but also provide a reference for demand forecasting and policy formulation. The models related to this field can be divided into two categories: the top-down approach and bottom-up approach. Most of the existing models are based on data for one economy; this makes it difficult to identify general results. This study attempts to use multi-economy data for analyzing the behavior of residential energy demand. For research purposes, we focus on useful energy demand elasticity with respect to GDP (PPP) per capita. We can estimate this elasticity as a function of GDP (PPP) per capita without considering additional factors for each economy. Using regression analyses, we found a linear correlation between the elasticity and GDP (PPP) per capita. The R^2 is about 0.66, which seems to be acceptable. An equation relating useful energy demand per capita to GDP (PPP) per capita was found after a further mathematical conversion. In our model, different economies share the same coefficient from the regression analysis, representing the general relationship between useful energy consumption per capita and GDP (PPP) per capita. In addition, every economy has its own coefficient to determine its deviation from the relationship. The latter coefficient reflects two categories of factors for each economy, the natural factors or so-called external uncontrollable factors, and the social factors or so-called internal controllable factors such as living habits and energy saving efforts. Finally, we test the effectives of the model by comparing our results to short-term actual data and to long-term projections of other research institutes.

1 Introduction

Residential energy consumption is the basis of human living. According to IEA statistics, residential energy consumption accounted for 24.4% of the world's total final energy consumption in 2009 (IEA 2011). In order to understand the residential energy demand, as well as to forecast the future, many models have been developed in recent years. Generally, the models can be divided into two categories: the top-down approach, which mainly uses econometric methods to analyze the relationship between residential energy and external drivers; and the bottom-up approach, which exhaustively analyzes all kinds of energy-using equipment and its energy consumption.

Houthakker (1951) studied British urban electricity consumption which initiated the econometric investigation of residential energy demand in a formal way. Since then, numerous papers have been published on the econometric approach and at least three improvements have been achieved. Firstly, the driving factors considered in the model are expanded to include population, income, fuel price, urbanization, and others. In addition, the focus has expanded from electricity to other fuels[1]. Secondly, identifying the co-integrating relationships became very popular in recent years. Since most of the research is based on the historical data, confirming the stability of the relationship between the independent variables and the dependant variable is a key factor when dealing with historical data[2]. Thirdly, research has focused on homogeneous groups of consumers instead of one representative consumer[3], which means structural analysis of household income and location was applied.

The bottom-up approach is a way of summing up end-use energy demands including space heating, water heating, lighting, electric appliances, etc. In each end-use, the demand will be the estimated number of appliances multiplied by an intensity factor based on surveys. McAleer (1982), Farahbakhsk et al (1998), Tanatvanit et al (2003) use this approach to analyze their economy's residential energy demand. This approach has an obvious benefit that it could explain the actual dynamics of residential energy demand. The approach is therefore used in some institutes where long-terms outlooks are regularly conducted, such as IEA (2007), LBNL (2011).

However, most of the models are based on data for one economy, and may then apply their findings to other economies. This method faces at least two challenges. Firstly, it is highly uncertain whether the experience of developed economies will match that of developing economies. In the econometric method, the income level is always the most important factor. However, developed economies accomplished the process of industrialization and urbanization at least 30 years ago, and in some economies it was over 100 years ago. Today, the technological conditions and consumer lifestyles are quite different. When a developing economy improves their income per capita from say 1000 US dollars to 10000 US dollars, it is hard to assume the economy will repeat the process of developed economies 30 years prior. Secondly, most of the developing economies lack detailed energy databases. The energy statistics systems, which follow international norms, were only established in recent years. In most developing economies adequate data useful for analysis is not available. In addition, developing economies have little experience in energy surveys and do not provide detailed consumption data for different energy end-uses, which restrains the usefulness of the bottom-up approach for developing economies. Sometimes, researchers use the data of developed economies to estimate the data for developing economies. Unfortunately, these kinds of estimates require a good deal of subjective judgment and the results cannot be accepted without reservations.

1 Some resent studies follow as: Anna Alberini and Massimo Filippini(2010), Mahdi H. Al-Salman(2007), Pernille Holtedahl,Frederick L. Joutz(2004), TheologoDergiade and Lefteris Tsoulfidis(2011), Roula Inglesi,Anastassios Pouris(2010).

2 Some resent studies follow as: Beenstock et al (1999), Clements and Madlener (1999), Narayan and Smyth (2005), Halicoglou (2007), Ziramba (2008).

3 Assimakopoulos (1992)

Such challenges are most obvious for international institutes where often a general model for an outlook for multiple economies is required. On the one hand, they need to make sure the methodology is the same for every economy or country and, on the other hand, they have to ensure that the estimation process is reasonably objective. The Asia Pacific Energy Research Centre (APERC) is an institute focused on energy issues in Asia Pacific region. It publishes an energy outlook for the 21 APEC member economies regularly, and improves its model constantly. In the APEC region, the difference between the development stages of member economies is very significant and their residential sector energy demand varies widely (Figure 1). The model described in this paper is APERC's attempt at finding a new approach for multi-economy energy demand projections.

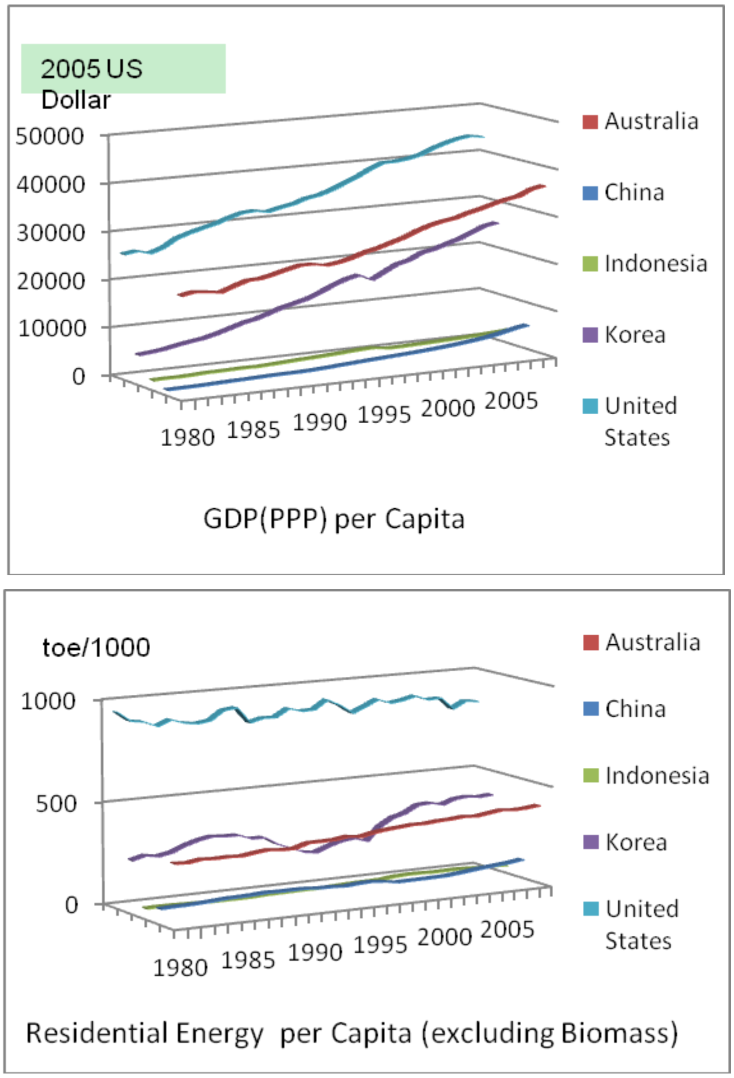

Figure 1: GDP and Residential Energy Demand of Some Economies in APEC

2 Methodology

Before conducting international research on residential energy demand, it is important to ensure the model is acceptable for different economies and could summarize the experience of the different economies. The top-down approach seems the more appropriate choice if it could explain general behavior across different economies. Top-down or econometrics approaches need to resolve three issues: the dependent variables, the independent variables and the exact formulation to explain the relationship between the variables.

We used the concept of "useful energy", which has been introduced by earlier research (LBNL 2008). It is noted that different fuels have different coefficients in terms of the ratio between the energy input and useful energy output. For example, when people use a coal product for heating, much of the heating value in coal is lost due to the heat dissipation in the oven and the flue. On the other hand, electricity or district heating (steam) can be converted almost completely into useful heat. By focusing on the useful energy, we can consider all fuels on a common basis. What we care about is the real demand for useful energy in the residential sector. To estimate useful energy, we multiplied the use of each fuel by a coefficient reflecting the fuel's estimated efficiency of conversion of useful energy. These coefficients were 0.3 for coal products, 0.8 for oil products, 0.8 for natural gas, 1.0 for electricity, 1.0 for district heating (steam), and 1.0 for distributed electricity or heat from renewable energy (such as solar, geothermal, wind) excluding biomass. Biomass was excluded from our analysis as good statistics on biomass consumption are generally unavailable. We focus on energy per capita in order to make consistent comparisons between economies with widely varying populations.

As we mentioned above, population, income, fuel price, urbanization and other factors are often included in residential energy models. Given the difficulties of obtaining good data for some economies, the simplest and most important variable should be selected. Judson, Schmalensee and Stoker (1998) pointed out that GDP per capita in PPP (purchasing power parity) alone explains over 80% of the variance of log per-capita energy consumption.

Considering GDP and energy demand growth, the APEC economies appear to be following a similar pattern at varying stages of their economic development. Figure 2 shows the change in energy demand in each economy from the year when their GDP per capita in PPP was two-thirds of what it was in 2008, but no earlier than 1980, to 2008, implying that it usually covers the most recent period in which GDP per capita in PPP increased by 50%. This variable time period allows for a consistent comparison of recent growth trends between slow-growing economies and fast-growing economies. For the slow-growing economies, we want a longer time period to get a reasonable estimate of the trend of their energy demand growth. However, for the faster-growing economies, we want to consider only their most recent experience, as the trend of energy demand growth may have changed with their growth over the longer term.

The graph clearly shows a pattern where the less-wealthy economies tend to have faster residential energy demand growth than the more wealthy economies. This relationship is to be expected, since the less wealthy economies are just reaching the point where their residents can buy home appliances (including air conditioners, space heaters, and water heaters) for the first time, causing their energy demand to grow rapidly with income. The residents of the more wealthy economies, on the other hand, generally already have home appliances. Although they may still buy more of them, or use them more intensively, as their income grows, their energy demand will grow more slowly with income. It is this observation that is the basis of our multi-economy residential demand model.

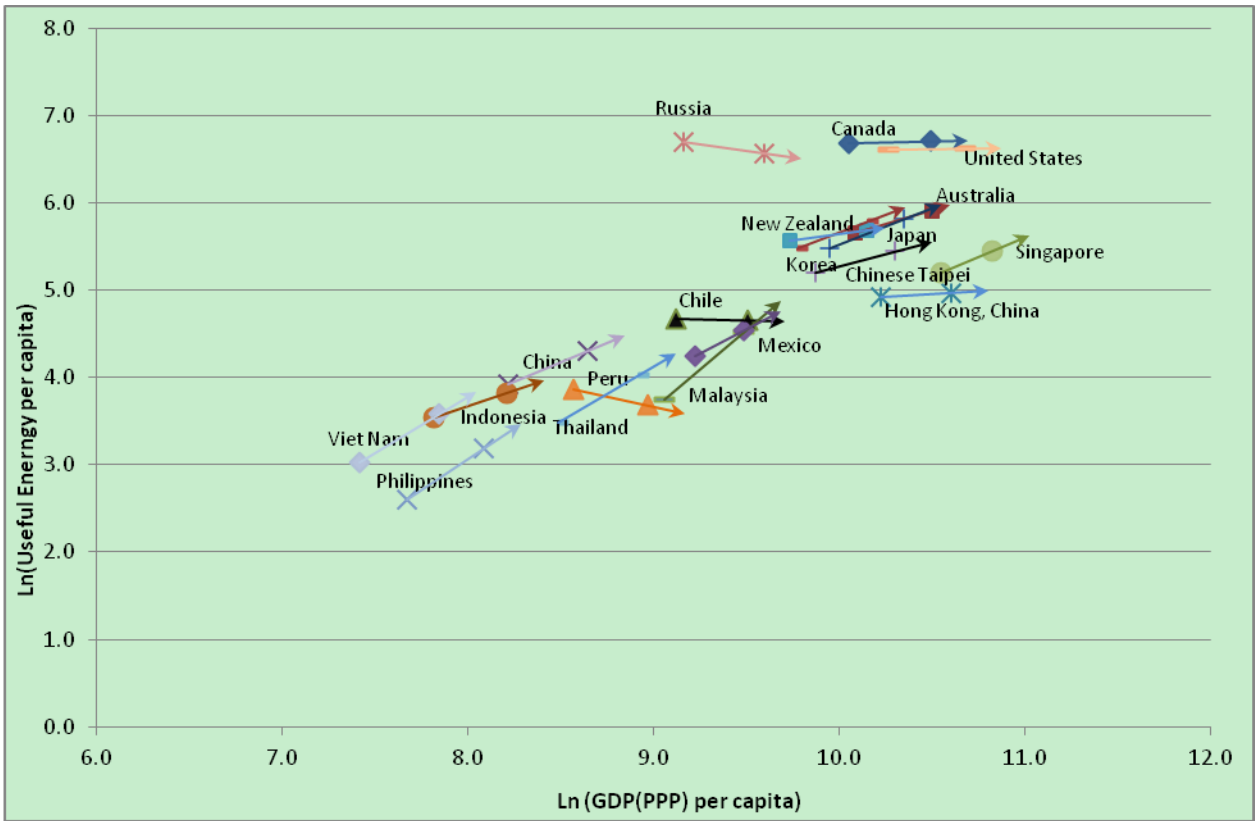

Figure 2 APEC Economies Residential Energy Demand Growth

3 Modeling

Following our methodology, we build an equation for elasticity based on historical data.

(1) $WE = \sum E_{fuel} \times W_{fuel}$

(2) $b_{ij} = d \ln(WE_{ij}) / d \ln(G_{ij})$

where, WE is useful energy per capita; E is the fuel demand per capita in the residential sector; W is the useful energy coefficient for the fuel; b is elasticity, with each variable transformed by a natural logarithm; G is GDP (PPP) per capita; i represents the year; and j represents the economy.

Then we calculate the log-transformed elasticity for each economy.

(3) $$b_{ij} = \frac{d \ln(WE_{ij})}{d \ln(G_{ij})} = \lim_{\Delta \to 0} \frac{\Delta \ln(WE)_j}{\Delta \ln(G)_j} \approx \frac{\ln(WE_{i',j}) - \ln(WE_{i,j})}{\ln(G_{i',j}) - \ln(G_{i,j})}$$

As in Figure 2, we use a time period for each economy starting from the year when their GDP per capita in PPP was two-thirds of what it was in 2008, but no earlier than 1980, to 2008. We use data from the Global Insight database for GDP data, and the IEA energy database for the energy data. Some economies had to be excluded including Peru and Russia, which changed their statistical classifications in 2007; Brunei, whose GDP per capita in PPP has declined since 1980; and Papua New Guinea, which does not collect residential sector energy statistics. The total sample includes 17 economies (see Appendix 1). In four additional economies, a time period shorter than the most recent period in which GDP per capita in PPP increased by 50% was used: two economies changed their statistical classifications (Chile in 1997, Malaysia in 1997); data was missing for one economy (Singapore from 1992 to 2001 for oil products); and GDP per capita did not grow by 50% since 1980 for one economy (Mexico).

Based on these samples, we first draw a scatter plot of log-transformed energy demand elasticity (equation 3) vs. 2008 per capita GDP in thousands of US dollars PPP as shown in Figure 3.

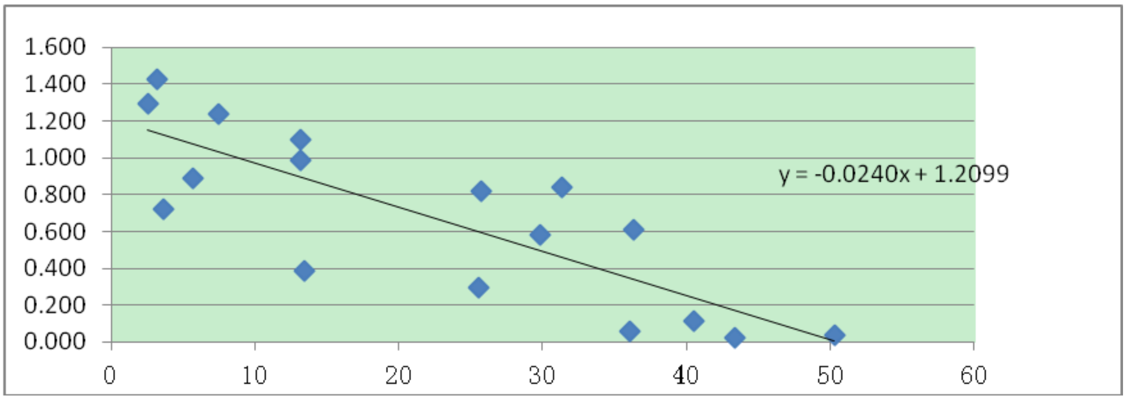

Figure 3: APEC Economies' Energy Elasticity vs. GDP per Capita

A simple linear regression of the form

$$(4) \qquad \frac{\ln(WE_{i'}) - \ln(WE_{2008})}{\ln(G_{i'}) - \ln(G_{2008})} = m_{1,2008} + m_{2,2008}\, G_{2008}$$

yielded the results shown in Table 1.

Table 1: Simple Linear Regression Result

m2	-0.02398571	m1	1.209875616
se2	0.004396935	se1	0.119209034
r2	0.664865006	sey	0.276084923
F	29.75808335	df	15
ssreg	2.268246949	ssresid	1.143343267

For the significance testing, the F-value of 29.76 is greater than the 0.05 critical value of F (1, 15) =4.54, indicating that GDP per capita is highly significant in explaining the log-transformed energy elasticity. For goodness of fit testing, the R-squared is 0.6649, indicating that GDP per capita can explain 66% of the variation in log-transformed energy elasticity, which we consider to be quite acceptable for long-term forecasting where there will always be huge uncertainties.

To use this model to project future residential energy demands, we start by noting that if we assume our 2008 estimates of the parameters m_1 and m_2 remain unchanged in future years, we can rewrite equation (4) as

$$(5) \qquad \frac{\ln (WE_{i'}) - \ln (WE_i)}{\ln (G_{i'}) - \ln (G_i)} = m_1 + m_2\, G_i$$

Then, we can solve for WE_i as follows:

$$(6) \qquad ln\, WE_i = \int \frac{d \ln(WE_i)}{d \ln(G_i)} d\, ln(G_i) \approx \int \frac{\ln (WE_{i'}) - \ln (WE_i)}{\ln (G_{i'}) - \ln (G_i)}\, d \ln(G_i)$$

$$= \int (m_1 + m_2\, G_i)\, d \ln (G_i)$$

$$= \int m_1\, d \ln(G_i) + \int m_2\, G_i\, d \ln(G_i) = \int m_1\, d \ln(G_i) + m_2 \int e^{\ln(G_i)}\, d \ln (G_i)$$

$$= [m_1 \ln(G_i) + k_1] + [m_2\, e^{\ln (G_i)} + k_2]$$

$$= m_1 \ln(G_i) + m_2\, G_i + k$$

$$(7) \qquad WE_i = e^{m_1 \ln(G_i) + m_2 G_i + k} = G_i^{m_1}\, e^{m_2 G_i}\, e^k$$

To convert this total useful-energy demand per capita back to total input fuel demand per capita we apply the equation

$$(8) \qquad E_i = \sum_{fuel} (WE_i * S_{fuel} / W_{fuel}),$$

where S_{fuel} is the share of each fuel measured in terms of useful energy. Unfortunately, these fuel shares are not easily modeled, as they depend on each economy's resources and energy policies. However, the projection of useful energy demand gives the policy maker or analyst a basis to further consider how to deal with future demand considering an economy's resources and current policies.

4 Results and Discussion

Our model is based on multi-economy data, which allows us to suggest some general findings applicable across economies.

First, the model indicates some general trends in residential energy demand with income. From equation (5), it is found that when G is less than about US$9000, the left side of equation (5) is more than 1, implying that residential energy demand grows faster than the GDP. When G exceeds US$9000, the growth rate of residential energy demand falls behind the GDP growth rate, until around US$50000 where the residential energy demand per capita has reached its peak. This general trend could be explained by the consumer's behavior. As the income of the consumers rise, their demand for residential energy grows more slowly as their basic needs are satisfied. At the same time, when consumers become richer, they can afford to invest in more energy efficient products. At around US$50,000 per capita, the improvements in energy efficiency may offset growth in demand, causing demand per capita to peak. It is interesting to speculate as to whether residential energy demand per capita might actually drop as an economy's GDP per capita rises above $50,000. At this point, we have insufficient data to draw any conclusions. In our model, we assume energy demand per capita will stay constant once the GDP (PPP) per capita is over US$50000.

Second, the model can take into account the effects of other factors on energy demand besides GDP per capita. Figure 2 indicates that every economy's useful energy demand per capita does not lie at single point for each value of GDP per capita; different economies have different residential energy demand levels. The deviation from the general trend can be represented by the value of k which can be calculated applying equation (7) in to each economy j in a particular year. We calculated these k_j for every economy based on 2008 actual demand data (see Appendix A). It is clear that Canada and United States have the highest k-value, while Hong Kong and Singapore have the lowest ones. Since the model already takes into account GDP per capita, the remaining differences must be explained by other factors. Such factors could be classified as 'external' or 'internal'. The former refer to the factors affected by the local environment, such as temperature or wind, while the later refer to human factors such as consuming habits or energy conservation efforts. In 2008, Hong Kong and Singapore use less than 20% of energy per capita in comparison to Canada and United States (see Appendix 1). The two economies generally have low energy use for heating, and a compact city design which naturally leads to lower energy demand. By comparing the k-values of different years for an economy, we could understand the economy's improvement due to internal factors, such as better consuming habits or larger energy conservation efforts, while the external factors would always be considered as fixed .

Third, the model provides a simple method for projecting residential energy use in a business-as-usual scenario. Both the coefficient reflecting the general trend with GDP and the coefficient reflecting a particular economy's deviation to the general trend are may change over time. When there are major changes in end-use technology or global life styles, the coefficient reflecting the general trend will change. If changes occur in a given economy, the coefficient reflecting the economy's deviation will be changed correspondingly. However in a business as usual (BAU) scenario, we could assume the coefficients are fixed. This approach can give results very similar to much more sophisticated models. For example, we did a long-term projection for Japan with 2008 as the base year. We compared it with the Institute of Energy Economics, Japan Outlook results (IEEJ, 2010). IEEJ publishes their projection annually and has long experience in Japanese energy issues. We use their macroeconomic assumptions and assume the fuel share is constant in the future. As shown in Figure 4, we find that the two projections have the same trend. Though the historical energy statistics are a little different, the matching growth rate shows that our model fits the Japanese situation very well.

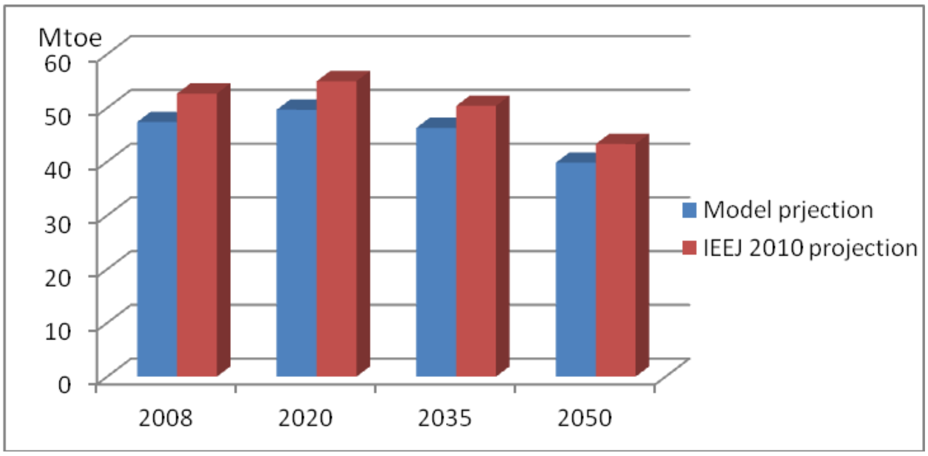

Figure 4: Comparison of Model Projections for the Japan Residential Sector

Table 2: Number in the Comparison of model projection

Japan		Actual	Forecast			Average Annual Growth rate (%)		
		2008	2020	2035	2050	2008-2020	2020-2035	2030-2050
Macroeconomic Indicators	Real GDP(Trillion CY2000 Yen)	544.1	656.8	767.2	850.6	1.6%	0.9%	0.7%
	Population(million)	127.69	122.82	110.74	95.20	-0.3%	-0.7%	1.0%
Energy demand projection	Model(Mtoe)	47.38	49.67	46.29	39.81	0.4%	-0.5%	-1.0%
	IEEJ 2010 (Mtoe)	52.67	54.96	50.38	43.29	0.4%	-0.6%	-1.0%

5 Conclusion

In conclusion, this model takes into account various factors that influence energy demand in the residential sector. It verifies the universal impact of per capita GDP and also reflects the influence of individual economy characteristics. The model is expected to be employed in two different ways. First, it can contribute to energy demand analysis in the residential sector, especially for the projection of business-as-usual scenario residential energy demand using common assumptions across economies. The model also be dynamically updated to provide projections based on the latest data, which could reflect current developments in the world or in specific economies. Second, assuming that the external factors for each economy can be treated as a constant, the model can be used to quantify the impact of the internal factors and to track their changes over time.

References

Anna Alberini and Massimo Filippini, 2010, "Response of Residential Electricity Demand to Price: The Effect of Measurement Error", CEPE Working Paper No. 75

Assimakopoulos, V., 1992, Residential energy demand modeling in developing regions: The use of multivariate statistical techniques, *Energy Economics*, 14(1), pp. 57-63.

Beenstock, M., E. Goldin, and D. Nabot, 1999, The demand for electricity in Israel, *Energy Economics*, 21, pp. 168-83.

Clements, M. P. and R. Madlener, 1999, Seasonality, cointegration and forecasting UK residential energy demand, Scottish *J. of Political Economy*, 46(2), pp. 185-206.

Halicoglou, F., 2007, Residential electricity demand dynamics in Turkey, *Energy Economics*, 29, pp. 199-210.

Holtedal, P. and F. L. Joutz, 2004, Residential electricity demand in Taiwan, *Energy Economics*, 26, pp. 201-24.

Houthakker, H. S., 1951, Some calculations on electricity demand in Great Britain, *Journal of the Royal Statistical Society. Series A (General)*, Vol. 114, No. 3 (1951), pp. 359-371.

IEA, 2007, World Energy Model – Methodology and assumptions, World Energy

IEA, 2011, IEA database, http://data.iea.org/ieastore/statslisting.asp

IEEJ,2010, EDMC handbook of energy & economic statistics in Japan 2011, The Institute of Energy Economics, Japan, pp. 264-267.

Judson, Schmalensee and Stoker, “Economic Development and the Structure of Demand for Commercial Energy”, *Energy Journal*, 1998.

LBNL (Lawrence Berkeley National Laboratory), 2008, Global Potential of Energy Efficiency Standards and Labeling Programs, see: http:// ies.lbl.gov/iespubs/LBNL-760E.pdf

Mahdi H. Al-Salman, 2007, Household Demand for Energy in Kuwait, *J. King Saud Univ.*, Vol. 19, Admin. Sci. (2), pp. 51-60

Michael A. McNeil, Virginie E. Letschert and Stephane de la Rue du Can, 2008, “Global Potential of Energy Efficiency Standards and Labeling Programs”, Lawrence Berkeley National Laboratory report LBNL-760E

Narayan, P. K. and R. Smyth, 2005, The residential demand for electricity in Australia: an application of the bounds testing approach to cointegration, *Energy Policy*, 33, pp.467-74.

Pernille Holtedahl and Frederick L. Joutz, 2004, “Residential electricity demand in Taiwan”, *Energy Economics* 26 (2004) 201–224

Roula Inglesi, and Anastassios Pouris, 2010, “Forecasting electricity demand in South Africa: A critique of Eskom’s projections”, *South African Journal of Science* Vol. 106

Subhes C. Bhattacharyya and Govinda R. Timilsina, 2009, “Energy Demand Models for Policy Formulation A Comparative Study of Energy Demand Models”, The World Bank Policy Research Working Paper 4866

TheologoDergiade and Lefteris Tsoulfidis, 2011, “Revisiting Residential Demand for Electricity in Greece: New Evidence from the ARDL Approach to Co- integration”, *Empirical Economics* (2011) Volume 41, Number 2, 511-531

Ziramba, E., 2008, The demand for residential electricity in South Africa, *Energy Policy*, 36, pp. 3460-66.

Appendix 1

Economy	Start Year			Ending Year			Growth of GDP (PPP)per capita	$b_{2008,j}$	$k_{2008,j}$
	Year	GDP PPP per capita (Thousand 2005 US Dollar)	Useful Energy per capita (toe/1000)	Year	GDP PPP per capita (Thousand 2005 US Dollar)	Useful Energy per capita (toe/1000)			
Australia	1988	23.99	287.19	2008	36.30	369.63	51%	0.61	2.4375
Canada	1983	23.20	798.57	2008	36.04	818.17	55%	0.06	3.2345
Chile	1998	10.40	94.90	2008	13.43	104.78	29%	0.39	1.8316
China	2004	3.71	50.75	2008	5.69	74.42	54%	0.89	2.3420
Hong Kong, China	1998	27.53	137.24	2008	40.48	143.36	47%	0.11	1.4588
Indonesia	1993	2.48	34.32	2008	3.69	45.61	49%	0.72	2.3293
Japan	1985	20.92	239.37	2008	31.30	336.16	50%	0.84	2.4020
Korea	1999	17.58	238.94	2008	25.76	327.09	47%	0.82	2.4775
Malaysia	1998	9.33	65.26	2008	13.19	91.77	41%	0.99	1.7147
Mexico	1980	10.16	70.16	2008	13.17	93.23	30%	1.10	1.7316
New Zealand	1982	16.91	262.36	2008	25.51	295.92	51%	0.29	2.3831
Philippines	1985	2.15	13.43	2008	3.24	24.17	51%	1.43	1.8404
Singapore	2002	39.67	149.05	2008	50.27	149.88	32%	0.04	1.4760
Thailand	1993	4.84	32.71	2008	7.47	55.99	54%	1.24	1.7714
Chinese Taipei	1996	19.44	180.29	2008	29.83	231.18	53%	0.58	2.0505
United States	1985	28.69	745.69	2008	43.39	753.39	51%	0.02	3.1038
Viet Nam	2001	1.66	20.61	2008	2.55	35.86	53%	1.30	2.5091