Reducing the Price of Development: The Global Potential of Efficiency Standards in the Residential Electricity Sector.

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Collaborative Standards and Labeling Program

Abstract

The last two decades have witnessed the development of minimum efficiency performance standards (MEPS) for appliances and lighting equipment as an effective policy for market transformation in the residential sector. In industrialized countries, government portfolios of standards programs promulgated to date will have a significant effect on sector consumption. For example, standards already written into law in the United States are expected to reduce energy sector consumption and carbon dioxide emissions by 8-9% by 2020[1]. Although in recent years the development of MEPS has spread throughout the globe, including many developing economies, the full potential of these programs is far from realized. Since much of the growth in global energy consumption over the next decades will come from the developing world, a global estimate of the potential impacts of standards programs that includes these countries is critical for prioritizing policy options.

This paper presents a step forward in the assessment of the global impacts of efficiency standard programs. Unlike previous assessments, it uses a bottom-up methodology to forecast residential end use consumption and evaluate the policy potential for each end use individually. Electricity consumption growth in developing countries over the next 20-30 years will be driven by households acquiring new appliances, in contrast to industrialized countries, where appliance markets are saturated. Currently, many households in developing countries do not have access to electricity, or may use electricity only for lighting and one or two appliances. As household incomes grow, however, more and more will purchase energy consuming equipment. Electricity consumption and the potential of mitigation by standards therefore depend on the affordability and purchase order of each end use. Unlike models that forecast total electricity consumption in proportion to per capita GDP, we forecast household electricity consumption by modeling ownership of individual appliances using an econometric parameterization calibrated to household survey data. By applying estimates of efficiency improvement for each end use according to current best practices, we then calculate the potential for mitigation of electricity consumption and related carbon dioxide emissions from standards programs. We believe this to be the first study to make such an evaluation with a global scope and at the end use level of detail.

Introduction – Standards and Labeling Programs Past and Future

For many decades, energy consumption and its associated greenhouse gas emissions have emanated predominately from the world's major industrial economies in North America, Western Europe, and Japan. This era is coming to a close, as developing countries, especially in Asia, are enjoying rapid economic growth. So far, the relationship between energy consumption and economic growth in these regions seems to be echoing the history of countries that experienced it decades ago. Growth in emerging economies is occurring even more rapidly, however. The resulting demand for power is straining an already inadequate energy infrastructure, causing environmental damage and hindering economic development. Fossil fuels are often imported, leaving national economies vulnerable to supply limits and price shocks. Global environmental impacts associated with energy consumption, including climate change will present significant non-economic limits to carbon emissions.

Figure 1 summarizes the current state of affairs and outlook for global energy consumption in the sector and fuel that is the focus of this paper – *residential electricity*. The projections correspond to the IPCC's Special Report on Energy Scenarios – Scenario B2, which forecasts intermediate economic growth and moderate population growth[1]. The figure shows that, by 2020, residential electricity consumption will have doubled. Most of the growth will come from the developing world. While consumption in the Pacific OECD countries, North America, and Western Europe will continue to grow, this growth is likely to be incremental – driven by larger homes and additional 'supplementary' appliances. On the other hand, the majority of households in the developing world currently consume very little commercial energy. The influence of income growth, urbanization and universal electricity access in these countries will create new utility customers, who can afford major appliances for the first time, qualitative shift in consumption. From 2020 on, the developing world will consume most of the world's residential electricity, and will further increase its share through 2030.

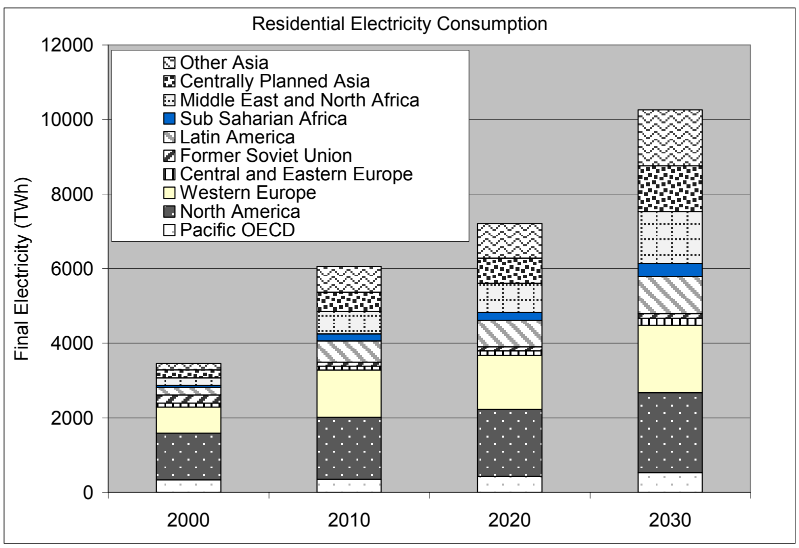

Figure 1 – Residential Energy Consumption by Region

To varying degrees, and in a variety of areas, industrialized countries have been successful in mitigating their consumption through efficiency. In particular, the adoption of energy efficiency standards and labeling programs (S&L) has demonstrated an ability to significantly reduce energy consumption in a cost effective way, and with little or no reduction in the utility provided to the end user. Minimum efficiency performance standards (MEPS) and information labels (both comparative and endorsement) have been implemented for a wide variety of equipment for all sectors and fuels. For example, the average new refrigerator sold in the U.S. today uses only a quarter of the electricity per year than those sold 30 years ago when standards and labels were first introduced, in spite of increases in size and added features. The U.S. program of national, mandatory energy-efficiency standards began in 1978 and has now reached 39 residential and commercial product standards. Projected annual residential carbon reductions in 2020 are approximately 35 metric tons, an amount roughly equal to 9% of 1990 residential carbon emissions [1].

[1] SRES electricity consumption projections are available only for the buildings (residential + commercial) sector. Results shown are from estimates of fraction attributable to residential sector only.

Similarly, the European Union has achieved significant results in efficiency improvement from its labeling program. In particular, the efficiency of refrigeration appliances improved by 29% between 1992 and late 1999, with about one-third of the impact attributable to labeling [2]. Without standards and labeling programs and voluntary agreements, electricity consumption in OECD countries in 2020 would be about 12% higher than is now predicted. Furthermore, these policies are estimated to generate a net cost savings of €137 billion in OECD-Europe by 2020 (IEA 2003)

S&L programs are no longer limited to industrialized countries. The number of countries throughout the world has increased dramatically over the past 15 years, from 12 in 1990 to over 60 in 2005 [3]. Most developing countries still do not have standards programs in place for many products, however.

S&L programs are mature in the major industrialized economies, and the impacts of such programs to date are well understood. Going forward, however, the global picture is not so clear. Besides the more routine forecasts of advances in energy efficiency in industrialized countries, predictions of future impacts of S&L programs must rely on estimates of: (1) the growth in use of energy-consuming equipment in developing countries (2) the baseline technology that is now being used in developing countries, and (3) the adoption of efficiency programs in these emerging economies.

To date, analyses that try to present a comprehensive picture of future efficiency scenarios are few. The goal of the research presented here is to improve the state of understanding for the potential of efficiency improvement in both industrialized and developing countries worldwide. It takes a global perspective, but assesses savings potential individually in 10 regions. It focuses on a single major product, refrigerators. A global perspective allows for a comparative evaluation of opportunities for support. The reason for concentrating on refrigerators is twofold. First, refrigerators constitute a major fraction of household energy consumption, especially in developing countries, and are among the first ‘major appliances’ adopted by low-income households. Their use is highly correlated to income, and therefore to economic growth. Second, refrigerators are relatively well-understood, since the ownership of refrigerators in developing countries is relatively well documented, and since there is a relative abundance of technical efficiency data.

Overview of Methodology

Previous estimates of global potential benefits have relied on sector level estimates based on the percentage of overall sector savings achieved to date in countries with mature programs. This paper goes beyond this to make an end use estimate. It trades detail for completeness, but provides a framework for extension to recover coverage through the addition of new products. Enduse level analysis is particularly appropriate for forecasts that include the developing world because the relative importance of enduses differs significantly between regions. For example many low–income households may use electricity only for lighting, refrigeration, and a television, so the percentage of sector consumption for refrigerators will be higher than in industrialized countries. An accurate assessment of enduse consumption relies on the ability to forecast household appliance ownership rates as a function of economic development.

The methodology brings together three main components comprising four analytical steps. The first component is appliance ownership modeling. We take advantage of previous work [4], which developed an econometric relationship between household income and refrigerator ownership in developing countries on a household basis. In Step 1 of the current analysis, we generalize this relationship to *predict average saturation (ownership) rates* as a function of national macroeconomic variables. This type of analysis is particularly relevant for refrigerators which, while highly sought-after, are relatively expensive. More than any other appliance, their ownership is determined largely by economic considerations.

The second component is to gather the best available estimates of baseline unit energy consumption and realistic potentials for unit efficiency improvement on a regional or national basis. Step 2 of the current analysis estimates baseline consumption by existing and new refrigerators and Step 3 estimates reduced energy use by new refrigerators from standards, along with feasible dates for standards implementation. Geographical detail is important in this component because there is significant variability in product classes. Secondly, efficiency technology varies significantly, largely dependent on the past history of standards. Countries with stringent standards already in place will have less room for improvement, while countries with no standards in place may still take advantage of ‘low-hanging fruit’. An accurate assessment of savings potential relies on knowledge of baseline energy consumption and costs and benefits of efficiency design option implementation. These are certainly not available for every country. Therefore, the best estimate relies on dividing the world into ‘technology regions’ that are thought to have a similar baseline and savings potential of certain ‘marker economies’ for which these data are available. Savings estimates are based on an assumption that moderate or stringent standards are implemented by 2010. Figure 2 shows the analysis flow, containing these two main components.

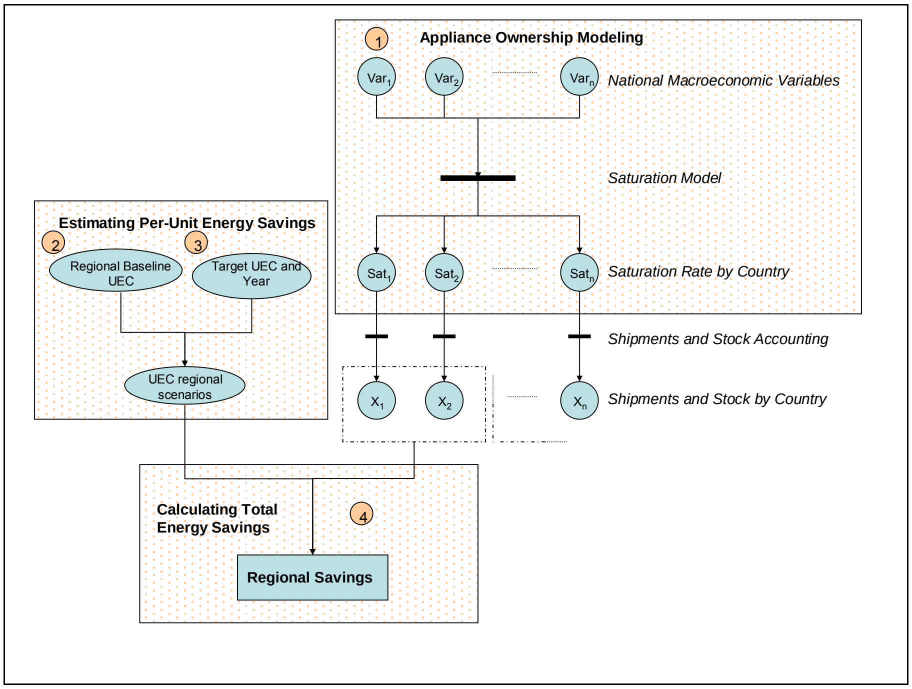

Figure 2 – Analysis Flow

The third component is the integration of the results of the first two components to estimate total energy savings. In Step 4 saturation results are combined with regional per unit savings scenarios through a stock accounting model that takes into account of the rate at which new products replace inefficient models. .The result is a region-by-region estimate of the final electricity consumption and savings for each year through 2030. In addition to providing a more accurate estimate of global savings potential from refrigerator standards, the methodology provides and expandable framework that links regional and global consumption forecasting to regional and country-based estimates of baselines, achievable targets, and timelines. It unifies two critical, but distinct areas of research – the forecasting of energy consumption in the face of dynamic economic growth in the developing world, and the real-world potential for well-established efficiency policies, and unites the macro- and micro-picture by focusing on individual end use and engineering-based country specific technologies.

Appliance Ownership Modeling

The forecast of energy used by refrigerators proceeded by developing an econometric formula relating saturation (ownership rate) to macroeconomic variables. Variables investigated were those for which both historical data and forecasts were available for a wide range of countries. The general strategy was to optimize the variables, parameters and form of the relationship in order to best explain the variation in current saturation levels between countries.

To begin the estimation of saturation rates, which is Step 1 of the current analysis, we gathered 60 average refrigerator saturation rates[2] for 57 countries across a wide range of economic development. These data were obtained from different sources, including standard of living surveys and general census surveys taken between year 1991 and 2002 (data were available for some countries for multiple years). Saturation rates from this sample vary from 0.008 (Chad 1998) to 1.29 (United States 2002) per household. These data are detailed in Appendix A.

Model Variables and Parameters

The variables found to best describe the range of refrigerator saturation rates in the data were: household income, urbanization percentage and electrification rate. Unavoidably, there is significant correlation between these variables, since urban households tend to have higher income, and the average income is low in countries where many people lack access to electricity. By far, the most significant determining variable for national average appliance ownership is average household income, but the other variables were also found to provide additional resolving power, since they serve as indirect indicators of the distribution of wealth and access to infrastructure.

Our estimate of base income is calculated from GDP per household per month. GDP is estimated through 2003 by the World Bank. In order to more accurately relate income, to ability to purchase appliances, household income is corrected for Purchase Power Parity. The factor *PPP* gives an equivalent measure of comparison of wealth between countries taking in account the difference in prices for a generic basket of goods, since in general, disposable income is be related to the cost of living[3].

In order to provide an accurate estimate of appliance saturation for a wide range of countries, input variables relied on publicly available global databases, such as those provided by UN agencies. Electrification rates are from various sources: IEA's World Energy Outlook (2002), various national census reports, demographic health surveys (DHS), and World Bank data. The general form of the saturation relationship follows a modified logistic 'S-shaped' function. In a simple binary choice model, maximum penetration is 100%. In the case of appliances however, saturation commonly exceeds 100%. For example, many households in industrialized countries own more than one refrigerator. Therefore, we use a modified logistic function

$$Sat = (K \times I)^{\lambda_a} \times \left[1 - \exp\left(-\left(bE^{\lambda_b} + cU^{\lambda_c}\right)\right)\right]^a$$

Where:

- Sat_i is the saturation of the appliance i
- I is the monthly household income
- U is the national percentage of urbanization
- E is the national percentage of electrification

A least squares fit to the data for each appliance yields the parameters given in Table 1.

Table 1 – Model Parameters for Refrigerator Saturation

Parameter	K	a	λa	b	λb	c	λc
Fit Value	0.137	1.24	0.208	0.0317	4.00	0.158	0.679

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2 We define the saturation rate as the average number of refrigerators per household, which can be greater than one.

3 We recognize, however that this factor may overcompensate in some cases, since prices of major appliances may not scale in the same way as the products used in evaluating *PPP*.

Figure 3 demonstrates the ability of the model to parameterize the saturation data. Each pair of data points represents a different country. The strong correlation between ownership and monthly income is evident, although many data points that fall off the main income trend are still relatively well modeled, indicating the resolving power of the other variables, which are not shown.

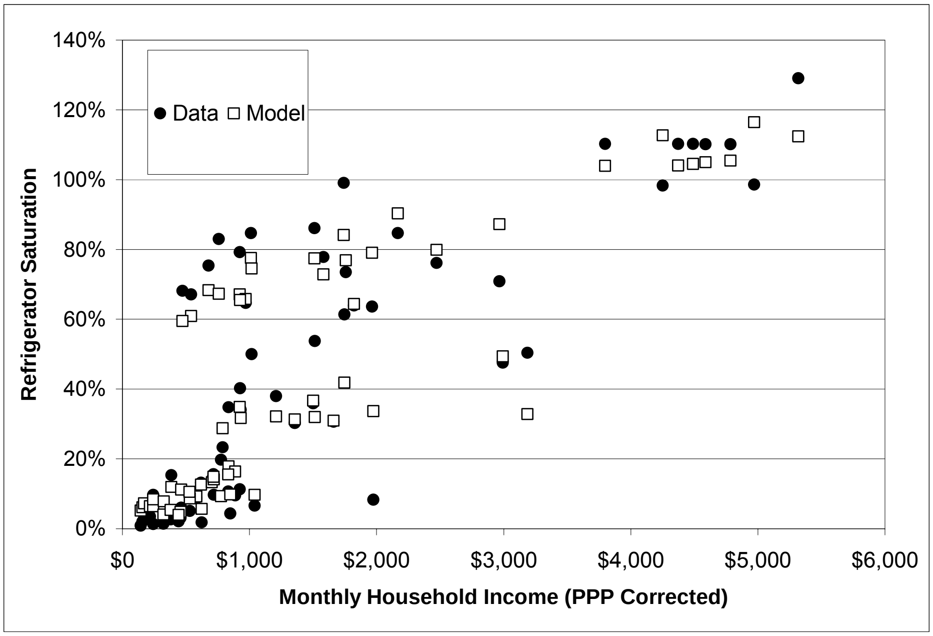

Figure 3 – Refrigerator Saturation vs. Monthly Household income

Forecasting Saturation

Once the relationship between macroeconomic variables and refrigerator saturation is constructed, ownership can be forecast according to a variety of scenarios, completing Step 1 in the current analysis. The forecast follows scenarios defined in IPCC's Special Report on Emissions Scenarios, which correspond to particular assumptions of economic growth on a region-by-region basis. We used SRES scenarios B2 as the default. For comparison, we also calculated results using SRES scenario A1, which assumes higher economic growth, and lower population growth. Average income growth rates for both scenarios are shown in Table 2.

Table 2 – Scenario Income Growth Rates by Region

Regions	B2, Intermediate Growth				A1, High Growth			
	2000-2010	2010-2020	2020-2030	**2000-2030**	2000-2010	2010-2020	2020-2030	**2000-2030**
Pacific OECD	1.2%	1.0%	0.7%	**1.0%**	1.3%	1.5%	1.5%	**1.5%**
North America	1.9%	0.8%	0.6%	**1.1%**	1.6%	1.6%	1.6%	**1.6%**
Western Europe	2.1%	1.3%	0.9%	**1.4%**	1.8%	1.8%	1.8%	**1.8%**
Central and E. Europe	2.4%	1.4%	2.7%	**2.2%**	5.5%	4.2%	4.5%	**4.7%**
Former Soviet Union	1.4%	1.8%	3.3%	**2.2%**	5.5%	4.2%	4.5%	**4.7%**
Latin America	0.7%	1.8%	2.6%	**1.7%**	5.0%	4.8%	4.7%	**4.8%**
Sub Saharan Africa	0.0%	1.1%	3.0%	**1.4%**	3.0%	2.8%	2.7%	**2.8%**
Middle East and N. Africa	-0.2%	0.3%	1.7%	**0.6%**	3.8%	3.6%	3.6%	**3.7%**
Centrally Planned Asia	5.9%	3.5%	2.9%	**4.1%**	5.4%	5.7%	6.7%	**5.9%**
Other Asia	2.6%	3.1%	2.4%	**2.7%**	5.2%	4.6%	4.2%	**4.7%**

Population and Urbanization forecasts were provided for each country by the United Nations Department of Economic and Social Affairs (UNDESA). Household size forecasts were provided for most, but not all countries by the United Nations Development Programme (UNDP). Where household size was not available, we used regional averages, weighted by population. We forecast electrification rates by assuming an electrification growth rate related to economic growth and to the current electrification rate.

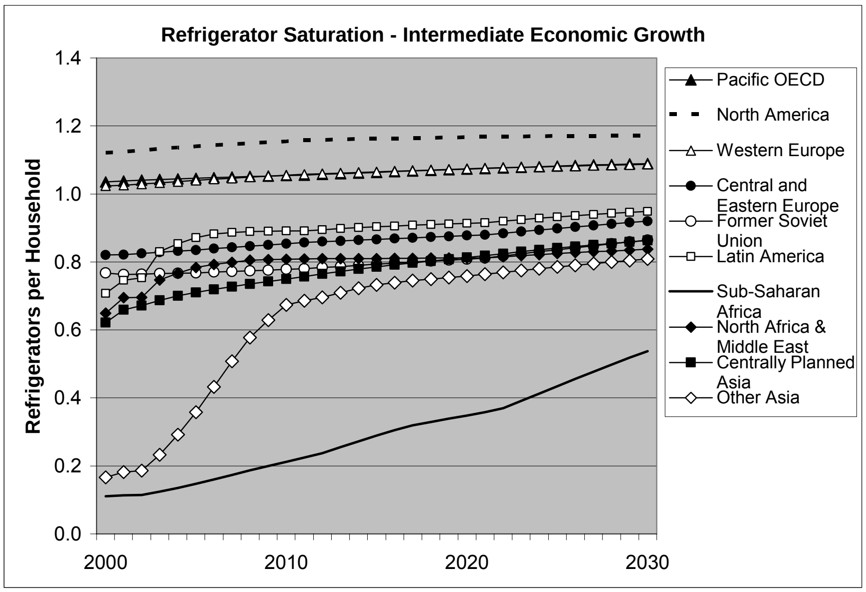

Figure 4 – Refrigerator Saturation Forecast by Region

Figure 4 shows the results of the forecast for the default economic growth scenario – Scenario B2. Individual countries are grouped into regions weighted by the number of households in each year. Saturation for the first three regions is already over one per household, but is not expected to increase much in the next three decades. Saturation is very low in the Other Asia region, which includes India, Indonesia and South-East Asia, but is expected go grow rapidly, nearly catching up to China (Centrally Planned Asia) by 2010. Ownership is expected to grow more slowly in Sub-Saharan Africa – by 2030, still only half of households will own a refrigerator.

Estimating Per-Unit Energy Savings

In order to estimate baseline refrigerator energy consumption, and potential for improvement via standards, we draw on data from 11 major economies. We then associate scenarios for these economies with other regions with similar products. In some cases, efficiency levels are assumed to parallel marker economies due to explicit policy harmonization. In others, policies are assumed to follow proxy economies after some delay. Some or all of each region is modeled in this way, except for Sub-Saharan Africa. For this region, we take the conservative approach of assuming no standards in light of the uncertainty over the future of refrigerator standards in those countries. The third column of Table 3 is the percentage of regional GDP for which future efficiency programs are modeled, either directly, or via marker economies.

Table 3 – Regions, Marker Economies, and % of GDP Addressed by Future Efficiency Programs

IPCC Region	Marker Economies	% of GDP (Region)	% of GDP (World)
1 - Pacific OECD	Australia/New Zealand + Japan	100%	18%
2 - North America	United States + Canada	100%	29%
3 - Western Europe	European Union	100%	31%
4 – Central and Eastern Europe	European Union	96%	1%
5 - Former Soviet Union	Russia	71%	1%
6 – Latin America	Brazil + Mexico	100%	6%
7 – Sub-Saharan Africa	European Union[1]	0%	0%
8 – Middle East + North Africa	European Union	37%	1%
9 – Centrally Planned Asia	China	85%	4%
10 – Other Asia	India + Korea	57%	3%
World			94%

[1] For Sub-Saharan Africa, the European Union is used as a proxy for baseline consumption, though some estimates put African refrigerator consumption much higher. No standards are assumed for Sub-Saharan Africa in this analysis.

Baseline Unit Energy Consumption and Scenarios

The following paragraphs provide detailed assumptions for each region covered. They describe product characteristics, history of standards to date, and likely degree and timeline of future improvement for each marker economy. We define two scenarios to serve the two steps in the analysis: Case 1, which includes the effect of standards to date, is the basis for Step 2 of the current analysis. Case 2, which includes the impact of future programs, is the basis for Step 3. We use MEPS as the model for efficiency programs, since we assume that a particular efficiency level is achieved in a certain year, based on cost effectiveness or the existence of such models already on the market. This does not exclude the contribution of labeling programs or voluntary programs, which could achieve the same level.

United States

Refrigerators in the United States are characterized by their large size, and relatively stringent efficiency regulations. U.S. refrigerator MEPS, implemented and updated in 1990, 1993 and 2001 are widely considered to be the most stringent in the world. It is unlikely that additional standards will produce dramatic further improvement in efficiency. Recent research [5] indicates, however, that, a further increase of about 10% would be cost effective, and therefore a potential target for standards. In Case 2, such a standard is assumed to take effect in 2010, while Case 1 assumes no further improvement.

Australia/New Zealand and Canada

Canadian refrigerators and those used in Australia and New Zealand are more similar to U.S. models than those used in Europe. Therefore, we use U.S. Unit Energy Consumption (UEC) as a proxy for these countries. In addition, refrigerator standards in both countries closely follow those of the United States, but for slightly different regions. Canadian policymakers generally harmonize efficiency standards with the U.S. due to the strong trade relationship and efforts arising from NAFTA [6]. Australia/New Zealand[4] has made a policy decision to align their MEPS with the most stringent standards in the world [7], which for refrigerators are currently those implemented in the U.S. For these reasons, both Case 1 and Case 2 are assumed equal to the U.S. for these countries.

[4] These two countries issue efficiency regulations jointly.

Japan

Japan has well-established and successful efficiency programs covering many types of equipment. As a result the consumption of the average refrigerator has decreased dramatically, from 1900 kWh in 1995 to 535 in 2004 [8]. We assume that by 2010, Japan's voluntary Top Runner program will result in an additional improvement of 10%.

European Union

Overall, there has been an estimated 27% net efficiency improvement for post-MEPS cold appliances on the EU market compared with pre-labeling efficiency levels [9]. According to the EU report "As a result of these efficiency improvements, the average energy consumption of cold appliances declined from about 450 kWh/year in 1990-92 to an estimated 364 kWh/year immediately post MEPS." The European *Energy Efficiency Index* (EEI) is calibrated with the pre-program baseline at 100. By 1999, the average EEI was already 75%. In spite these improvements, further improvements would still be highly cost effective, with the least life-cycle cost occurs at about EEI of about 50 [10]. Therefore we assume that, in Case 2, the average EEI will decrease to 55, which corresponds to the current 'A' level.

Eastern Europe

Countries included in the expansion of the European Union to 25 states and candidate countries cover 96% of GDP in this region. As member states, they will be required to adopt EU MEPS and comparative labels. Due to the already close trade ties with the EU, we assume that products are similar. In Case 1, we assume that harmonization occurs by 2009. In Case 2, harmonization occurs by 2007, and adoption of more stringent EU standards occurs simultaneously in 2010.

Russia

Russian refrigerators have already experienced improvement efficiency. A recent publication [11] reports that between 1993 and 1999, the capacity of typical refrigerators in Russia doubled, while energy consumption remained constant. In Case 1, current consumption levels are expected to prevail. In Case 2, further technological advancement and increased trade is assumed to facilitate S&L programs, which will result in an equaling of the current EU efficiency levels by 2010, and match the EU 2010 levels by 2015.

Korea

Korea shows similar evidence of the impact of labeling as does the European Union [12]. In that country, refrigerator efficiency improved by 18% from the time that labels were implemented in 1993 till 2000. We assume that through continuation of this program, and with the possible addition of MEPS, Korean refrigerators will reach the EU 'A' level by 2010.

Brazil

Brazil has had a successful labeling program for many products since 1984, and is currently considering MEPS for refrigerators. A recent analysis based on the most popular Brazilian refrigerator models suggests that an efficiency improvement of 39% would be cost effective [13].Case 2 therefore assumes MEPS at this level of efficiency implemented in 2010.

Central and South America

Central and South American markets are assumed to closely follow those of Mexico and Brazil, respectively, with some lag time. In Case 1, we assume a Central American baseline at the level of Mexico before standards implementation (1995), and South American baseline at current Brazilian level. Regional (UNDP/GEF) programs are under development or consideration for Central America, ANDEAN and ConoSur regions. Case 2 assumes that, as a result of the success of these programs, Central America will reach current Mexican levels, and all of South America will reach the Brazilian 2008 standards by 2010.

Mexico

Mexico has a well established refrigerator efficiency program with both MEPS and labels. The first set of Mexican refrigerator MEPS were enacted in 1995, and have had several updates. Mexican standards parallel those of the United States, with the last MEPS being equivalent to U.S. standards enacted in 1993. Because of the labeling program and strong trade between the two countries, however, manufacturers based in Mexico have managed to continue efficiency improvements such that Mexican units are roughly equivalent to the 2001 U.S. standards. Case 1 therefore assumes no further improvement of Mexican efficiency, but Case 2 assumes an additional 10% improvement by 2010, as in the case of the U.S.

China

China first implemented MEPS for refrigerators in 1989. Since then, they have updated standards twice in 2000, 2004 and will do so again in 2007. These standards will make the efficiency of Chinese refrigerators comparable to current EU levels. We assume that in Case 2, they will make a further improvement to the 2010 EU standards, in terms of efficiency increase.

India

The average consumption of Indian refrigerators is growing over time, due to the increase in market share of larger two-door frost-free units. India is currently in the process of implementing both standards and comparative labels. An analysis of typical Indian refrigerators [14], suggests that efficiency can be improved by 45% cost effectively. In Case 2, we assume that standards will be made more stringent over time, reaching 45% improvement by 2010

North Africa

MEPS exist for refrigerators in Egypt and Tunisia [15]. Standards for appliances are under consideration in Algeria [16] and Jordan. Refrigeration products are assumed to be generally of the same class and size as in Western Europe. We assume that in the absence of further standards, typical consumption will remain at pre-standards EU levels, but that in Case 2, expansion of standards will lead to meeting current EU levels by 2010.

The assumptions described above are summarized in Table 4.

Table 4 Summary of Baseline and Efficiency Scenarios

	Case 1	**Case 2**	**2010 UEC Case 1 (KWh)**	**2010 UEC Case 2 (KWh)**
United States	MEPS in 1990, 1993, 2001	MEPS in 2010 increase efficiency by 10%.	562	506
Canada	Synchronized with U.S.	Synchronized with U.S.	562	506
European Union	Average EEI decreased from 100 in 1992 to 75 in 1999	Average meets current ‘A’ level by 2010	364	268
Australia / New Zealand	AUS/NZ MEPS in line with U.S. MEPS after 2005	Synchronized with U.S.	562	506
Eastern Europe	Lags EU by 10 years	Meets current EU standards by 2007, synchronized by 2010	364	268
China	MEPS in 2000, 2004 and 2007.	Average meets current ‘A’ level by 2010	489	353
Russia	Significant improvement between 1993 and 1999	Match EU 1999 MEPS by 2010. Average meets current ‘A’ level by 2015.	420	243

India	No Standards	45% improvement by 2010.	548	301
Korea	Efficiency improved 18% from 1993 -2000	Average meets current 'A' level by 2010	536	402
Japan	UEC decreased from 1900 kWh in 1995 to 535 in 2004 from Top Runner Program	Additional improvement of 10% from Top Runner Program	535	482
Brazil	No additional standards.	39% improvement by 2010.	493	237
Mexico	Follows U.S. with some lag.	Synchronized with U.S.	341	307
Central America	Pre-standard Mexican Levels	Meets current Mexican levels by 2010	564	307
South America	Remains at Current Brazilian Levels	Meets improved Brazilian levels by 2010	493	237
North Africa	Remains at pre-standard EU levels	Achieves current EU levels by 2010	445	364

Calculating Total Energy Savings

In the final step, Step 4, of the current analysis, we calculated refrigerator final electricity consumption and savings for each year in the forecast by bringing the two previous analysis elements together in a spreadsheet model. The econometric saturation forecast provides the basis for stock accounting. The size of the refrigerator market in each country has two components. First purchases are equal to the difference in the total stock (saturation times the number of households) in each year compared to the previous year. Replacement purchases are then estimated according to a normally distributed retirement probability function assuming an average lifetime of 15 years, and a standard deviation of 2 years.

The Unit Energy Consumption (UEC) of refrigerators sold in each region for Case 1 and Case 2 is then calculated for each year by summing the consumption of each cohort according to the UEC in shipments in each year. Savings in each year is the difference in total consumption between the two cases. Savings increases steeply after the year of program implementation as more and more efficient refrigerators are brought into the stock. Table 5 shows refrigerator consumption in both cases. We use the B2 Scenario as a reference.

Table 5 – Consumption and Savings Results by Region – B2 Economic Growth Scenario

	Case 1 Consumption			Case 2 Consumption			Savings		
	Region 1-3	Region 4-10	Total	Region 1-3	Region 4-10	Total	Region 1-3	Region 4-10	Total
Year	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh
2005	225	328	553	225	328	553	0	0	0
2010	211	409	619	209	390	599	2	19	20
2015	200	451	650	187	397	584	12	54	66
2020	201	490	691	179	393	573	22	96	118
2025	205	545	751	177	413	590	29	132	161
2030	212	596	808	179	441	620	32	156	188

According to the ownership model, and subsequent stock estimation, refrigerator consumption in regions 4-10 already accounts for 59% of global refrigerator consumption. By 2030, in the absence of aggressive efficiency programs, this fraction will have grown to 74%. Not surprisingly, the great majority of potential savings will also be dominated by these regions, because not only will they possess larger stocks, but there is more room for improvement.

We estimate annual global savings from refrigerator efficiency programs to be 118 TWh in 2020, and 188 TWh in 2030. By this year, once the stock has been completely replaced with efficient product, S&L programs will have reduced refrigerator consumption by 23% relative to Case 1. This also corresponds to over a third of current (2005) refrigerator consumption, and 2.3% of total residential electricity consumption in that year. Electricity savings are converted to primary (input) energy savings and carbon dioxide emissions mitigation according to country-by-country evaluations of electricity generation fuel mix, as provided by the International Energy Agency (2002 data). IEA also provides electricity carbon factors for most countries. Primary energy savings and carbon dioxide emission mitigation global totals are given in Table 6. In addition, the table shows savings and emissions for a high economic growth scenario (SRES A1). Savings in the high economic growth case are on the order of 10% higher than for the intermediate growth case. This is due to the more rapid accumulation of stock with higher incomes. The difference between scenarios can be taken as indicative of the sensitivity of this type of analysis to uncertainties in forecasting macroeconomic driver variables.

Table 6 – Primary Energy Savings and Carbon Dioxide Emissions Mitigation

	Primary Energy Savings		**CO_2 Mitigation**	
	Intermediate Growth (B2)	**High Growth (A1)**	**Intermediate Growth (B2)**	**High Growth (A1)**
Year	**MTOE**	**MTOE**	**Mt (CO_2)**	**Mt (CO_2)**
2010	5	6	16	17
2015	16	17	44	47
2020	28	30	77	83
2025	38	42	106	116
2030	45	50	124	139

Conclusions and Outlook

In conclusion, we believe that the analysis presented gives the most accurate estimate to date of the level of refrigerator efficiency savings that could be achieved throughout the world. In addition to being based on specific program scenarios in each country or region, it makes a country-specific evaluation of refrigerator consumption, given specific assumptions about economic growth. We believe that this adds insight into the global picture, and allows for a comparison of the different opportunities at the regional level.

In the longer term, we hope to have shown the usefulness of a framework that unifies a generic econometric relationship for product ownership and engineering data. This framework provides the potential of straightforward expansion of the analysis of efficiency programs, in both scope and detail. The product ownership model can be replicated to other products, like air conditioners and washing machines provided sufficient country data. The unit consumption inputs can be further disaggregated as data for specific countries becomes available, and can also be expanded to cover other products. The methodology presented therefore provides a basis for the first ever estimate of the full global potential of S&L programs.

Finally, an important tool in evaluating efficiency programs is the estimation of financial impacts, such as net financial savings to consumers. Such an analysis could be built up from the current energy parameters, in combination with local energy prices and equipment costs.

References

[1] S. Meyers, J. McMahon, M. McNeil and X. Liu *Realized and Prospective Impacts of U.S. Energy Efficiency Standards for Residential Appliances.* - pp. 42, June 2002

[2] P. Bertoldi *European Union Efforts to Promote More Efficient Equipment.* European Commission, Directorate General for Energy,

[3] S. Wiel and J.E. McMahon *Energy-Efficiency Labels and Standards: A Guidebook for Appliances, Equipment, and Lighting, 2nd Edition* 2005

[4] M. A. McNeil and V. E. Letschert *Forecasting Electricity Demand in Developing Countries: A*

Study of Household Income and Appliance Ownership Proc. of ECEEE Summer Study 2005, Mandelieu, France Ed.: European Council for an Energy Efficient Economy

[5] G. Rosenquist, M. A. McNeil, M. Iyer, S. Meyers and J. E. McMahon *Efficiency Standards for Equipment: Additional Opportunities in the Residential and Commercial Sectors.* Energy Policy. - pp. In Press

[6] S. Wiel, L. V. W. McGrory and L. Harrington *Energy Efficiency Standards and Labels in North America: Opportunities for Harmonization* Proc. of ACEEE Summer Study, Pacific Grove, CA Ed.: American Council for an Energy Efficient Economy

[7] L. Harrington and S. Holt *Matching World's Best Efficiency Standards - Australia's Success in Adopting New Refrigerator MEPS* Proc. of ACEEE Buildings Summer Study 2002, Pacific Grove, CA August 2002. Ed.: American Council for an Energy Efficient Economy

[8] IEA *Cool Appliances - Policy Strategies for Energy-Efficient Homes* International Energy Agency,

[9] P. Waide *Cold II: The Revision of Energy Labelling and Minimum Energy Efficiency Standards for Domestic Refrigeration Appliances* European Commission, December 2000

[10] P. Waide, B. Lebot and P. Harrington *The Historical and Potential Impacts of Residential Electrical Equipment Energy Efficiency Policies in the OECD* Proc. of EEDAL, Turin, Italy October 2003. Ed.: European Commission Joint Research Center

[11] G. Aslanyan and S. Molodtsov *Energy Efficiency Standards and Labels for Residential Appliances as an Important Direction of the Russian Energy Conservation Policy in Households* Proc. of EEDAL, Turin, Italy October 2003. Ed.: European Commission Joint Research Center

[12] KEMCO - pp.

[13] E. A. Vendrusculo, G. Queiroz, G. Jannuzzi, N. Mendes, T. Borges and J. Pomilio *Technical Improvement of Residential Refrigerator in Brazil: Energy Efficiency Analysis* International Energy Initiative - Latin America,

[14] P. Bhatia *Development of Energy-Efficiency Standards for Indian Refrigerators.* ASHRAE Transactions: Research. - pp.

[15] K. Lihidheb and P. Waide *The Tunisian Standards and Labelling Programme* Proc. of ECEEE Summer Study 2005, Mandelieu, France June 2005. Ed.:

[16] M. S. Bouzeriba, D. E. Bouzera, W. Lutz and P. Waide *Energy Efficiency Standards and Labelling of Household Appliances in Algeria - From Programme Design to Implementation* Proc. of EEDAL, Turin, Italy October 2003. Ed.: European Commission Joint Research Center

Appendix – Saturation Rate Data

Country	Year	Monthly .Income	Elec	Urb	Sat	Country	Year	Monthly .Income	Elec	Urb	Sat
United States	2002	$5,318	100%	79%	129%	Bolivia	1998	$933	60%	59.4%	34.0%
Japan	1999	$4,491	100%	65%	110%	Guatemala	1999	$1,662	67%	43.1%	30.6%
Japan	2002	$4,375	100%	65%	110%	Morocco	1992	$1,358	71%	48.4%	30.3%
France	2002	$3,798	100%	76%	110%	Nicaragua	1998	$791	48%	54.5%	23.3%
Japan	1991	$4,784	100%	63%	110%	Yemen	1997	$776	50%	23.6%	19.7%
Japan	1996	$4,589	100%	65%	110%	Côted'Ivoire	1999	$718	50%	41.7%	15.6%
Croatia	2000	$1,742	100%	58%	99%	Nigeria	1999	$385	40%	39.5%	15.3%
Singapore	1991	$4,251	100%	100%	98%	Ghana	1998	$704	45%	40.2%	14.1%
Turkmenistan	2000	$1,513	100%	45%	86%	Senegal	1997	$620	30%	43.8%	13.2%
Bulgaria	2000	$1,013	100%	69%	85%	Indonesia	1997	$924	53%	35.6%	11.3%
Jordan	1997	$2,168	95%	78%	85%	India	1999	$835	43%	26.6%	10.6%
Albania	2000	$759	100%	42%	83%	Zambia	2002	$242	12%	35.1%	9.7%
Kazakhstan	1999	$926	100%	56%	79%	Cameroon	1998	$719	20%	44.7%	9.7%
Brazil	1996	$1,581	95%	78%	78%	Haiti	2000	$528	34%	35.6%	9.5%
CostaRica	2000	$2,474	96%	59%	76%	Mauritania	2001	$887	22%	57.7%	9.5%
Armenia	2000	$677	100%	65%	75%	Comoros	1996	$583	29%	30.4%	8.7%
Thailand	2000	$1,758	82%	31%	74%	VietNam	1997	$1,975	76%	22.2%	8.3%
Mexico	2000	$2,967	95%	75%	71%	Guinea	1999	$1,040	16%	28.8%	6.6%
Uzbekistan	1996	$475	100%	38%	68%	Benin	2001	$464	22%	42.3%	6.0%
Kyrgyzstan	1997	$542	100%	36%	67%	Mali	2001	$532	11%	30.2%	5.1%
Egypt	2000	$970	94%	42%	65%	Togo	1998	$851	9%	30.8%	4.3%
DominicanRep	1999	$1,823	91%	57%	64%	Kenya	1998	$328	8%	30.0%	3.8%
Colombia	2000	$1,964	81%	75%	64%	Mozambique	1997	$218	7%	26.2%	3.5%
Belize	2000	$1,749	79%	48%	61%	BurkinaFaso	1999	$460	13%	15.2%	3.1%
Panama	1997	$1,514	76%	55%	54%	Niger	1998	$380	7%	18.2%	2.6%
SouthAfrica	1998	$3,187	66%	53%	50%	Uganda	2001	$442	4%	12.0%	2.1%
Romania	2000	$1,018	100%	55%	50%	Tanzania	1999	$157	11%	26.9%	2.0%
Gabon	2000	$2,994	31%	81%	48%	Cambodia	2000	$623	16%	16.9%	1.8%
China	2002	$928	99%	36%	40%	Rwanda	2000	$323	6%	13.6%	1.4%
Philippines	1998	$1,210	87%	54%	38%	Madagascar	1997	$242	8%	25.5%	1.3%
Peru	2000	$1,502	73%	73%	36%	Chad	1997	$146	2%	22.2%	0.8%
Honduras	2000	$835	55%	44%	35%						