# Enduse Global Emissions Mitigation Scenarios (EGEMS): A New Generation of Energy Efficiency Policy Planning Models

Michael A. McNeil
Lawrence Berkeley National Laboratory
One Cyclotron Rd, MS 90R4000
Berkeley CA 94720-8136
tel: +1.510.486.6885
email: MAMcNeil@lbl.gov

Stephane de la Rue du Can
Lawrence Berkeley National Laboratory
One Cyclotron Rd, MS 90R4000
Berkeley CA 94720-8136
tel: +1.510.486.7762
email:SADeLaRueDuCan@lbl.gov

James E. McMahon
Lawrence Berkeley National Laboratory
One Cyclotron Rd, MS 90R4000
Berkeley CA 94720-8136
tel: +1.510.486.6849
email:JEMcMahon@lbl.gov

## Keywords

Greenhouse gas emissions, emissions scenarios, modelling, energy demand, forecasting, end use, bottom-up, China, India, refrigerators, air conditioners.

## Abstract

This paper presents efforts to date and prospective goals towards development of a modelling and analysis framework which is comprehensive enough to address the global climate crisis, and detailed enough to provide policymakers with concrete targets and achievable outcomes. In terms of energy efficiency policy, this requires coverage of the entire world, with emphasis on countries and regions with large and/or rapidly growing energy-related emissions, and analysis at the 'technology' level – building end use, transport mode or industrial process. These elements have not been fully addressed by existing modelling efforts, which usually take either a top-down approach, or concentrate on a few fully industrialized countries where energy demand is well-understood. Inclusion of details such as appliance ownership rates, use patterns and efficiency levels throughout the world allows for a deeper understanding of the demand for energy today and, more importantly, over the coming decades. This is a necessary next step for energy analysts and policy makers in assessment of mitigation potentials.

The modelling system developed at LBNL over the past 3 years takes advantage of experience in end use demand and in forecasting markets for energy-consuming equipment, in combination with known technology-based efficiency opportunities and policy types. A particular emphasis has been placed on modelling energy growth in developing countries. Experiences to date include analyses covering individual countries (China and India), end uses (refrigerators and air conditioners) and policy types (standards and labelling). Each of these studies required a particular effort in data collection and model refinement – they share, however, a consistent approach and framework which allows comparison, and forms the foundation of a comprehensive analysis system leading to a roadmap to address the greenhouse gas mitigation targets likely to be set in the coming years.

## Introduction

Unlike other papers presented by the authors as contributions to the *Summer Study*, other conferences and as journal articles, this paper does not present a quantitative study of the impacts of a particular policy in a particular geographical context. Instead, it draws on the experience of our own work, and that of others, to consider a new

This work was supported by LBNL Strategic Planning Support Activity funds under the U.S. Department of Energy Contract No. DE-AC02-05CH11231

analytical framework, and to suggest a particular methodological approach. The quantitative basis of the model put forth is not entirely novel – in fact, we draw as much as possible on 'tried-and-true' approaches recognized and accepted in the energy efficiency community. Instead, the innovation we suggest is a building up of these methodologies to cover a wide variety of policies impacting many energy demand sectors and end uses, and a widening of scope to cover the entire world.

The development of *Enduse Global Emissions Mitigation Scenarios (EGEMS)* is motivated by a shift (perhaps overdue) in the overarching energy efficiency policy vocabulary from *savings* to *targets*. In the past, the desire for savings allowed for each efficiency program to independently claim beneficial impacts. Now, the requirement to meet emissions targets mandates that programs and policies be considered collectively, in order for high-level planners to understand what is necessary, and how most effectively to get there. Ultimately, however, whether or not goals are met depends on the success of programs targeting individual sectors and enduses[1] – therefore, a high level of drill-down capability is called for, in addition to comprehensiveness.

The paper is organized to answer three basic questions. The first of these is "What is needed"? This section presents an argument for comprehensive, bottom-up, and policy-specific modelling of greenhouse gas (GHG) mitigation measures. A second question is "How do we get there?", which is addressed in a presentation of the methodology proposed, and results of some of the first applications of the model. Finally, we make suggestions of "What more should be done?" , in terms of additional components and considerations which would provide policymakers and stakeholders with a truly useful analysis tool.

The authors acknowledge that achievement of the goals put forth here is an ambitious undertaking. Further, we recognize that no single research group has the breadth of experience to cover all of the areas we wish to address. Therefore, it is our hope that this paper will serve not only to inform, but to encourage discussion, input and critique from our colleagues at the *Summer Study* and beyond.

## What is needed?

Over the past several decades, energy efficiency policies have provided significant benefits in the form of economic savings, reduction of pollution, and easing of supply constraints, with each policy standing on its own as providing benefits to society. In the context of human-induced climate change, it is no longer sufficient that each policy provide a net benefit: instead, governments and other actors must consider a comprehensive *roadmap* of actions which, in their totality will deliver sufficient reductions in carbon emissions to ensure that greenhouse gas concentrations do not exceed acceptable levels[2].

Actual climate change policies are implemented on all levels: international, national, provincial, or local. Their success or failure at mitigating climate change is, however, a global question. Currently, no roadmap exists at the global level, and no model has been elaborated in sufficient detail to allow one. Several global energy models exist but often consider the impacts of a limited set of policies, such as a carbon tax. None have the flexibility of calculating the mitigation impacts of specific policy measures addressing specific sectors and none are fully transparent in their assumptions and methodology. A transparent road-mapping model allowing policy impact assessment at a global level is the natural next step in climate policy research.

Elaboration of a comprehensive, actionable roadmap requires four main elements:

- Both deep and broad understanding of the end uses through which energy flows, and the means of reducing energy consumption through new technologies and changes in behaviour.
- Identification and forecasting of the major drivers of demand for energy services to establish the most likely future path that will emerge if no intervention is made.
- Identification of policies and behavioural options that are technically possible, economically viable and for which implementation is feasible.
- Accurate prediction of the success of both proven and innovative policies to overcome market barriers and increase the contribution of high-efficiency technologies and low-consumption behaviours on a wide scale, and the interaction of these policies.

The ultimate conclusion of a roadmap is an integration of these elements, providing an implementable set of concrete policies that will lead to an achievement of emissions reduction goals with maximum probability.

---

[1] Some major policies, such as price-based polices will address large areas of energy demand indescriminately; their effectiveness, however, is likely to be sector and/or end use dependent.

[2] One of the best examples of a comprehensive, integrated approach to energy-related greenhouse gas mitigation is *California's Energy Efficiency Strategic Plan (California Public Utility Commission 2008).* This document details measures in detail, and outlines an implementation plan for each.

### *Why global?*

The most obvious argument for creating a global model is the nature of the climate problem itself. Climate change is driven by overall global emissions of GHG-therefore knowledge of the global baseline is needed in order to gauge the effectiveness of energy efficiency policy in addressing the problem. Second, the issue will likely not be addressed by individual countries or regions acting unilaterally, but as part of a negotiation. Therefore, while individual countries may have their own mitigation commitments, these targets will be set with reference to actions by other countries. Particular importance will be paid to the relative commitments of industrialized and developing countries. This requires that accurate and reliable (believable) forecasts exist for developing countries (especially the large ones). Furthermore, it requires that assessments of energy demand and carbon mitigation potential be made using consistent metrics and methodologies. Finally, developing countries have a particular interest in the development of a global model. In most cases, energy demand is not as well-understood by these governments compared to those in more industrialized regions, and such a model may be of significant value in the planning of their own reduction strategies, as well as more general economic and infrastructure planning. Finally, the model takes a general approach of including and generalizing policies that have so far been successful, usually in developed countries. For this reason, the policy scenarios put forward may provide policymakers in developing countries with a precedent to go forward.

### *Why comprehensive?*

In addition to a new urgency to reduce energy consumption, the climate crisis presents the policymaker with a mandate to make deep cuts in emissions, rather than take more incremental steps. In fact, it remains uncertain whether the totality of economically feasible and politically acceptable policies currently at our disposal will result in the necessary reductions. For this reason, a policy model cannot serve as a guide towards climate stabilization unless it includes a wide range of policies across all sectors. This scope must extend even beyond energy efficiency itself, to clean sources of energy, changes in behaviour, and GHG sinks. Another feature of a 'deep cuts' scenario is that policies will have interaction effects, compete for space in the market, and create redundancies not appearing in scenarios that act 'at the margin'.

### *Why bottom-up?*

Global energy models generally fall into the category of top-down or bottom-up models, or can combine elements of both. Top-down models project energy use based on elasticity of energy consumption to economic (GDP) growth according to historical trends, while bottom-up models base their projections on end-use-technology penetrations and energy intensity. The main drawback of top down models in constructing a roadmap is the lack of sufficient detail to analyze the effect of policies targeted at sub-sectors and individual technologies, such as the effect of standard and labelling programs, building codes, energy intensity targets in specific industries, etc...

Development of global bottom-up models is recent and has been motivated by the need to assess global energy efficiency technical potentials. Only two global bottom-up models exist: the International Energy Agency's Energy Technology Perspective MARKAL model and a recent model developed by the McKinsey Global Institute. The currently existing global models present prospects for key energy technologies and assess their potential to save energy in the future. The IEA ETP model also describes measures that overcome barriers to the implementation of these technologies. However, neither model evaluates the impacts of specific policy measures. With the integration of parameters such as the age of the technology employed today and its life time, bottom-up models can answer specific questions about policy intervention such as the time it will take until impacts become evident (implementation rate) or the breadth of the impact on the energy system (scalability). Currently, available global models leave a gap between technology penetration and implementation of specific policies[3].

There is evidence for the need of a bottom-up model at the global level that can be used by all and improved by all. In the last IPCC assessment report on Mitigation of Climate Change, the authors provided a list of technical options with GHG mitigation potentials and associated cost for each sector analyzed. Yet, one of the most difficult tasks for scientists participating in this report was the reconciliation of chapters that examined technology options with reduced net emissions of greenhouse gases, "bottom-up" studies, and chapters that reported cost estimates from economic "top-down" studies. A new modelling effort that transparently integrates all sectors would be of a great value to the 5th IPCC assessment report to be published in 2012 and to anyone else desiring to assess energy savings options.

---

[3] McKinsey recently collaborated with the Vattenfall Institute to develop a "cost curve" representing technology saving opportunities ranked by technology cost per unit of carbon dioxide mitigated. This cost curve shows a large untapped potential to save energy at negative net cost. A roadmapping effort would seek to elaborate the non-economic barriers producing such a market failure and recast the achievable potential in terms of policies designed to overcome such barriers.

A bottom-up analysis of potential energy savings from efficiency programs is not unprecedented. Two studies in particular demonstrate the possibility of using detailed technology data to evaluate past or project potential savings covering many enduses in large markets. The first of these, completed at LBNL (McMahon et al., 2003) evaluates savings to date and in the future of all U.S. federal minimum efficiency performance standards (MEPS) for residential equipment promulgated till the date of the study. This analysis compared the efficiency level of equipment sold under the MEPS requirements to the likely baseline through 2030, and arrived at a cumulative total national energy impact of standards of 63 EJ. In addition, by comparing the projected equipment price and operating cost under standards to the base case, the study found that by the same year, U.S. standards will have saved 130 billion $US at present value in 2003. Another study, performed by the International Energy Agency (IEA, 2003), projected the savings in the hypothetical scenario that a wide range of residential appliances in IEA member countries would reach an efficiency level of maximum cost-effectiveness. That study found that if implemented, policies achieving these efficiency levels could reduce electricity demand in IEA member country households by 24% in 2010 and by 33% in 2030. The EGEMS project seeks to extend these types of analyses, with some loss of detail, to a wider range of end use sectors, and a global geographical scope.

## How do we get there?

The Energy Analysis Department (EAD) at LBNL has a history of performing detailed analysis of specific energy efficiency policies for the United States Department of Energy and other U.S. government agencies spanning several decades. In particular, EGEMS draws significantly on methodologies developed for the analysis of U.S. federal minimum efficiency performance standards (MEPS) for appliances and lighting. In these analyses, overall impacts of MEPS to U.S. consumers are calculated as part of a National Impacts Analysis (NIA). The NIA projects the total energy savings to all consumers resulting from the standard over a long time horizon (usually extending several decades from the date of standards implementation). The analysis considers projected sales of new appliances entering the stock as an extrapolation of the current market, and primary drivers of sales, such as building construction and replacement lifetimes. The methodologies of the NIA analysis provide one analytical foundation for EGEMS.

In addition to this experience, EGEMS also draws on expertise in EAD in analyzing energy demand around the world, particularly in developing countries. For over 20 years, EAD's International Energy Studies group has provided unique insights into energy use and efficiency in these countries through a series of reports and publications. These studies often focus on individual sectors and particular industries, but also include country-level investigations and cross-country comparisons. EGEMS takes advantage of this experience through use of end use level data already collected, but also as a guide for the development of detailed and reliable datasets for developing countries.

### *Bottom-Up Methodology*

A bottom up approach consists of gathering information on detailed activity variables that drive energy consumption, such as car ownership, refrigerator saturation, steel production and surveys to assess energy used at the end-use level. Data on energy use are then combined with data describing activities to form intensity of energy use. Drivers of energy are then projected according to economic growth while energy intensity are estimated and forecast using assumptions about technology efficiency and usage patterns. GHG emissions depend on the fuel used. At the macro level for example, the drivers affecting growth of $CO_2$ emissions in an economy include the rate of population growth (activity), the size and structure of the economy (depending on consumption patterns and stage of development), the amount of energy consumed per unit of activity (intensity), and the specific carbon emissions of the fuel mix used. Our discussion of the drivers is guided by the terms of the so-called Kaya identity (Kaya, 1989) as given by:

$$CO_2 = Pop \times \frac{GDP}{Pop} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

The development of a global bottom-up energy demand model has to date focused largely on the buildings sectors. Energy demand in households has been the subject of several case studies covering specific appliances and regions (McNeil et al., 2005), (McNeil et al., 2006), (McNeil et al., 2007),(Letschert et al., 2007), (Letschert et al., 2008). More recently, this analysis has been extended to cover nearly all end uses commonly used in the residential sector, and a commercial sector model has been added (McNeil et al., 2008).

These studies share a common analysis framework, called the Bottom Up Energy Analysis System (BUENAS). BUENAS has now been expanded to the global level, and covers both the residential and commercial sub-sectors.

The strategy of the model is to construct the analysis in a modular way. The first module models demand for energy services (*activity*) at the end use level, while a second considers the final energy used to provide those services in the base case, and builds a high-efficiency scenario based on meeting equipment efficiency targets by a specified year. A third module tracks market penetration and stock turnover for efficient products. Finally, these three components are brought together, and savings are calculated as the difference in consumption and emissions in the efficiency scenario versus the base case. The analysis framework is shown in Figure 1. It is envisioned that additional energy demand sectors and policy types will be added to the model utilizing the same modular structure (see below). The function and methodology of each module are described in the sections that follow.

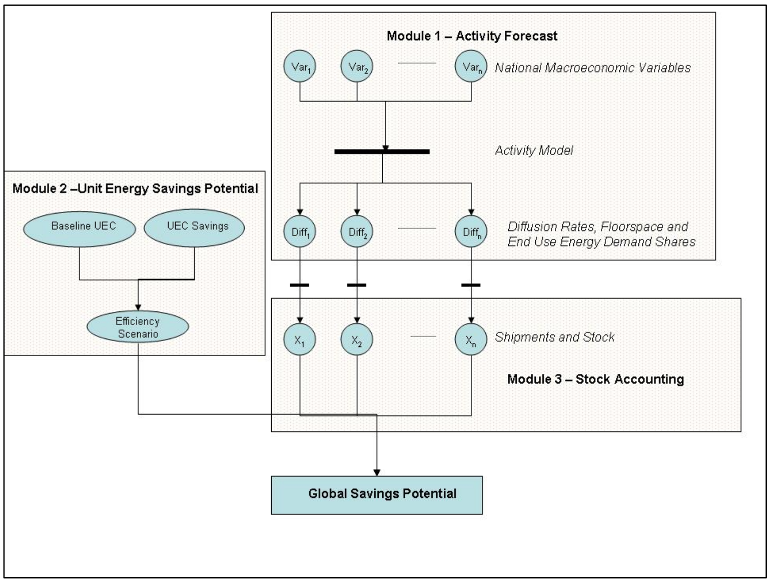


*Figure 1 – Bottom-up Energy Analysis System (BUENAS) Flowchart*

## *Module 1 – Activity Forecasting*

The first step in modelling energy demand is to forecast *activity*. Activity is a general concept that describes the demand for energy services. Often, energy service activity closely follows economic activity. Examples include industrial production quantities, passenger mobility, freight transport volume, passenger aviation miles travelled, or crop area irrigated. In households, activity is described in terms of ownership of energy-consuming appliances and lighting, as well as per household heating and cooling loads. In the commercial sector, it is given in terms of the density of equipment per unit area of floor space. In this section, we present the modelling of residential appliance ownership as an example of the modelling technique, which can be generalized to other sectors.

Appliance ownership is projected according to a diffusion[4] model using readily-available national-level variables as inputs. A logistic function[5] describes the penetration of appliances in the households. Over 300 data points were gathered in development of the global residential model for the following equipment: lighting fixtures refrigerators, air conditioners, washing machines, fans, televisions, stand-by products[6], and electric water heaters. The generic form of the diffusion of all appliances is modelled with the same functional form, given by:

$$Diff_c = \frac{\alpha}{1 + \gamma \exp\left(\beta_{inc} I_c + \beta_{elec} E_c + \beta_{Spe} U_c\right)}$$

Where:

| | |
|---|---|
| $Diff_c$ | is the diffusion of the appliance for the country *c*. |
| $\alpha$ | is the maximum diffusion, which may be greater than 1. |
| $I_c$ | is the monthly household income, given by GDP divided by the number of households in the country. |

[4] The term "diffusion" refers to the number of products per household, which can be greater than one.
[5] Because of its S-shape, the logistic function is often used in consumer choice models
[6] The number of products using stand-by consumption is based on total standby wattage divided by 5W which is assumed to be the average device stand-by power.

$E_c$ is the national electrification rate.

$U_c$ is the national urbanization rate.

$\gamma$ and $\beta$ are scaling parameters.

The collected data points, allow determination of the model parameters ($\beta$ values) for each appliance using regression (after linearization). Figure 2 shows the relation between the model and the data for the three (3) variables for refrigerators. Each variable has a significant influence on the large variation of diffusion around the world.

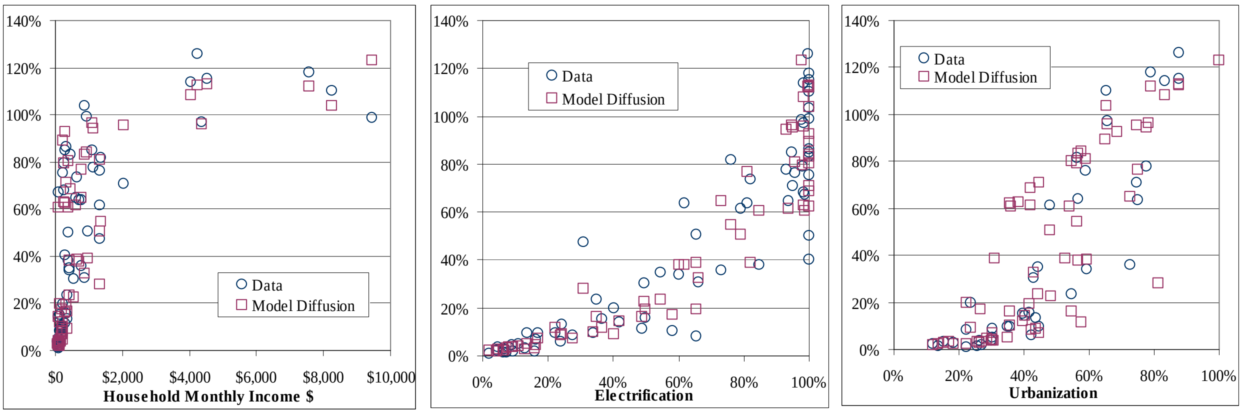


*Figure 2 – Linear Regression Results by Variable for Refrigerators*

The diffusion relationship for appliances serves two purposes. First, it allows for interpolation of ownership rates to countries for which no data are available, thus allowing an estimate for all countries. Second, the relationship allows for extrapolation of ownership rates into the future, serving as the primary driver for the energy demand forecast. The basic assumption of the forecast is that, as developing country households reach income levels currently enjoyed in more wealthy countries, ownership rates will resemble the current rates in the wealthier countries[7]. In order to provide global coverage, an effort was made to parameterize ownership in terms of macroeconomic variables that are available for a wide range of countries. Urbanization forecasts for most countries are available from UNDESA. Recent data on electrification rates for developing countries are available for most countries, but there is no forecast for them. Therefore, the analysis uses a model of electrification driven by GDP per capita (see McNeil et al., 2008 for more details). In general, GDP growth is an exogenous input to the model. We do not attempt to make a forecast of economic growth, but take these from other macroeconomic modeling efforts, usually considering a range of possibilities. Because of the explicit dependence at the end use level on economic growth, the model in this way is ideally suited to describe the variation in energy demand from alternative economic scenarios.

In order to capture as much of the household's energy consumption as possible, the model includes space heating, fuel-based water heating and cooking equipment. These enduses are utilized by nearly every household, but not necessarily via electric appliances. Therefore, for these, the activity module estimates fuel type market shares. For lighting, the market share of the type of fixture (incandescent, linear fluorescent or compact fluorescent) is important for energy consumption. Finally, since air conditioning is highly climate dependent, a climate variable (cooling degree days) is used as a driver of air conditioner ownership (McNeil et al., 2007).

## *Module 2 - Unit Energy Consumption and Savings Potential*

The second module, which determines the energy consumption to provide the services modelled in Module 1, resembles a database. The output of Module 2 is twofold

- Unit Energy Consumption (UEC) of technologies currently in use and on the market (*baseline UEC*).
- A range of high efficiency technology options with which to construct efficiency scenarios (*efficiency case UEC*).

The characterization of potential savings at the end use level necessarily requires an understanding of the efficiency potentials of individual technologies. In principle, this is a very complicated task, because it relies on understanding the prevailing technologies for every major end-use in every country in the world and technologies available for their substitution. Fortunately, however, we can draw on the experience of international markets and best practices

---

[7] There is some doubt about this assumption, since technological developments tend to lower the prices of appliances over time, thus making them more accessible.

to make some simplifying assumptions, and reasonable approximation. In particular, past studies by the authors have modelled unit energy consumption and efficiency at the regional, rather than country level[8,9]. However, the model allows for country-specific analysis when sufficient data are available. The definition of high efficiency levels is dependent on the type of scenario being modelled. Three different criteria are commonly used in developing energy efficiency targets.

- *Technical potential* – implementation of the highest efficiency equipment currently on the market, or assumed to be commercialized during the forecast period.
- *Economic potential* – implementation of the highest efficiency equipment which provides net economic benefit to the consumer.
- *Achievable potential* – implementation of the highest efficiency equipment likely to be adopted, given economic and political constraints, in addition to other non-financial barriers.

The selection of efficiency targets is discussed further below in our discussion of *Standards and Labelling for Buildings*, which represents a case study of efficiency scenario development.

## *Module 3 – Stock Accounting and Calculation of Energy Savings*

Efficiency programs create savings by transforming the market in such a way that new products flowing into the market use, on average, less energy than they would be in the absence of programs. However, the overall impact varies as it depends on the rate of penetration of the efficient products. As new products are installed, and old ones are retired, the product stock as a whole requires less fuel inputs and generates fewer emissions. In order to characterize these, the stock accounting model includes the following steps:

1. Energy consumption of new stock is calculated according to efficiency trends in the Base Case and Efficiency Scenario.
2. A retirement model tracks products remaining in the stock and their UEC.
3. The difference between energy consumption of the stock in the Base Case and Efficiency Scenario yields energy savings.

In any market transformation program, the efficiency of the entire equipment stock does not shift instantaneously. In particular, programs such as appliance standards and labelling only affect *new* equipment, not retrofits. For example, homeowners with refrigerators and air conditioners already installed at the time the government makes a new minimum efficiency requirement will not be required to purchase high efficiency equipment to substitute their old equipment[10]. Instead, the equipment will continue to operate until it wears out, and will be replaced with equipment affected by the policy. In addition, purchases of equipment for new homes, or by first-time buyers entering the market, will be affected[11].

In this method, we consider the stock of each end-use in each year, and make an estimate of the portion of each that are impacted by programs in place starting in a particular year. For example, none of the stock of residential refrigerators in 2009 will be affected by an efficiency standard implemented in 2010. After this date, the incremental stock (due to new households and increased diffusion) will be regulated by the program, and therefore will operate at the 2010 efficiency level. In addition, some of the previously existing stock will have been retired, and replaced by more efficient equipment than would have been the case in the absence of the program.

The total stock of equipment $S_c$ in a given year $y$ for each country $c$ is given by

$$S_c(y) = Diff_c(y) \times HH_c(y),$$

where $HH_c(y)$ is the number of households. In each year after 2009, the pre-2010 stock decreases due to retirements. The time it takes to retire all of the pre-program stock depends on the average life of the product. Depending on the lifetime of the product, the stock in each cohort gradually decreases as equipment wears out[12].

---

[8] The exception is residential air conditioning and space heating, which have an income and/or climate dependence. For these end-uses, we consider end-use consumption on a country-by-country basis.

[9] Regional definitions were adopted from the IPCC *Special Report on Emissions Scenarios(SRES)*

[10] This is not necessarily the case for some programs, which can target retrofits through a buy-back program, for example.

[11] The model does not consider the case in which an equipment owner replaces still-operating equipment specifically in order to improve efficiency.

[12] The survival function of appliances used varies depending on detail and scope of the study. For a detailed study on refrigerators, (McNeil et all, 2006), a statistical survival function specific to that product was used to determine retirements and replacements in each year. For a more recent comprehensive analysis (McNeil et al., 2008) survival was parameterized more crudely, by assuming that the portion of the cohort surviving in each year decreases linearly over time until it reaches zero in 1.5 times the average lifetime.

Figure 3 shows an example of the stock accounting, for the particular case of refrigerators in Asia (excluding China) (McNeil et al., 2008). The example shown assumes a scenario of efficiency standards in 2010, with an upgrade in 2020. The stock accounting algorithm divides the stock in each year into the corresponding categories of when they entered the stock.

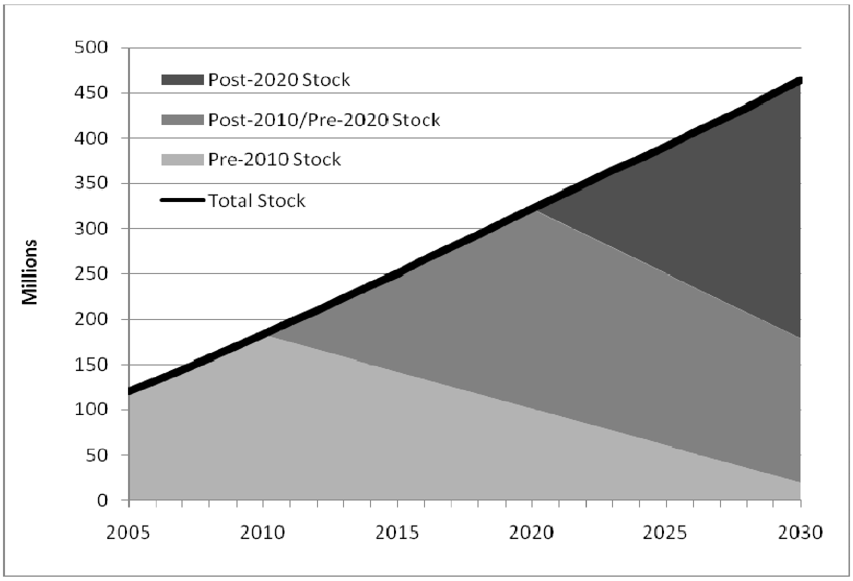


*Figure 3 – Stock of Asian Refrigerators by category. (Source: McNeil et al., 2008)*

Once the amount of stock in each category is estimated, calculation of delivered (site) energy demand is given by summing each component of the stock in each year, according to the UEC of each. Savings is then calculated as the difference between demand in the high-efficiency versus the base case.

## *Standards & Labelling Analysis for Buildings*

This section presents the first policy analysis application using the BUENAS model which covers an entire sector at the global level (McNeil et al., 2008). In this case, both residential and commercial buildings are included. The structure of the commercial buildings model is similar to the residential model described in the previous section. The activity module for commercial building is constructed in terms of building floor space and end use density instead of number of households and appliance ownership. This analysis focused on energy efficiency standards and labelling (EES&L) programs, and considered the entire world, broken up into 10 regions.

Funding for the global study performed by LBNL was provided by the Japanese Ministry of Economics, Trade and Industry via a contract with the Collaborative Appliance and Standards Labelling Program (CLASP). CLASP is a non-profit organization with a mission to provide technical support the successful implementation of EES&L programs throughout the world. As such, the study had the goal of assessing the potential carbon mitigation from this type of policy, if it were applied throughout the world. In creating efficiency scenarios for this study, attention was focused on those countries and regions already having advanced programs (and therefore, relatively efficient baseline), and those with little experience in efficiency policy, or public awareness of efficiency. On the other hand, we judged that those countries with greater access to high efficiency products would find it feasible to implement more aggressive standards than those entering the EES&L arena for the first time. Finally, an emphasis was placed on targets thought to be achievable given sufficient political support, but not dependent on dramatic advances in technology or reduction in costs.

We defined a two-tier timeline for the implementation of EES&L. The first tier is for a set of programs assumed to be implemented in 2010. The target levels for this tier represent already available technologies that provide incremental, but not dramatic improvement. A more fully-realized efficiency potential is modelled as the second tier, which would come into effect in 2020. This case does not represent the 'technological potential', but a more pragmatic 'maximum achievable' level. For simplicity, achievement of target efficiencies were modelled as mandatory minimum efficiency performance standards (MEPS), that is, with the assumption that the entire market achieves the target by the implementation date (lower efficiency products are banned from the market.) Alternatively, market transformation can be achieved by other types of programs, including comparative labelling (such as the EU mandatory labelling scheme) or endorsement labelling (such as the U.S. Energy Star program). In general, these types of programs yield a distribution of efficiencies, with average efficiency at our MEPS level, thus providing equivalent savings.

At this point, a word on the definition of efficiency scenarios and its relation to cost-effectiveness is in order. The most detailed and data-intensive analyses of the potential impacts of standards and labelling programs take cost-effectiveness into account in an integral way, often defining the optimum policy in terms of 'economic potential' that is, the market transformation that maximizes net economic benefits to consumers[13,14]. These benefits can be quantified by a variety of different metrics, including least life cycle cost, cost of conserved energy, or benefit to cost ratios. Although desirable, it is not practical to perform this type of analysis for a large number of countries, due to scarcity of data on equipment and energy prices. Instead, cost effectiveness and achievability are inferred by making reference to international best practices. Specifically, in the case of EES&L efficiency levels were chosen which are already currently the target of standards in a major market or already have a significant market share in a major market. Use of these levels implies cost effectiveness in two ways. First, already implemented standards are often set by performing detailed cost benefit analysis beforehand. Second, the presence of a significant market share implies at least the perception of cost-effectiveness to consumers.

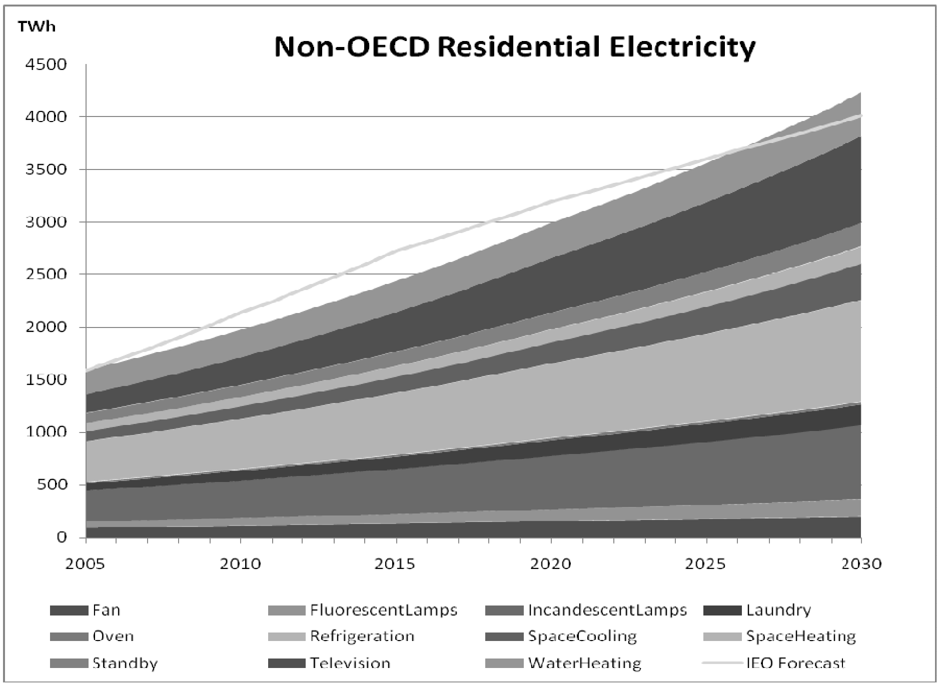


*Figure 4– Base Case electricity demand in non-OECD countries (Source: McNeil et al., 2008)*

A few figures demonstrate some of the important results of the EES&L study. First, Figure 4 shows the forecast of electricity demand from developing and transition (non-OECD) economies. In this figure, base case electricity demand for each residential end use is shown as a separate area colour, and these are added together. For comparison, the figure also shows a reference 'macro' scenario – in this case provided by the U.S. Department of *Energy's International Energy Outlook* 2007 (USEIA, 2007). It is important to note that, while the bottom-up model was not calibrated to the reference scenario, the agreement is rather good. This can be interpreted to mean that the bottom-up model includes those enduses accounting for the great majority of residential demand, and that diffusion rates and UEC values are accurate enough to closely reproduce macro trends.

[13] Examples of these include recent analyses of potentials for the United States (Rosenquist et al., 2006) and IEA countries (IEA, 2003)
[14] U.S. appliance MEPS follow a modified version if this approach. In setting these standards, U.S. DOE is directed towards the highest efficiency level that does not result in net positive LCC to consumers (on the condition that the corresponding technology is market ready and its production does not adversely impact manufacturers.

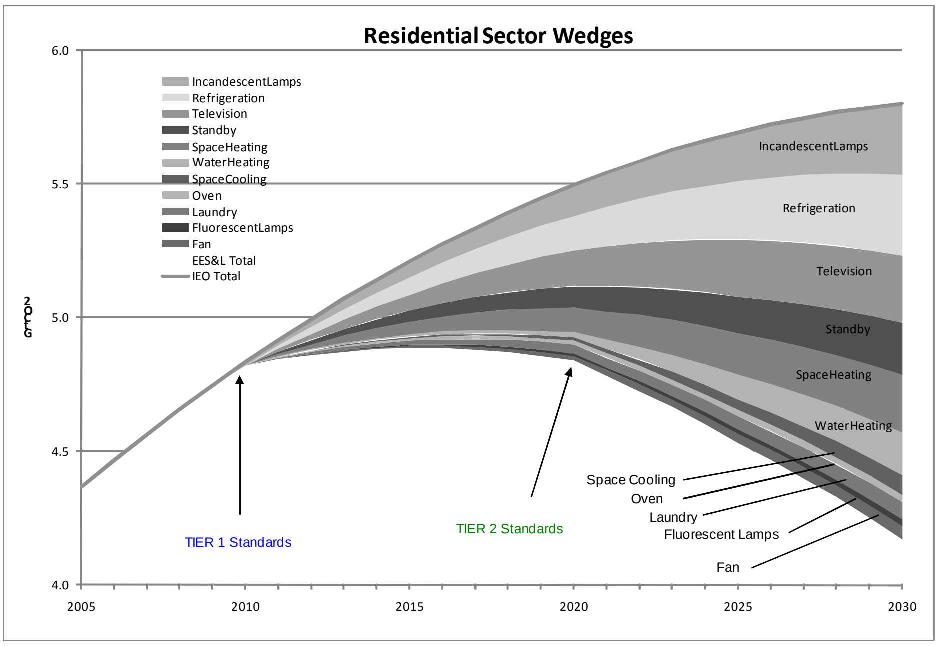


*Figure 5 – 'Wedge' graph of residential energy savings by end use. ( Source:  McNeil et al., 2008)*

Figure 5 shows a representation of carbon emission savings by end use in the residential sector.  This view shows the leading enduses that offer the greatest potential for emissions reductions – incandescent lamps, refrigeration and televisions.  It also displays the important results that EES&L alone has the potential – if pursued aggressively and throughout the world – to level residential sector emissions by 2020 and, with a second tier of standards implemented in that year, begin to turn down emissions relative to 2010 levels.  Finally, Figure 6 shows the geographical distribution of emissions mitigation potential in 2020 and 2030.  The figure indicates that by 2020, China (CPA) and the rest of Asia (SAS-PAS) each offer more mitigation potential than any other region, largely due to the current relative low efficiency of appliances in those regions.  By 2030, these regions show an even higher mitigation potential, but mitigation in the North America region (NAM) is comparable by this time, due to the very high efficiency targets in this region assumed in the scenario.

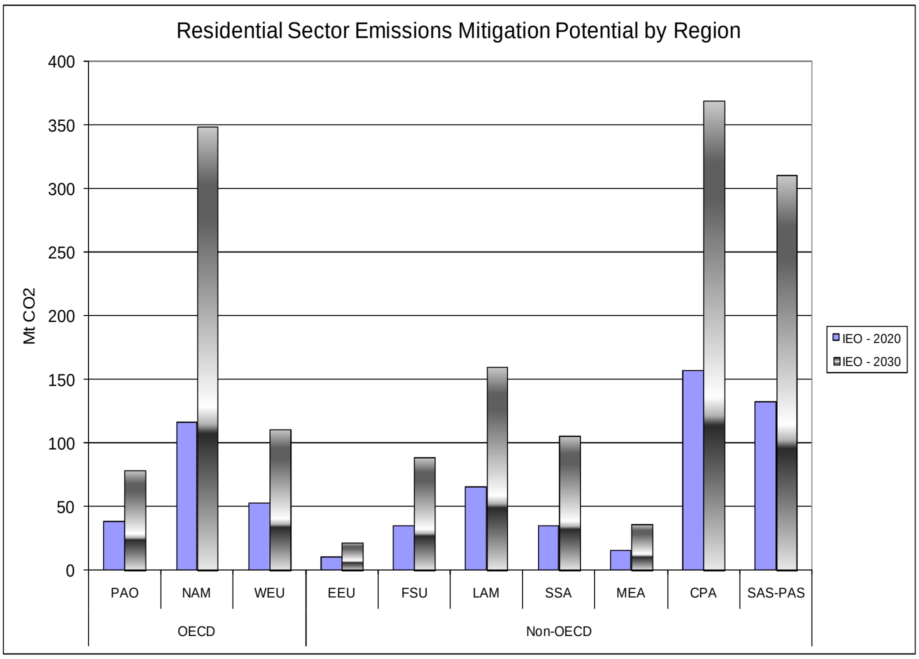


*Figure 6 –Residential emissions mitigation in 2020 and 2030 by region*

As a final result of the analysis, we compare the results for a single program type (EES&L), with the estimated *total* potential for $CO_2$ emissions mitigation in buildings recently published by the IPCC (Levine, et al. 2007).  This comparison indicates that EES&L can contribute significantly towards fulfilling the potential for emissions mitigation in the buildings sector, and is therefore one of the most important government policies for combating climate change.  The IPCC study was not limited to EES&L programs; rather it considered market transformation mechanisms as a whole. Our analysis indicates that EES&L programs could account for about 27% of total "zero cost" potential in 2020, and about 50% of the potential in 2030 from all energy efficiency measures. The remaining potential could presumably be achieved through all other approaches, including building codes, utility programs, incentives, and behavioral changes.

## What more should be done?

The previous section provided a description of the first application of the EGEMS methodology to an entire energy demand sector (buildings) for a specific policy type (EES&L). The ultimate goal of the model, however, entails extension of the framework to all sectors, and consideration of a wide range of policies. In this section, we present a list of additional work which has been completed, or is in progress and a (much longer) list of further areas of research to accomplish this goal.

In addition to the global EES&L analysis, EAD has completed two studies focusing on large developing countries - China and India (Zhou et al., 2008, de la Rue du Can et al, 2009). Each study presents a detailed characterisation of end-use energy demand across all sectors. This work provides unique information on patterns of energy consumption, trends in saturation and usage of energy-using equipment, technological change including efficiency improvements, and links between urbanization and energy demand. Further work is currently underway, particularly for China, which will refine the results of the previous study, and provide detailed efficiency scenarios built up from the end use level.

A second application of the model was to provide an analysis of potential impacts of an initiative to rapidly increase the scope and effectiveness of EES&L programs. This study, which concentrates on five regions: the United States, European Union, China, India and Latin America, considers the carbon emissions mitigation that could be achieved by 2030 by programs implemented or supported in the next five years (by 2014). The scenarios developed represent a practical assessment of realizable achievements of a specific program, given adequate financial and political support. Finally, EAD is engaged in a study of the opportunities for carbon mitigation through utility-based demand-side management (DSM) programs in seven large economies in the Asia-Pacific region[15]. This work requires the first extension of the model to include policies other than EES&L.

### *Extension to all energy demand sectors*

In addition to residential and commercial buildings, the bottom-up framework is also appropriate for modelling of the transport, industrial and agricultural sectors. As in the case of buildings, energy demand and carbon emissions will likely be addressed by policies affecting particular technologies and sub-sectors. The table below gives a sample of some of the demand end uses to be included in the model. Generally, end use activity can be modelled according to macroeconomic projections, such as GDP per capita, GDP value added per sector and land use intensity. In some cases, there may be some interaction between subsectors, such as the need for steel, cement and aluminium for construction of buildings and transport infrastructure.

| **Sector** | **Sub-Sector** | **Module** | **To be Modelled** |
|---|---|---|---|
| Transport | Passenger | Activity | Personal Automobile Ownership |
| | | | Rail and Bus Passenger Mobility |
| | | Intensity | Automobile Fuel Efficiency |
| | | | Bus Fuel Efficiency and Alternative Fuels |
| | Freight | Activity | Road Freight Transport |
| | | Intensity | Truck Fuel Efficiency and Modal Shifts |
| Industry | Steel and Cement | Activity | Building and Road Construction |
| | Aluminium | Activity | Construction and Manufacturing |
| | Ethylene | Activity | Chemical Industry and Plastics Manufacturing |
| | Ammonia | Activity | Agricultural Activity and Fertilizer Use |
| | Other Manufacturing | Activity | Motor Electricity Demand |
| | Steel and Cement | Intensity | Use of Recycled Materials (scrap) |
| | All Sub-Sectors | Intensity | Process Efficiency |
| | Other Manufacturing | Intensity | Motor Efficiency |
| Agriculture | Farm Equipment | Activity | Arable Land Used and Level of Mechanization |
| | | Intensity | Farm Equipment Fuel Efficiency |
| | Irrigation | Activity | Area of Crops Using Groundwater Irrigation |
| | | Intensity | Pumping Efficiency |

[15] Australia, Canada, China, India, Japan, Rep. of Korea and the United States

## *Financial analysis*

As mentioned in the previous section, the cost of implementing efficiency technologies, and the financial saving due to reduced energy expenditures have so far been included only implicitly in the model. There are two important reasons to provide a more explicit treatment. First of all, a mature global model should consider the variability of costs across countries, which can be considerable. In addition, costs are likely to vary over time, as general technological improvements and economies of scale will make high-efficiency goods more affordable. On the other hand, energy costs are likely to rise in the long term as demand outpaces supply, as least-cost energy supply options are abandoned for environmental reasons and as subsidies are phased out. Furthermore, cost-analysis may prove to be more crucial in the transport and industrial sectors. In the transport sector, vehicle prices represent a large fraction of household income, so that significant vehicle price increases may cause high-efficiency options to be unaffordable, or politically untenable. In all sectors, accurate assessment of the financial gain to consumers and society as a whole from adoption of cost-effective policies depends on data at the level of end use technologies. This data is not yet incorporated in the model.

A second reason for an increased focus on costs concerns the extension of the model to cover price-based policies. The two main price-based options, which have been discussed widely, are cap-and-trade schemes, such as are already in place in the European Union and some regions of the United States, and carbon taxes. For each of these schemes, the mitigation impact of the policy depends crucially on the decision by energy users to either invest in efficiency, or suffer a financial penalty. The most prominent subject of price-based policies are large industrial players and power companies, who will likely base their decisions on cost-benefit analysis, which could be modelled effectively given sufficient cost data.

The collection of cost data sufficient to significantly parameterize a wide range of technologies, regions and policy types requires a large-scale effort. The main component of this task is the establishment of engineering cost curves, that is, the relationship between the cost of a particular piece of equipment and its efficiency performance. This relationship will be established for each end use in each demand sector, and will cover the world's regions to the extent that data availability allows. Some of the areas of focus of the research effort should be:

- Fuel prices, including impacts of subsidies.
- Appliance price variability across countries.
- Residential, commercial and industrial sector electricity tariffs.
- Costs associated with installation and retrofit of baseline and 'best practice' industrial facilities.
- Historical trends of equipment manufacturing costs – technology 'learning curves'.
- Likely/planned caps and carbon market prices.
- Carbon tax scenarios.

## *Energy supply module*

So far, this paper has discussed modelling of the demand side of the energy equation, which is of interest in itself and is the usual area of focus for the authors (and most attendees of the *Summer Study*). In development of greenhouse mitigation policy scenarios, however, this is not sufficient. The nature of energy supply will also be of critical interest in the coming years, since without a serious transformation of how we produce useful energy, as well as use it, human society is unlikely to significantly alter the current climate trajectory. Furthermore, the transition to less carbon-intensive forms of electricity will have non-trivial interactions with demand-side efforts, especially where fuel substitution is encouraged (an example is the adoption of electric and 'plug-in' hybrid vehicles which will increase demand on electricity grids). For these reasons, areas of research in on the energy supply side should include:

- Carbon capture and storage potential.
- Economic and feasible implementation of wind, solar and nuclear power.
- Price-based policies - cap and trade scenarios and carbon tax impacts.
- Interactions between electricity grid and electric vehicles.
- Power-plant and petroleum refining (transformation sector) efficiency.
- Interactions between renewable electricity and energy efficiency.
- Energy load-curve and its relevance for particular types of renewable energy.

### *Scenario tool and technology database*

Finally, we propose two elements that are supplemental to the model, but add to its usefulness to both policymakers and the energy analysis community. The first of these is a 'scenario tool' interface for use by policymakers and other modellers. This interface is envisioned as a user-friendly 'front end' to the analysis framework. The tool would incorporate a 'scenario builder' providing the option to combine carbon mitigation options across sectors and approaches (technological as well as policy instrument implementation) to evaluate emission reduction pathways. The tool would provide global results, but allow for drill-down to the sector, end use and technology level. The main (but not exclusive) anticipated use of the tool would be to allow for various combinations of policies, and to make an evaluation of the relative contribution to emissions reductions of each. In addition, the tool would allow for customization of model parameters, either to assess the impacts of alternative futures in the base case (e.g. impacts of economic growth), or to refine or extend the scenarios described in the 'out-of-the-box' version.

The analysis framework and user tool would both be driven by an underlying database of parameters that will be the output of major data collection efforts. A second supplemental element will consist in making this database available to the energy analysis community in a transparent and convenient format. This database will include key modelling parameters, technology penetration levels, regional level data, base efficiencies, and achievable efficiency targets. Publication of such a database would allow for more detailed customization of model parameters, and facilitate revision and improvement of parameters from a wide community of users. In addition to the database, a "databook" could be published representing the compilation of all data used in the modelling framework.

## Conclusion

We hope that this paper has presented a convincing argument for the development of comprehensive and global bottom-up energy demand forecasts, and a framework for articulating realistic and detailed scenarios for carbon emission mitigation policies. We have presented the methodology and results of the analysis of one sector and a particular policy type in order to make the usefulness, feasibility and challenges of such an approach more concrete. As the previous section demonstrates, however, the EGEMS model as envisioned is far from complete. Inclusion of all of the elements required to create meaningful climate policy roadmaps will require an extensive effort, but also the guidance and input from our colleagues in the international energy analysis community. The *Summer Study* is the ideal venue for beginning the dialogue and collaboration that will be necessary, and we hope that the subject matter is of interest to the attendees and readers of the proceedings.

## References

IEA (2003). Cool Appliances, Policy Strategies for Energy Efficient Homes. Paris, International Energy Agency.

De la Rue du Can, S., M. A. McNeil, and J. Sathaye (2009). India Energy Outlook: End Use Demand in India to 2020, LBNL (forthcoming).

De la Rue du Can, S., V.E. Letschert, M.A. McNeil, N. Zhou and J. Sathaye (2009). Residential and Transport Energy Use in India: Past Trends and Future Outlook, LBNL(forthcoming).

Kaya, Y.(1989) Impact of Carbon Dioxide Emissions on GNP Growth: Interpretation of Proposed Scenarios, Geneva, Intergovernmental Panel on Climate Change, Response Strategies Working Group

Letschert, V. and M. McNeil (2007). Coping with Residential Electricity Demand in India's Future - How Much Can Efficiency Achieve? ECEEE Summer Study. Côte d'Azur, France.

Letschert, V. E. and M. A. McNeil (2008). The Boom of Electricity Demand in the residential sector in the developing world and the potential for energy efficiency. ACEEE Buildings Summer Study. Pacific Grove, CA.

Levine, M., D. Urge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. M. Mehlwana, S. Miragedis, A. Novikova, J. Rilling and H. Yoshino (2007). Residential and Commercial Buildings. Climate Change 2007; Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC, Cambridge University Press.

McMahon, J.E., M. McNeil, X. Liu, Impacts of US federal energy efficiency standards for residential appliances, Energy, Volume 28, Issue 8, June 2003, Pages 755-767, ISSN 0360-5442, DOI: 10.1016/S0360-5442(02)00188-3.

McNeil, M. and V. Letschert (2007). Future Air Conditioning Energy Consumption in Developing Countries and what can be done about it: The Potential of Efficiency in the Residential Sector. ECEEE Summer Study. Côte d'Azur, France.

McNeil, M. A., V. E. Letschert and S. d. l. R. d. Can (2008). Global Potential of Energy Efficiency Standards and Labeling Programs, LBNL for METI.

McNeil, M. A., V. E. Letschert and S.Wiel (2006). Reducing the Price of Development: The Global Potential of Efficiency Standards in the Residential Electricity Sector. EEDAL, London.

Rosenquist, G., M. McNeil, M. Iyer, S. Meyers and J. McMahon (2006). "Energy efficiency standards for equipment: Additional opportunities in the residential and commercial sectors." Energy Policy 34(17).

USEIA (2007). International Energy Outlook 2007, Energy Information Administration.

Zhou, N., M. McNeil, D. Fridley, J. Lin, L. Price, S. d. l. R. d. Can, J. Sathaye and M. Levine (2007). Energy Use in China: Sectoral Trends and Future Outlook.