Part II – Methodology

1. Introduction

The remainder of this document provides the details of the BUENAS methodology and data sources. It is intended for a technical audience and assumes some familiarity with the parameters used in energy demand and policy modeling. The structure of the document progresses "backwards" from end product to basic inputs, beginning in Section 2 with the definitions of the main outputs of the model, in the form of equations. The mathematical flow of the model is then mapped to a set of modules and key data inputs in Section 3. The mechanics of key modeling components are described in Section 4, and a description of the construction of scenarios is given in section 5.

While the document provides sufficient detail to trace the calculation of energy demand for all end uses, countries and scenarios, two types of data are omitted. First, some details already described in [3] and [4] are omitted and these references are cited instead. Second, many of the actual data streams are not provided in the document, but in the accompanying *BUENAS Inputs Spreadsheet*, an Excel file developed as a container and documentation tool for important data streams and assumptions in BUENAS. Some of the tables of inputs and references that appear here are generated from the BUENAS Inputs Spreadsheet directly. The structure of the spreadsheet file with a description of each sheet, is provided as an Appendix.

The original version of BUENAS was built as a database using Microsoft Access, with intermediate outputs and final results presented using Excel pivot tables. A major part of the preparation for peer review of the model involved porting the model to a more optimal platform. The most important features sought in a new software platform were:

- Transparency – All parameters and assumptions should be made easily visible to the reviewer;
- Portability – The model should be available in a single package not requiring integration of separate programs;
- User Interface – The user should easily be able to view tables and graphs of results, intermediate outputs and input variables.

The platform chosen for this peer review and subsequent versions of BUENAS is the Long Range Energy Alternatives Planning model (LEAP). LEAP is an integrated energy-environment modeling tool designed and disseminated by the Stockholm Environment Institute. It is an accounting model that relies on inputs of end use activity and intensity, but performs stock accounting and scenario structure given technology lifetime distributions. It provides a wide range of easy to understand tables and graphs well-suited to the needs of energy model developers. Finally, LEAP has a wide and growing community of users around the world and is increasingly becoming a standard platform for energy demand projection. Use of LEAP requires a moderate license fee for users in industrialized countries. It is provided free of charge for developing country users[7].

2. BUENAS Equations

The two main outputs of BUENAS are national-level final energy savings and carbon dioxide emissions mitigation. Final energy (electricity or fuel) savings is important because final energy demand is the driver of capital-intensive generation capacity additions and fuel imports. Final energy demand is also the quantity directly paid for by consumers. Carbon dioxide forms the majority of greenhouse gas emissions and is therefore the most important environmental impact of energy consumption. Reducing these emissions is a primary goal of energy efficiency policy in the era of climate change. The current version does *not* calculate financial impacts of efficiency policy due to the data requirements needed to include them. However, financial impacts will be included in the next version of the model. Primary energy inputs to electricity are also not considered, although carbon emissions are a rough proxy for them.

The following equations are implemented in LEAP to produce emissions mitigation and final energy savings results.

Emissions Mitigation

BUENAS calculates carbon dioxide mitigation from final energy savings:

$$\Delta CO_2(y)=\Delta E(y) \times f_c(y)$$

- $\Delta CO_2(y)$=CO_2 mitigation in year y
- $\Delta E(y)$=Final Energy Savings in year y
- f_c=carbon conversion factor (kg/kWh or kg/GJ) in year y

Final Energy Savings

BUENAS calculates final energy savings (electricity or fuel) by comparing *Efficiency Case (EFF)* energy demand and *Business as Usual (BAU)* energy demand:

$$\Delta E(y)=E_{BAU}(y)-E_{EFF}(y)$$

- E = final energy demand

2.1. Residential Sector Activity Equations

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[7] For more information on LEAP, visit http://www.sei-us.org/software/leap.html

BUENAS calculates final energy demand according to unit energy consumption of equipment sold in previous years:

$$E_{BAU}=\sum_{age} Sales(y\text{-}age)\times UEC_{BAU}(y\text{-}age)\times Surv(age)$$

- *Sales (y)* = unit sales (shipments) in year *y*
- *UEC(y)* = unit energy consumption of units sold in year *y*
- *Surv(age)*=probability of surviving to *age* years

Stock Turnover (mostly done by LEAP)

When unit sales (shipments) are not given as direct data inputs then BUENAS derives them from increases in stock and replacements:

$$Sales(y)=Stock(y)-Stock(y-1)+\sum_{age} Ret(age)\times Sales(y\text{-}age)$$

- *Stock (y)* = Number of units in operation in year *y*
- *Ret(age)* = probability that a unit will retire (and be replaced) at a certain age

Survival function and retirement function are related by:

$$Surv(age)=1-\sum_{age} Ret(age)$$

Stock

Stock is rarely given directly as input data. Instead, if sales data are not available, BUENAS uses appliance diffusion (ownership) rates:

$$Stock(y) = Diffusion\ (y)\ \times HH(y)$$

- *Diffusion (y)* = Number of units (owned and used) per household in year *y*
- *HH(y)* = Number of households in year *y*.

In turn, diffusion rates are generally not given by input data, but are projected according to a macroeconomic model:

$$Diffusion(y)=\frac{\alpha}{1+\gamma\times exp(\beta_1\times I(y)+\beta_2\times U(y)+\beta_3\times E(y))}$$

- *I(y)*=household income (*GDP* per household) in year (*y*)
- *U(y)*=urbanization rate in year (*y*)
- *Elec(y)* = electrification rate in year (y)
- $\alpha,\gamma,\beta_1,\beta_2,\beta_3$ = model parameters (described in [4])

2.2. Commercial Sector Activity Equations

Sales data are scarce for most commercial end uses. In this sector, BUENAS models commercial floor area and end use intensity, since these data are more readily available from national statistics:

$$E_{BAU}=\sum_{age} Turnover(y\text{-}age)\times uec_{BAU}(y\text{-}age)\times Surv(age)$$

- $Turnover\ (y)$=equipment floor space coverage added or replaced in year y.
- uec (y) energy intensity (kWh/m^2) of equipment installed in year y (lower case used to distinguished from unit energy consumption ,UEC).

Turnover is driven by increases in floor space, and replacement of existing equipment occupying floor space.

$$Turnover(y)= F(y)\text{-}F(y\text{-}1)+\sum_{age} Ret(age)\times Turnover(y\text{-}age)$$

- $F\ (y)$=total commercial floor space in year y.

When floor space is not given by direct data inputs, it is modeled as the product of two components:

$$F(y) = N_{SSE}(y)\times f(y)$$

In this equation, N_{SSE} is the number of service sector employees and f is the floor space per employee. N_{SSE} is the product of the economically active population P_{EA} and the service sector share SSS:

$$N_{SSE}(y) = P_{EA}\times SSS(y)$$

Floor space per employee is modeled in a similar way to residential appliance diffusion:

$$f(y)=\frac{a}{1+\ \gamma\ \times exp(\ \beta''\times i(y))}$$

- $i(y)=GDP$ per capita in year (y)
- $\alpha,\beta',\beta'',\gamma$= model parameters (described in [18])

2.3. Industrial Sector Activity Equations

When sales data and unit energy consumption are not available for industrial motors, they are modeled as a function of industrial value added GDP:

$$E(y)_{BAU}=GDP(y)_{IND}\times\ \varepsilon\ \times p$$

- $GDP(y)_{IND}$=*GDP* value added of industrial sector in year (*y*)
- ε = electricity intensity per unit of industrial GDP [8]
- *p* = percentage of electricity from electric motors[9]

3. Model Components and Data Flow

Figure 3 shows a flowchart of the BUENAS calculations implemented in the LEAP platform. The equations presented above are presented in the flowchart as flowing from right to left, that is, from final result to data inputs. Some of these equations are implemented in LEAP as user-defined calculations while others are built in as part of the functionality of the platform. In general, LEAP calculates national level energy savings given stock or sales of each equipment type combined with a time series of *marginal final energy intensity*, that is, annual energy consumption of new units entering the stock. Carbon dioxide emissions are calculated from final energy demand using a customized calculation. Activity modeling when not driven directly by a time series of product sales is also implemented with a custom calculation.

Much of the modeling in BUENAS is accomplished by input of data streams into LEAP, which then calculates energy demand using built-in stock accounting functions. The two main inputs provided in this way are (1) product sales or stock time series and (2) unit energy consumption time series.

All data inputs used in the LEAP model are stored in an Excel file called *BUENAS Inputs Spreadsheet.xlsx*. This file serves as a 'database' for the variables used in the model. It also contains documentation regarding the primary sources of these data. Finally, the inputs spreadsheet indicates the model version (by date), which can be correlated to a version of the LEAP database named with the same date. The sheets and areas of this spreadsheet are defined in the Appendix.

The legend of Figure 3 shows the different component type of the models. These are:

1. *Data or Assumption* – These are direct inputs to the model documented in the *BUENAS Inputs Spreadsheet*. In the case of data from other sources, the reference of the primary data source is listed. In cases where no data are available, assumptions are sometimes made.
2. *Calculation* – These are computations governed by the equations in the previous section. These are either built in to LEAP, or are user-defined.
3. *Data or Calculation* – This can be either a direct data input or a calculation. The main example of this is the projection of unit sales. When available, these data are input directly in the model. If no such data are available, sales are modeled from stock as an intermediate

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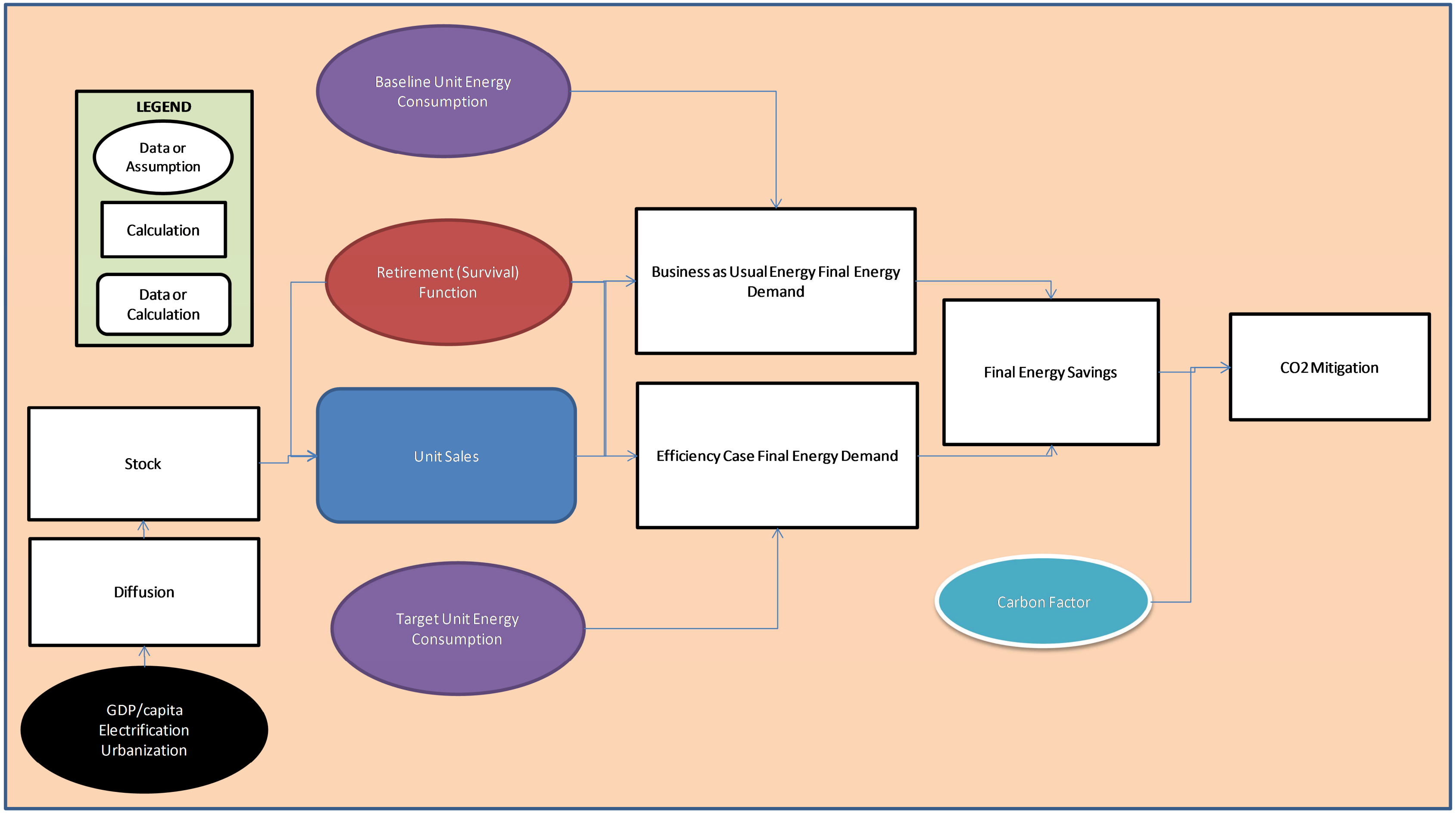
[8] Industrial GDP - PPP Units - Development Data Group, The World Bank. 2007. 2007 World Development Indicators Online. Washington, DC: The World Bank. Available at: http://go.worldbank.org/3JU2HA60D0. Industrial Electricity Consumption from the International Energy Agency.

[9] From literature. Sources provided in *BUENAS Inputs Spreadsheet.*

result. Stock in turn can be a direct input or from a model of appliance ownership (diffusion).

Figure 3 – Flowchart of BUENAS Calculation



Note: Stock and Diffusion can be entered directly into the model as data, but this is rare.

The equations and structure of BUENAS are well-established and are relatively stable. Generally they follow widely accepted practices of energy demand calculation and stock turnover analysis[10]. Much of the current and future development of BUENAS therefore consists of gathering and refining data inputs. In particular, the scope of the model is currently primarily limited by data availability.

GDP per Capita, Electrification and Urbanization – Macroeconomic parameter data, either historical or forecast, are provided by the World Bank and United Nations agencies, based on data supplied officially from national agencies,

Unit Sales or Stock – The number of units of appliances sold (and in the stock) in each year originate from a number of sources. The most common of these are the models used by countries to evaluate the impacts of their own efficiency programs[11]. Other sources include industry reports and market research firms. A summary of sources of unit sales or stock data is given in Table 4.The numbers in the table indicate the source of data, as numbered in the references section.

Table 4 – Sources of Unit Sales or Stock Data

	Country / Economy										
Product	AUS	BRA	CAN	EU	IND	JAP	KOR	MEX	RUS	USA	ZAF
Boilers			[10]	[20]						[21]	
Central Air Conditioners	[7]		[10]					[22]		[23]	
Clothes Dryers										[24]	
Clothes Washers				[25]							
Commercial Clothes Washers										[26]	
Cooking Equipment										[27]	
Direct Heating Equipment										[28]	
Dishwashers				[25]							
Distribution Transformers			[29]		[30]					[29]	
Electric Motors				[31]				[22]			
Fans					[32]					[33]	
Fluorescent Ballasts										[34]	
Freezers				[35]						[36]	
Furnace Fans										[23]	
Furnaces			[10]							[23]	
Lighting				[37]						[38]	
Pool Heater										[39]	
Refrigerators	[40]			[41]				[22]		[36]	
Room Air Conditioners	[7]		[10]	[42]						[43]	
Standby Power				[44]						[45]	
Televisions	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]
Washing Machines								[22]			
Water Heaters				[47]				[22]		[48]	

Baseline Unit Energy Consumption – Annual energy consumption of appliances arises from a combination of appliance size, efficiency and usage patterns. Like unit sales, this parameter is often

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[10] This does not exclude further development of *analysis features*, that. That is inclusion of previously unaccounted for impacts or second order corrections. Some of these are listed in Section 6.

[11] The most common of these are the Technical Support Documents used in the development of US federal appliance standards and Preparatory Studies used to support the European Commission's Ecodesign standards.

available from efficiency program studies or from the efficiency metrics definitions of countries with EES&L programs. Estimates and algorithms for UEC are less frequently found in the energy literature. A summary of sources of baseline unit energy consumption data is given in Table 5. Cases where unit energy consumption was generated by assumption are indicated with an ‘A’. The numbers in the table indicate the source of data, as numbered in the references section.

Table 5 – Sources of Unit Energy Consumption Data

Product	Country / Economy											
	AUS	BRA	CAN	EU	IDN	IND	JAP	KOR	MEX	RUS	USA	ZAF
Boilers			[10]	[20]								
Central Air Conditioners	[7]		[10]						[23]		[23]	
Cooking Equipment											[49]	
Cooking Products											[49]	
Direct Heating Equipment											[28]	
Dishwashers				[50]								
Dryers				[51]							[24]	
Fans	[52]	[52]	[52]	[52]	[52]	[52]	[52]	[52]	[52]	[52]	[52]	[52]
Freezers				[53]							[36]	
Furnace Fans			[23]								[23]	
Furnaces			[10]								[23]	
Lighting	[54]		[54]	[55]		[54]	[55]	[55]	[54]	[55]	[54]	
Pool Heater											[39]	
Pool Heaters											[39]	
Refrigerators	[40]	A	[36]	[53]	[56]	[56]	[57]	[57]	[58]	A	[36]	A
Room Air Conditioners	[59]	[3]	[60]	[42]					[58]		[43]	[3]
Standby Power	[40]	[10]	[22]	[44]	[7]	[61]	[62]	[31]	[46]	[52]	[63]	[64]
Televisions	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]	[46]
Washing Machines				[65]				[25]	[58]			
Water Heaters	[66]		[48]	[47]					[58]		[48]	
Commercial Clothes Washers											[26]	
Distribution Transformers			[29]			[30]					[29]	
Electric Motors	[67]	[68]	[31]	[31]	[67]	[67]	[67]	[67]	[31]	[67]	[31]	[67]
Direct Cool						[56]						
Frost Free						[56]						
Window			[10]	[42]		[69]			[58]			
Split												
Central Air Conditioners (inc. HP)											[23]	
Motors			[63]	[31]							[63]	

Target Unit Energy Consumption – Unit energy consumption of a high efficiency scenario is typically available only for standards already in progress (‘Recent Achievements’ scenario). Otherwise, target energy consumption is derived according to known performance achievements in other countries. This type of efficiency target is the subject of the *Best Practice Scenario*, which is described in Section 5.

Retirement (Survival) Function – The retirement function gives the probability that equipment will fail or be taken out of operation after a certain number of years. Retirement functions data are given for some equipment types by national analyses and follow common functional forms, such as Normal (Gaussian) or Weibull distributions. The Weibull distribution is commonly used to model equipment failure. Often, however, there are no data available to describe the particularities of the distribution. In those cases, BUENAS uses a normal distribution as a default. The mean value of this distribution, or average lifetime, is taken from the literature. In some cases, particularly in the U.S. studies, lifetimes were derived or tested by comparing historical sales and stock data. In general, however, lifetime estimates depend on anecdotal reports from industry experts and are subject to considerable uncertainty.

Carbon Factor – The carbon factor is the constant of proportionality between final electricity consumption and carbon dioxide emissions. Carbon factor is a result of plant efficiency, transmission and distribution losses and the generation fuel mix. Carbon factors in the base year 2005 are taken from [70]. The projection of carbon factor is derived using the base year data, and scaling by the trend of IEA's World Energy Outlook (WEO) 2006 [71], which takes into account expected improvement in plant efficiency, reduction of transmission and distribution losses, and reduced dependence on fossil fuels for electricity generation. The analysis does not consider the difference between average and marginal carbon which, while more accurate, are difficult to forecast given the available data.

4. Activity, Stock Turnover and Intensity Methodology

One advantage to using the LEAP model as a platform for BUENAS is that many of the energy demand calculations are built in. These include standard stock turnover calculations. Given a sales input, base year vintage distribution and lifetime distribution, LEAP generates yearly stock and vintage of each equipment type. LEAP's internal calculations also keep track of the total energy demand of the stock, taking into account the evolution of unit energy consumption of each cohort or marginal *final energy demand*. If neither stock nor shipments are given as direct inputs into the model, BUENAS uses an alternative method for projecting residential appliance activity originally developed for the first version of the model. This methodological approach is the subject of Section 4.1. Section 4.2 deals with methodologies employed for commercial building and industrial motors modeling, which use more aggregate calculations of intensity and activity than the residential sector.

4.1. Residential Appliance Activity

Three different methods are used to estimate the total stock of a particular residential end use. For each region and end use, the highest accuracy method is chosen for which sufficient data are available. In order of decreasing accuracy, the methods are:

1. Stock based on historical and projected flows of products (unit sales).
2. Stock from historical and projected ownership rates – sales derived from stock increases and replacement rates.
3. Stock from econometric modeling driven by macroeconomic trends – sales derived from stock increases and replacement rates.

The original global version of BUENAS relied on a generic model of household ownership for all residential end uses and all regions. In the present version of the model, it is used for India and Latin American countries, as well as end uses in the United States for which sales data were not available. The details of the model development are not given here, but can be found in [3] and [4][12]. The diffusion relation is assumed to follow a logistic functional form and depend on GDP per household (income), urbanization rate and electrification rates according to the following general equation:

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[12] Parameters in the journal article differ from those used in the current version of the model, which uses Purchase Power Parity to evaluate household income, while (McNeil and Letschert 2010) used market exchange rates.

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

In this equation, *c* is the country index. Parameters for each end use are given in Table 6. The full details of the development of the model and the data used to derive the parameters are provided in [4].

Table 6 – Residential model Diffusion Parameters

Points of Light			ln γ	β_{Inc}	β_{Elec}	β_{Urb}
α	40	*Coefficient*	2.204	-3E-05		
Observations	42	*Standard Error*	0.18	3.0E-06		
R^2	0.71	*t-Stat*	12.45	-10.00		
Refrigerators			ln γ	β_{Inc}	β_{Elec}	β_{Urb}
α	1.4	*Coefficient*	4.84	-1.3E-05	-3.59	-2.24
Observations	64	*Standard Error*	0.197	4.82E-06	0.27	0.59
R^2	0.92	*t-Stat*	24.508	-2.77	-13.42	-3.78
Televisions			ln γ	β_{Inc}	β_{Elec}	β_{Urb}
α	3	*Coefficient*	3.701	-2.5E-05	-2.39	
Observations	46	*Standard Error*	0.134	4.96E-06	0.31	
R^2	0.85	*t-Stat*	27.584	-5.07	-7.66	
Room Air Conditioners			ln γ	β_{Inc}	β_{Elec}	β_{Urb}
α	*ClimateMax*	*Coefficient*	4.843	-6.9E-05		
Observations	24	*Standard Error*	0.503	9.82E-06		
R^2	0.69	*t-Stat*	9.635	-7.04		
Fans			ln γ	β_{Inc}	β_{Elec}	β_{CDD}
α	3	*Coefficient*	0.798	9.79E-07	-1.13	3.41E-04
Observations	11	*Standard Error*	0.968	4.82E-06	0.98	1.34E-04
R^2	0.79	*t-Stat*	0.824	0.20	-1.15	2.55
Standby Power Devices			ln γ	β_{Inc}	β_{Elec}	β_{Urb}
α	12	*Coefficient*	1.266	0.00		
Observations	20	*Standard Error*	0.508	0.00		
R^2	0.40	*t-Stat*	2.492	-3.43		

In the case of fans, cooling degree days are used as a driving variable of ownership. Air conditioner ownership is also highly climate dependent. To model this, the diffusion equation for air conditioners is multiplied by a *climate maximum* parameter ranging from 0 to 1. Climate maximum is given by the following equation, as determined in (McNeil et al, 2009)

$$ClimateMaximum = 1.0 - 0.949 \times \exp(-0.00187 \times CDD)$$

This equation utilizes the climate parameter *cooling degree days* (*CDD*), which integrate total hours in a year during which outdoor temperatures exceed a reference defined as a cooling threshold. Cooling degree days are the main climate parameter determining cooling load, though other factors, such as humidity, are also important. Country specific parameters, including activity, and efficiency scenarios are given in the following sections.

4.2. Commercial and Industrial Sector Modeling

Floor Space Projection

The ‘commercial’ sector refers to all buildings that are not used as residences, or part of industrial facilities (also called ‘tertiary’ or ‘service’ sector). For the purposes of modeling, the commercial sector is distinguished from the residential sector in several important ways. First, buildings and end use equipment can vary greatly in size, from a room air conditioner used in a corner market to large chillers used in the largest office buildings. Second, data on these buildings and on the equipment installed in them is generally more sparse than for residences. Finally, residential end uses tend to be the first target of efficiency programs with commercial end uses targeted later. Such programs are an important source of insight into the consumption and further savings potential of upcoming programs.

Much of the emphasis for the commercial model involves the projection of commercial floor space. While current floor space estimates are available for some countries, in general projections are not. The strategy for determining floor space is to separately model the percentage of employment in the tertiary sector of the economy and the floor space per employee engaged in this sector. Service sector share (*SSS*) is multiplied by the total number of employees which is determined by:

- *Economically Active Population* $P_{EA}(y)$ from the International Labor Organization projected to 2020 and extrapolated thereafter [72].
- *Unemployment Rate* $R_U(y)$ from the International Labor Organization [72]till 2005, and projected to 2005 regional average by 2020.

SSS is modeled as a function of GDP per capita in terms of purchasing power parity (PPP). *SSS* data are available from the World Bank for a wide range of countries and for different years. The relationship between *SSS* and GDP per capita is modeled in the form of a log-linear equation of the form:

$$SSS(y) = a \times \ln(I(y)) + b$$

The parameters *a* and *b* are determined to be 0.122 and -0.596, respectively. More detail about the data used to determine these parameters can be found in [3].

Using these components, the number of service sector employees N_{SSE} is given by

$$N_{SSE}(y)=P_{EA}(y)\times(1-R_U(y))\times SSS(y)$$

Floor space per employee, denoted *f(y)* is, like *SSS*, assumed to be a function of per capita income only. The relationship assumes a logistic functional form:

$$f(y)=\frac{a}{1+\gamma\times \exp(\beta''\times i(y))}$$

In this equation, the maximum value α is set to 70 m^2 per employee, which was larger than any of the observed data. The variable I denotes GDP per capita and β'' and γ were determined to be -9.9×10^{-5} and 6.04 respectively.   More detail about the data used to determine these parameters can be found in [3].

End Use Intensity

Generally, it is difficult or near-impossible to model commercial end use intensity according to stock flows of specific equipment types due to data limitations. Therefore, end use intensity estimation takes an aggregate approach. End-use intensity is composed of *Penetration*, *Efficiency* and *Usage*. Penetration takes into account the effect of economic development on increased density of equipment expressed in Watts per m^2, and is assumed to be a function of GDP per capita only. Relative efficiency is estimated from specific technologies and usage is given by hours per year. Savings between the high-efficiency and the business as usual case arise from percentage efficiency improvements.

Lighting

Lighting efficiency is estimated as the fraction in the stock of lighting types: T12, T8 and T5 fluorescent tubes, incandescent lamps, CFLs, Halogen lamps and other lamps. In addition, relative efficiency of fluorescent lamp ballasts contributes to overall lighting efficiency. Assumptions for lighting energy intensity, and the subsequent calculation of penetration are provided in [3]. The result is a model of penetration according to a logistic function,

$$p(W/m2) = \frac{\alpha}{1 + \gamma \times e^{\beta \times I(y)}}$$

The variable $I(y)$ denotes GDP per capita and α, β and γ are found to be 16.0, -7.78×10^{-5} and 3.55 respectively.

Space Cooling

Space cooling energy intensity is of course a strong function of climate, but also economic development. Its dependence on cooling degree days (CCD) is assumed to be linear. The dependence on GDP per capita, which we call “availability”, takes a logistic form:

$$Int(kW/m2) = \frac{\alpha}{1 + \gamma \times e^{\beta \times I(y)}} \times (a + b \times CCD)$$

In order to separate the effect, the climate dependence is determined from U.S. data, where availability is assumed to be maximized. Once modeled in this way, the climate dependence can be divided out of final energy intensity data to yield availability as a function of GDP per capita. The parameters for space cooling intensity determined in this way are:

$$\alpha=1.8,\ \beta=0.00011,\gamma=8.83;\ a=9.7193,\ b=0.0123$$

Space cooling efficiency is determined according to estimates of market shares of room air conditioners, central air conditioners and chillers, prevailing base line technologies and feasible efficiency targets (see[3])

Refrigeration

Due to a scarcity of data for commercial refrigeration, space cooling *penetration* is assumed to have the same shape as lighting, that is, the availability of space cooling increases as a function of per capita GDP in the same proportion as for lighting, but with a different coefficient of proportionality *A*.

$$Int(kWh/m2) = \frac{A}{1+\gamma e^{\beta I(y)}}$$

The penetration curve is then calibrated to data from the United States, which has a refrigeration intensity of 9.94 kW/m^2. The resulting value of *A* is 10.61 kW/m^2. In the high efficiency scenario, an improvement of 34% is assumed to be possible [73]in all countries.

Industrial Motors Activity

Electricity demand and savings potential for electric motors is treated in the same way for all regions except for the European Union, for which a motor stock projection is provided in the Ecodesign preparatory study [31]. The model for industrial motor activity used in BUENAS is somewhat simplistic. For all countries outside of the EU, total electricity consumption of motors as a fraction of industrial electricity is used as the activity variable, according to the following formula:

$$Elec(y) = GDPVA_{IND}(y) \times \varepsilon \times p$$

In this equation, $GDPVA_{IND}$ is the value added to GDP from the industrial sector. The variable ε is the electricity intensity of the industrial sector, that is, the amount of electricity consumed for each dollar of industrial value added. This variable is taken from historical energy consumption data (from IEA) and divided by $GDPVA_{IND}$ from the World Bank in the base year. Multiplying ε and $GDPVA_{IND}$ for the base year simply gives back reported industrial electricity consumption in that year and, since ε is assumed constant, industrial electricity consumption in the projection simply grows at the same rate as $GDPVA_{IND}$. The fraction *p* is the percentage of industrial electricity passing through motors[13]. Multiplying the three variables together then gives motor electricity consumption in each year through 2030.

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[13] Sources by country or region given in *BUENAS Inputs Spreadsheet*.

5. High Efficiency Scenario Details

BUENAS currently contains two policy-driven high-efficiency scenarios that are compared to the Business As Usual (BAU) case in order to evaluate impacts of efficiency policy steps. The first of these is called the *Recent Achievements Scenario*, while the second is the *Best Practice Scenario.*

The *Recent Achievement Scenario* is concrete and highly specific. It is meant to quantify the impacts of efficiency programs already implemented or in progress. Three types of policy or 'groups' are considered. These are:

Group 1 Regulations implemented between January 1, 2010 and April 1, 2011 (effective date)
Group 2 Regulations issued between January 1, 2010 and April 1, 2011 (announcement date)
Group 3 Regulations in progress between January 1, 2010 and April 1, 2011 (with scheduled announcement date)

Of these, Group 3 is the most speculative, since regulations 'in progress" could be at a wide range of development, from a proposal to act, to a nearly complete process. For definiteness, we include only those regulations that have a specific implementation date associated with them. Even with this definition, many regulations in this category lack sufficient definition and data to support our analysis.

To date, only mandatory minimum efficiency performance standards (MEPS) are included in the *Recent Achievements Scenario*, but future versions may include labeling programs and financial incentive programs. In addition, only selected standards in the United States, European Union, Canada, Mexico and Korea are captured. This list is being continually expanded to include all recent standards implemented by participants of SEAD and possibly Clean Energy Ministerial members.

The second major scenario included in BUENAS considers the potential impacts of regulations in the near to medium term. This scenario corresponds roughly to the scenario used in the first "Global Potential" study[3], which included aggressive but achievable levels in all countries. There are many possible ways of defining such targets including cost-effectiveness, removal of a certain fraction of models from the market or best available technology. Due to data limitations, the most practical of these has been to rely on an evaluation of best practices. The best practice scenario assumes that all countries adopt stringent standards in modeled end uses by 2015, where 'stringent' is interpreted in the following way:

1. Where efficiency levels are readily comparable across countries: the most stringent standard issued by April 1, 2011 anywhere in the world.
2. Where they are not: the most stringent comparable (e.g., regional) standard issued by April 1, 2011.
3. In the case where an obvious best comparable standard was not available, an efficiency level was set that was deemed to be aggressive or achievable, such as the most efficient products in the current rating system.

In addition, the best practice scenario assumes that standards are further improved in the year 2020, by an amount estimated on a product-by-product basis.

Table 7 and Table 8 summarize the references and assumptions used in modeling the *Recent Achievements Scenario and Best Practice Scenario.* The following variables are shown:

Group – Category of regulation: 1 = implemented, 2 = announced, 3 = in progress
End Use – Appliance type covered by the regulation
ISO – International Standards Organization 3 – letter country code
Standard Year – Year that regulation takes effect
UEC_{BC} – Unit Energy Consumption in the *Business as Usual Case*[14]
Reference – Source of Unit Energy Consumption data
Ref ID – number of reference in References section below
UEC_{RA} , UEC_{BP} – Unit Energy Consumption in the *Recent Achievements or Best Practice Scenario*
% Imp – Percentage improvement between *Business as Usual* Case and *Recent Achievements* Scenario
Assumptions / Definition – Definitions provided by regulatory documents or assumptions made regarding best practice in developing the scenario

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[14] While efficiency is generally assumed to be constant in the Business as Usual case, Unit Energy Consumption can change over time according to usage trends.

Table 7 – References and Definitions of Recent Achievements Scenario

Group	End Use	Product Class	Units	ISO	Std. Yr	UEC_{BC}	Reference	Ref ID	UEC_{RA}	Reference	Ref ID	% imp.	Assumptions / Definition
2	Refrigerators	All	kWh/yr	USA	2014	577	U.S. Rulemaking Documents	[36]	481	U.S. Rulemaking Documents	[36]	17%	TSL 2
2	Refrigerators	Top Mount	kWh/yr	USA	2014	520	U.S. Rulemaking Documents	[36]	404	U.S. Rulemaking Documents	[36]	22%	TSL 2
2	Refrigerators	Side by Side	kWh/yr	USA	2014	716	U.S. Rulemaking Documents	[36]	612	U.S. Rulemaking Documents	[36]	15%	TSL 2
2	Refrigerators	Bottom Mount	kWh/yr	USA	2014	556	U.S. Rulemaking Documents	[36]	533	U.S. Rulemaking Documents	[36]	4%	TSL 2
2	Refrigerators	Others	kWh/yr	USA	2014	603	U.S. Rulemaking Documents	[36]	568	U.S. Rulemaking Documents	[36]	6%	TSL 2
1	Refrigerators		kWh/yr	EU	2010	251	Ecodesign Documents	[41]	262	Ecodesign Documents	[53]	-4%	
3	Refrigerators		kWh/yr	MEX	2014	369		[58]	309	CONUEE	[58]	16%	Same % improvement as U.S. (Harmonization Scenario)
2	Room Air Conditioners		kWh/yr	USA	2014	529	U.S. Rulemaking Documents	[43]	494	U.S. Rulemaking Documents	[43]	7%	
2	Room Air Conditioners	PC1	kWh/yr	USA	2014	387	U.S. Rulemaking Documents	[43]	342	U.S. Rulemaking Documents	[43]	12%	CSL3
2	Room Air Conditioners	PC3	kWh/yr	USA	2014	598	U.S. Rulemaking Documents	[43]	565	U.S. Rulemaking Documents	[43]	6%	CSL3
2	Room Air Conditioners	PC5a	kWh/yr	USA	2014	459	U.S. Rulemaking Documents	[43]	451	U.S. Rulemaking Documents	[43]	2%	CSL2
2	Room Air Conditioners	PC5b	kWh/yr	USA	2014	535	U.S. Rulemaking Documents	[43]	531	U.S. Rulemaking Documents	[43]	1%	CSL1
2	Room Air Conditioners	PC8a	kWh/yr	USA	2014	474	U.S. Rulemaking Documents	[43]	458	U.S. Rulemaking Documents	[43]	3%	CSL2
2	Room Air Conditioners	PC8b	kWh/yr	USA	2014	706	U.S. Rulemaking Documents	[43]	688	U.S. Rulemaking Documents	[43]	2%	CSL2
3	Room Air Conditioners		kWh/yr	EU	2014	381	Ecodesign Documents	[42]	190	Ecodesign Documents	[42]	50%	MEPS 2012 Scenario
3	Room Air Conditioners		EER	MEX	2014	3		[58]	3.0	CONUEE	[58]	7%	Same % improvement as U.S. (Harmonization Scenario)
2	Room Air Conditioners		kWh/yr	CAN	2011	2160		[69]	561		[60]	74%	
1	Room Air Conditioners		kWh/yr	AUS	2010	1771		[7]	1557		[59]	12%	
2	Central Air Conditioners (inc. HP)		kWh/yr	USA	2016	3075	U.S. Rulemaking Documents	[23]	2915	U.S. Rulemaking Documents	[23]	5%	
2	Central Air	SAC-CO	kWh/yr	USA	2016	2384	U.S. Rulemaking	[23]	1965	U.S. Rulemaking	[23]	18%	TSL 4

Group	End Use	Product Class	Units	ISO	Std. Yr	UEC_{BC}	Reference	Ref ID	UEC_{RA}	Reference	Ref ID	% imp.	Assumptions / Definition
	Conditioners (inc. HP)						Documents			Documents			
2	Central Air Conditioners (inc. HP)	SAC-BC	kWh/yr	USA	2016	2242	U.S. Rulemaking Documents	[23]	1857	U.S. Rulemaking Documents	[23]	17%	TSL 4
2	Central Air Conditioners (inc. HP)	PAC	kWh/yr	USA	2016	2645	U.S. Rulemaking Documents	[23]	2143	U.S. Rulemaking Documents	[23]	19%	TSL 4
2	Central Air Conditioners (inc. HP)	SHP	kWh/yr	USA	2016	5047	U.S. Rulemaking Documents	[23]	4943	U.S. Rulemaking Documents	[23]	2%	TSL 4
2	Central Air Conditioners (inc. HP)	PHP	kWh/yr	USA	2016	5335	U.S. Rulemaking Documents	[23]	5199	U.S. Rulemaking Documents	[23]	3%	TSL 4
2	Lighting	Incandescent Lamps	kWy/yr	USA	2014	46		[74]	46	U.S. Rulemaking Documents		*	67 W 1.9 hours per day
1	Lighting	Incandescent Lamps	kWh/yr	EU	2012	22	Ecodesign Documents	[55]	22	Ecodesign Documents	[55]	*	
2	Lighting	Fluorescent Lamp Ballasts	kWy/yr	USA	2014	31	U.S. Rulemaking Documents	[34]	31	U.S. Rulemaking Documents		3%	
2	Washing Machines		kWh/yr	MEX	2014	75	CONUEE	[58]	60	CONUEE	[58]	20%	
1	Washing Machines		kWh/yr	EU	2012	233	Ecodesign Documents	[25]	221	Ecodesign Documents	[65]	5%	
1	Washing Machines		kWh/yr	KOR	2011	233		[25]	151			35%	Same as EU
2	Dryers	Electric Dryers	kWh/yr	USA	2015	695	U.S. Rulemaking Documents	[24]	677	U.S. Rulemaking Documents	[24]	3%	0.1 % cost effective efficiency improvement
2	Dryers	Gas Dryers	GJ/yr	USA	2015	3	U.S. Rulemaking Documents	[24]	3	U.S. Rulemaking Documents	[24]	1%	
1	Cooking Products	Electric	kWh/yr	USA	2015	153	U.S. Rulemaking Documents	[49]	152	U.S. Rulemaking Documents	[49]	1%	0.19% cost effective efficiency improvement
1	Cooking Products	Gas	GJ/yr	USA	2012	0.9	U.S. Rulemaking Documents	[49]	1	U.S. Rulemaking Documents	[49]	10%	No Cost Effective Improvement
2	Furnaces	NWGF	GJ/yr	USA	2015	35	U.S. Rulemaking Documents	[23]	32	U.S. Rulemaking Documents	[23]	7%	TSL 4
2	Furnaces	MHF	GJ/yr	USA	2015	43	U.S. Rulemaking Documents	[23]	37	U.S. Rulemaking Documents	[23]	15%	TSL 4
2	Furnaces	OF	GJ/yr	USA	2015	70	U.S. Rulemaking Documents	[23]	70	U.S. Rulemaking Documents	[23]	0%	TSL 4
2	Furnaces	EF	kWh	USA	2015	586	U.S. Rulemaking Documents	[23]	586	U.S. Rulemaking Documents	[23]	0%	TSL 4

Group	End Use	Product Class	Units	ISO	Std. Yr	UEC_{BC}	Reference	Ref ID	UEC_{RA}	Reference	Ref ID	% imp.	Assumptions / Definition
2	Water Heaters	Electric	kWh/yr	USA	2015	2491	U.S. Rulemaking Documents	[48]	2305	U.S. Rulemaking Documents	[48]	7%	TSL 5
2	Water Heaters	Gas Storage	GJ/yr	USA	2015	17	U.S. Rulemaking Documents	[48]	16	U.S. Rulemaking Documents	[48]	3%	TSL 5
2	Water Heaters	Gas Storage	GJ/yr	CAN	2013	17		[48]	15		[48]	12%	Newly announced canadian standards come into effect in 2013
3	Water Heaters	Gas Storage	GJ/yr	AUS	2010	15		[3]	13		[3]	16%	
2	Water Heaters	Gas Instantaneous	GJ/yr	USA	2010	11	U.S. Rulemaking Documents	[48]	11	U.S. Rulemaking Documents	[48]	2%	TSL 5
3	Water Heaters	Gas Instantaneous	GJ/yr	AUS	2010	11		[48]	11	U.S. Rulemaking Documents	[48]	2%	
2	Water Heaters	Gas	GJ/yr	MEX	2014	21	CONUEE	[58]	19	CONUEE	[58]	10%	
3	Water Heaters	Gas	kWh/yr	EU	2013	3136	Ecodesign Documents	[47]	3105	Ecodesign Documents	[47]	1%	Useful Energy from Ecodesign, Efficiency taken as MEPS level in the 2010 US rulemaking
3	Water Heaters	Elec	kWh/yr	EU	2013	2056	Ecodesign Documents	[47]	1799	Ecodesign Documents	[47]	12%	
3	Water Heaters	Oil	kWh/yr	EU	2013	3491	Ecodesign Documents	[47]	3209	Ecodesign Documents	[47]	8%	
3	Boilers	Gas	kWh/yr	EU	2012	14503	Ecodesign Documents	[20]	12459	Ecodesign Documents	[20]	14%	
3	Boilers	Elec	kWh/yr	EU	2012	11602	Ecodesign Documents	[20]	10217	Ecodesign Documents	[20]	12%	
3	Boilers	Oil	kWh/yr	EU	2012	14503	Ecodesign Documents	[20]	12163	Ecodesign Documents	[20]	16%	
2	Boilers		GJ/yr	CAN	2010	81		[10]	79		[10]	2%	
1	Standby Power		kWh/yr	EU	2010	17	Ecodesign Documents	[44]	7	Ecodesign Documents	[44]	59%	
1	Pool Heater		GJ/yr	USA	2013	35	U.S. Rulemaking Documents	[39]	33	U.S. Rulemaking Documents	[39]	4%	TSL 2
1	Direct Heating Equipment		GJ/yr	USA	2013	20	U.S. Rulemaking Documents	[28]	20	U.S. Rulemaking Documents	[28]	3%	TSL 2
1	Freezers	All	kWh/yr	USA	2014	529	U.S. Rulemaking Documents	[36]	347	U.S. Rulemaking Documents	[36]	34%	TSL 2
2	Freezers	Up Right	kWh/yr	USA	2014	671	U.S. Rulemaking Documents	[36]	420	U.S. Rulemaking Documents	[36]	37%	TSL 2
2	Freezers	Chest	kWh/yr	USA	2014	394	U.S. Rulemaking Documents	[36]	278	U.S. Rulemaking Documents	[36]	30%	TSL 2
3	Freezers		kWh/yr	EU	2010	285	Ecodesign	[51]	234	Ecodesign	[53]	18%	

Group	**End Use**	**Product Class**	**Units**	**ISO**	**Std. Yr**	**UEC_{BC}**	**Reference** Documents	**Ref ID**	**UEC_{RA}**	**Reference** Documents	**Ref ID**	**% imp.**	**Assumptions / Definition**
2	Dishwashers		kWh/yr	EU	2012	350	Ecodesign Documents	[25]	304	Ecodesign Documents	[50]	13%	Assumes DW is not part of the special category "10 place settings" AND includes SB
2	Motors	0.75-7.5 kW (1.1 kW)	kWh/yr	EU	2017	1485	Ecodesign Documents	[35]	1461	Ecodesign Documents	[31]	2%	IE3 by 2017
2	Motors	7.5-75 kWH (11 kW)	kWh/yr	EU	2017	19800	Ecodesign Documents	[31]	19479	Ecodesign Documents	[31]	2%	IE3 by 2017
2	Motors	> 75 kW (110 kW)	kWh/yr	EU	2017	396000	Ecodesign Documents	[31]	389571	Ecodesign Documents	[31]	2%	IE3 by 2017
1	Motors	0.75-7.5 kW (1.1 kW)	kWh/yr	USA	2010	1361	Ecodesign Documents	[31]	1339	U.S. Rulemaking Documents	[63]	2%	NEMA Premium by 2010 (EISA)
1	Motors	7.5-75 kWH (11 kW)	kWh/yr	USA	2010	19235	Ecodesign Documents	[31]	18922	U.S. Rulemaking Documents	[63]	2%	NEMA Premium by 2010 (EISA)
1	Motors	> 75 kW (110 kW)	kWh/yr	USA	2010	392550	Ecodesign Documents	[31]	386178	U.S. Rulemaking Documents	[63]	2%	NEMA Premium by 2010 (EISA)
1	Motors	0.75-7.5 kW (1.1 kW)	kWh/yr	CAN	2011	1361	Ecodesign Documents	[31]	1339	U.S. Rulemaking Documents	[63]	2%	Harmonization with US by 2011
1	Motors	7.5-75 kWH (11 kW)	kWh/yr	CAN	2011	19235	Ecodesign Documents	[31]	18922	U.S. Rulemaking Documents	[63]	2%	Harmonization with US by 2011
1	Motors	> 75 kW (110 kW)	kWh/yr	CAN	2011	392550	Ecodesign Documents	[31]	386178	U.S. Rulemaking Documents	[63]	2%	Harmonization with US by 2011
1	Distribution Transformers	All Types	kWh/yr	USA	2010	10794		[29]	5702	U.S. Rulemaking Documents	[29]	47%	
1	Distribution Transformers		kWh/yr	CAN	2010	10794		[29]	5702	U.S. Rulemaking Documents	[29]	47%	Canada announced harmonization with U.S. MEPS effective 2010.
2	Commercial Clothes Washers		kWh/yr	USA	2013	3102		[26]	2582	U.S. Rulemaking Documents	[26]	17%	

Table 8 – References and Definitions of Best Practice Scenario

End Use	Product Class	Units	ISO	Std. Yr	UEC_{BC}	Reference	Ref ID	UEC_{BP}	Reference	Ref ID	% imp.	Assumptions / Definition
Refrigerators		kWh/yr	USA	2014	577.1	DOE Final Rule	[36]	481	DOE Final Rule	[36]	20%	Ratio from 2014 Standard
Refrigerators		kWh/yr	MEX	2015	369.0	IIE 2005	[75]	295.2		[75]	25%	
Refrigerators		kWh/yr	CAN	2015	*577.1*	*assumed equal to US*		*481.2*			20%	
Refrigerators		kWh/yr	EU	2014	279	Ecodesign	[41]	232	A+	[41]	40%	EU A++ Level
Refrigerators		kWh/yr	RUS	2015	597	Same size as Europe, Level C		232			40%	
Refrigerators		kWh/yr	ZAF	2015	597	Same size as Europe, Level C		232			40%	
Refrigerators		kWh/yr	IDN	2015	328	*assumed equal to India*		323	5 Star Phase 1		49%	India 5 Star Phase 2
Refrigerators		kWh/yr	BRA	2015	597	Same size as Europe, Level C		232	A+		40%	EU A++ Level
Refrigerators		kWh/yr	IND	2015	327.7	McNeil & Iyer 2009	[56]	323	5 Star Phase 1		49%	Indian Labeling Program 5 Star Phase 1
Refrigerators		kWh/yr	AUS	2015	412	Australian TSD (3E)	[40]	323	6 Star Ref	[40]	35%	Australian Labeling Program, 10 Star
Refrigerators		kWh/yr	JAP	2015	519.04	Top Runner Target		429.0	Next Top Runner, 21% more efficient (2005-2010 improvement)		21%	Ratio from 2015 Standard
Refrigerators		kWh/yr	KOR	2015	519.04	Top Runner Target		429.0			21%	
RAC		EER	USA	2014	2.87	DOE Final Rule	[43]	3.65	Top Runner		27%	
RAC		EER	CAN	2015	3.18	4E Benchmarking		3.58			13%	
RAC		EER	MEX	2015	2.78	4E Benchmarking		3.42			23%	
RAC		SEER	EU	2012	3.17	Ecodesign, MEPS 2012 Scenario-personal communication	[42]	3.95	Ecodesign, MEPS 2012 Scenario-Personal communication Philippe Riviere		24%	
RAC		SEER	RUS	2015	*3.17*	*assumed equal to EU*		*3.95*			24%	
RAC		EER	IND	2015	2.63	CLASP Impact Study		3.23	Top Runner		23%	
RAC		EER	IDN	2015	*2.53*	*assumed equal to India*		*3.23*			27%	
RAC		EER	AUS	2015	2.90	4E Benchmarking		3.33			15%	
RAC		EER	ZAF	2015	*2.78*	*assumed equal to Mexico*		*3.42*			23%	
RAC		EER	BRA	2015	*2.78*	*assumed equal to Mexico*		*3.42*			23%	
RAC		EER	JAP	2015	*2.88*	*assumed equal to Korea*		*3.23*			12%	
RAC		EER	KOR	2015	2.88	4E Benchmarking		3.2			12%	
LCD		kWh/yr	USA	2012	102.5	LBNL Technical Study	[46]	96.2	Super Efficiency Scenario, Cost Effective Target DBF+Dimming	[46]	5.00%	Standard 5% more efficient than baseline in every year
LCD		kWh/yr	MEX	2012	71.4	LBNL Technical Study	[46]	60.6		[46]	5.00%	
LCD		kWh/yr	CAN	2012	82.0	LBNL Technical Study	[46]	77.0		[46]	5.00%	
LCD		kWh/yr	EU	2012	64.6	LBNL Technical Study	[46]	60.9		[46]	5.00%	
LCD		kWh/yr	RUS	2012	69.1	LBNL Technical Study	[46]	63.2		[46]	5.00%	
LCD		kWh/yr	ZAF	2012	72.0	LBNL Technical Study	[46]	64.8		[46]	5.00%	
LCD		kWh/yr	IDN	2012	*72.0*	LBNL Technical Study	[46]	*64.8*		[46]	5.00%	
LCD		kWh/yr	BRA	2012	70.2	LBNL Technical Study	[46]	67.2		[46]	5.00%	

End Use	Product Class	Units	ISO	Std. Yr	UEC_{BC}	Reference	Ref ID	UEC_{BP}	Reference	Ref ID	% imp.	Assumptions / Definition
LCD		kWh/yr	IND	2012	70.5	LBNL Technical Study	[46]	60.6		[46]	5.00%	
LCD		kWh/yr	AUS	2012	70.5	LBNL Technical Study	[46]	63.6		[46]	5.00%	
LCD		kWh/yr	JAP	2012	70.8	LBNL Technical Study	[46]	67.5		[46]	5.00%	
LCD		kWh/yr	KOR	2012	70.5	LBNL Technical Study	[46]	63.6		[46]	5.00%	
Stand By		kWh/yr	USA	2015	17.2	Ecodesign	[44]	3.6	Ecodesign	[44]	402%	0.1 W standard
Stand By		kWh/yr	MEX	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	CAN	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	EU	2013	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	RUS	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	ZAF	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	IDN	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	BRA	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	IND	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	AUS	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	JAP	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Stand By		kWh/yr	KOR	2015	17.2	Ecodesign	[44]	3.6		[44]	402%	
Water Heater	Electric	kWh/yr	USA	2015	2491	DOE, TSD 2010		2305	DOE, FR 2010		90%	
Water Heater	Electric	kWh/yr	CAN	2015	2491	*assumed equal to US*		*2305*	DOE, FR 2010-assumes same % imp		90%	Heat Pump, DOE FR 2010
Water Heater		kWh/yr	EU	2013	2161	*Useful energy from Ecodesign study, efficiency from USDOE rulemaking*		1799	Efficiency target same as US FR,2010		EER=2.35	Heat Pump, DOE FR 2010
Water Heater	Electric	kWh/yr	AUS	2015	3603	McNeil et. al 2008	[3]	3262	McNeil et. al 2008		10%	Ratio from 2015 Standard
Water Heater	Gas Storage	GJ/yr	USA	2015	16.8	DOE, FR 2010		16.3	DOE, FR 2010		24%	Condensing, DOE FR 2010
Water Heater	Gas Storage	GJ/yr	MEX	2014	20.90	CONUEE		18.81	CONUEE		11%	Ratio from 2015 Standard
Water Heater	Gas Storage	GJ/yr	CAN	2015	16.8	*assumed equal to US*		*16.3*	DOE, FR 2010-assumes same % imp		24%	Condensing, DOE FR 2010
Water Heater	Gas Storage	GJ/yr	AUS	2015	15.37	Global model Baseline+Savings from Syneca report	[66]	13	Syneca Consulting, 5 star std		19%	Ratio from 2015 Standard
Water Heater	Gas Instantaneous	GJ/yr	USA	2015	11.3	DOE, FR 2010		11.1	DOE, FR 2010		16%	Condensing
Water Heater	Gas Instantaneous	GJ/yr	AUS	2015	11.3	US baseline		9.2	Syneca Consulting, 6 star std		22%	Ratio from 2015 Standard
Incandescent Lamps		% IL	USA	3 tier	Phase out by 2020	LBNL Assumption		Phase out by end of 2014	EISA		67%	100Lm/W LEDs (CFLs 60Lm/W)
Incandescent Lamps		% IL	CAN	3 tier	Phase out by 2020	LBNL Assumption		Phase out by end of 2014			67%	

End Use	Product Class	Units	ISO	Std. Yr	UEC$_{BC}$	Reference	Ref ID	UEC$_{BP}$	Reference	Ref ID	% imp.	Assumptions / Definition
Incandescent Lamps		% IL	Others	3 tier	Phase out by 2030	LBNL Assumption		Phase out by end of 2014			67%	
Fluorescent Ballast		%	USA	2015	80%	Harmonization Report		87.80%	Ecodesign Directive	[76]	4%	BAT from Harmonization Report
Fluorescent Ballast		%	CAN	2015	78%	Global Model		87.80%		[76]	4%	
Fluorescent Ballast		%	MEX	2015	*80%*	*assumed equal to US*		87.80%		[76]	4%	
Fluorescent Ballast		%	EU	2017	80%	Harmonization Report	[54]	87.80%		[76]	4%	
Fluorescent Ballast		%	RUS	2015	78%	McNeil et. al 2008	[3]	87.80%		[76]	4%	
Fluorescent Ballast		%	ZAF	2015	78%	McNeil et. al 2008	[3]	87.80%		[76]	4%	
Fluorescent Ballast		%	IDN	2015	70%	McNeil et. al 2008	[3]	87.80%		[76]	4%	
Fluorescent Ballast		%	BRA	2015	78%	McNeil et. al 2008	[3]	87.80%		[76]	4%	
Fluorescent Ballast		%	IND	2015	70%	McNeil et. al 2008	[3]	87.80%		[76]	4%	
Fluorescent Ballast		%	AUS	2015	80%	*assumed equal to EU*		87.80%		[76]	4%	
Furnace		GJ/yr	USA	2015	34.7	Final Rule 2011	[40]	32.3	Final Rule 2011	[40]	28.5	Condensing
Furnace		GJ/yr	CAN	2015	79	Energy Use Datahandbook 2008	[10]	73	*assumed equal to US, scaled*		8%	Ratio from 2015 Standard
Furnace Fan		kWh/yr	USA	2015	285.32	Final Rule 2011	[40]	265.3	Scales with Fuel Consumption of NWGF		8%	
Furnace Fan		kWh/yr	CAN	2015	*643*	*assumed equal to US, scaled*		598	*assumed equal to US, scaled*		8%	
Central AC		kWh/yr	USA	2016	3234.8	Final Rule 2011	[40]	2915	Final Rule 2011	[40]	11%	
Central AC		kWh/yr	CAN	2015	1,698	Energy Use Datahandbook 2008	[10]	1630	Same % Improvement as US		4%	
Central AC		kWh/yr	AUS	2015	432	Energy Use in Australia in the residential sector 1986-2020	[22]	414			4%	
Freezer		kWh/yr	USA	2014	529.3	Final Rule 2011	[77]	347	Final Rule 2011	[77]	52%	
Freezer		kWh/yr	EU	2014	233.4	Ecodesign	[41]	223	Ecodesign Directive	[41]	5%	

6. Discussion of Uncertainty

A well-established methodology exists for establishing the uncertainties in a mathematical model, given reliable estimates of uncertainties in the inputs. Unfortunately, errors are generally not well-defined for most model inputs in BUENAS. Therefore, a robust quantification of uncertainties is not possible. Instead, this discussion presents the general level of uncertainty of key variables and their impact on the final results. There are two general categories of uncertainties associated with BUENAS inputs:

- Errors in determination of “data-driven” parameters
- Uncertainties forecast parameters due to difficulty in predicting the future

In principle, the first of these could be reduced or eliminated with sufficient data, while the second are “irreducible” to the extent that the future is difficult to predict. Parameters that are “data-driven” include energy efficiency and product class market shares, usage patterns, lifetimes and sales. Critical forecast variables include sales growth rates, population and household size, economic growth and evolution of baseline efficiency. Finally, a third category of parameters includes efficiency targets chosen in each policy case. These “scenario” variables are essentially the choice of the modeler, and do not imply an uncertainty *per se*.

The following sections describe the general level of uncertainty in the most important input variables and assess their effect on energy and savings calculations. We characterize levels of uncertainty as “low” (0-5%), “moderate” (5%-15%) or “significant” (>15%). Even these categories, however, are just estimates. Although we have attributed a quantitative description, the actual levels of uncertainty for each variable may be different depending on the country, specific product, and even the year in question. They should be viewed as indicative levels of uncertainty

6.1. Data-Driven Variables

Historical Sales – In many cases, the sales forecast is driven off of current or historical sales using a growth rate, calibrated to long-term diffusion rates. In this case, future sales scale directly with historical sales. When these data are available, the uncertainty on them is generally **low**, but the impact on the final results is **moderate**.

Lifetime – The equipment lifetime impacts sales through replacement rates when sales are forecasted using saturation modeling. Impacts sales only indirectly when sales are forecasted using historical growth rates or are taken from secondary sources, which generally have access to high-quality data. Therefore, while the uncertainty on lifetime is **significant**, the overall impact of lifetime on the sales forecast is **moderate**.

Base Year Efficiency Distribution– In countries and appliance groups with existing standards or labeling programs, the uncertainty on this parameter is **low** because the distribution is close to the minimum, and/or the market shares are known. Where no standards or labels exist, the uncertainty on base year efficiency distribution is **moderate**. Because efficiency directly impacts UEC, the resulting uncertainty in these two cases is **low** or **moderate**, respectively.

Usage – The dependence of UEC on usage varies greatly among end uses. End uses that are highly dependent on usage include lighting, air conditioning, water heating and space heating. For these equipment types, the uncertainty and impact on UEC is **significant**.

6.2. Forecast Parameters

Shipments Growth Rates – In cases where historical sales are trended forward, the assumed growth rate has a direct effect on stock and turnover. The uncertainty and impact of this variable is **significant**.

Population and Household Size – Demographic parameters have a direct effect on sales when a diffusion model is used. These trends are modeled carefully and probably have only **moderate** uncertainty over the forecast period. The overall affect on uncertainty of results is **low**.

GDP Growth Rate – The GDP forecast affects the projection of commercial floor space, appliance diffusion and industrial motor energy. GDP growth rates are assumptions and are associated with a **significant** level uncertainty. The impact of GDP growth on energy forecast is **moderate** to **significant**, depending on the country and appliance group.

Urbanization and Electrification – Like population and economic growth, these parameters affect sales when a diffusion model is used. These trends are modeled carefully and probably have only **moderate** uncertainty over the forecast period. The overall effect on uncertainty of results is **low**.

Efficiency and Product Class Trends – Appliance markets are constantly evolving, with changes in product classes and technology types driven by consumer preferences and technological innovations. In the case of major white goods, these changes can be gradual and incremental, whereas in electronics, for example, changes can be extremely rapid, making anticipation of trends difficult even a few years in the future. The uncertainty of these parameters is therefore **moderate** to **significant**. Obviously, the impact of these changes can be wide ranging and can dramatically impact energy consumption. The overall effect on the results is therefore also **moderate** to **significant**.

Electricity Carbon Factor – Electricity carbon dioxide emissions are calculated as the product of electricity demand and an *electricity carbon factor* taken from IEA base year data forecasted according to trends in the *World Energy Outlook* [71]. The projection of electricity carbon factors is based on expectations of the carbon intensity of new generation capacity. The uncertainty of this projection can be characterized as **moderate**. Since emissions are directly proportional, they can also be characterized as **moderate**.

Field Consumption Variability- Efficiency for many equipment types modeled in BUENAS is estimated according to ratings determined according to standardized test procedures. Differences between rated and actual installed (field) consumption due to variable ambient conditions and use pattern s have long been known to exist and have been recently studied (see for example [78]). The uncertainty from this variability is **moderate**, and has a **moderate** impact on estimates of energy demand and savings.

Rebound Effects – ‘Rebound effects’ refers to the increase in usage of energy that is a direct impact of increased efficiency. *Macroeconomic* rebound effects refer to the general increase in economic activity due to reductions in consumer energy expenditures. *Direct* rebound effects refer to increases in appliance usage due to a perceived or actual reduction in expenditures as a result of efficiency. Neither effect is included in BUENAS, although there are plans to include them in future versions. Estimates of rebound effects are variable and often controversial, but we characterize them as **moderate**, with a **moderate** impact on savings results.

Table 9 – Summary of Level of Uncertainty and Impact of Results by Variable

Variable	**Level of Uncertainty**	**Impact on Results**
Data-Driven Variables		
Historical Sales	**low**	**moderate**
Lifetime	**significant**	**moderate**
Base Year Efficiency Distribution	**low** to **moderate**	**low** to **moderate**
Usage	**significant** for some equipment types	**significant** for some equipment types
Field Consumption Variability	**moderate**	**moderate**
Rebound Effects	**moderate**	**moderate**
Forecast Parameters		
Shipments Growth Rates	**significant**	**significant**
Population and Household Size	**moderate**	**low**
GDP Growth Rate	**significant**	**moderate** to **significant**
Urbanization and Electrification	**moderate**	**low**
Efficiency and Product Class Trends	**moderate** to **significant**	**moderate** to **significant**
Electricity Carbon Factor	**moderate**	**moderate**

In conclusion, there are significant areas where the accuracy of results produced by BUENAS could be improved through various means, primarily through better data. On the other hand, there will always be uncertainties in forecasting and these are likely to be significant. In fact, overall, the forecast parameters identified in **Table 9** more often have a “significant” effect on the results. This aspect of the modeling should be taken into account when considering opportunities for increasing model precision.