LBNL-5722E

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Bottom-Up Energy Analysis System – Methodology and Results

Michael A. McNeil, Virginie E. Letschert, Stephane de la Rue du Can and Jing Ke

Environmental Energy Technologies Division

June 2012

This work was supported by the Climate Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Acknowledgements

Development of the BUENAS model has taken place over several years, and has benefitted from a great number of colleagues, including those at LBNL, in the international energy policy community, and among our sponsors. From LBNL the authors would like to acknowledge Nicholas Bojda and Puneeth Kalavase, who contributed to recent updates and quality assurance. For their contributions to and review of the analysis we thank Gregory Rosenquist, Won Young Park, Nakul Sathaye, Nihar Shah, Amol Phadke, Jayant Sathaye and James McMahon from LBNL. In addition we received invaluable insight from international colleagues, including Tanmay Tathagat, Jun Young Choi, Lloyd Harrington, Itha Sánchez, Margarito Sánchez, Anibal de Almeida and Philippe Rivière. Special thanks go to Kevin Lane and Louis-Benoit Desroches for their careful review. We also acknowledge our sponsors and project managers for their support, enthusiasm and flexibility. They include Christine Egan, Yamina Saheb, Frank Klinckenberg and Allison Fan of CLASP and John Mollet of International Copper Association. Finally, we are particularly indebted to Stephen Wiel for planting the seed that grew into BUENAS.

Table of Contents

Part I – Model Overview and Results

1. Introduction

A central component of strategies to combat climate change focuses on energy use, which is the primary generator of greenhouse gas emissions. In the minds of policy makers on local, national and international stages, therefore, two important questions result from this consensus: "*what kinds of policies encourage the appropriate market transformation to energy efficiency?*"; and "*how much impact can these policies have?*". LBNL's Bottom Up Energy Analysis System (BUENAS) contributes to the answering of these questions by considering the likely impacts of a specific subset of possible efficiency policies on a global scale.

BUENAS is an end use energy demand projection model developed by Lawrence Berkeley National Laboratory (LBNL) in the United States of America with support from the Collaborative Labeling and Appliance Standards Program (CLASP), the International Copper Association (ICA) and the United States Department of Energy (USDOE). As the name suggests, BUENAS is a tool to model energy demand by various types of energy consuming equipment and aggregate the results to the end use, sector or national level. BUENAS is designed as a policy analysis tool which creates scenarios differentiated by the level of actions taken – generally toward higher energy efficiency. Impacts of policy actions towards market transformation are calculated by comparing energy demand in the "business as usual" case to a specific policy case. BUENAS shares elements with a variety of models[1], including models of energy savings supporting the USDOE's appliance standards program. The characteristics that distinguish BUENAS are that it covers multiple countries, models energy demand at the technology level and projects efficiency improvement based on specific targets known to be achievable.

The main objective of the development of BUENAS is to provide a global model with sufficient detail and accuracy for technical assessment of policy measures such as energy efficiency standards and labeling (EES&L) programs. In most countries where energy efficiency policies exist, the initial emphasis is on household appliances and lighting. Often, equipment used in commercial buildings, particularly heating, air conditioning and ventilation (HVAC) is also covered by EES&L programs. In the industrial sector, standards and labeling generally covers electric motors and distribution transformers, although a few more types of industrial equipment are covered by some programs, and there is a trend toward including more of them. In order to make a comprehensive estimate of the total potential impacts, development of the model prioritized coverage of as many

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[1] See 1. Mundaca, L., et al., *Evaluating Energy Efficiency Policies with Energy-Economy Models.* Annual Review of Environment and Resources, 2010. **35**: p. 305-44. for a survey of energy-economy models used to evaluate efficiency policy

end uses commonly targeted by EES&L programs as possible, for as many countries as possible. The model generally did *not* cover:

- Industrial processes
- 'Miscellaneous' end uses, or end uses not typically included in EES&L programs.

As mentioned above, BUENAS projects energy demand in order to calculate impacts of current, proposed or possible policies. National energy demand of each end use is constructed according to the following modification of the Kaya identity[2].

$$Energy = \frac{Activity \times Intensity}{Efficiency}$$

In this equation, *Activity* refers to the size of the stock, e.g., number of refrigerators or the air conditioned area of commercial buildings. *Intensity* is driven by the usage and capacity of each unit, such as the size of a water heater or the hours of use of a room air conditioner. Finally, *Efficiency* is the technological performance of the equipment, which can be affected by government policies.

BUENAS is implemented using the Long-Range Energy Alternatives Planning system (LEAP), developed by the Stockholm Environment Institute. LEAP is a general-purpose energy accounting model in which the model developer inputs all data and assumptions in a format that is then transparent to other users.

BUENAS projects energy consumption by end use from 2005 (base year) to 2030. The strategy of the model is to first project end use activity, which is driven by increased ownership of household appliances, and economic growth in the commercial and industrial sectors. The total stock of appliances can be modeled either according to an econometric diffusion model or according to unit sales projections, if forecasts are available. Electricity consumption or intensity of the appliance stock is then calculated according to estimates of the baseline intensity of the prevailing technology in the local market. Finally, the total final energy consumption of the stock is calculated by modeling the flow of products into the stock and the marginal intensity of purchased units, either as additions or as replacements of old units according to equipment retirement rates. The high efficiency or "policy" scenario is created by the assumption of increased unit efficiency relative to the baseline starting in a certain year. For example, if the average baseline unit energy consumption (UEC) of new refrigerators is 450 kWh/year, but a MEPS taking effect in 2012 require a maximum UEC of 350 kWh/year, the stock energy in the policy scenario will gradually become lower than that of the base case scenario due to increasing penetration of high-efficiency units under the standard. By 2030, the entire stock will generally be impacted by the standard.

The remainder of Part I of this document is devoted to providing an overview of the scope, applications, scenario definitions and results of the model (Sections 2-5). Part II provides the details of the methodology used to construct national level energy demand scenarios. In order to increase the usability of the document, not every modeling detail is included in the documentation. In some cases, we refer to previous documents to avoid redundancy. Foremost among these are [3] which describes the first construction and application of the model and [4], a journal publication that details the ownership model of residential appliances. In addition, this document can be considered a companion to the *BUENAS Inputs Spreadsheet*, an Excel spreadsheet developed as a container and documentation tool for important data streams and assumptions in BUENAS. The *BUENAS Inputs Spreadsheet* has been designed with documentation in mind. The goal of its construction and format are to allow advanced reviewers of the model and other members of the international energy analysis community to "drill down" to specific assumptions and data sources. In some cases, summaries of the data contained in the spreadsheet are provided in the document, with particular attention to assumptions and citations.

2. Scope of BUENAS

The first version of the model, completed in 2008, covered the entire world, broken into 10 regions, and relied heavily on extrapolation of 'marker country' data to represent an entire region. The current version of BUENAS diverges from global coverage and regional breakdowns. Similarly, the first version of the model made rough estimates of some end uses where equipment data were not available, in order to cover the great majority of energy demand in buildings. The current version places a higher value on detail and accuracy at the expense of some comprehensiveness. For example, the first version of the model included space heating and cooling in buildings for all countries and four other major end uses in the commercial sector, even though the details of equipment used for these end uses are not well known for many countries. In the current version, by contrast, many of these end uses were omitted for some countries due to the uncertainty of the data.

2.1. Country Coverage

BUENAS covers 12 countries individually, with the 27 Member States of the European Union modeled as a single 'country'. Countries currently included in BUENAS are: Australia, Brazil, Canada, European Union, India, Indonesia, Japan, Republic of Korea, Mexico, Russia, South Africa and the United States. Chinese appliance energy demand and efficiency potential has also been modeled in detail by LBNL[5]. LBNL's China appliance model is a component of the China 2050 Energy Model, which includes all energy demand sectors. The LBNL China appliance model (including industrial motors and distribution transformers) is currently being adapted to BUENAS and will be an integrated part of the model in the next version.

Since the model covers most of the world's large economies, the fraction of global energy consumption represented by modeled countries is large. According to IEA data on total energy demand in 2005[6], the countries covered account for 62% of global final; energy demand if China is not included. Once China is incorporated into the model, country energy coverage will total 77% of global demand. The breakdown of energy demand percentage by countries included in BUENAS is shown in Table 1 **[6]**.

Table 1 – Energy Consumption Percentage by Countries Included in BUENAS

Region	**% Energy**	**Country**	**% Energy**
Pacific OECD	8%	Australia	1.1%
		Japan	4.6%
		Korea	1.9%
North America	23%	United States	20.5%
		Canada	2.4%
Western + Eastern Europe	17%	European Union	15.6%
Former Soviet Union	9%	Russia	5.7%
Latin America	6%	Mexico	1.5%
		Brazil	1.8%
Sub-Saharan Africa	3%	South Africa	1.1%
Middle East + No. Africa	5%	-	-
Centrally-Planned Asia	16%	China	15.0%
South Asia - Other Pacific Asia	9%	India	4.7%
		Indonesia	1.6%
Total	**96%**	**Total without China**	**62%**
		Total including China	**77%**

Source [6]. 2005 data.

2.2. End Use Coverage

BUENAS covers a wide range of energy-consuming products, including most end uses generally covered by Energy Efficiency Standards and Labeling (EES&L) programs around the world. End uses currently covered are:

- Residential Sector: Air Conditioning, Cooking + Dishwashing, Fans, Lighting, Refrigeration, Space Heating, Standby, Televisions, Water Heating and Laundry
- Commercial Building Sector: Air Conditioning, Lighting, Refrigeration, Space Heating and Laundry
- Industrial Sector: Electric Motors and Distribution Transformers

In order to cover as many end uses as possible, the model as originally created sacrificed some detail and products were grouped into categories rather than being modeled as individual technologies (e.g. refrigerators and freezers are grouped into a single "refrigeration" category). Since only major end uses were covered, total energy consumption modeled does not equal total sector consumption. However, the end uses covered are estimated to include over 80% of the residential and commercial building sectors. In the industrial sector, only electric motors over 750 kW are covered. This type of motor typically accounts for over half of industrial electricity consumption.

In the original "regional" version of BUENAS, an attempt was made to make an estimate for every end use for every region, even in the absence of data. This required the use of proxy data; that is, the assumption that data for one country applies to the entire region, and in some cases to multiple regions. In addition, useful energy consumption[2] for heating and cooling was modeled by heating and cooling degree days (see [3]). In the current version of the model, the strategy prioritizes accuracy over comprehensiveness and therefore minimizes the use of proxy data with the consequence that significant gaps remain in the coverage. In fact, some of the end uses listed above are modeled for only one or two countries. A continuing effort will be made going forward to address these gaps as reliable country-specific data are made available. Table 2 summarizes the end use coverage in the current version of the model by country/economy.

Table 2 – BUENAS End-use / Country Coverage

Sector	End Use Category	Appliance	AUS	BRA	CAN	EU	IDN	IND	JPN	KOR	MEX	RUS	USA	ZAF
⊟ Residential	⊟ Air Conditioning	Air Conditioner	■		■	■	■	■	■	■	■	■	■	■
		Central AC	■		■						■		■	
	⊟ Cooking + Dishw ashing	Cooking Products				■							■	
	⊟ Fans	Fan	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Lighting	Lighting	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Freezers	Freezers				■							■	
		Refrigerator	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Space Heating	Boiler			■	■								
		Furnace			■								■	
		Electric Space Heating							■				■	
	⊟ Standby	Standby	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Television	Television	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Water Heating	Water Heater	■		■	■			■		■		■	
	⊟ Laundry	Clothes Dryers											■	
		Washing Machine				■				■	■		■	
⊟ Commercial	⊟ Air Conditioning	Space Cooling	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Lighting	Lighting	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Refrigeration	Refrigeration	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Space Heating	Electric Space Heating											■	
	⊟ Laundry	Commercial Clothes Washers											■	
⊟ Industry	⊟ Motors	Motor	■	■	■	■	■	■	■	■	■	■	■	■
	⊟ Distribution Transformers	Distribution Transformers	■		■			■	■	■	■	■	■	

By summing up the energy demand estimates modeled by equipment included in Table 2, it is possible to evaluate the energy demand by BUENAS as a fraction of sector within each economy. These estimates are shown in Table 3.

Differences between the sum of energy demand in BUENAS and top-down estimates from national statistics arise primarily from end uses that are not included in the model. However, differences may also indicate over- or underestimates in the BUENAS. These two effects are difficult to identify in bottom up modeling. Finally, the top-down estimates are also subject to uncertainty, as evidenced by significant differences between sources. For these reasons, the table should be understood as a rough guide of the level of coverage of the model instead of an exact measure. In some cases, top-down data were not available at a level of detail necessary to make a meaningful comparison.

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[2] "Useful" energy refers to only energy needed to provide comfort, and does not include losses from inefficiency, which were subsequently added.

Table 3 – Percentage of Final Energy in BUENAS by Country, Sector and Fuel in 2005[3]

Sector	Fuel	AUS	BRA	CAN	EU	IND	IDN	JAP	KOR	MEX	RUS	ZAF	USA	Total
Residential	Electricity	56%	105%	27%	N/A	100%	N/A	53%	69%	69%	36%	N/A	59%	**60%**
	Gas	32%	0%	92%	N/A	N/A	N/A	72%	0%	N/A	0%	N/A	65%	**44%**
	Total	46%	58%	62%	57%	N/A	7%	61%	23%	N/A	4%	N/A	62%	**50%**
Commercial	Electricity	36%	50%	27%	N/A	56%	N/A	38%	22%	72%	22%	N/A	64%	**52%**
	Gas	0%	0%	0%	N/A	N/A	N/A	0%	0%	N/A	0%	N/A	54%	**36%**
	Total	29%	44%	13%	21%	N/A	33%	27%	18%	N/A	9%	N/A	60%	**37%**
Industrial	Electricity	N/A	58%	37%	N/A	54%	N/A	102%	59%	44%	40%	N/A	79%	**64%**
	Gas	N/A	0%	0%	N/A	N/A	N/A	0%	0%	0%	0%	N/A	0%	**0%**
	Total	N/A	38%	17%	18%	N/A	18%	73%	45%	15%	9%	N/A	22%	**21%**

Sources: [7],[8],[9],[10],[11],[12-14],[15], [16],[17]

Table 3 shows that BUENAS coverage in residential electricity is the highest of the three sectors, with BUENAS demand accounting for at least half of the sector demand, where data are available. Sector totals are weighted by sector energy for each fuel where these data are available. Residential gas coverage is significant only for Australia, Canada, Japan and the U.S., where sufficient data were available to model space heating and/or water heating. Commercial sector electricity coverage is lower than residential sector electricity coverage, but high for some countries where space cooling is important, because BUENAS includes this end use (in addition to lighting, which is usually the main commercial building end use). Commercial building gas coverage is zero for all countries except for the United States due to lack of available data for commercial space heating and water heating. Finally, in the industrial sector electricity coverage is moderate while gas is not covered in BUENAS. This is to be expected since motors, which are covered, generally account for a significant portion of industrial electricity. A significant amount of electrical energy in industry comes from heavy industry processes such as electric arc furnaces in the steel sector. These types of industrial processes are not covered in BUENAS. Likewise, most of the non-electric fuel use in industry comes from heavy industrial heating processes, which are out of the scope of BUENAS.

In some instances, the comparison of BUENAS to top-down estimates exposes some apparent overestimations in the model. Examples of these are residential electricity in India and Brazil and industrial electricity in Japan. While much of residential electricity in Brazil and India is concentrated in end uses covered by BUENAS (lighting, refrigeration and air conditioning), the total should of course not exceed 100% of the actual reported consumption. This is likely due to an overestimate of energy demand in one or more of the end uses. It should be pointed out, however, that there is significant variation in reported electricity consumption in India, due to significant "non-technical losses" (electricity theft) in the residential sector in India. In addition, BUENAS models demand, not consumption. These two approaches differ by up to 20% in India due to chronic shortages. These two effects may also explain the apparent overestimate by BUENAS. The overestimate of industrial electricity in Japan is likely due to overestimation of energy consumption of motors in that country. This difference may be the subject of a calibration in subsequent

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[3] Final, or 'delivered' energy does not include electricity input energy or losses in transmission or distribution. Percentages of 'primary' energy inputs would therefore be significantly different.

versions of the model.

3. Applications of BUENAS to Date

The original objective in the construction of a global model was to provide the best assessment to date of the potential for energy savings and greenhouse gas emissions reductions from energy efficiency standards and labeling (EES&L) programs. Since that time, the model has been applied to more specific policy scenarios and has provided insight specific to particular regions.

3.1. Potential Studies

The original development of BUENAS commissioned by the Collaborative Labeling and Appliance Standards Program (CLASP), was intended to provide a more precise estimate of the potential impacts of EES&L programs worldwide. Until the development of BUENAS, rough estimates of the global potential of EES&L programs were based on a percentage savings of residential and commercial energy use by region (10-15% of residential + commercial energy in emerging economies is one commonly used estimate). This first project using BUENAS completed in 2008 produced a much more detailed (and therefore more accurate and defendable) global estimate[18]. The primary (but not exclusive) motivation of that project was to bring attention on the global stage of the value of EES&L policies. A secondary accomplishment of this project was to rank the potential impacts from EES&L policies among various countries or regions and among various energy-consuming products. The details of this project, including the details of the original model methodology are provided in [3]. Beginning in 2010, BUENAS has been used to support the activities of the Super-Efficient Appliance Deployment initiative (SEAD), an activity within the Clean Energy Ministerial process. A main use of BUENAS within SEAD is to provide analysis of the remaining potential impacts of appliance efficiency programs specifically for SEAD member countries, in addition to reporting impacts from ongoing progress of efficiency programs.

3.2. Planning and Prioritization

Subsequent to the initial development of the model, much of the model development focused on those regions that are high-priority targets of ClimateWorks Foundation, a major funder of CLASP. During 2008-2009, the model was used primarily as a planning tool for CLASP, in order to refine potential estimates for only the highest priority end uses, which may be the subject of CLASP's short and medium-term activities in its role as a ClimateWorks Best Practice Network (BPN).

In addition to this multi-country planning role, BUENAS has also been used as a tool to look closely at the potential for efficiency improvement in individual countries. For example, the International Copper Association supported the use of BUENAS as a tool to evaluate the cost-effective efficiency potential for the United States [19]. This effort will be followed by studies for other countries. In addition, BUENAS has been used as a tool in collaboration with CLASP to support the development of MEPS in developing countries, particularly Mexico, Chile and member states of the Association of South East Asian Nations (ASEAN). In this manner, BUENAS is used as a prioritization tool, highlighting end uses with most significant improvement potential.

4. Energy Demand Scenario Definitions

In constructing a model of energy demand, every attempt is made at accuracy. This includes collecting the best data on market trends, technologies, use patterns and regulations. The accuracy of these parameters is subject to an objective definition of correctness. The definition of scenarios used to evaluate potential policy impacts, on the other hand is a choice made by the analyst. There is undoubtedly some level of subjectivity in this definition. It is critical, however, that scenarios be clearly described, and used uniformly/consistently in order to allow correct interpretation of results.

4.1. Business As Usual Scenario

Any evaluation of the impacts of a policy, either prospective or retrospective, must define a baseline for comparison. In order to do this, BUENAS creates a Business as Usual (BAU) case that projects energy demand by end use through the year 2030. Much of the modeling content of BUENAS is contained in the construction of the BAU case, and the other scenarios are modifications of it. Most important in the construction of the BAU scenario is the projection of growth in energy demand, which is driven by growth in both activity and intensity. One notable feature of the BUENAS scenarios is that activity and intensity projections are assumed equal for all scenarios. This assumption implies that scenarios differ *only* by the efficiency of products – changes in stock of equipment and usage patterns are not included as effects of policy.

In addition to growth in activity and intensity, the BAU case also includes a specific assumption of efficiency. By default the BUENAS BAU case assumes “frozen efficiency” from 2010 on, that is, while usage may evolve over time, the efficiency of new products remains constant. Exceptions to this arise when projections are available that include ‘market-driven’ efficiency improvements[4], which are then included in BUENAS. The assumption of frozen efficiency is a consequence of the absence of systematic estimates of market-driven improvement, which are likely end-use specific. A current research project will attempt to develop end-use specific estimates of market-based efficiency improvement for implementation in subsequent versions of BUENAS[5].

4.2. Recent Achievements Scenario

BUENAS provides estimates of the impacts of minimum efficiency performance standards (MEPS) programs in countries participating in SEAD in order to demonstrate the effectiveness of these programs and the potential results of augmenting and accelerating them through international cooperation, including the SEAD program. One category of impacts to be presented is those from existing regulations. The following regulations have so far been modeled, according to the schedule of announcement and implementation:

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[4] Examples are forecasts made by national governments for the purpose of setting regulations.

[5] Market-driven efficiency improvement is also omitted by default in high-efficiency scenarios, creating a somewhat compensating effect to its omission in the BAU scenario.

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

The current version of BUENAS includes only MEPS. Subsequent versions of the model are expected to include the impact of labeling programs.

4.3. Best Practice Scenario

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 because it includes efficiency improvements judged to be ambitious but achievable for all countries. There are many possible ways of defining global potential, including cost-effectiveness, removal of a certain fraction of low-efficiency models from the market, or adoption of best available technology. Due to data limitations, the most practical approach 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. This scenario either assumes that the same level of improvement made in 2015 is repeatable in 2020 or assumes that a specific target, such as current 'best available technology' is reached by 2020.

5. Results

The main outputs of the BUENAS model are impacts of appliance efficiency policies, either achieved, planned, or potential. Table 4 shows savings in 2030 for the *Recent Achievements Scenario*. As defined in the previous section, the achievement of these savings depends on a wide variety of factors with various levels of certainty. The savings shown correspond to MEPS implemented since 2010 or in development for a subset of countries modeled by BUENAS. Savings from Category 1 and 2 MEPS are relatively certain, since these regulations are already defined and have a definite implementation date. Savings from Category 3 are more speculative, since the parameters of these regulations have not been finalized. Assumptions for these MEPS are taken from preparatory studies when available; otherwise, assumptions are made based on international benchmarks. Details of the construction of this scenario are given in Part II of this document.

Table 4 – Energy and Emissions Savings in 2030 for MEPS since January 2010 – Recent Achievements Scenario

Category	Quantity	Unit	Australia	Canada	EU	Korea	Mexico	US	Total
1.Implemented	Electricity	TWh	1.9	1.9	56.0	1.7		197.1	**259**
	Gas	PJ						6.3	**6**
	CO_2	mt	1.4	0.4	18.8	0.7		112.7	**134**
2.Announced	Electricity	TWh		7.5	21.8		0.4	0.8	**30**
	Gas	PJ		20.3			67.4	44.2	**132**
	CO_2	mt		1.6	7.3		4.0	8.0	**21**
3.In Progress	Electricity	TWh			74.3		3.2	22.9	**100**
	Gas	PJ	6.4		204.0			1.1	**211**
	CO_2	mt	0.4		40.0		2.1	21.2	**64**
Total	Electricity	TWh	1.9	9.3	152.1	1.7	3.6	220.7	**389**
	Gas	PJ	6.4	20.3	204.0		67.4	51.6	**350**
	CO_2	mt	1.8	1.9	66.2	0.7	6.1	141.9	**219**

It should be noted that omission of a country in Table 4 does not imply a low level of MEPS activity in the country. For example, Japan has one of the most aggressive and expansive efficiency standards program in the world (the Top Runner program). These results were not included because of a lack of data in the current version of the model. The scope of this analysis will be widened in future versions of the model. For the same reason, not all MEPS could be included for the countries that were covered. For example, while Korea implemented several MEPS in the period considered, only those that were easily modeled could be included. The remainder will require additional research to evaluate energy consumption and baseline efficiency levels.

Of the countries studied, the United States and Europe show by far the highest expected achievements in terms of projected energy savings. This is due to both the size of these two large economies, the high level of efficiency activities, and the wider availability of data.

Table 5 shows savings in 2030 for the *Best Practice Scenario* for countries included in Table 2. The best practice scenario is the best estimate for what is feasibly achievable from appliance efficiency policies. There is necessarily some subjectivity and incompleteness in these results, but they are meant to be indicative of the scale of the potential and the breakdown by end use. Details of the construction of this scenario are given in Part II of this document.

Table 5 – Energy and Emissions Demand and Savings Potential in 2030 – Best Practice Scenario

		2030 Demand			2030 Savings			2030 Percent Reduction		
		Elec	Gas	CO_2	Elec	Gas	CO_2	Elec	Gas	CO_2
Sector	**End Use**	TWh	PJ	mt	TWh	PJ	mt	TWh	PJ	mt
Residential	Air Conditioning	576		214	114		52	20%		24%
	Fans	149		100	77		54	52%		53%
	Lighting	379		195	111		55	29%		28%
	Refrigerators & Freezers	479		201	118		56	25%		28%
	Space Heating	129	11236	776	0	482	38	0.2%	4%	5%
	Standby	201		97	135		93	67%		95%
	Television	151		66	13		6	8%		10%
	Laundry	147		76	31		20	21%		26%
	Water Heating	413	3922	322	133	429	98	32%	11%	31%
Sub Total		**2695**	**15158**	**2082**	**731**	**911**	**477**	**27%**	**6%**	**23%**
Commercial	Lighting	1356		611	322		147	24%		24%
	Refrigeration	364		155	90		39	25%		25%
	Space Heating	116		259						
Sub Total		**2739**		**1434**	**610**		**274**	**22%**		**19%**
Industry	Distribution Transformers	612		323	82		141	13%		44%
	Motors	4482		2141	160		97	4%		5%
Sub Total		**5094**		**2465**	**242**		**238**	**5%**		**10%**
Grand Total		**10529**	**15158**	**5981**	**1583**	**911**	**988**	**15%**	**6%**	**17%**

As Table 5 shows, overall potential emissions reductions for the scope of equipment covered is about 988 Mt of CO_2, or about 4.5 times what has been achieved since January 2010. This would imply very significant achievements in the past two years. We note, however, that this calculation is highly dependent on the actual achievements of in-progress standards. Table 5 also shows that a significant percentage of electricity and gas would be saved in the Best Practice scenario. Savings are compared to demand in 2030. Electricity savings is most pronounced in the residential sector, where savings of 27% are projected. Electricity savings are similar, at 22% in the commercial sector. In general, savings are much smaller for fuels. This is because some major space heating and water heating technologies are not yet included in the model, and because space heating in particular is already a relatively high efficiency end use[6]. Similarly, savings from industrial motors are small in percentage terms.

Finally, it is interesting to note that the initial ‘regional’ version of BUENAS showed total emissions savings potential of 1.4 Gt of CO_2 for buildings only. These results are reasonable due to the decreased coverage of end uses and countries in the current version of BUENAS.

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[6] Due to the large footprint of space heating, however, savings in absolute terms from this end use can be very large.

As with all forecasting models, there are significant areas of uncertainty involved in the BUENAS results. While these are somewhat difficult to quantify, a qualitative description of the level of uncertainty of input variables and their subsequent effect on model outputs is possible. This discussion is given in a section below following the description of relevant input variables.

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:

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

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

- E = final energy demand

2.1. Residential Sector Activity Equations

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:

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

- $Stock\ (y)$ = 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:

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

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:

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

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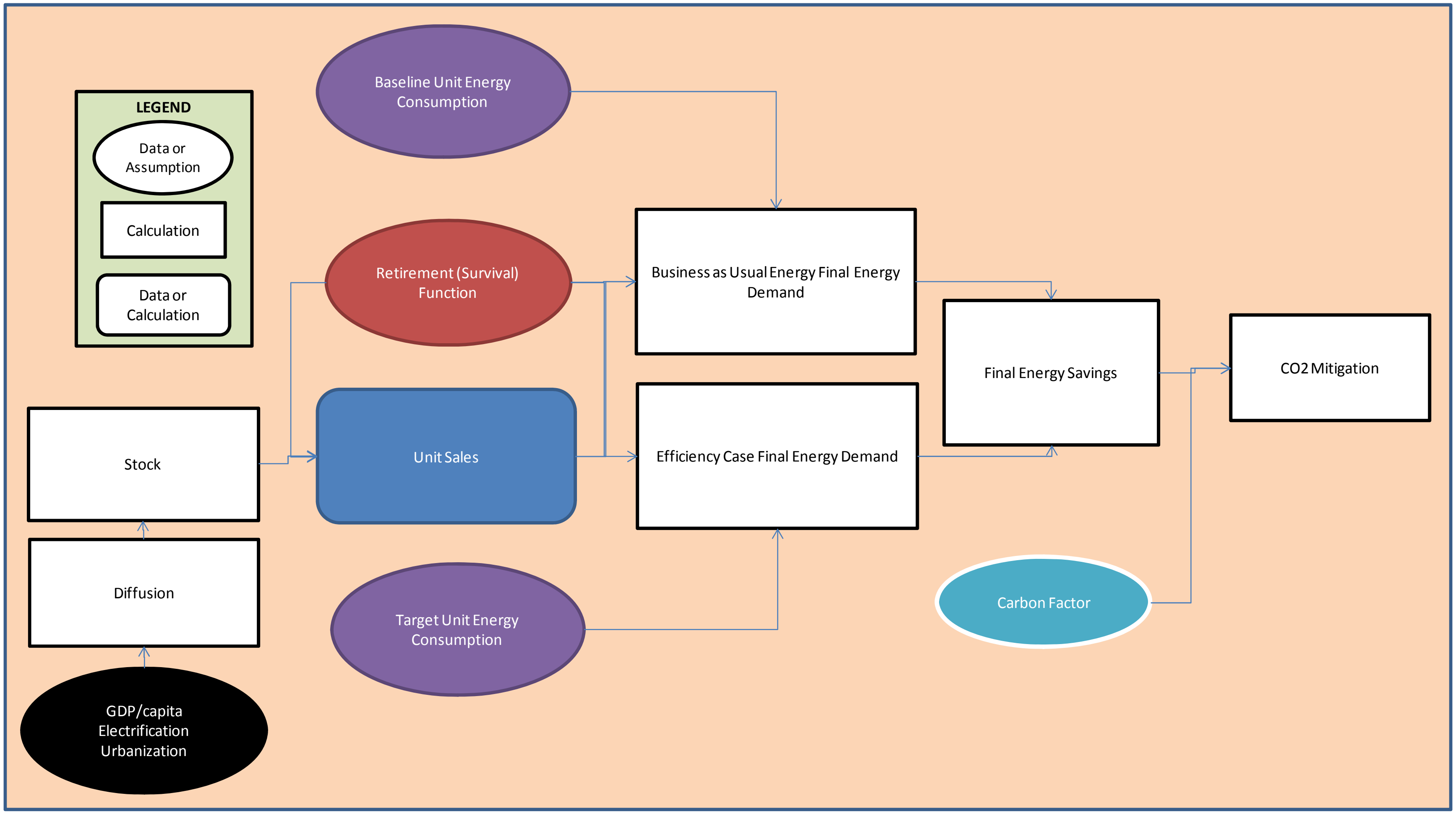
[8] Industrial GDP - PPP Units - Development Data Group, The World Bank. 2007. 2007 World Development Indicators Online. Washington, DC: The World Bank. Available at: http://go.worldbank.org/3JU2HA60D0. Industrial Electricity Consumption from the International Energy Agency.

[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

Product	Country / Economy										
	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			$\ln \gamma$	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			$\ln \gamma$	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			$\ln \gamma$	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			$\ln \gamma$	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			$\ln \gamma$	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			$\ln \gamma$	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:

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

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:

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

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%		[76]	4%	
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%	Ecodesign Directive	[76]	4%	BAT from Harmonization Report
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%	
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			4%	
Central AC		kWh/yr	AUS	2015	432	Energy Use in Australia in the residential sector 1986-2020	[22]	414	Same % Improvement as US		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%	Ratio from 2015 Standard

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.

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.

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APPENDIX – BUENAS Inputs Spreadsheet Contents

Sheet / Area	Description
Macroeconomic Time Series	Variables used in econometric forecasting and stock calculations
Population	National population forecasts
Household Size	Average number of persons per household
Number of Households	Total number of households per country
GDP per capita Growth Rates	Economic growth scenarios by region
GDP per Capita	GDP per capita calculated from GDP and population forecasts
GDP Per Household	Household income from GDP per capita and household size
Electrification	Percentage of households connected to the grid
Urbanization	Forecast of percentage of population in urban areas
Diffusion and Floorspace	Modeling parameters of diffusion and commercial floorspace
Residential Appliance Diffusion	Model parameters of appliance ownership
Service Employment Shares	Percentage of employees in tertiary sector
Floorspace Per Employee	Commercial building area per employee
Cooling Degree Days	Cooling degree days by region
Tertiary Sector	Commercial building sector parameters
Economically Active Population	Total national workforce
Unemployment Rate	Percentage unemployment forecast
Employment	Net employment
Product Sales and Stock	Product market parameters
Unit Sales	Forecast of units sold
Unit Stock	Forecast of units operating in stock
Stock in 1980	Historical base year stock
Commercial End Use Intensity	Energy use per square meter by end use
Unit Energy Consumption - BAU	Annual unit energy consumption in Business As Usual Scenario
Unit Energy Consumption - EFF	Annual unit energy consumption in Achieved Impacts Scenario
Unit Energy Consumption - Best Practice	Annual unit energy consumption in Best Practice Scenario
BP Targets	Best practice efficiency definitions
Market Shares	Product class market shares
Motors Analysis	Industrial electric motors activity parameters
Lifetimes	Equipment lifetime probability distributions
Carbon Factor	Emissions rate per unit electricity delivered
Metadata	Sources and references of modeling parameters