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Potential Impact of Lighting and Appliance Efficiency Standards on Peak Demand: The Case of Indonesia

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Abstract

By now, the value of lighting and appliance energy efficiency standards to reduce power plant fuel inputs, thereby saving money, reducing harmful pollution, mitigating climate change and enhancing energy security is well-known. As important as these benefits may be to developing country governments, even more critical in their view may be the reduction of peak demand, since power shortages (due to insufficient capacity) damage economic productivity and generation capacity increases commit scarce capital to power plant construction that could be used toward other important development goals.

This paper uses LBNL (Lawrence Berkeley National Laboratory)'s BUENAS (Bottom-Up Energy Analysis System) model to forecast demand reductions from energy efficiency in a major developing country – Indonesia. Indonesia was chosen for its tropical climate (making cooling important to peak load) and because its level of development which suggests rapid growth of appliance uptake over the next two decades. The model considers future demand growth for 10 separate residential electrical end uses, three commercial building end uses, and considers industrial electricity in the aggregate. The model then combines the total electricity demand by appliance in each year with end use demand curves for each using data from Indonesia (if possible) and areas of similar climate. The resulting analysis finds that peak load may increase 3 times in Indonesia over the next 20 years in the business-as-usual case, primarily driven by space cooling with an important component from lighting and refrigerators. Applying BUENAS efficiency scenarios of cost-effective potential and best available technology indicates a potential peak load reduction of 13% and 37% in 2030, respectively.

Introduction

By now, the value of lighting and appliance energy efficiency standards to reduce power plant fuel inputs, thereby saving money, reducing harmful pollution, mitigating climate change and enhancing energy security is well-known. As important as these benefits may be to developing country governments, even more critical in their view may be the reduction of peak demand, since power lshortages (due to insufficient capacity) damage economic productivity and generation capacity increases commit scarce capital to power plant construction that could be used toward other important development goals.

Over the past decade, Lawrence Berkeley National Laboratory (LBNL) has developed two main modeling tools to provide ex ante analysis of the impacts of minimum energy performance standards (MEPS) for specific equipment types in specific countries. These are the Policy Analysis Modeling System (PAMS[1]) and the Bottom-Up Energy Analysis System (BUENAS). These models are similar in that they combine assessments of baseline efficiency with regulated efficiency improvements, costs and projections of equipment markets (sales forecasts) in order to yield energy, environmental and financial impacts on an annual basis to a long-term horizon (usually 2030). However, while PAMS is a single-appliance model with an emphasis on cost-effectiveness metrics, BUENAS covers multiple countries and products simultaneously.

Initial development of BUENAS was supported by CLASP. It has since been supported by multiple sponsors and is currently the main modeling platform for the SEAD (Super Efficient Appliance Deployment) initiative. BUENAS quantifies savings for minimum energy performance standards (MEPS) recently passed by the 15 SEAD member economies [1], as well as potential savings under scenarios such as the most stringent cost-effective MEPS, and adoption of best available

[1] More information available at https://ies.lbl.gov/project/policy-analysis-modeling-system

technologies [2]. Until now, BUENAS has measured impacts in terms of total energy saved in TWh or PJ and the related financial impacts and greenhouse gas emissions in MT CO_2.

This paper describes an extension of the BUENAS model to evaluate growth of peak electricity demand and potential reductions from energy efficiency policies. These quantities are most closely related to electricity generation capacity, and therefore the amount of capital investments required by a rapidly developing economy for power plant construction. In order to demonstrate this capability, we model peak load in a major developing country – Indonesia. Indonesia was chosen for its tropical climate (making cooling important to peak load) and because its level of development which suggests rapid growth of appliance uptake over the next two decades. The model considers future demand growth for ten separate residential electrical end uses, three commercial building end uses, and considers industrial electricity in the aggregate.

Under the SEAD initiative, LBNL is collaborating with the Indonesian Ministry of Energy and Mines Resources in order to improve and validate the BUENAS model developed for Indonesia. While the current analysis focuses on Indonesia as a case study for demonstrating peak demand modeling capability, a more accurate forecast of end use demand and energy savings potential will be available as a result of the upcoming collaboration.

Methodology

The extension of the BUENAS energy demand and savings model to produce estimates of peak load requirements and reductions requires combination of average annual energy demand with the hourly load profile of energy use. In order to draw meaningful conclusions, these must be specified for each end use individually, since the time of use, or *load profile* varies significantly between end uses. Furthermore, projections of total future supply requirements necessitate relatively comprehensive coverage across end uses and sectors. Therefore, while the emphasis of the study is on the contribution from residential appliances, all major electricity-consuming sectors are covered.

BUENAS Indonesia Model

The main objective of the BUENAS model is to provide sufficient detail and accuracy for quantitative assessment of policy measures such as appliance 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, distribution transformers and lighting. Recently, though, a few more types of industrial equipment are covered by some programs, and there is a trend toward including more of them.

BUENAS projects energy consumption by end use from a 2010 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, floor space in the commercial sector and economic growth in the industrial sector. For most major appliances, the stock of appliances is projected from unit sales data. In cases where these data are not available, ownership rates can be modeled through econometric diffusion equations developed by the authors [3]. Electricity consumption or intensity of the appliance stock is then calculated according to estimates of the baseline intensity of the prevailing technology. Finally, the total final energy consumption of the stock is calculated by modeling the flow of products into the stock and the efficiency 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 2015 requires 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. More details on the BUENAS methodology are given in [2].

End-use Load Profiles

In this study, the average daily load curve for Indonesia is modeled using appliance and sector specific load profiles. End use load profile data generally originates from time of use surveys or metering and vary by climate, season and customer type. While these data are becoming more common, they are not available for every end use in every country. Wherever possible, this study used load profiles specific to Indonesia. In the case that these were not available, we used load profiles from other countries and locales with a similar climate to Indonesia, such as Malaysia and India. Table 1 provides the list of load profiles used in this study by end-use, sector, source, and region. Since the climate in Indonesia is characteristically tropical with abundant rainfall, high temperatures and high humidity throughout the country, only one characteristic load profile was considered for each end use and/or sector. Standby power losses are assumed not to vary by geography, and are estimated from a European Commission source.

Table 1 End-use load profiles used in this study

End-Use	Sector	Source	Geographical Region
Lighting	Residential	[4]	Indonesia
Lighting	Commercial	[5]	Gujarat, India
Air conditioners	Residential	[6]	Kansai, Japan
Air conditioners	Commercial	[5]	Gujarat, India
Televisions	Residential	[5]	Gujarat, India
Refrigerators	Residential	[7]	India
Refrigerators	Commercial	[5]	Gujarat, India
Fans	Residential	[8]	Jahor Bahru, Malaysia
Rice cookers	Residential	[9]	Osaka City, Japan
Other Residential*	Residential	[9]	Osaka City, Japan
Standby Power	Residential	[10]	Europe
Industry	Industrial	[11]	Indonesia

** Other Residential represent kettle and clothes washer.*

Figures 1-3 show the normalized profiles used in this study for the residential, commercial and industrial end uses respectively. The residential sector is built up from individual end uses. The "other residential" includes kettles, electric irons, and clothes washers. Individual end uses are not defined for the industrial sector, which has a relatively flat load profile compared to the other sectors. In this case, the total sector load profile is taken directly from Indonesian data. For comparison, each load profile is normalized so that the average load on each curve is equal to one. The normalized load for each hour is multiplied by the average hourly end use energy consumption in order to get total end use load by hour on a typical day. The calculation is as follows:

Load at t (MW) $_{(end\ use)}$ **=** ***Average hourly energy consumption (MW)*** $_{(end\ use)}$ × ***Load on normalized curve at t*** $_{(end\ use)}$

Average hourly energy consumption (MW) $_{(end\ use)}$ **=** ***Annual energy consumption (TWh)*** $_{(end\ use)}$ ***/ 8760***[2] ***/*** 10^6

[2] 8760 is the number of hours in a year

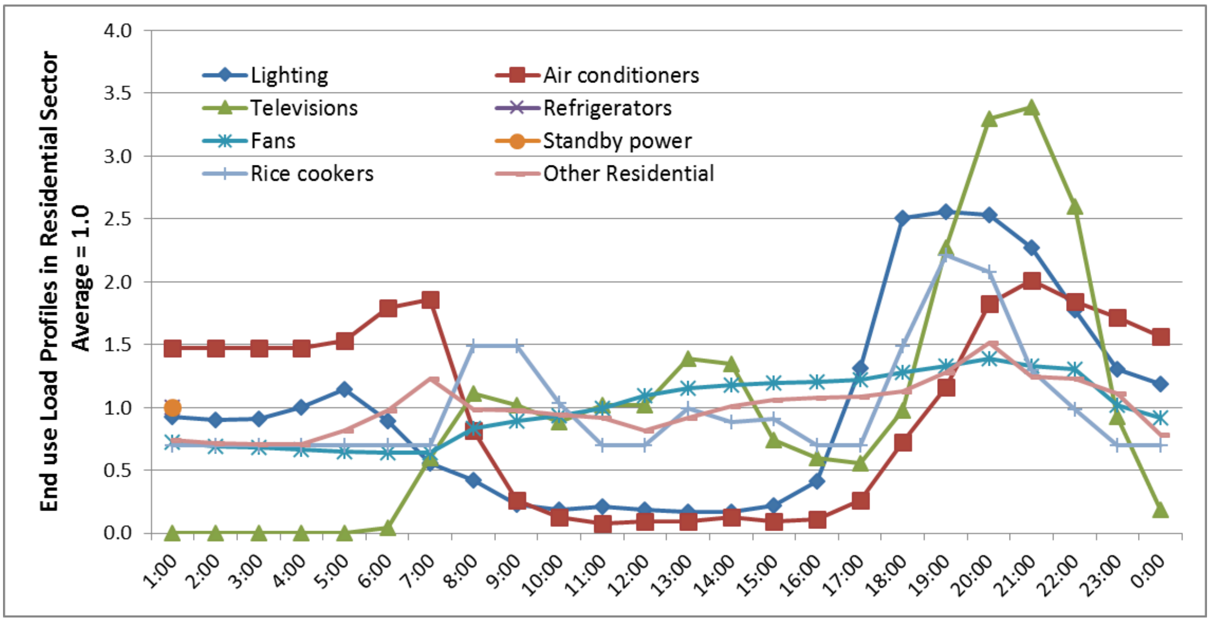


Figure 1 Residential sector Load Profiles Normalized to the average = 1.0

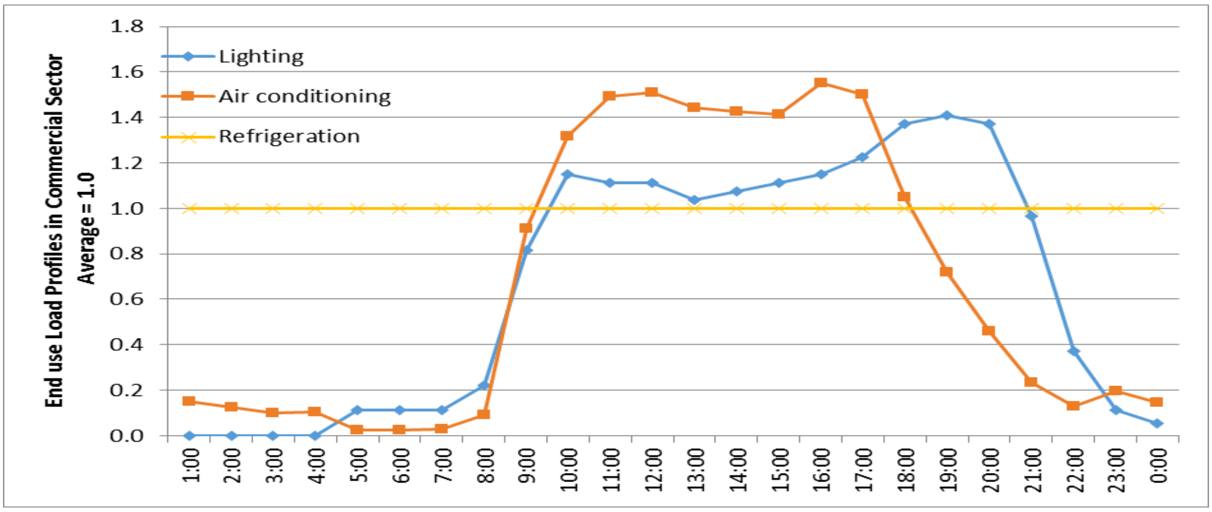


Figure 2 Commercial sector load profiles normalized to the average = 1.0

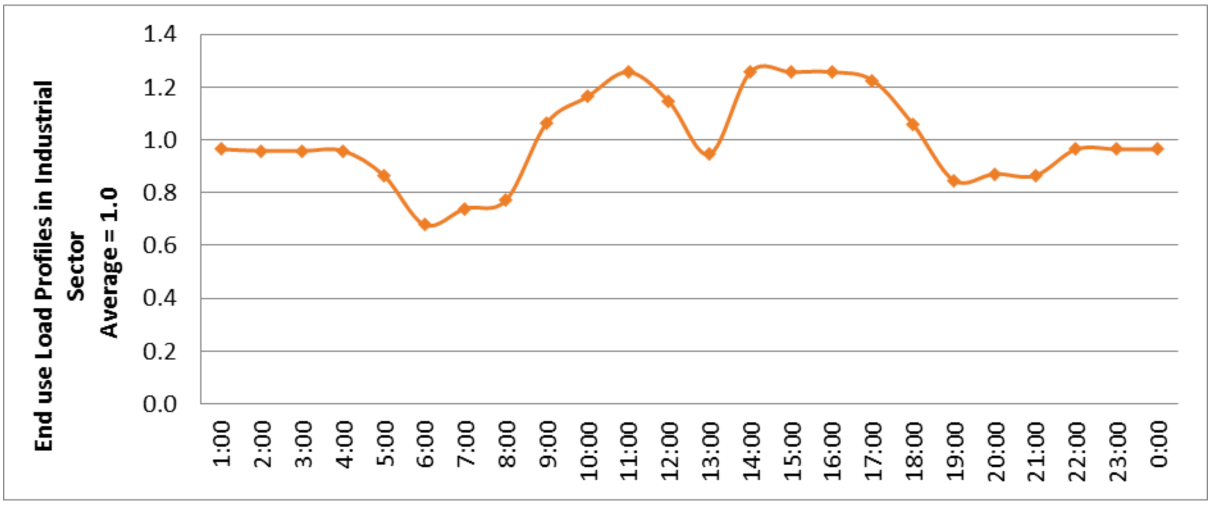


Figure 3 Industrial sector load profiles normalized to the average = 1.0

Business as Usual (BAU) Projections

The population of Indonesia in 2010 was 240.7 million, making it the world's fourth most populous country. About half of the population still lives in rural areas [12]. The UN predicts that 60.3% of the population will be urbanized by 2025 [13]. It is assumed that the population in Indonesia increases over time with an average annual growth rate of 1% (see Figure 4). In the periods past 2010, the gross domestic product (GDP) per capita increases at an assumed average growth rate 3.9% and reaches to 8837 US$(2007) in 2030. Table 2 provides the household size and electrification ratios assumed in this study. Household size decline 0.8% and electrification ratio increases 1.8% per year as average until 2030.

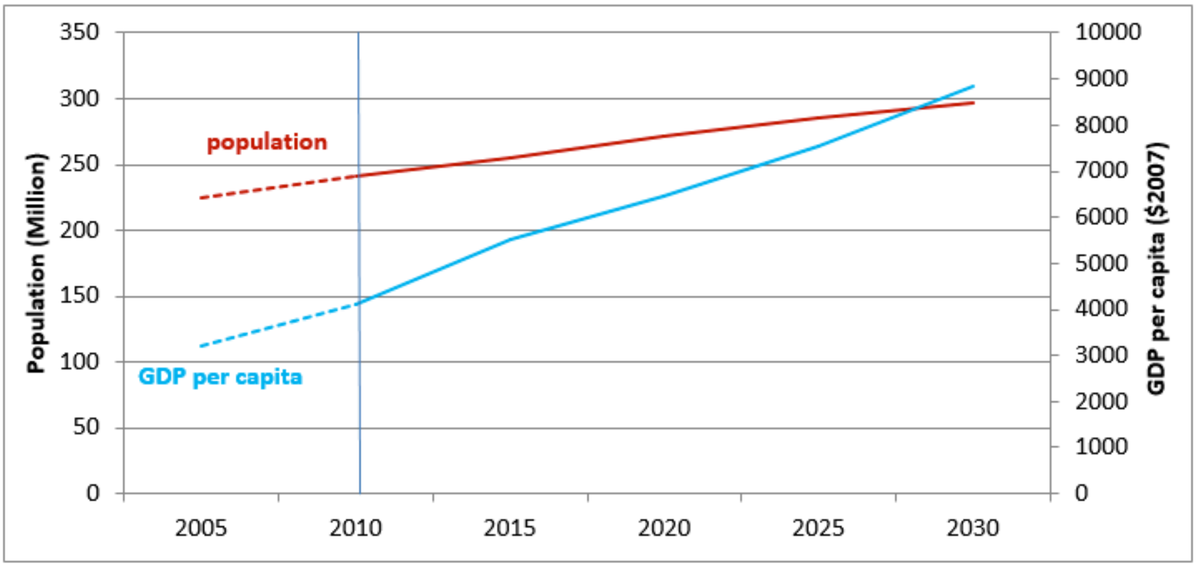


Figure 4 Population and GDP growth modeled in the study
(Source: [13] for population growth, [14] for GDP per capita growth)

Table 2 Household size and electrification rate modeled in the study

	2010	2015	2020	2025	2030
Household size	3.9	3.73	3.63	3.49	3.32
Electrification rate	70%	79%	90%	97%	100%

When possible, stock of appliances in the residential sector are modeled by a stock turnover analysis using historical sales data (Euromonitor [15], BSRIA [16]) combined with appliance lifetime estimates. Diffusion (ownership) levels for these years are then calculated by dividing the stock by the number of households in the country. Diffusion and stock are extrapolated to 2030 using BUENAS macroeconomic modeling, which uses GDP, electrification, urbanization, climate parameters and population as drivers.

Diffusion level of the equipment in this study are low in the base year, with the exception of ceiling fans and televisions For example, we find that only 31% of the households have a refrigerator in 2010, and luxury items like air conditioners is owned by a very small portion of the country (diffusion level of 8% in 2010). Even if the market is rapidly moving to LCD and LED flat screen televisions, we find that most of the households still own CRT televisions, which is the most inefficient television group in the market. The current low rates of appliance ownership (i.e., diffusion) coupled with high economic growth rates imply that Indonesia is poised for rapid growth in electricity demand, particularly in the residential sector. As can be seen, rapidly growing sales (driven by GDP and population) yields significant increases in the total number of appliances in the stock in residential sector in the medium and long term, especially for large appliances like refrigerators and air conditioners, as can be seen in Figure 5.

Figure 5 Projected diffusion (units per household) of residential appliances (2000-2030)

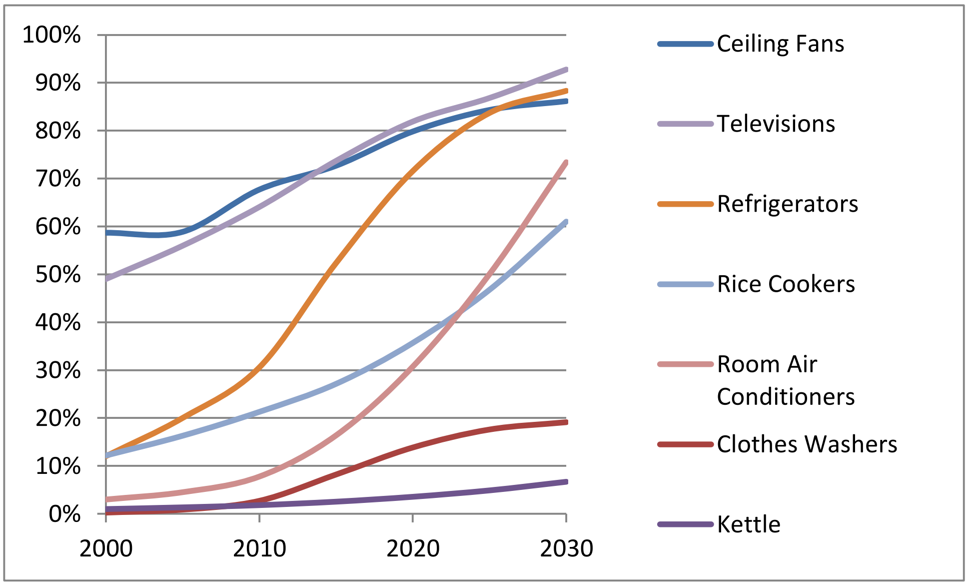


Table 3 shows the average unit energy consumption (UEC) of all appliances considered. Most of these UEC are based on proxies from other countries. For example, the UEC of a typical air conditioner in Indonesia has been taken from India given the similarities in climate and income. With this assumption, air conditioners consume almost 2.5 times more electricity than the next largest item, a refrigerator. Therefore, one could expect a large impact on electricity consumption and peak load with moderate increases in air conditioners ownership.

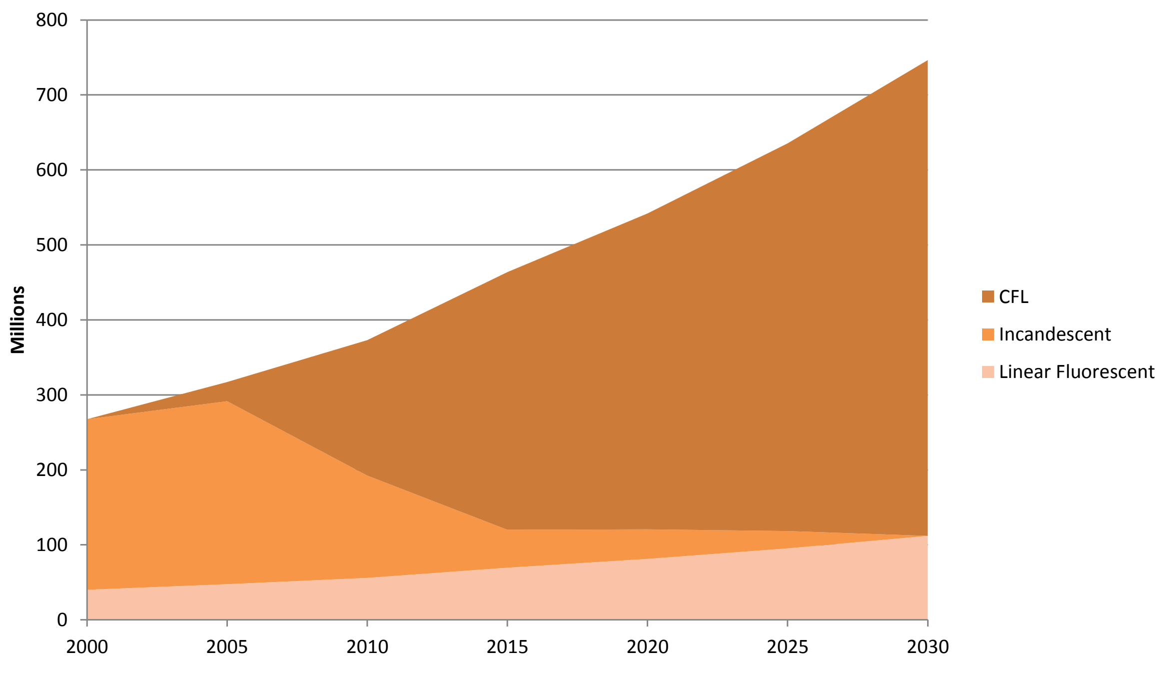
The BAU scenario assumes frozen efficiency with the exception of lighting (assumes a progressive phase-out of incandescent lighting by 2030) and televisions (assumes progressive efficiency improvements in CRT, LCD and plasma). In addition, we model two different types of refrigerators; direct cool refrigerator with 337 kWh/yr, frost-free refrigerator with 675 kWh/yr. Refrigerator capacity and efficiency is modeled with reference to the Indian market [7]. It is assumed that diffusion of frost-free refrigerators would be higher in Indonesia in the long term. Thus, the weighted average of UEC increases between 2010 and 2030 (see Table 3).

Table 3 Assumed UEC of appliances in the residential sector (kWh/yr)

	2010 UEC	2020 UEC	2030 UEC	Source
Air Conditioners		1,416		[7]
Refrigerator	574	618	650	[7]
Television				
LCD	233	53	53	[17]
CRT	192	176	176	[17]
Plasma	305	224	224	[17]
Fans		224		[18]
Clothes Washer		150		[19]
Rice Cooker		242		[19]
Kettle		216		[19]

Figure 6 shows the market share of different lighting types used in Indonesia between 2000 and 2030. Incandescent lamps, which are the most energy consuming lighting type has a very high share in 2005. However, its share gradually decreases and reaches zero in 2030. Unlike other appliances, sales data for lighting are not available. Therefore, diffusion rate projections for this end use are modeled econometrically (See [3]).

Figure 6 Lighting Stock by technology in the residential sector (BAU assumptions)



* CFL (Compact fluorescent lights)

We used BUENAS model to forecast end-use electricity consumption in the commercial sector for Indonesia [2].The end-use included in the commercial sector are lighting, space cooling and refrigeration. BUENAS bottom-up energy demand totals were then scaled up to match commercial electricity consumption in the base year.

For the industry sector, we assumed that electricity demand grows with growth in GDP.

We then apply the load curves by applying the method described above, and account for transmission and distribution losses of 9% [20]. and compare the peak load results with peak from national statistics and find that the modeled peak load (25.8 GW) is 4.4% higher than the realized peak load

(24.7 GW) in 2010 [21]. While the agreement between modeled peak load and actual peak is small, we caution against interpreting this agreement as an indication of very high precision. We would not expect exact agreement, in fact, because there are undoubtedly some end uses not captured by the model, such as small plug loads. On the other hand, since load is often not met, realized peak load is somewhat lower than peak demand. These compensating errors may contribute to the apparent agreement seen in results.

BAU Results

The daily load curve represents the total electricity consumption by all end use equipment in operation at any given hour. Development of Indonesia's average daily load curve between 2010 and 2030 is illustrated in Figure 7. Indonesia's modeled electricity demand at peak hour under BAU assumptions is projected to increase by 67% (to reach 43.0 GW) in 2020 and by 184% (to reach 73.1GW) in 2030, compared to 25.8 GW at 2010. Meeting this demand growth would require the addition of the equivalent electricity generation of 34 and 95 500-MW power plants in 2020 and 2030, respectively.

Figure 7 also shows the details of electricity consumption on load curve in 2010 by sectors and end uses. As can be seen, in 2010, peak load is mostly driven by residential lighting. Almost 25% of electricity at peak hour is used by lighting. In addition, televisions, which account for 14% of the peak load, and residential lighting together have almost same electricity demand at peak hour, compared to commercial and industrial sectors together (which account for 38% of the peak demand), in 2010.

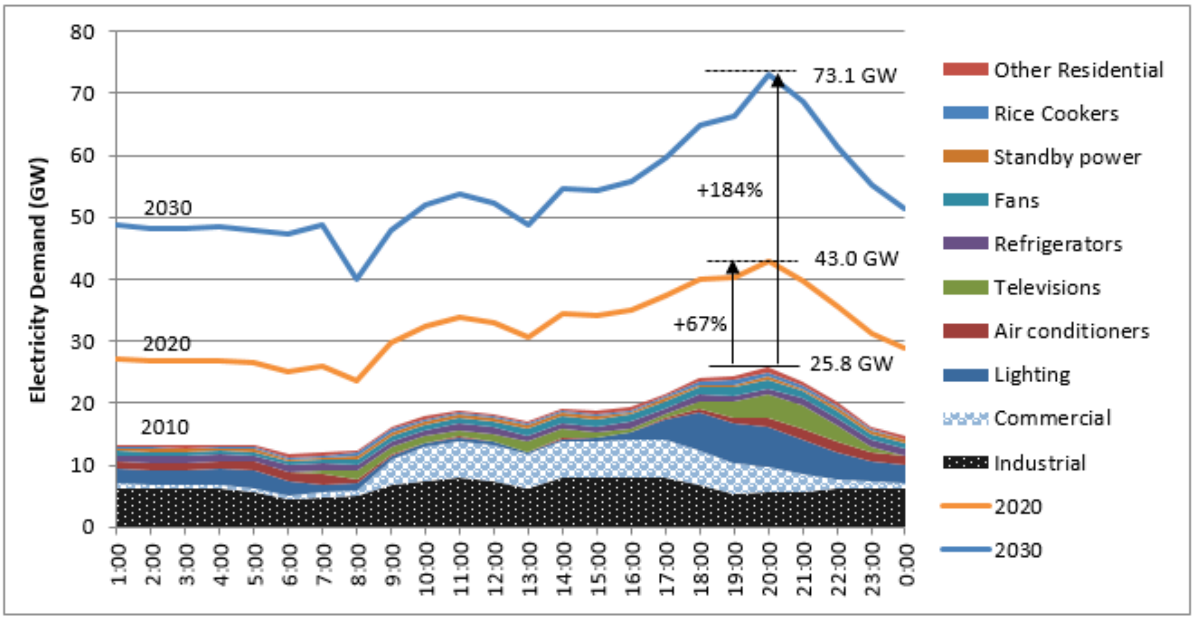


Figure 7 Development of Indonesia's average daily load curve in the BAU scenario between 2010 and 2030

Figure 8 shows the details of the load curve in 2030 in the BAU scenario. In 2030, the electricity demand at the peak is mostly distributed among residential air conditioners (29%), commercial and industrial sectors (18% and 20%), residential lighting and refrigerators (10% and 8%). As can be seen, the share of residential air conditioners, lighting, and refrigerators is larger than the share of commercial and industrial sectors at the peak in 2030. Particularly, contribution of air conditioners to peak load grows roughly five times between 2010 and 2030. Together with its high UEC levels, residential air conditioners have a large impact on peak load in 2030. On the other hand, the share of lighting at peak decreases, due to progressive phase-out of incandescent lamps.

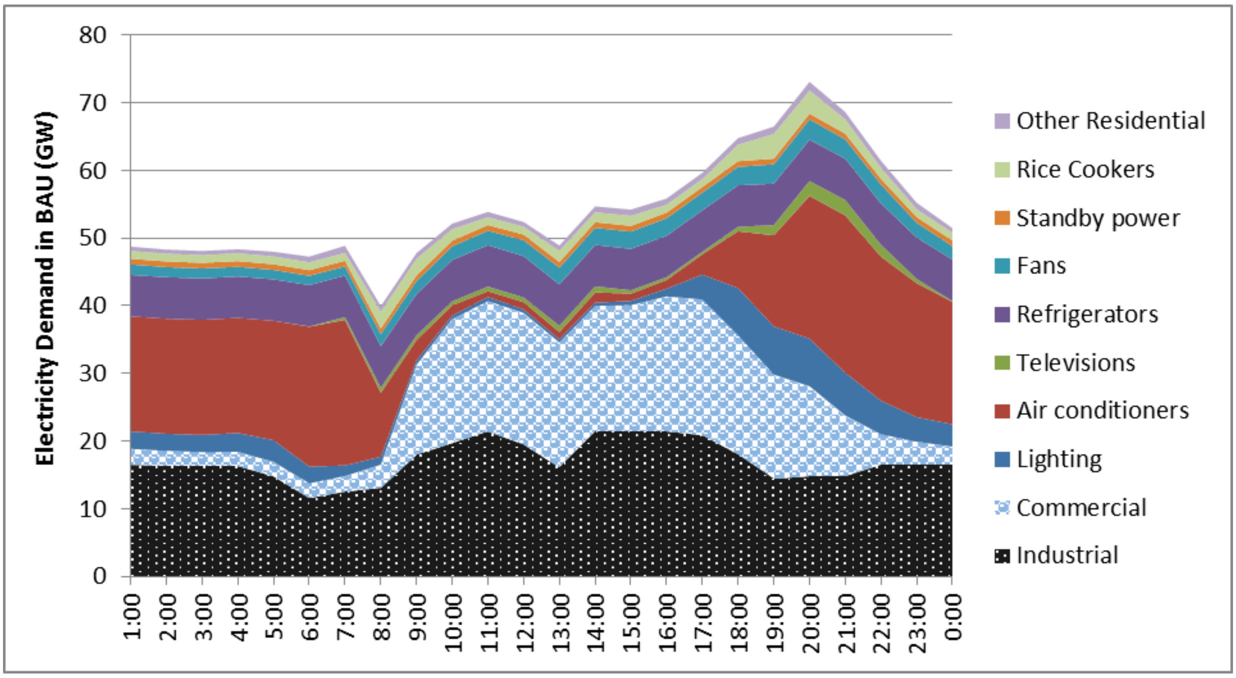


Figure 8 Indonesia average daily load curve in the BAU scenario in 2030 by end use and sector

High Efficiency Scenarios

Two efficiency improvement scenarios are analyzed within the scope of this study in addition to the *BAU*: namely, *CEP* and *BAT*. These scenarios are taken from [22] and [23].

The scenario assumptions on lighting and unit energy consumption of appliances are summarized in Table 4 and 5.

- The ***CEP*** **(Cost Effective Potential) scenario** takes into consideration efficiency targets that provide the maximum energy savings that result in a net benefit to the consumer (even with subsidized electricity tariffs). It is only available for the residential sector.
- The ***BAT*** **(Best Available Technology) scenario** evaluates the technical potential for energy efficiency afforded by the best technologies currently available on the market or designed from high efficiency components. It is only available for the residential sector end-uses, commercial lighting, air conditioners, and refrigerators.

Table 4 Lighting market shares in 2020 and 2030 considered in the scenarios

	BAU			CEP			BAT		
	2010	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Incandescent	37%	7%	0%	37%	0%	0%	37%	0%	0%
CFL	48%	78%	85%	48%	85%	85%	48%	0%	0%
LED	0%	0%	0%	0%	0%	0%	0%	85%	85%
Linear Fluorescent Lamps	15%	15%	15%	15%	15%	15%	15%	15%	15%

Table 5 Unit energy consumption in BAU, CEP, and BAT scenarios in 2020 and 2030 (kWh/yr)

	BAU		CEP		BAT	
	2020	**2030**	**2020**	**2030**	**2020**	**2030**
Air Conditioners	1,416	1,4156	1,000	1,000	637	637
Refrigerators	618	650	345	370	117	117
Televisions						
LCD	53	53	53	53	14	14
CRT	176	176	N/A in CEP	N/A in CEP	N/A in BAT	N/A in BAT
Plasma	224	224	N/A in CEP	N/A in CEP	14	14
Fans	224	224	164	164	103	103
Clothes Washers	150	150	150	150	135	135
Rice Cookers	242	242	242	242	242	242
Kettles	216	216	216	216	216	216

Scenario Results

Due to the introduction of more energy efficient lighting, appliances and equipment, peak load increases more slowly in the *CEP* and *BAT* scenarios than in the BAU scenario. Between 2010 and 2030, Indonesia's peak load grows by 147% (i.e., to 63.6 GW) in the *CEP* scenario, and by 84% (i.e., to 47.3 GW) in the BAT scenario. These scenarios project a need for 76 and 43 large power plants, respectively, compared to 95 in the BAU scenario. These results indicate 19 and 51 fewer large power plants in the *CEP* and *BAT* scenarios.

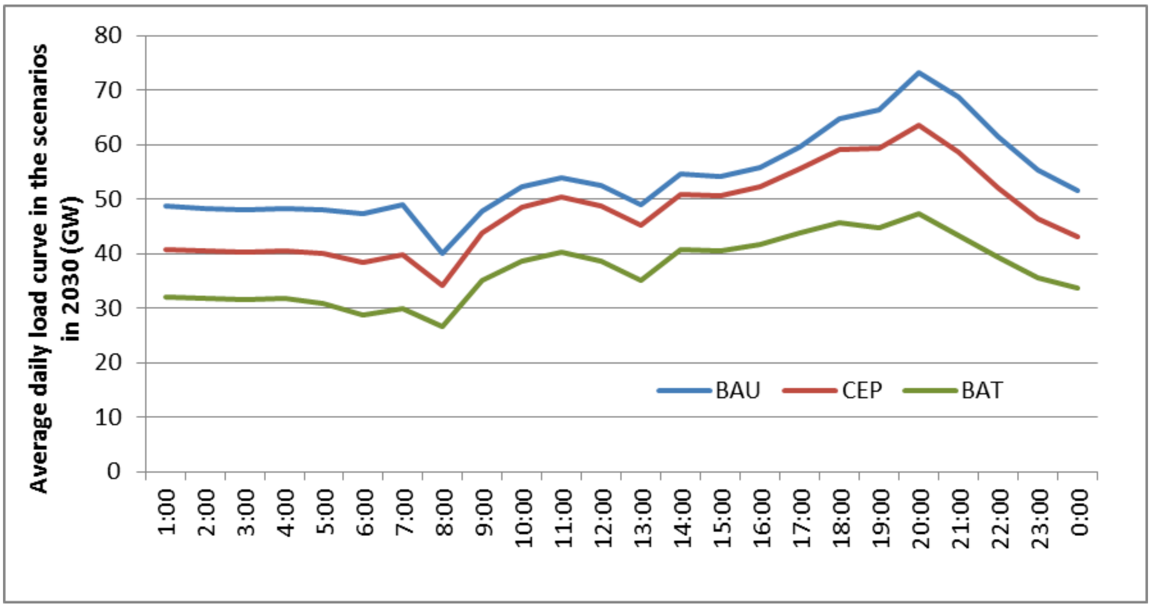


Figure 9 Indonesia average daily load curve in the scenarios in 2030

Figures 10 and 11 show the details of the energy savings in the *CEP* and *BAT* scenarios compared to the BAU scenario in 2030. Electricity demand at peak hour is reduced by 13% and 35% in the *CEP* and *BAT* scenarios, respectively, relative to *BAU*. Air conditioners and refrigerators are the end-uses that contribute most to the reduction of peak load (see Table 6). These end uses reduce the peak load by 8% (12 fewer large power plants) and 3% (5 fewer large power plants), respectively, in 2030, in the CEP scenario. In the BAT scenario, in contrast, 16% (23 fewer large power plants) and 6% (9 fewer large power plants) of the peak load reduction is from refrigerator and air conditioners, respectively, in 2030. In the BAT scenario, commercial sector also decreases the peak load 6% as a consequence of efficiency improvement in commercial lighting, air conditioners, and refrigerators.

The energy required for lighting is reduced significantly in both scenarios due to complete replacement of incandescent lighting by CFLs in the *CEP* scenario and by LEDs in the *BAT* scenario. Likewise, efficiency improvement of refrigerators and air conditioners in the *CEP* and *BAT* scenarios result in much lower energy demand from those end-uses.

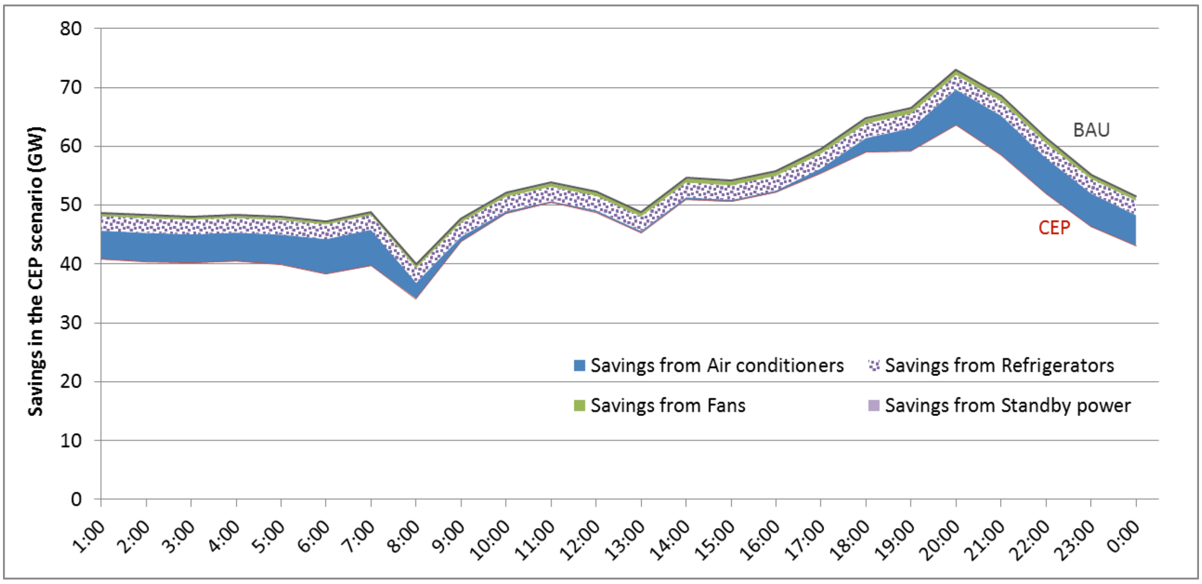


Figure 10 Savings in the CEP scenario in 2030, compared to BAU

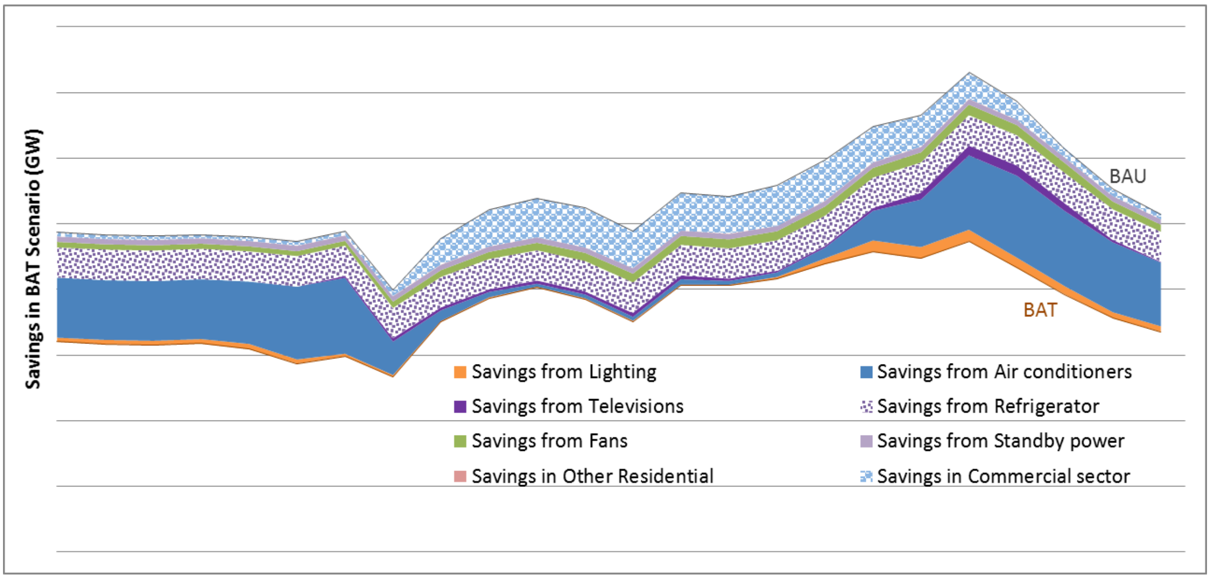


Figure 11 Savings in the BAT scenario in 2030, compared to BAU

Note 1: Savings in Commercial sector is aggregate representation of efficient lighting, air conditioners, and refrigerators in the BAT scenario

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Table 6 Contribution of sectors and end-uses to reduction of peak demand in 2020 and 2030 in the CEP and BAT scenarios

	2020				2030			
	Reduction in CEP		Reduction in BAT		Reduction in CEP		Reduction in BAT	
	(GW)	(%)	(GW)	(%)	(GW)	(%)	(GW)	(%)
Lighting	0.82	1.90%	2.1	4.9%			1.8	2.4%
Refrigerator	0.96	2.22%	1.7	4.1%	2.5	3.4%	4.6	6.3%
Air conditioner	1.10	2.57%	2.1	4.8%	6.1	8.3%	11.3	15.5%
Fans	0.38	0.88%	0.8	1.8%	0.8	1.1%	1.6	2.2%
Televisions			0.7	1.7%			1.5	2.1%
Standby power	0.08	0.19%	0.5	1.1%	0.1	0.2%	0.8	1.1%
Other residential							0.0	0.1%
Commercial sector			1.1	2.6%			4.1	5.6%
Industrial sector								
TOTAL	3.3	7.76%	9.0	20.9%	9.5	13.0%	25.7	35.2%

Conclusion

The analysis presented in this paper demonstrates the potential for extending an energy savings model (BUENAS) to include peak load reduction effects. Results are promising for the case study chosen, which considers likely achievable energy efficiency improvements in the Indonesian appliance and equipment market. First of all, the BAU projection of end use demand concludes that peak electricity load, and therefore generation capacity needs may increase in Indonesia by roughly 3 times over the next 20 years. In order to meet this demand, we estimate that Indonesia will have to build 95 new 500 MWpower plants, confirming concerns about infrastructure constraints, the threat of continued shortages, a massive burden on available capital, and environmental concerns. Alternatively, we find that scenarios that include comprehensive energy efficiency programs could reduce 2030 peak load from 13% to 35% in 2030. With peak load projected to grow by a factor of 3, this corresponds in a reduction in peak load growth of about a fifth to over half.

Importantly, most of these projected savings could come from aggressively targeting just a few residential end uses. For example, air conditioners efficiency alone could save between 6.1-11.3 GW in 2030, corresponding to 12 to 23 500-MW power plants, requiring an investment of several billions of dollars. In other words, potentially billions of dollars of power sector capital could be saved by a targeted program with relatively few actors and stakeholders. While there are likely increased costs to consumers for higher efficiency equipment, in the cost effective potential (CEP) scenario, these capital costs are completely recovered through reduction of consumers energy bills and consumers see a benefit -a past study found that the cost-effective potential in Indonesia could yield to 5 Billion USD savings by 2030 [22]. Programs such as EES&L have a long track record of success in achieving these potential savings and best practices are well known. In fact, the Indonesian government has already embarked on such a set of programs, the effectiveness of which will be largely determined by political will, stakeholder buy in and government technical capacity.

In conclusion, we believe that the results presented here effectively demonstrate a strong incentive for developing countries to aggressively pursue efficiency of domestic appliances for reasons not only of consumer welfare and environmental concerns but also energy security and economic development. Programs to address appliance efficiency in these countries should enjoy a high investment priority therefore, among both developing country governments and the international community that supports their development.

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