LBNL-1005921

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Prospective Evaluation of the Energy and CO_2 Emissions Impact of China's 2010 – 2013 Efficiency Standards for Products

Nina Khanna, Nan Zhou, David Fridley and
China Energy Group
Energy Technologies Area
Lawrence Berkeley National Laboratory

Michael McNeil
International Energy Studies Group

July 2016

This work was supported by Energy Foundation China through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Prospective Evaluation of the Energy and Emissions Impact of China's Efficiency Standards for Products

Nina Khanna, Nan Zhou, David Fridley
China Energy Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

Michael McNeil
International Energy Studies Group

Executive Summary

Since China introduced its first mandatory minimum energy performance standards (MEPS) for eight major household products in 1989, its MEPS program has expanded significantly to cover nearly 60 residential, industrial and commercial products. In June of 2012, the pace of standards development for new and revised standards was further accelerated with the launch of the national "100 Energy Efficiency Standards." Initiatives. An unprecedented 21 MEPS were adopted by China from 2012 to 2013, compared to only 7 MEPS adopted from 2010 to 2011. The Chinese MEPS program now covers 15 products in the residential sector, 15 types of commercial and office equipment, 14 types of industrial equipment and 13 lighting products, making it one of the most comprehensive MEPS program in the world. This study provides an updated prospective evaluation of the potential energy and CO_2 impact of 23 of the 28 MEPS adopted by China from 2010 to 2013.

This study updates a previous analysis (Zhou et al. 2011) by quantifying the additional potential energy and CO_2 reductions from the newest standards that have been adopted since 2010. The most recent actual and projected sales, usage, and efficiency data were collected for 14 product categories covered under 23 MEPS adopted between 2010 and 2013. Three scenarios are then used to quantify the energy and CO_2 reduction potential of the one-time implementation of these 23 MEPS, including a baseline counterfactual scenario, the actual MEPS scenario and a best available technologies efficiency scenario. The setting of the baseline efficiency is crucial to determining the savings potential of the new and revised MEPS and international best available technology efficiency levels, as it reflects the market average in the absence of MEPS. For this study, the average baseline is based on either the reported 2010 market-average efficiency if sales-weighted efficiency data is available for new product MEPS and selected products with revised MEPS, or the minimum efficiency requirement of the previous MEPS for products with revised MEPS from 2010 to 2013 that do not have sales-weighted efficiency data. Using sales-weighted efficiency data for the baseline help capture market transformation that has already occurred prior to the implementation of the MEPS, and can better differentiate the savings that are attributable to MEPS. The efficiency levels of best available technologies are taken from recent reviews of international commercially available best available technologies.

We find that the one-time adoption of the 23 new or revised MEPS from 2010 to 2013 for the 14 categories of products evaluated in this study could reduce cumulative electricity consumption by 1517 TWh and CO_2 emissions reduction by over 1.5 billion tonnes CO_2 between 2010 and 2030 compared with the baseline scenario without these new or revised MEPS as seen in Table ES-1. MEPS for small and medium motors, televisions, external power supplies and copier, printer and fax machines had the largest energy savings potential and CO_2 emissions reduction. Televisions and electric motors MEPS have the largest savings potential, together accounting for more than half of annual electricity savings by 2020 and cumulatively savings from 2010 to 2030. Televisions are projected to hold relatively large energy savings potential as a result of having the largest projected sales amongst all residential and commercial equipment, while motors are very energy-intensive equipment used by many industries.

Table ES-1: MEPS Scenario Potential Energy Savings and CO_2 Emissions Reductions

	Electricity Savings (TWh)				CO2 Emissions Reductions (Mt CO2)			
	2010	**2020**	**2030**	**Cumulative**	**2010**	**2020**	**2030**	**Cumulative**
Room AC: Fixed Speed	0.1	0.3	0.0	4.0	0.1	0.3	0.0	4.1
Room AC: Variable Speed	0.0	3.2	6.3	64.4	0.0	3.2	6.0	63.8
TV	0.0	14.0	18.1	235.8	0.0	14.2	17.4	235.0
Clothes Washers: Front Load	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clothes Washers: Top Load	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3
CFLs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Linear Fluorescent Lamps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Small Motors	0.0	16.5	31.6	333.4	0.0	16.7	30.3	330.9
Medium Motors	0.0	8.8	19.9	192.5	0.0	9.0	19.1	190.7
Large Motors	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
External Power Supplies	0.0	10.5	15.8	186.3	0.0	10.7	15.1	185.6
Microwave	0.1	0.7	1.0	13.0	0.1	0.7	1.0	13.0
Copier Printer and Fax Machine	0.0	8.0	14.5	155.3	0.0	8.2	13.9	154.0
Desktop Computer	0.0	5.8	6.4	98.2	0.0	5.9	6.2	98.5
Laptop Computer	0.0	1.5	2.1	27.5	0.0	1.6	2.0	27.5
Kitchen Rangehood	0.0	3.6	9.0	80.5	0.0	3.6	8.6	79.6
Heat pump water heaters	0.0	0.4	2.0	12.0	0.0	0.4	1.9	11.8
Set-top box	0.6	4.7	7.6	95.0	0.6	4.7	7.3	95.2
Distribution Transformers	0.6	1.0	0.8	18.9	0.6	1.1	0.7	19.1
Total	***1.3***	***78.9***	***135.1***	***1517.2***	***1.4***	***80.2***	***129.5***	***1509.2***

Note: LEDs were not evaluated for lighting. CFLs, linear fluorescents, front-load clothes washers and large motors had zero savings through 2030 because the baseline efficiency and revised/new MEPS efficiency were the same.

In 2030, annual electricity savings from the one-time implementation of these MEPS would be equivalent to the output of 28 1-GW typical coal-fired power plants and 1.3 times the annual generation output of the Three Gorges Dam as seen in Figure ES-1.

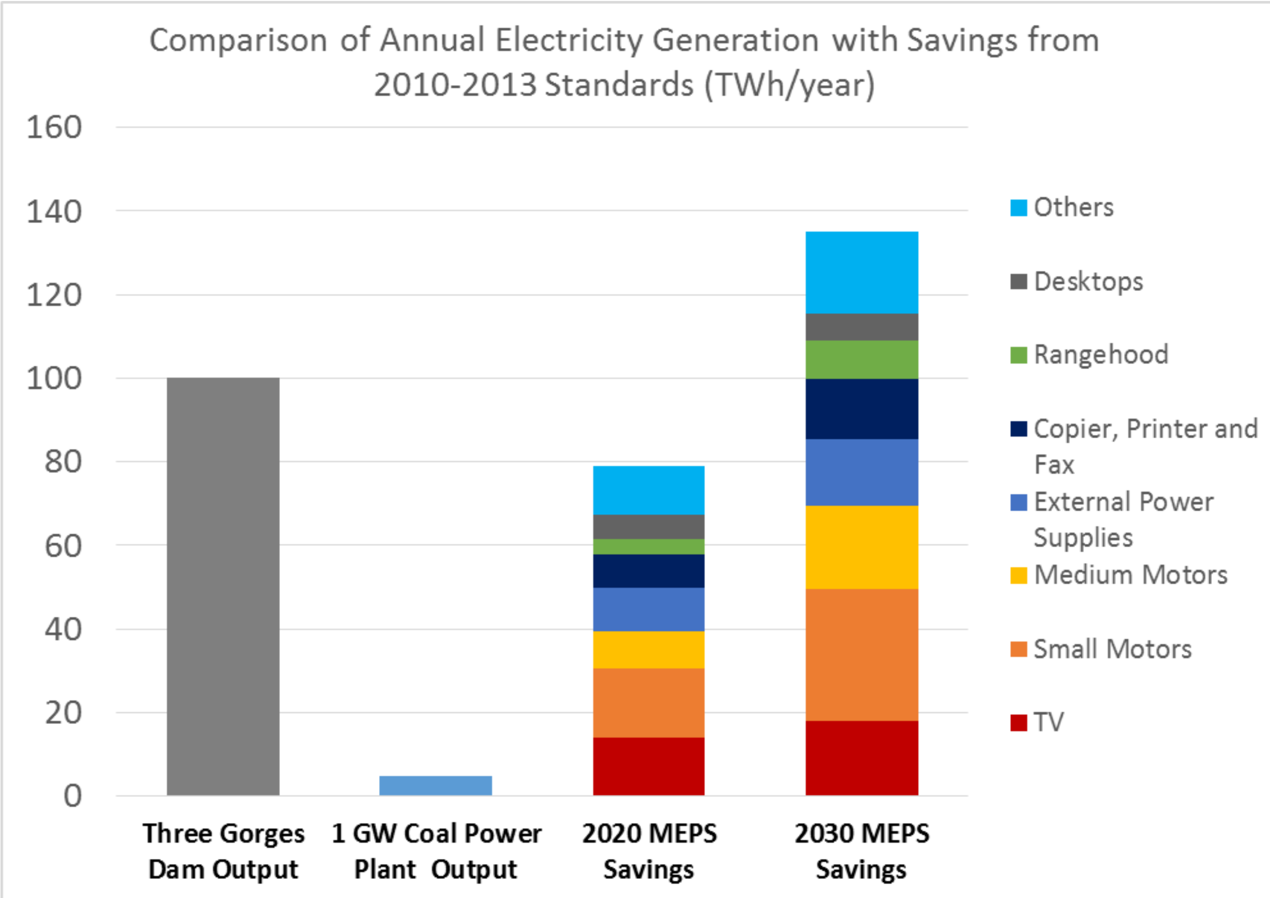

Figure ES-1: Comparison of Annual Electricity Generation with Savings from 2010-2013 MEPS

Some revised product MEPS, including those for CFLs, front-load clothes washers, fixed-speed room air conditioners, and distribution transformers have little or no impact because market transformation had already occurred faster than expected prior to implementation of the revised MEPS. These product markets had already overtaken target efficiency levels because of fast technological improvements and changing consumer preferences as well as the market transformation impacts resulting from the mandatory energy information label and the large-scale national subsidies for efficient products implemented between 2009 and 2012. Limited data makes it very difficult to disaggregate the market transformation impacts of different market drivers and policies and shows that properly characterizing the market dynamics related to MEPS development and revisions are crucial to setting an appropriate baseline for developing new or revised MEPS efficiency thresholds. This is especially important for China, which sets its MEPS more incrementally with revisions implemented every 3-4 years generally, than other countries such as the US which tends to significantly move the market with more stringent MEPS that are adopted over a longer time period.

Although some of the revised MEPS had limited energy savings compared to the baseline, there is still very large remaining potential as indicated by the gap from the latest MEPS requirements and the current Chinese or international best available technology levels for 10 selected products. Depending on the product, there is still untapped energy savings potential ranging from around 10% for medium and large motors, CFLs, and external power supplies to upwards of 40% savings potential for LCD-LED televisions, room air conditioners, and front-load clothes washers. Possible areas of improvement for achieving some of these untapped energy savings potential and increasing the impact of future MEPS revisions include shortening the time lag between revisions for all products and adopting more stringent requirements for MEPS with long revision cycles, collecting and utilizing more detailed and real-time data to provide greater insight into quickly changing market dynamics and transformation that has already occurred, and improving coordination between the efficiency thresholds for MEPS, label grades and subsidies.

Table of Content

List of Tables

List of Figures

Prospective Evaluation of the Energy and Emissions Impact of China's Efficiency Standards for Products

Nina Khanna, Nan Zhou, David Fridley
China Energy Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

Michael McNeil
International Energy Studies Group

1. Introduction

China first introduced mandatory minimum energy performance standards (MEPS) for eight major household products in 1989 to improve the minimum efficiency levels of high energy-consuming equipment in widespread use. Since then, China has rapidly expanded its MEPS program to become one of the world's largest programs, covering not only common household appliances, but also lighting products, office and commercial equipment, transport and industrial equipment. As of 2015, China had adopted 57 MEPS, covering 15 household appliances, 13 lighting products, 14 industrial equipment, 5 office equipment and 10 commercial equipment. In addition, China also adopted a mandatory categorical energy information label (China Energy Label) in 2005 that covers a subset of products regulated by MEPS. The China Energy Label program, which has also grown over its 10 year existence, is linked directly to MEPS levels and complements the minimum efficiency standards by helping further promote market transformation towards higher efficiency products.

Over the last five years, the pace of standards development for both new and revised standards has been accelerated under the auspice of the national "100 Energy Efficiency Standards" initiative launched by the National Development Reform Commission (NDRC) and Standardization Administration of China (SAC). In June of 2012, NDRC and SAC kicked-off the Project on Promoting a Hundred Efficiency Standards by convening industry associations, research institutions, technical committees on standardization and standard-setting institutions. The initiative aimed to adopt 100 energy-saving standards, including energy consumption limits for energy-intensive industrial production processes, MEPS for products and equipment, and standards for energy measurements, energy management and energy audits for enterprises. By the end of 2012, a total of 109 new standards had been published. A second phase of the "100 Energy Efficiency Standards" has been initiated for 2014 to 2015, with the aim of adopting another 100 new and revised energy-related standards over these two years.

As part of the two phases of "100 Energy Efficiency Standards" initiative, an unprecedented 21 MEPS were adopted by China from 2012 to 2013, compared to only 7 MEPS adopted from 2010 to 2011. This included 5 new MEPS for new products and 2 revised MEPS in 2012, and 6 new MEPS and 8 revised

MEPS in 2013. In 2014, an additional 8 MEPS were adopted including 5 new MEPS and 3 revised MEPS. In total, China adopted 21 new product MEPS from 2010 to 2014 and increased the total product coverage of its MEPS program by over 30%.

These new and revised standards are expected to help contribute to both national 12th Five-Year Plan (FYP) targets for reducing energy and carbon intensity per unit of GDP, respectively, by 16% and 17%, as well as the longer-term Copenhagen Accord CO_2 intensity reduction target for 2020 and the most recently announced CO_2 peaking target and intensity reduction target for 2030. While the potential savings of each new or revised standard is estimated when the standard is developed, the total potential impact of these new and revised standards on China's national energy and CO_2 emissions reductions have not been evaluated and quantified. Similarly, their combined contribution to the national energy and carbon intensity reduction targets are not known. This report will help quantify the total energy and CO2 emissions reduction impact of China's newest MEPS, and identify gaps for improvement in future standard-setting.

A previous 2011 study (Zhou et al. 2011) evaluated the total potential impacts of China's standards and labels for 37 products that had been implemented as of 2009, assuming continuous improvement of these standards over time. This study seek to update that prospective evaluation of China's MEPS program by quantifying the additional potential energy and CO_2 reductions from the newest standards that have been adopted since 2010. For MEPS adopted between 2010 and 2013, we collected the most recent actual and projected sales data, usage data and efficiency criteria in collaboration with the China National Institute of Standardization (CNIS) and using available market data and literature review. We then developed bottom-up modeling methods that incorporates stock turnover models where possible to evaluate the potential savings of these MEPS from 2010 through 2030. Unlike the previous study, this study focuses on quantifying only the impact of the newest standards over time, and does not attempt to evaluate the additional savings from continuous improvement of the new standards over time. For selected key products, we also compare the potential energy savings of the newest MEPS with the current best available technologies' efficiency levels based on the latest technological trends and international standards. The results of this study is intended to provide important information on the effectiveness and potential impacts of China's most recent efficiency standards, including information that can serve as the basis for comparison for actual impacts in future program evaluations. The findings of this study can also be used to identify important implications for standard-setting under the 13th FYP period and beyond.

The next section of this report will review in-depth the product scope of this study, the bottom-up modeling framework we used, as well as energy demand scenarios and detailed modeling parameters for each specific equipment type. The third section focuses on the results of our analysis, including the energy and CO_2 reductions from the MEPS evaluated and the remaining potential savings that can be captured if best available technologies' efficiency levels were adopted instead. The fourth section provides key findings and implications of our analysis, including the MEPS with largest savings potential, remaining gaps with best available technologies efficiency and policy implications for the 13th FYP period.

2. Methodology

2.1. MEPS and Product Scope

Of the 28 new and revised MEPS that were adopted from 2010 to 2013, we evaluated the potential impact of 23 MEPS. We excluded 5 MEPS in our analysis because of data limitations for four specific types of industrial equipment and 1 specific commercial product with limited scale of deployment. The four excluded MEPS are:

- GB 26920.1-2011 Commercial Refrigerating Appliances: Part 1 Refrigerated Display Cabinets with Remote Condensing Unit,
- GB 28381-2012 Centrifugal Blower Fan,
- GB 30253-2013 Permanent Magnet Asynchronous Motors,
- GB 30254-2013 Cage Three-Phase High Voltage Induction Motors
- GB 29540-2013 Lithium Bromide Absorption Chillers.

Table 1 shows the revised standards from 2010 to 2013 included in our analysis and Table 2 shows the new product standards from 2010 to 2013 that were included.

Table 1. Revised Chinese MEPS from 2010 to 2013 in Analysis

Current (Revised) Standard and Product		Previous Standard Replaced
GB 12021.3-2010	Room air conditioners	GB 12021.4-2004
GB 18613-2012	Small and medium three-phase asynchronous motors	GB 18613-2006
GB 17896-2012	Tubular fluorescent lamp ballast	GB 17896-1999
GB 19043-2013	Double-capped fluorescent lamps for general lighting service	GB 19043-2003
GB 19044-2013	Self-ballasted fluorescent lamps for general lighting service	GB 19044-2004
GB 19415-2013	Single-capped fluorescent lamps	GB 19415-2003
GB 24850-2013	Flat panel TVs	GB 24850-2010
GB 21455-2013	Variable speed room AC	GB 21455-2008
GB12021.4-2013	Clothes washers	GB 12021.4-2004
GB 20943-2013	External Power Supply	GB 20943-2007
GB 20052-2013	Three-phase distribution transformers	GB 20052-2006
GB 21521-2014	Copier, printers and fax machines	Replaces GB 21521-2008 for Copiers, and replaces GB 25956-2010 for Printers and Fax Machines

Table 2. New Chinese Product MEPS from 2010 to 2013 in Analysis

New Product Standards

GB 25956-2010	Printer/fax machine*
GB 25957-2010	TV receiver box
GB 24849-2010	Microwave
GB 26969-2011	Solar water heater
GB 28380-2012	Computer
GB 29142-2012	Single-capped electrodeless fluorescent lamps
GB 29143-2012	Ballasts for electrodeless fluorescent lamps
GB 29144-2012	Self-ballasted electrodeless fluorescent lamps with general lighting service
GB 30255-2013	Non-directional self-ballasted LED lamps for general lighting service
GB 29539-2013	Kitchen rangehoods
GB 29541-2013	Heat pump water heaters

*Note: GB 25956-2010 is replaced by GB 21521-2014 for Copiers, Printers and Fax Machines

For our analysis, we grouped these 23 covered MEPS into 14 major product categories. This was done by combining 2 MEPS for fixed and variable-speed room air conditioners into 1 room air conditioner category with 2 technology types, and 8 MEPS for different lighting products into 1 major lighting category with 3 key technology types of compact fluorescent lightbulbs (CFL), linear fluorescent light and LED light. Because 2 revised MEPS were adopted in 2010 and 2014 for printers and fax machines as noted above, we used 1 category of multi-functional imaging equipment to cover copiers, printers and fax machines.

In addition, for the two MEPS for clothes washers and computers, we also further separated each product category into two major technology types (fixed-speed and variable-speed room air conditioners, and desktop and laptop computers) based on the MEPS specifications. Table 3 shows the product categories and related technology types used to represent and analyze 23 MEPS in this study.

Table 3. Product classification for MEPS evaluation

Sector	Product Category	Product Sub-category for technology
Residential	Room air conditioner	Fixed-speed
		Variable-speed
	Televisions	LCD
	Television set-top box	
	Clothes washer	Front-load/Horizontal impeller
		Top-load/Vertical drum
	External power supplies	
	Microwave	
	Kitchen rangehood	
	Heat pump water heater	
	Solar water heater	
	Computer	Desktop

		Laptop
	Multi-functional imaging equipment (copier/printer/fax machine)	
Lighting	Lighting	CFL
		Linear Fluorescent
		LED
Industrial	Three-phase distribution transformers	
	Small and medium three-phase asynchronous motors	

2.2. Modeling Framework and Methodology

This study uses the Bottom-up Energy Systems Analysis (BUENAS) framework to analyze the expected change in appliance and equipment ownership, usage, and energy efficiency from the base year of 2010 through 2030. BUENAS is a bottom-up stock accounting model that predicts energy consumption for each type of equipment according to estimates of annual unit energy consumption and scaled by projections of equipment stock. While the model includes 16 end use categories and covers 11 individual countries plus the European Union, only the China-specific equipment types are used in this analysis. More information on BUENAS can be found in McNeil et al. 2012 and McNeil et al. 2013. Major drivers for increased appliance and equipment ownership and usage for some products are economic activity (e.g., household income, GDP growth and GDP per capita growth), persons per household, dwelling area and urbanization rates. Correlating sales with ownership rates, including saturation effects avoids the potential for overstating long term sales rate growth. Note that costs of the products are not considered in the model, with the assumption that the incremental cost of the efficient appliances will be offset by their energy savings as shown in previous studies such as McNeil et al. 2011.

The projection of the sales for these products is made based on stock and vintage analysis where possible. For key household appliances, a saturation forecast was developed based on macroeconomic drivers' projections and the historical experience in developed countries such as Japan and the U.S. This avoids the problem of forecasting sales growth and the potential for overstating ownership rates, because the target saturation rates are then "backcasted" into implied sales figures, accounting for retirement of a percentage of the stock in each year. For other products, particularly industrial and commercial products, where saturation forecasts are not feasible, sales forecasts are used to project future sales and to calculate the stock for a given year.

For each scenario, the total energy consumption of each appliance (measured in terms of electricity) is calculated by the model using given assumptions about annual unit energy consumption, lifetime, and calculated stock. For some products such as air conditioners, expected changes in the average size of models and of usage patterns that impacts total electricity consumption are taken into consideration. Since the only difference among the three scenarios is the efficiency levels of appliances resulting from MEPS implementation and possible adoption of best available technologies' levels of efficiency, the subsequent divergence in modeled energy consumption from the frozen scenario can be attributed to energy savings from different pace of efficiency improvements.

For each product, lifetime assumptions, historical and projected Chinese sales and stock data for each product were provided and/or reviewed by CNIS where possible and collected from Chinese statistical sources, published market studies, analysis of recent growth trends, and historical experiences of other developed countries.

2.2.1. Shipments and Diffusion Rate

Calculation of unit equipment sales (shipments) and stock turnover is essential in understanding the rate at which products enter the household population and thus impact the overall energy consumption. This shipments rate impacts both the base case and efficiency scenarios. After the standard is passed, savings come from the households acquiring the appliances for the first time but also from replacement of older products by efficient products as they are retired.

For the key household appliances of room air conditioners, televisions, and clothes washers, shipments are calculated as the sum of the first purchases and replacements. The first purchases are the increase in appliance stock from one year to the next, where stock is the product of number of households and the diffusion rate measured in China as the number of units owned per 100 households. Replacements are calculated based on the age of the appliances in the stock and a retirement function that gives the percentage of surviving appliances in a given vintage. The incremental retirement function is derived from a normal distribution around the average lifetime of the product.

$$Shipments = First\ Purchases + Replacements \quad (1)$$

First purchases are shipments due to increases in the stock, either from new households, increases in diffusion, or urbanization. Replacements are given from past shipments according to Equation 2.

$$Replacements(y) = \sum_{i=1}^{L} Shipments\ (y-i)\ \times Retirements\ (i) \quad (2)$$

For air conditioners, televisions, and clothes washers, diffusion rates of each year were calculated based on a regression model developed in an earlier study (Letschert et al., 2009), in which the diffusion of the appliances is a function of household income, as given by the following equation:

$$Diff\,(year) = \frac{\alpha}{1+\gamma \exp\left(\beta_{Inc} \times I(year)\right)} \quad (3)$$

In Equation 3, all parameters are determined separately for urban and rural households. The parameter α is the maximum diffusion per 100 households, which may be greater than 100. For rural households, α is the diffusion in urban household for the same income level. *I* (*year*) is the average per household income in *year* and γ and β_{Inc} are scale parameters. In the case of air conditioners in urban households a dummy variable (β_{year}) was added to the equation to account for the rapid diffusion of that technology when it becomes more available and affordable. Details about methodology used to establish these equations can be found in Letschert et al. 2009.

For other products including residential products that may not reach 100% household saturation, commercial and industrial products, data on a baseline 2010 sales and forecast for future sales were collected through an extensive literature review and online survey of market research. An annual growth rate for sales is assumed for these products based on the best available data, with cross-checking of future sales projections and stock projections to ensure the results are reasonable.

Figure 1 shows the projected sales for key products used in this study.

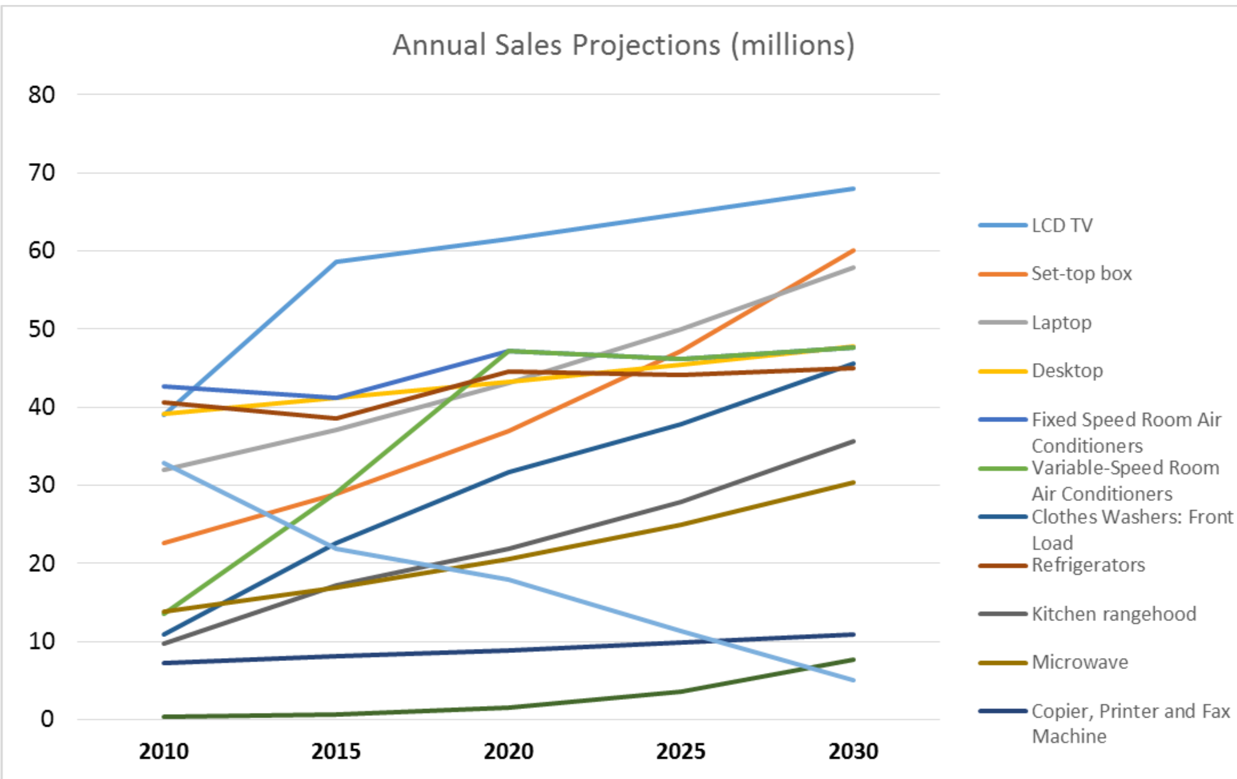

Figure 1. Annual Sales Projections by Product

2.2.2. Lifetime and Retirement Function

In Equation 2, *Retirement* (*i*) is the probability of retirement in each year after installation, up to the maximum lifetime L. For products that were previously modeled in the Zhou et al. 2011 study, the old lifetime assumptions were reviewed and updated. Specifically, the maximum lifetime assumptions for each of these products are taken from published reports specific to China, literature review and online searches, and input from CNIS when available. The lifetime assumption for each product are shown in Table 4.

Table 4. Average Lifetime Assumptions for MEPS Products

Product	Maximum Lifetime	Source
Room air conditioner	12 years	Letschert et al. 2012
Televisions	4.5 years	http://www.eccn.com/news_2012060407325011.htm
Television set-top box	5 years	CNIS
Clothes washer	10 years	Previous 2011 analysis
External power supplies	5 years	CNIS
Microwave	8 years	Previous 2011 analysis
Kitchen rangehood	14 years	http://www.appliance.net/2007/home-appliance-life-span-102
Heat pump water heater	12 years	Average of 10-15 years reported lifetime, http://home.gz.fang.com/news/2011-03-02/4601222.htm
Solar water heater	12.5 years	Wei et al. 2014
Computer	5 years	CNIS
Multi-functional imaging equipment (copier/printer/fax machine)	10 years	http://www.lexmarknewsblog.com/what-is-the-ideal-life-span-for-your-devices/
Lighting: CFL	5 years	Letschert et al. 2012
Lighting: Linear Fluorescent	15 years	Letschert et al. 2012
Three-phase distribution transformers	30 years	Letschert et al. 2012
Small and medium three-phase asynchronous motors	12, 15 and 20 years depending on the capacity	McNeil et al. 2011

For all products, a normal distribution is used as the retirement function where the maximum lifetime is the mean with 50% of the stock of a given product retiring at the lifetime L. Figure 2 shows the cumulative distribution function for the retirement of a computer with a lifetime of 5 years as an example of the normal distribution used for retirement. Although the lifetime is 5 years, the normal distribution retirement function means that there will still be a small share of computers remaining after its 5 year lifetime and it will take over 10 years for all of the computers of a given year to be phased out and retired from the market.

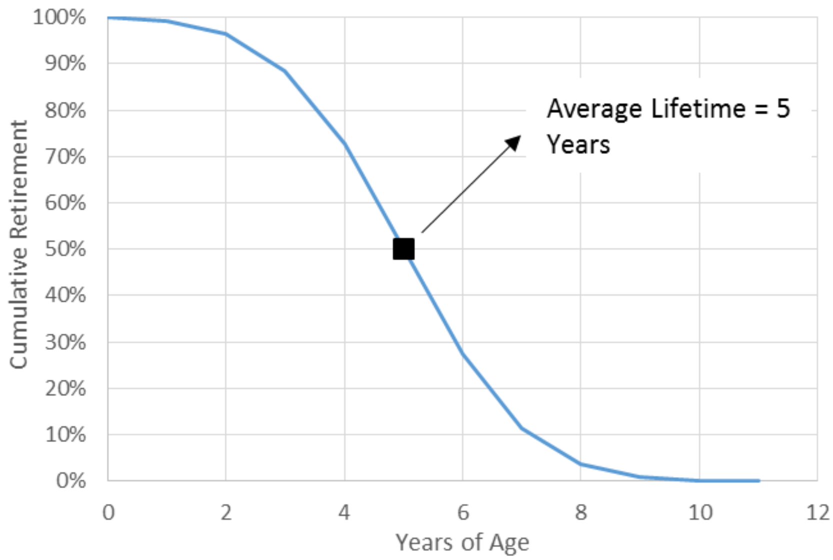

Figure 2. Cumulative distribution function of the retirement of a product with 5 year lifetime

2.3. Energy Demand Scenarios

In this study, we developed three different energy demand scenarios for evaluating the impact of the new MEPS: a baseline scenario, a MEPS scenario and a Best Available Technologies (BAT) scenario. The definitions and underlying assumptions for each of these scenarios are described below.

2.3.1. Baseline Scenario

The baseline scenario, or what is commonly known as a counterfactual "frozen" scenario, is used to evaluate the impact of S&L programs based on the absence of any appliance efficiency policy. It assumes that an appliance's energy intensity as measured by its unit energy consumption (UEC) per year is frozen at the average baseline level prior to the implementation of the new or revised MEPS. The baseline efficiency is assumed to remain frozen or constant through 2030 in the absence of product-specific data on autonomous technology improvements.

For this study, the baseline is set by calculating the UEC based on one of two levels:

- New MEPS Products and Selected Products with Revised MEPS: the reported 2010 market (e.g., sales-weighted) average efficiency of that product if sales-weighted efficiency data is available
- Most Products with Revised MEPS: the minimum efficiency requirement of the previous MEPS for products that were already covered by MEPS

Table 5 summarizes the basis used for making the baseline efficiency assumption for each of the 14 products included in the quantitative analysis.

Table 5. Summary of Basis for Baseline Efficiency Assumption by Product

Product	Basis for Baseline Efficiency Assumption
Room Air Conditioner	2010 sales-weighted average efficiency
LCD TVs	2010 model-weighted average efficiency
Clothes Washers	2010 sales-weighted average efficiency
CFLs	2010 sales-weighted average efficiency
Double-capped Fluorescent	2003 MEPS requirement (same as 2013 revised MEPS)
Small and Medium Three-Phase Motors	2006 MEPS requirement
External Power Supplies	2007 MEPS requirement
Three-Phase Distribution Transformers	2010 sales-weighted average efficiency
Microwave	2010 market average efficiency
Copier/Printer/Fax Machine	2010 market average efficiency
Desktop and Laptop	CNIS estimate of 2010 market average
Kitchen Rangehood	2010 market average efficiency
Heat Pump Water Heaters	2008 MEPS requirement
Set-top Box	CNIS estimate of 2010 market average

As seen in Table 5, for selected major household appliances that were covered by a previous MEPS prior to 2010, the preferred baseline efficiency level is set at the reported 2010 sales-weighted reported average efficiency level if this data is available through the CNIS White Paper or other data sources. For these key energy-consuming residential products, the actual market average efficiency is used where possible because using the previous MEPS level as a market-average baseline is likely outdated and will not reflect market transformation that has occurred since the previous MEPS was implemented. This could result in underestimated market-average efficiency, and overestimating the savings potential of the revised MEPS.

This is particularly true for products such as room air conditioners, clothes washers, televisions, and lighting products, which were included in the “Benefit to the People” Energy Efficient Subsidy program and lighting subsidy program that began in June 2009 and continued through 2012. For these products, the subsidy dramatically increased the market adoption of energy efficient models as indicated by sales-weighted market shares of the different China Energy Label efficiency grades. As a result, the sales-weighted, market average efficiency for these products in 2010 was already equal to or higher than the subsequent revised MEPS level. In these cases, we used the 2010 reported sales-weighted average efficiency rather than the previous MEPS as the baseline. More in-depth comparison of the assumed market-average baseline efficiency based on sales-weighted data and the old and revised MEPS efficiency requirements for each specific product are presented in section 2.4.

For products that were not previously covered by a MEPS, the baseline efficiency was also set at an average efficiency level for the 2010 market. This average efficiency level was determined through literature review and online searches of the best available market efficiency data, or based on CNIS input where possible.

2.3.2. MEPS Scenario

The second scenario is a MEPS scenario which is used to measure the impact of the 23 new or revised MEPS implemented between 2010 and 2013. Under the MEPS scenario, the UEC of a given product is calculated using the minimum efficiency requirement set by the new or revised MEPS. The UEC of a given product will decrease from the baseline level to the new MEPS level beginning with the year that the MEPS is implemented and is expected to remain constant thereafter. In other words, for every product, there is a one-step improvement in efficiency and decrease in UEC that is directly attributed to the adoption of the new or revised product. Because this study is focused solely on quantifying the specific impacts of MEPS adopted from 2010 to 2013, future expected improvements in efficiency as a result of future standard revisions are not considered in this study as it was considered in the previous Zhou et al. 2011 study.

2.3.3. Best Available Technologies Scenario

The third scenario is the Best Available Technologies scenario, which is only applicable to a subset of the key products that are commonly used outside of China. These products include room air conditioners (fixed- and variable-speed), clothes washers, refrigerators, CFL, televisions, external power supplies, and three-phase motors. The BAT efficiencies, as described in greater detail for each product in section 2.4, are based on the latest technological trends and most stringent international standards for product models that are comparable in scale and configuration to the Chinese MEPS products. In many cases, the BAT efficiency level represents the maximum achievable energy-efficient design from technologies that have been commercialized but are not yet widely in use. The BAT efficiency levels were identified using recent studies that reviewed LBNL technical analyses for the SEAD Initiative and for the U.S. Department of Energy’s standard-setting process, preparatory studies for the European Union’s Ecodesign program and the Japanese Top Runner program targets. By comparing the most recent MEPS levels to the international BAT efficiencies, this scenario helps quantify the remaining potential energy savings and CO_2 emissions reductions for a given product in China. It highlights the “efficiency gap” between current Chinese MEPS and the current BAT levels in the world.

2.4. Equipment Data, Assumptions and Modeling Parameters

2.4.1. Room Air Conditioners

The room air conditioner market in China has undergone significant growth in the last five years with annual sales reaching 58 million units in 2012. The continued growth since 2008, when ownership levels already reached an average of 100 units owned per 100 households, is driven by increasing household income and demand for greater thermal comfort as well as the efficient appliances subsidy program. We calibrated historical sales of fixed speed and variable speed room air conditioners to actual reported data through 2012 in the annual White Paper published by CNIS (CNIS, various years). For future years, total sales were back-calculated and calibrated using the household diffusion function based on growing household incomes. The 2012 share of fixed speed is calculated based on actual sales to be 58%, versus 42% of variable-speed in 2012. Given the rapid market shift towards more efficient variable speed air conditioners in the last five years, with its share increasing from 10% in 2007 to 42% in 2012, we assume that variable speed air conditioners' share of total room air conditioner sales will reach the Japanese level of 100% in 2030.

To calculate the average unit energy consumption for the different scenarios, we based our assumptions about usage on actual survey data (which are the same for all scenarios) and the average efficiency metric defined in MEPS as COP for fixed-speed and SEER for variable-speed. For the unit energy consumption (UEC), we define usage as 185 hours of operation per year for both fixed-speed and variable-speed room air conditioners. We only considered the hours used for cooling for variable-speed room air conditioners because the Chinese MEPS only regulates the cooling energy performance of room air conditioners. The 185 usage hours is calculated based on results from a 2012 survey of 1450 households in 25 provinces, which found an average operating hours of 3.8 hours per day for 1.6 months out of a year across the different climate zones (Zheng et al. 2014). For the COP and SEER, we assume that the market-average unit has a capacity of 2300W, the most common size, for both fixed-speed and variable-speed room air conditioners. The average COP and subsequent UEC based on 185 hours of use per year are for the three scenarios are:

Baseline scenario:

- Fixed-speed: COP of 3.31 W/W, based on the reported 2010 sales-weighted market average efficiency for units with less than 4500 W (CNIS 2012). This is significantly higher than the old 2004 MEPS criteria of a COP of 2.6 W/W. The baseline UEC is calculated to be 129 kWh/unit/year.
- Variable-speed: SEER of 3.95 w-h/W-h, based on the reported 2010 sales-weighted market average efficiency for units with less than 4500 W (CNIS 2012). This is also significantly higher than the old 2008 MEPS criteria of a SEER of 3.0. The baseline UEC is calculated to be 108 kWh/unit/year.

MEPS Scenario:

- Fixed-speed: COP of 3.37 W/W, based on a post-MEPS average efficiency for units with capacity of less than 4500 W that is calculated using rolled-up 2010 market shares of sales[1]. Calculated UEC of 126 kWh/unit/year.
- Variable-speed: SEER of 4.41 w-h/W-h, based on a post-MEPS average efficiency for units with capacity of less than 4500 W that is calculated using rolled-up 2010 market shares of sales. Calculated UEC of 96 kWh/unit/year.

[1] The rolled-up market shares assume that the share of products with efficiency below the revised MEPS requirement will be raised to just meet MEPS level and that shares of products exceeding the MEPS level will remain unchanged.

BAT Scenario:

- Fixed-speed: COP of 6.0 W/W based on engineered best available technology based on the best components available on the international market (Letschert et al. 2013). Calculated UEC of 71 kWh/unit/year.
- Variable-speed: SEER of 7.3 for China specifically based on engineered best available technology based on the best components available on the international market (Letschert et al. 2012). Calculated UEC of 58 kWh/unit/year.

2.4.2. Televisions

As with room air conditioners, future television sales are projected based on the household diffusion function with future household income as the main economic driver. Of the three main types of television technology – CRT, plasma and LCD-LED – we only considered LCD-LED technology in our analysis since that is the scope of the flat panel TV MEPS. Historical market shares of LCD-LED televisions were calibrated to data collected by DisplaySearch as reported in Park et al. 2011. Specifically, LCD-LED's share of the Chinese television market increased rapidly from 22% in 2007 to 91% in 2012. Future projections of LCD-LED televisions share reaching 100% in 2015 is based on feedback and discussion with CNIS researchers on the phase-out of plasma and CRT televisions.

For the television energy consumption, we assume that the market-average unit has a diagonal screen size of 40 inches with an average rated capacity of 100 W based on personal communication with researchers at China's Energy Research Institute (Personal communication ERI 2014). We assume that because of limited residential space in urban high-rise apartments, the average screen size will not grow significantly through 2030. The usage assumptions are also based on the 2012 residential household survey, which found average operating hours of 3.3 hours per day for televisions (Zheng et al. 2014). Televisions are assumed to be on standby for the remaining 20.7 hours per day.

In terms of energy efficiency, the average efficiency of LCD-LED televisions have improved significantly over the last five years both as a result of technological improvement as well as market transformation brought on by policies such as the efficient appliances subsidy programs. Similar to other residential appliances such as room air conditioners and clothes washers covered by the national subsidy programs that started in 2009 and continued through 2012, the model-weighted average energy efficiency index (EEI) of LCD-LED televisions increased substantially from 1.1 in the first quarter of 2011 to 1.8 in mid-2012 (Zheng et al. 2013). This is particularly evident in comparing the model-weighted and sales-weighted shares of Grade 1 televisions in early 2011 compared to mid-2012 when the new efficiency thresholds for high efficiency televisions were announced, as seen in Figure 3. After the public announcement of the two-tiered subsidy thresholds levels for high efficiency televisions in May 2012, with subsidies offered only for LCD-LED televisions with EEIs of 1.7 or 1.9 or greater, Grade 1 televisions dominated all television models entering the market and accounted for 81% of all LCD-LED television sales in mid-2012 (Zheng et al. 2013).

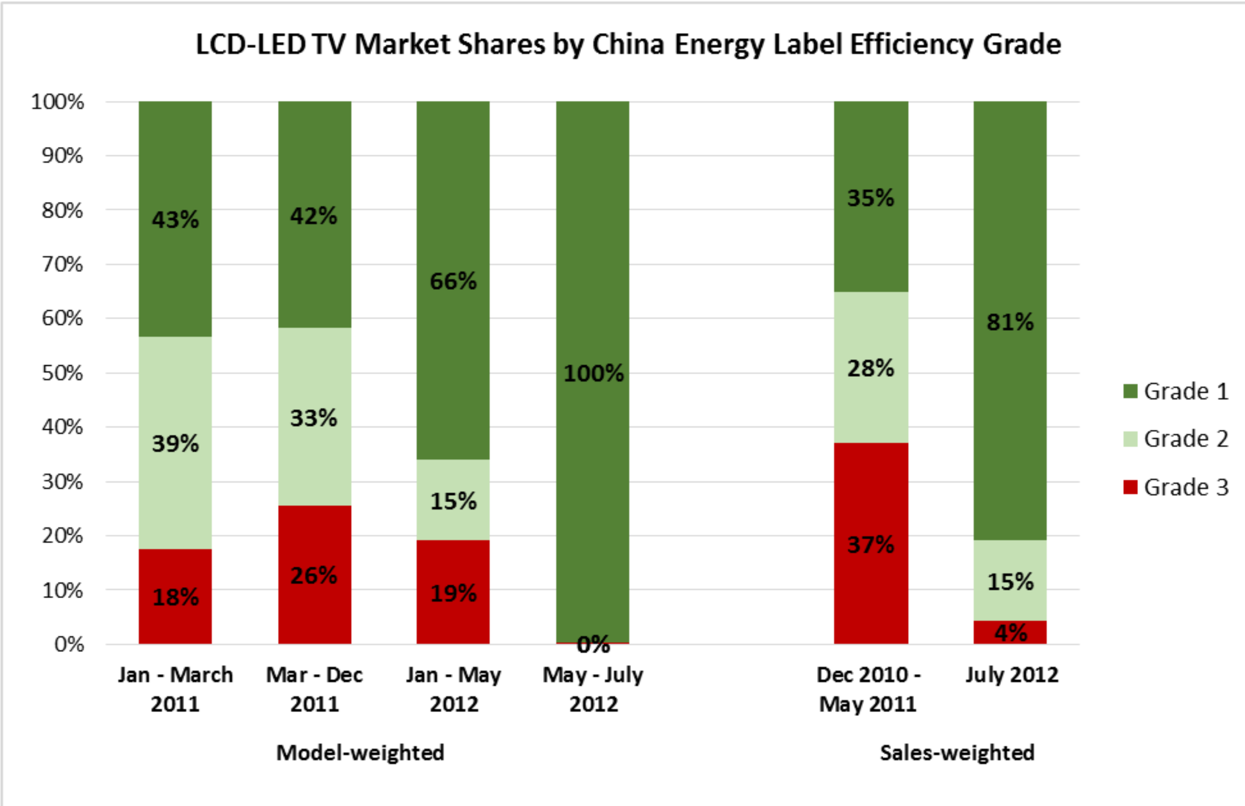

Figure 3. LCD-LED Television Model-Weighted and Sales-Weighted Efficiency Shares

Sources: Model-weighted and July 2012 sales-weighted shares data taken from Zheng et al. 2013 and Li et al. 2013. Dec. 2010 to May 2011 sales-weighted shares data from China Market Monitor, Ltd.

Unlike the other subsidized products, however, televisions are also unique in that the LED backlighting technology has also improved substantially, which is also reflected in the rising and dominating share of Grade 1 televisions in the market by early 2012. In terms of television sales, the market shares of Grade 1 and 2 efficient televisions increased quickly during this same period, albeit the efficient market shares for sales were slightly lower and lagged behind model-weighted shares. Nevertheless, Grade 3 televisions were pushed out from comprising one-third of total sales to only 4% of total sales by mid-2012.

LCD-LED televisions represent a unique case of rapid market transformation as a result of both policy and technological progress, where the market transformed so quickly that it overtook target MEPS efficiency levels by the time the revised MEPS has been implemented. As seen in Table 6, the model-weighted and sales-weighted EEI of televisions by mid-2012 had already surpassed the Grade 3 threshold and MEPS requirement that were implemented on October 1, 2013. This reduces the savings potential of the 2013 revised television MEPS, but also reflects the large potential impact of other market transformation policies of subsidies and energy labeling in moving the market.

Table 6. Comparison of Market Average EEIs and MEPS Requirements for LCD-LED Televisions

	2010 MEPS	2011	2012	2013 MEPS
Grade 1	1.4			2.7
Grade 2	1.0			2.0
Grade 3 /MEPS	0.6			1.3
Market-average model-weighted EEI		1.1	1.4	
Market-average sales-weighted EEI		0.99	1.31	

Note: 2011 and 2012 average EEIs calculated using 2010 MEPS efficiency thresholds for Grades 1 – 3.

In light of the rapid LCD-LED television market transformation and the available data on model-weighted and sales-weighted efficiency shares, we calculated a sales-weighted average EEI for the baseline scenario and used that to evaluate the potential savings from the revised MEPS requirement of 1.3 EEI.

The efficiency criteria and calculated UECs for the three scenarios are:

Baseline scenario:

- Active mode UEC: 120.4 kWh/unit/year based on 100W rated capacity and 2010 sales-weighted average EEI of 0.99
- Standby mode: standby power consumption of 1W as stated in the 2010 MEPS, standby UEC of 7.5 kWh/unit/year
- Total UEC of 128 kWh/unit/year

MEPS scenario:

- Active mode: energy consumption is assumed to improve by 24% based on the 24% improvement in EEI from 0.99 sales-weighted average in 2010 to the MEPS requirement of 1.3 in the 2013 revised MEPS. Active mode UEC is calculated to be 91.5 kWh/unit/year.
- Standby mode: standby power consumption of 0.5W as stated in the 2013 revised MEPS. Standby mode UEC of 3.8 kWh/unit/year.
- Total UEC of 95.3 kWh/unit/year

BAT scenario:

- Active mode: we make the conservative assumption that active mode stays the same as the MEPS scenario since LCD-LED televisions are already very efficient, and further significant efficiency improvements would require switching to a new technology such as organic LED televisions. Active UEC remains at 91.5 kWh/unit/year.
- Standby mode: standby power consumption is reduced to the best available technology of 0.1 W based on Letschert et al. 2012. Standby UEC of 0.76 kWh/unit/year.
- Total UEC of 92.3 kWh/unit/year

2.4.3. Television set-top box

In 2012, television set-top box sales reached 25 million units. We project that future sales will grow at 5% annually from 2012 through 2030 based on input from CNIS researchers. For 2010 base year sales, we backcasted sales from 2012 by also assuming a 5% annual growth rate from 2010 to 2012.

For calculating energy consumption, we only consider the base set and ignore additional added functions such as internet connectivity. The usage hours is assumed to be the same as televisions, with 3.3 hours of active use per day and 20.7 hours of standby per day. Both active and standby-mode are considered in calculating the UEC for the baseline and MEPS scenario:

Baseline scenario:

- Active mode: the 2010 pre-MEPS market-average active mode consumption of 12 W prior to the adoption of MEPS based on feedback from CNIS. Active mode UEC is calculated as 14 kWh/unit/year.
- Standby mode: assume that 2010 pre-MEPS standby power consumption is double the 2010 MEPS requirement of 3 W based on the trends of pre- and post-MEPS requirements for standby in other products.
- Total UEC: 60 kWh/unit/year

MEPS scenario:

- Active mode: 20% MEPS improvement from 2010 baseline to active mode consumption of 9.6 W based on CNIS input. Calculated active mode UEC of 12 kWh/unit/year.
- Standby mode: 3 W standby maximum power consumption for standby mode as stated in 2010 MEPS. Calculated standby mode UEC of 23 kWh/unit/year.
- Total UEC: 34 kWh/unit/year

2.4.4. Clothes washers

Total clothes washer sales are calibrated to 2012 using actual sales data reported in the CNIS White Paper (CNIS, various years). Future sales are back-calculated using a household diffusion function driven by household income. The total clothes washer sales are then divided into top-load (also known as vertical drum) and front-load (also known as horizontal impeller) washers based on their technology shares of the clothes washer market. In 2012, top-load clothes washers are reported to hold 57% of the clothes washer market in China, declining quickly from 84% share in 2009 (Evans 2014). We assume that by 2030, China's clothes washer market will closely resemble the European market, with front-load clothes washers dominating with 90% share of the market and top-load clothes washers with only 10% share (Hofman 2011).

Energy consumption for clothes washers is based on usage assumptions of 260 cycles per year with average load of 5 kilograms from previous MEPS analysis and the MEPS efficiency criteria of energy consumption per cycle per kg.

Baseline scenario:

- Top-load clothes washer: energy consumption of 0.02 kWh/cycle/kg based on the reported 2010 sales-weighted market average efficiency for top-load washers (CNIS 2012). This is significantly lower than the old 2004 MEPS energy limit of 0.032 kWh/cycle/kg. The baseline UEC is calculated to be 26 kWh/unit/year.
- Front-load clothes washer: energy consumption of 0.19 kWh/cycle/kg based on the reported 2010 sales-weighted market average efficiency for front-load washers (CNIS 2012). This is significantly lower than the old 2004 MEPS energy limit of 0.35 kWh/cycle/kg. The baseline UEC is calculated to be 247 kWh/unit/year.

MEPS scenario:

- Top-load clothes washer: energy consumption limit of 0.0199 kWh/cycle/kg based on a post-MEPS average efficiency that is calculated using rolled-up 2010 market shares of sales. Calculated UEC of 25.9 kWh/unit/year.
- Front-load clothes washer: energy consumption limit of 0.19 kWh/cycle/kg based on a post-MEPS average efficiency that is calculated using rolled-up 2010 market shares of sales. Calculated UEC of 247 kWh/unit/year.

BAT Scenario

- Front-load clothes washer: UEC of 92 kWh/unit/year based on China Energy Label Grade 1 average clothes washer found in the Chinese market in 2010 in McNeil et al. 2011.

2.4.5. External Power Supplies

In 2010, new external power supplies capacity totaled 10 million W (CNIS 2014). In order to estimate a total number of units of external power supplies, the total sales of 10 million W is divided by an assumed average unit rated capacity of 26 W based on findings from the 2005 Power Supply Global Testing study (Fridley et al. 2005). From 2010 to 2030, a constant average annual growth rate of 6% is assumed with external power supply sales growing from 385 million units in 2010 to 1018 million units in 2030. This 6% growth rate is lower than the average annual growth rate of 15% from 2007 to 2011, but results in a reasonable average ownership rate of 9 external power supplies per household in 2030.

Energy consumption for external power supplies take into consideration both active and standby modes. For active mode, we assume 8 hours of active mode usage based on feedback from CNIS. For standby mode, we assume the remaining 16 hours is in standby. This is likely to be an overestimate since the external power supplies may be unplugged for a portion of the non-active mode time.

Baseline scenario:

- Active mode: average rated capacity of 26 W per unit with 8 hours of active mode usage, resulting in active UEC of 76 kWh/year

- Standby mode: average standby mode power consumption of 0.75 W per unit from 2007 MEPS with 16 hours of standby mode, resulting in standby UEC of 4 kWh/year
- Total UEC: 80 kWh/unit/year

MEPS scenario:

- Active mode: 1% improvement in active mode power consumption based on feedback from CNIS with 8 hours of usage, resulting in active UEC of 75 kWh/unit/year
- Standby mode: standby mode power consumption of 0.3 W per unit in 2013 revised MEPS with 16 hours of standby mode, resulting in standby UEC of 2 kWh/unit/year
- Total UEC: 77 kWh/unit/year

BAT scenario:

- Active mode: same as MEPS scenario, active UEC of 75 kWh/unit/year
- Standby mode: standby mode power consumption reduce to 0.1 W per unit based on best available technology internationally for standby power consumption as reported in Letschert et al. 2012. Standby UEC of 0.6 kWh/unit/year
- Total UEC: 76 kWh/unit/year

2.4.6. Microwave

From 2008 to 2011, microwave sales in China grew from 14 to 16 million per year, with total reported sales of 15 million units in 2010 (CNIS, various years). Future microwave sales are expected to grow with the growth of urban population and households, and we assume a continuation of the 4% average annual growth rate experienced from 2008 to 2011 through to 2030.

For energy consumption, both active and standby mode power consumption are considered. In the absence of China-specific data, the hours of active mode use was taken from the assumed 71 hours per year usage used in the 2012 U.S. standard-setting analysis for microwaves (DOE 2013). The microwave is assumed to be on standby mode for the remaining 8689 hours per year.

Baseline scenario:

- Active mode: 2010 market average power consumption of 921 W per unit based on residential energy consumption survey (Zheng et al. 2014) with 71 hours per year. Active UEC of 65 kWh/unit/year
- Standby mode: standby power consumption of 1 W per unit based on doubling of new MEPS requirement following pre- and post-MEPS trends. Standby UEC of 9 kWh/unit/year
- Total UEC of 74 kWh/unit/year

MEPS scenario:

- Active mode: same as baseline UEC in the absence of information on active mode effciency improvement post-MEPS. Active UEC of 65 kWh/unit/year

- Standby mode: standby power consumption of 0.5 W per unit as specified in 2010 MEPS. Standby UEC of 4 kWh/unit/year
- Total UEC of 69 kWh/unit/year

2.4.7. Kitchen rangehood

In 2013, kitchen rangehood sales were reported to reach 13.25 million after growing at an annual average growth rate of 12.1% for the last 9 years (China Industry Research Network 2014). We back-calculated the 2010 sales to be 9.7 million using the 12.1% annual average growth rate. From 2013 to 2030, we assume that kitchen rangehood sales will grow at a slower average rate of 6% per year based on our previous 2011 analysis.

Energy consumption of kitchen rangehoods considers active use mode and off-mode. Kitchen rangehoods are assumed to be in active use mode for 0.5 hours per day based on the hours of usage of cook stoves and other kitchen equipment reported in the 2012 residential energy consumption survey (Zheng et al. 2014). The rangehoods are assumed to be in off-mode for the remaining 23.5 hours per day.

Baseline scenario:

- Active mode: 2010 market average active mode power consumption is assumed to be 200 W based on Chinese news reports (Beijing Business News 2014), resulting in active UEC of 36 kWh/unit/year
- Off-mode: the average off-mode power consumption is assume to be doubled the 2013 MEPS requirement for off-mode power consumption, or 3 W. The resulting off-mode UEC is 26 kWh/day.
- Total UEC of 62 kWh/unit/year.

MEPS scenario:

- Active mode: active mode power consumption is assumed to improve by 33% from 2010 baseline level to 134 W. This is based on the new MEPS requirement that the total pressure efficiency (全压效率) increase from reported 10% market average in 2010 to 15% in the new 2013 MEPS. Active UEC is calculated to be 24 kWh/unit/year.
- Off mode: Off-mode power consumption MEPS limit of 1.5 W is assumed as specified in the 2013 MEPS. Off-mode UEC is calculated to be 13 kWh/unit/year.
- Total UEC of 37 kWh/unit/year.

2.4.8. Heat pump water heater

Heat pump water heater sales in China in 2011 was only 460,000. However, rapid growth is expected as heat pump water heaters become more popular in China with water heating industry experts predicting annual average growth rates of 17% through 2018 (Gansu Jinchuan Solar Co. Ltd 2013). We assume that the 17% annual average growth rate will continue through 2030, reaching annual sales of 12.7 million by

2030 given China's large residential water heating market and trends of sustained growth in other heat pump water heater markets.

Energy consumption of heat pump water heater is calculated using the energy efficiency criteria of COP in W/W. The average unit is assumed to have a heating capacity of 5.5 kW based on the average size listed for residential heat pump water heaters manufactured by SIRAC Air Conditioning Equipment Co. Ltd, the top brand manufacturer in the Chinese market (SIRAC 2015). We only considered active mode energy consumption with active mode usage assumed to be 0.5 hours per day based on the residential energy consumption survey results reported in Zheng et al. 2014.

Baseline scenario:

- Pre-MEPS energy efficiency as measured by COP (W/W) is assumed to be 16.7% higher than the post-MEPS level, with a COP of 3.17. This is based on the efficiency improvement in SEER from 3 to 3.5 for the MEPS level from the 2008 to 2013 MEPS for heat pump variable speed air conditioners.
- Active mode UEC is calculated to be 317 kWh/unit/year.

MEPS scenario:

- 2013 MEPS requirement of COP of 3.7 W/W for the common category of normal style, once-through, circulation heating (普通型, 一次加热，循环加热) model
- Active mode UEC is calculated to be 271 kWh/unit/year

2.4.9. Solar Water Heater

As a technology that is intended to replace and substitute fossil fuel-based water heating technologies, solar water heaters do not directly save energy, but rather, is intended to displace other energy forms such as LPG, natural gas and electricity. As a result, a qualitative assessment of the 2011 MEPS was conducted rather than a quantitative evaluation of the energy savings potential.

China is the world's leading consumer of solar water heaters, with over 70% of global installed capacity in 2014 and accumulated installed area of 413 million m^2 in 2014 with a total capacity of 289.5 GW_{th} (REN21, 2015). Domestic demand for solar water heaters is primarily from residential households in suburban areas in large cities, small and medium-sized cities and towns with 90% combined market share. The annual installed area of solar water heaters in China exceeded 257 million m^2 in 2012 (Zhang et al. 2014), but fell to 52.4 million m^2 in 2014 (REN 21, 2015)

There are two main types of solar water heating technologies: flat plate collectors and evacuated tube collectors. In recent years, the Chinese market has been increasingly dominated by evacuated or vacuum tube system water heaters with a 35% market share in 1997 rising to a 95.4% market share in 2007 (Li and Hu, 2005; Han et al., 2010). China thus differs from the EU and other countries where flat plate collector systems dominate the solar water heating market with an 86% share in the EU. Compared to flat plate collectors, the evacuated vacuum tube system is more efficient in minimizing heat loss to the environment through a vacuum created between the two glass collector tubes. The average thermal conversion efficiency of solar water heaters is greater than 35% (Wei et al. 2014). The solar collector area ranges from 2 to 3 m^2 with typical water tanks having a total capacity of 150 to 200 liters and has a designed lifetime of 10 to 15 years.

According to data from the China National Accreditation Service for Conformity (CNAS), solar water heaters on the Chinese market already had relatively high coefficients of thermal performance ranging from 28% to over 60%, depending on the specific type of water heater design, prior to the introduction of the 2011 MEPS. Specifically, 54% of the market share already achieved Grade 1 or Grade 2 requirements for coefficient of thermal performance with only 46% of the market at the MEPS or Grade 3 level (CNAS 2014). After the introduction of MEPS, the market share of solar water heaters achieving Grade 1 requirements increased significantly from 21% to 69% (CNAS 2014). In addition to MEPS, policies including the national "Home Appliances to the Countryside" and "Benefits to the People" subsidies and local subsidies promoting solar water heaters have contributed significantly to increasing the share of Grade 1 and 2 solar water heaters. Some provinces such as Zhejiang province, a key production base responsible for over 20% of national production, have introduced local policies requiring the installation of solar water heaters in single-family homes as well as technical standards to control the performance quality and safety of solar water heaters (Han et al. 2010).

2.4.10. Computers

In this study, computers are divided into the two main technology categories of desktop computers and laptop computers. In 2012, annual sales of desktop computers reached 40 million while laptop sales reached 34 million (CNIS 2014). The sales of desktop computers are assumed to grow at an average rate of 1% per year through 2030 based on input from CNIS. Laptop sales, on the other hand, are assumed to grow at a slightly higher average rate of 3% per year through 2030 based on input from CNIS.

The assumed UECs of desktop and laptop computers were also based on input from CNIS.

Baseline Scenario:

- 250 kWh/unit/year for desktops and 70 kWh/unit/year for laptops

MEPS scenario:

- 10% improvement in UEC, resulting in 225 kWh/unit/year for desktops and 63 kWh/unit/year for laptops

2.4.11. Multi-functional imaging equipment

For copiers, printers and fax machines, the representative product category considered in this study is a color multifunctional copier, printer and fax machine. In 2012, the sales of multi-functional devices were

7.6 million according to CNIS and future growth of sales is expected to be relatively slow at an average rate of 2% annually through 2030.

The energy consumption assumptions for multifunctional copier, printer and fax machine takes into consideration the change in product classification in the newest 2014 MEPS. Specifically, copiers were previously covered separately as a single product category by a 2008 MEPS while printers and fax machines were covered by a 2010 MEPS. In 2014, these two product categories were merged into a single category of imaging equipment in the 2014 MEPS. This change in product categories impacts the assumed baseline UEC in this study.

Baseline scenario:

- UEC is calculated based on the 2010 market-average typical energy consumption of 10.19 kWh/unit/week as reported in the CNIS White Paper. The unit of typical energy consumption assumes 5 days of on-mode power consumption and 2 days of off-mode power consumption.
- Average annual UEC is calculated to be 530 kWh/unit/year.

MEPS scenario:

- Revised MEPS UEC is assumed to be 389 kWh/unit/year, based on CNIS input about the relative efficiency improvement of the 2014 MEPS.

2.4.12. Lighting products

As discussed in section 2.1, we consolidated the 8 MEPS adopted between 2010 and 2013 for lighting products into 1 major lighting category with the 3 key technologies of CFLs, linear fluorescents and LED lighting. Only the energy savings potential of CFLs and linear fluorescents are quantified, since LED is a new and quickly evolving technology that makes it very difficult to define a 2010 market average baseline to measure against the 2013 MEPS requirements.

Both CFL and linear fluorescent light bulbs are assumed to be used 1240 hours per year based on our communication with CNIS. In addition, we assume that the average demand for lighting output is 900 lumens. The UEC can then be calculated by dividing the average lumens per watt for the lightbulb by 900 lumens, and multiplying the total watts needed by 1240 hours per year.

CFLs are projected to grow from a total stock of 1202 million lightbulbs in 2010 to 4351 million lightbulbs in 2030 based on household saturation forecasts, with an average of 9 CFL per household by 2030. Linear fluorescents are projected to grow from a total stock of 572 million bulbs to 1088 million bulbs in 2030 based on household saturation forecasts, with an average of 2 linear fluorescents per household. The household saturation forecasts are based on the complete phase-out of incandescent lightbulbs by 2020 due to ongoing implementation of the Incandescent Lightbulb Ban. We also assume rising market shares of LEDs to 50% by 2020, with CFLs as the remaining share. The same stock projections are used for all scenarios.

For defining the baseline average and MEPS lighting efficacy, we considered the average lightbulb to be the most common category of 9-14 W lightbulbs. We also looked at the efficacy requirements for lightbulbs under the RR, RZ color hue.

Baseline scenario:

- CFL: 2010 sales-weighted market average of 55.1 lm/W (CNIS, 2011), or calculated UEC of 20.3 kWh/bulb/year.
- Linear Fluorescent: 2003 MEPS requirement of 53 lm/W in the absence of sales-weighted data, or calculated UEC of 21.1 kWh/bulb/year.

MEPS scenario:

- CFL: 53 lm/W based on 2013 MEPS requirement of 48-53 lm/W for the most common bin of 9-14 W lightbulbs. Calculated UEC of 21.1 kWh/bulb/year.
- Linear Fluorescent: 2013 MEPS requirement remains at 53 lm/W

BAT scenario:

- CFL: 60 lm/W for good quality CFLs based on analysis in Letschert et al. 2012. Calculated UEC of 18.6 kWh/bulb/year.

2.4.13. Three-phase distribution transformers

The estimated total stock of three-phase distribution transformers is calculated based on projections of China's total electricity generation from the Reference Scenario of the bottom-up energy end-use outlook collaborative study, Reinventing Fire: China, conducted jointly with China's Energy Research Institute and the U.S. Rocky Mountain Institute. The underlying assumption is that all generated electricity will pass through distribution transformers. The total stock of transformer units is then divided into the two major types of oil-filled and dry-type transformers, with the share of oil-filled transformers assumed to remain at the historical level of 56% through 2030. Within these two categories, the stock of transformer units are further sub-divided into the major size categories of 50 kVA, 160 kVA, 400 kVA, 630 kVA, 1250 kVA and 2000 kVA using constant market shares derived from historical data on the total capacities for each size category and average capacity. Table 7 shows the resulting projected stock of distribution transformers by type and size category.

Table 7. Projected Stock of three-phase Distribution Transformers by Type and Size Category for Key Years, 2010 - 2030

Unit: millions	2010	2015	2020	2025	2030
Oil Type - 50 kVA	1.68	2.19	2.95	3.67	4.37
Oil Type - 160 kVA	2.92	3.95	5.32	6.62	7.88
Oil Type - 400 kVA	1.31	1.74	2.34	2.91	3.47
Oil Type - 630 kVA	0.59	0.79	1.07	1.33	1.58
Oil Type - 1250 kVA	0.41	0.57	0.76	0.95	1.13

Oil Type - 2000 kVA	0.10	0.15	0.20	0.24	0.29
Dry Type - 50 kVA	0.20	0.27	0.37	0.46	0.54
Dry Type - 160 kVA	0.45	0.62	0.83	1.03	1.23
Dry Type - 400 kVA	0.44	0.62	0.84	1.04	1.24
Dry Type - 630 kVA	0.46	0.62	0.83	1.03	1.23
Dry Type - 1250 kVA	0.66	0.80	1.07	1.34	1.59
Dry Type - 2000 kVA	0.12	0.15	0.20	0.25	0.29

To calculate the unit energy consumption of distribution transformers, additional assumptions were made about the load factor and hours of operation. We assumed a constant load factor of 0.5 and 8760 annual operating hours. The UEC can then be calculated as a function of no-load loss, load loss and load factor. In order to determine the appropriate load and no-load losses for each size category, the transformers have to be further broken out into different efficiency shares of S9, S10, S11, S12, S13 and SH15. The baseline efficiency of distribution transformers is defined as the 2006 MEPS requirement by the "S9" specification, while the revised 2013 MEPS efficiency is defined by the "S11" specification for oil-type transformers and by the "S10" specification for dry-type transformers. Historical sales shares for these different efficiency classes from 2006 to 2009 were obtained from online market research data and from 2010 to 2012 were obtained from the CNIS White Papers (CNIS, various years).

As seen in Figure 4, the market efficiency of dry-type and oil-filled distribution transformers improved rapidly, with the S9 class corresponding to the 2006 MEPS efficiency pushed out of the market in 2012 for both types of transformers. For oil-filled transformers, the S11 class (corresponding to the revised 2013 MEPS efficiency levels) share of all sales already reached 84%, suggesting that the vast majority of the market was already at or above the revised MEPS level prior the MEPS implementation in October 2013.

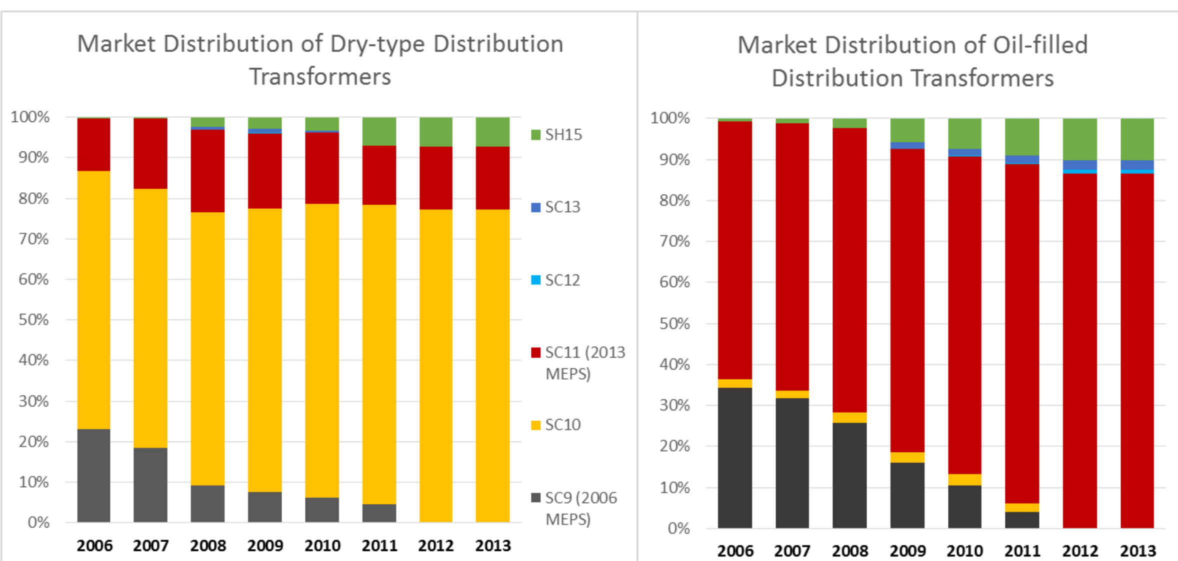

Figure 4. Market Distribution of three-phase Dry-type and Oil-filled Distribution Transformers by Efficiency Class

Sources: All China Marketing Research, 2010; CNIS, various years.

The three scenarios of Baseline, MEPS and BAT are then defined as:

Baseline scenario:

- The baseline scenario takes into account the trend in the market of transformers meeting or exceeding the MEPS level of S11 or S10. This trend is extrapolated till the entire market reaches the MEPS level and then frozen. Market shares of efficiency categories within the broader "below MEPS" or "at or above MEPS" categories are held constant.

MEPS scenario:

- Efficiency market shares follow the baseline scenario till the MEPS year, after which the share of "at or above MEPS" is held constant at 100%. Market shares within efficiency categories meeting the MEPS are held constant.

BAT scenario:

- SH15 for oil-type transformers and SCH15 for dry-type transformers.

2.4.14. Small and medium three-phase asynchronous motors

To calculate the stock of the three-phase asynchronous motors, we used the projected total electricity use of motors in individual industrial subsectors from the bottom-up energy end-use model developed as part of the Reinventing Fire: China study. More specifically, the electricity use of motors in each of 14 specific industrial subsectors were calculated using the Reinventing Fire: China analysis's projected total electricity consumption for each specific subsector multiplied by the motors systems' share of electricity use for each specific subsector. Each industrial sector's projected electricity consumption is based a bottom-up analysis with physical and/or economic drivers of energy use and sector-specific fuel mix. The motors systems' electricity use as a share of total electricity use in each industrial sector is taken from U.S. Department of Energy data and used as an international proxy for China as seen in Figure 5.

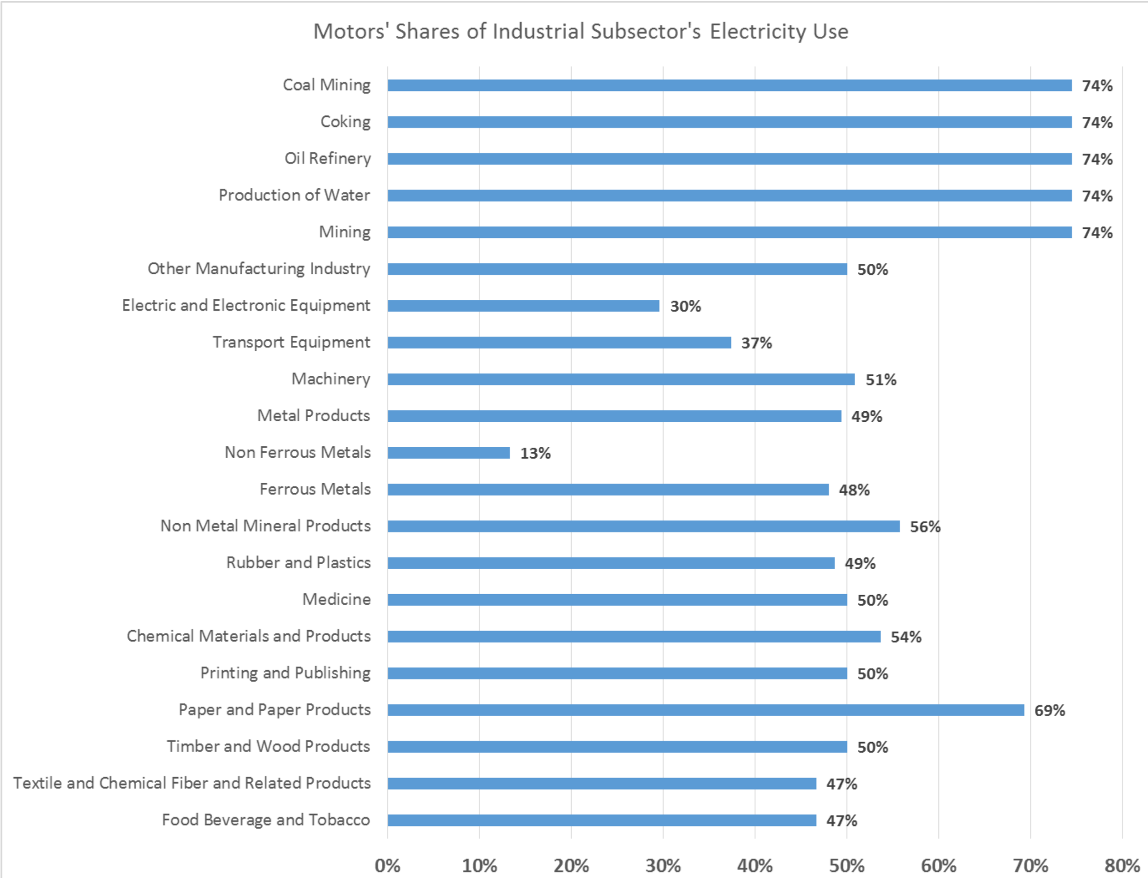

Figure 5. Comparison of Assumed Motors' Share of Industrial Subsector Electricity Use

Electric motors' total electricity consumption are then divided into three classes of motors by class, including 0.75 to 10 kW rated capacity, 10 to 100 kW rated capacity and greater than 100 kW capacity, based on European data on the shares of electricity consumption for each of these three size categories. The installed capacities of each of these three size classes are then back-calculated by dividing the motors' total electricity consumption by the average hours of operation for each class size, which is again taken from European data (Almeida et al. 2006). Table 8 shows the projected installed motor capacities by motor size bins.

Table 8. Installed Motor Capacities by Motor Size Bins for Selected Years, 2010 - 2030

	Assumed Annual Hours of Use	Installed Motor Capacity (GW)				
	hours/year	2010	2015	2020	2025	2030
0.75 - 10 kW	2500	74	106	142	172	199
10 - 100 kW	4000	123	177	237	286	331
>100 kW	7000	79	114	152	184	213

Lastly, the rated capacities for each class size is divided by an average, representative "unit" with rated capacity of 1.1 kW, 11 kW and 110 kW for the three class sizes to calculate the total stock of motors units in each class as shown in Table 9.

Table 9. Estimated Motors Stock by Motor Size Bins for Selected Years, 2010 – 2030

	Assumed Average Unit Size	Estimated Stock of Motors (million units)				
	kW/unit	2010	2015	2020	2025	2030
0.75 - 10 kW	1.1	67.2	96.3	129.1	156.1	180.5
10 - 100 kW	11	11.2	16.1	21.5	26.0	30.1
>100 kW	110	0.7	1.0	1.4	1.7	1.9

For the efficiency improvement, the 2006 and 2012 MEPS were referenced and the minimum efficiency criteria for a 4-pole electric motors for the representative capacities of 1.1 kW, 11 kW and 110 kW were used as the baseline and MEPS efficiency criteria, respectively. The BAT efficiencies for these three size categories of motors were taken from international best available technologies. Table 10 compares the efficiencies and subsequent average UECs for the three class sizes of motors under the three scenarios.

Table 10. Electric Motors Average Efficiency and UEC by Capacity Size and Scenario

	Motors' Efficiency			Motors UEC (kWh/unit/year)		
	Baseline (2006 MEPS)	***2012 MEPS***	***BAT***	***Baseline (2006 MEPS)***	***2012 MEPS***	***BAT***
0.75 - 10 kW	76.2%	81.4%	86%	2,750	2,574	2,354
10 - 100 kW	88.4%	89.8%	93%	44,000	43,314	40,943
>100 kW	94.5%	94.5%	98%	770,000	770,000	757,969

2.5. CO_2 Emissions Calculations

The CO_2 emissions results are calculated from the electricity results by multiplying kWh consumed by a dynamic, projected CO_2 emissions factors for electricity that take into consideration China's evolving fuel mix for the power sector. Specifically, the projected emissions factors shown in Table 11 below are taken for a reference scenario of development in the power sector, which represents case in which only policies in 2010 (including the announced renewable capacity targets) continue to have effect and autonomous technological improvements (e.g., incremental efficiency improvements in coal-fired generation) occurs, from the recently completed Reinventing Fire: China 2050 study. By 2030, 27% of China's projected electricity generation is expected to be from renewable power with additional 9% from nuclear power.

Table 11. Projected CO_2 Emissions Factors for Electricity

	2010	2015	2020	2025	2030
Electricity CO_2 Emissions Factor (kg CO2/kWh)	0.75	0.68	0.67	0.64	0.61

3. Results

The energy and CO_2 emissions results of this analysis are presented in two sections. In the first section, the total electricity savings and CO_2 emissions reduction of the MEPS scenario relative to the baseline scenario are presented for all 14 product categories examined. In the second section, the electricity savings and CO_2 emissions reductions of the BAT scenario relative to the baseline and MEPS scenarios are presented for the subset of products for which targets can be established using international BAT efficiency levels. These savings potential are intended to represent the remaining efficiency gap between the latest MEPS and international BAT levels.

3.1. MEPS Scenario Savings

3.1.1. Potential Electricity Savings

The one-time adoption of the 23 new or revised MEPS from 2010 to 2013 for the 14 categories of products evaluated in this study could reduce cumulative electricity consumption by 1517 TWh between 2010 and 2030 compared with the baseline scenario without these new or revised MEPS. Table 12 shows the annual potential electricity savings for key years as well as the cumulative potential electricity savings from 2010 to 2030 for each product category.

Table 12. Annual Electricity Savings under MEPS Scenario, in TWh (Baseline Minus MEPS Scenario)

	2010	2015	2020	2025	2030	Cumulative
Room AC: Fixed Speed	0.1	0.3	0.3	0.1	0.0	4.0
Room AC: Variable Speed	0.0	0.8	3.2	5.2	6.3	64.4
TV	0.0	5.6	14.0	17.2	18.1	235.8
Clothes Washers: Front Load	0.0	0.0	0.0	0.0	0.0	0.0
Clothes Washers: Top Load	0.0	0.0	0.0	0.0	0.0	0.3
CFLs	0.0	0.0	0.0	0.0	0.0	0.0
Linear Fluorescent Lamps	0.0	0.0	0.0	0.0	0.0	0.0
Refrigerators	0.0	0.0	0.0	0.0	0.0	0.0
Small Motors	0.0	5.8	16.5	25.9	31.6	333.4
Medium Motors	0.0	3.0	8.8	15.1	19.9	192.5
Large Motors	0.0	0.0	0.0	0.0	0.0	0.0
External Power Supplies	0.0	4.8	10.5	13.0	15.8	186.3
Microwave	0.1	0.4	0.7	0.8	1.0	13.0
Copier Printer and Fax Machine	0.0	2.3	8.0	12.4	14.5	155.3
Desktop Computer	0.0	3.9	5.8	6.1	6.4	98.2

Laptop Computer	0.0	1.0	1.5	1.8	2.1	27.5
Kitchen rangehood	0.0	1.1	3.6	6.3	9.0	80.5
Heat pump water heaters	0.0	0.1	0.4	0.9	2.0	12.0
Set-top box	0.6	3.4	4.7	5.9	7.6	95.0
Distribution Transformers	0.6	0.8	1.0	1.0	0.8	18.9
Total	***1.3***	***33.4***	***78.9***	***111.8***	***135.1***	***1517.2***

As seen in Figure 6, televisions and electric motors are the two largest contributors to electricity savings under the MEPS scenario of all the products evaluated, together accounting for half and 52% of the annual electricity savings in 2020 and 2030, respectively. Small motors alone account for nearly one-quarter of the annual electricity savings because of the large stock of small motors and the large absolute unit energy savings between the old and revised MEPS. Despite a lower absolute unit energy savings under the revised MEPS when compared to the 2010 weighted-average market efficiency, televisions still hold relative large energy savings potential as a result of having the largest projected sales amongst all residential and commercial equipment. In cumulative terms, the total reduction from the revised motors standard amounts to 333 TWh for small motors and 193 TWh for medium motors, while the revised standard for flat panel televisions could save 234 TWh from 2010 to 2030. The top five products combined accounts for 74% of annual electricity savings in 2030.

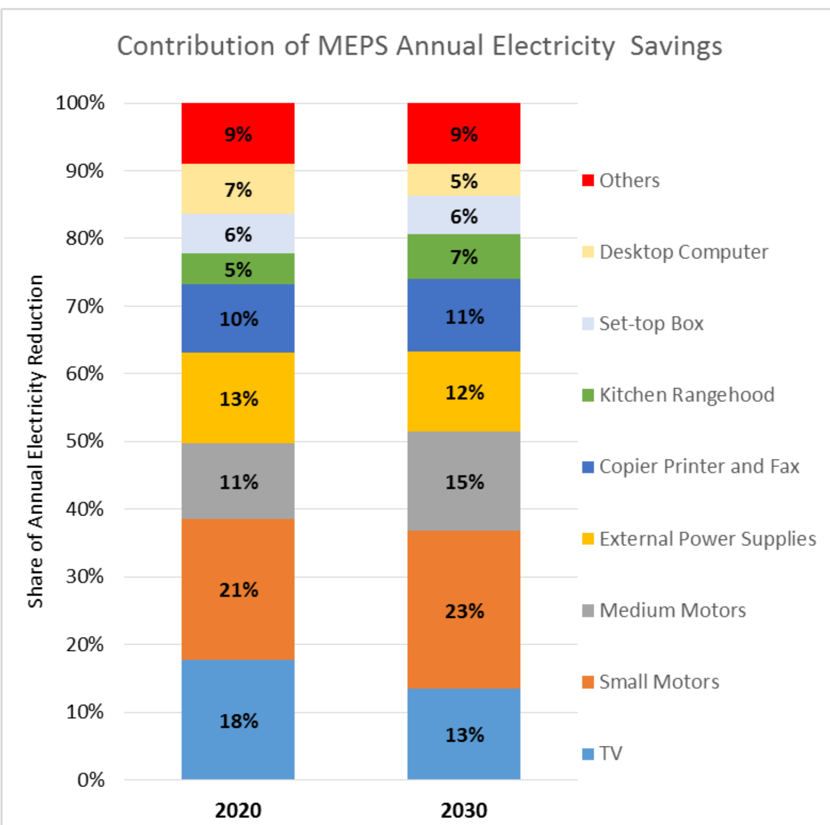

Figure 6. Contribution of MEPS Annual Electricity Savings by Product

Note: Others include fixed speed and variable speed room AC, top-load clothes washers, microwave, laptop computer and heat pump water heaters, distribution transformers. No savings for CFL, front-load clothes washer and refrigerators.

This finding is similar but also different from our previous 2011 analysis, which identified motors and air conditioners (not televisions) as the top two products with the greatest savings potential. In this updated analysis, the savings potential from the variable-speed room air conditioners MEPS is much smaller with annual savings of only 6 TWh in 2030, although savings grow over time as the market share of variable-speed room air conditioners increase. Variable air conditioners achieve cumulative savings of 64 TWh, or only 4% of the total cumulative electricity savings from MEPS. Savings from fixed-speed room air conditioners decline over time as fixed-speed room air conditioners are phased out of the market and replaced by more variable-speed room air conditioners.

The significantly lower electricity savings potential from the revised MEPS for fixed-speed and variable-speed room air conditioners can be attributed to the relatively high sales-weighted market average baseline efficiency in 2010, which in turn can be traced back to the impact of the high efficient room air conditioners subsidy program that was launched in June 2009. Corresponding to the duration of the subsidy program, the share the most efficient Grade 1 and efficient Grade 2 variable-speed room air conditioners of total models on the market increased from only 17.5% in 2008 to 59% in 2009 (CNIS 2010). In addition, this study only considered energy savings in cooling.

Figure 7 shows that in 2030, annual electricity savings from the one-time implementation of these MEPS would be equivalent to the output of 28 1-GW typical coal-fired power plants and 1.3 times the annual generation output of the Three Gorges Dam.

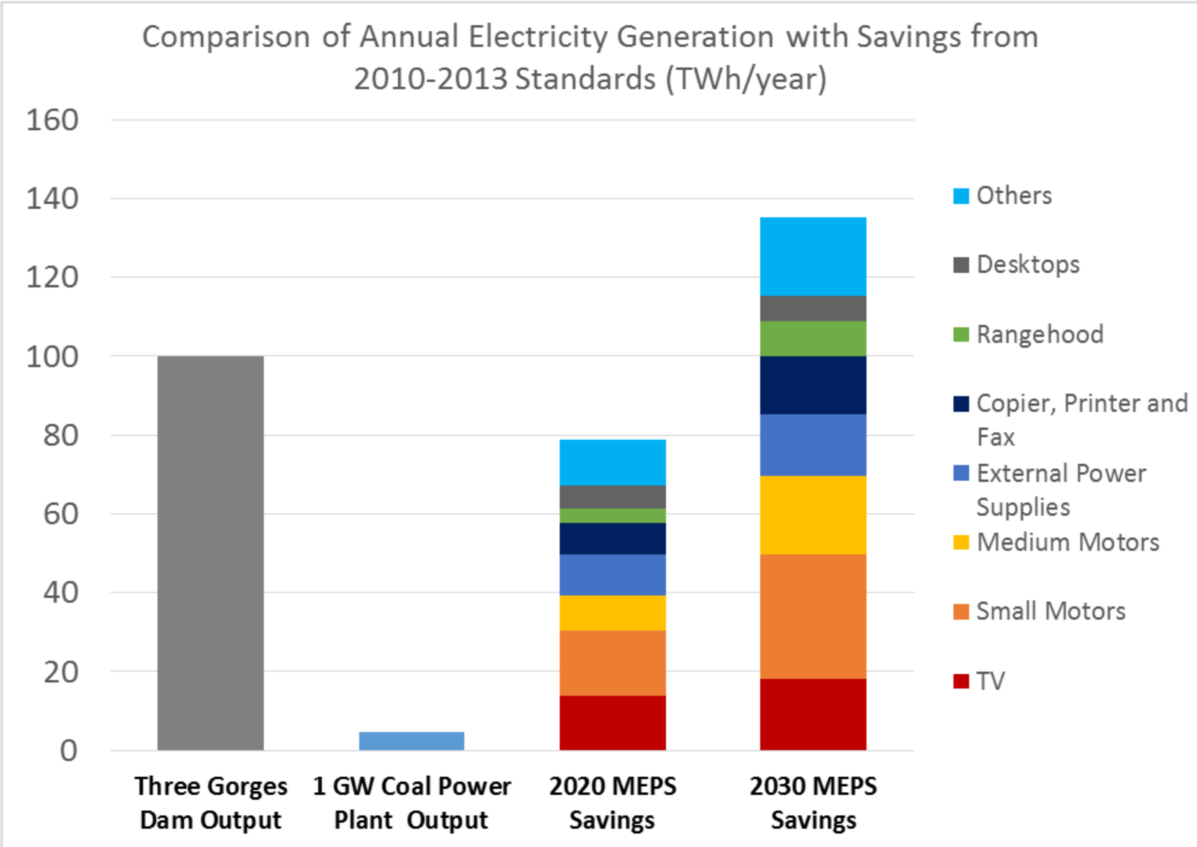

Figure 7. Comparison of MEPS Annual Electricity Savings with Supply-side Power Generation Output

Note: Others include fixed speed and variable speed room AC, top-load clothes washers, microwave, laptop computer and heat pump water heaters, distribution transformers. No savings for CFL, front-load clothes washer and refrigerators.

3.1.2. Potential CO_2 Emissions Reductions

Over the period of 2010 through 2030, these electricity savings would result in cumulative CO_2 emissions reduction of over 1.5 billion tonnes. In 2030, annual CO_2 emissions could be reduced by 130 Mt CO2 as a result of the electricity savings achieved by the one-time adoption of new or revised MEPS between 2010 and 2013 as seen in Table 13 and Figure 8.

Table 13. Annual CO_2 Emissions Reductions under MEPS Scenario, in Mt CO_2 (Baseline Minus MEPS Scenario)

	2010	2015	2020	2025	2030	Cumulative
Room AC: Fixed Speed	0.1	0.3	0.3	0.1	0.0	4.1
Room AC: Variable Speed	0.0	0.9	3.2	5.1	6.0	63.8
TV	0.0	5.9	14.2	16.9	17.4	235.0
Clothes Washers: Front Load	0.0	0.0	0.0	0.0	0.0	0.0

Clothes Washers: Top Load	0.0	0.0	0.0	0.0	0.0	0.3
CFLs	0.0	0.0	0.0	0.0	0.0	0.0
Linear Fluorescent Lamps	0.0	0.0	0.0	0.0	0.0	0.0
Refrigerators	0.0	0.0	0.0	0.0	0.0	0.0
Small Motors	0.0	6.1	16.7	25.6	30.3	330.9
Medium Motors	0.0	3.2	9.0	14.9	19.1	190.7
Large Motors	0.0	0.0	0.0	0.0	0.0	0.0
External Power Supplies	0.0	5.0	10.7	12.8	15.1	185.6
Microwave	0.1	0.4	0.7	0.8	1.0	13.0
Copier Printer and Fax Machine	0.0	2.4	8.2	12.3	13.9	154.0
Desktop Computer	0.0	4.1	5.9	6.0	6.2	98.5
Laptop Computer	0.0	1.0	1.6	1.8	2.0	27.5
Kitchen rangehood	0.0	1.2	3.6	6.2	8.6	79.6
Heat pump water heaters	0.0	0.1	0.4	0.9	1.9	11.8
Set-top box	0.6	3.6	4.7	5.9	7.3	95.2
Distribution Transformers	0.6	0.9	1.1	1.0	0.7	19.1
Total	***1.4***	***35.0***	***80.2***	***110.3***	***129.5***	***1,509.2***

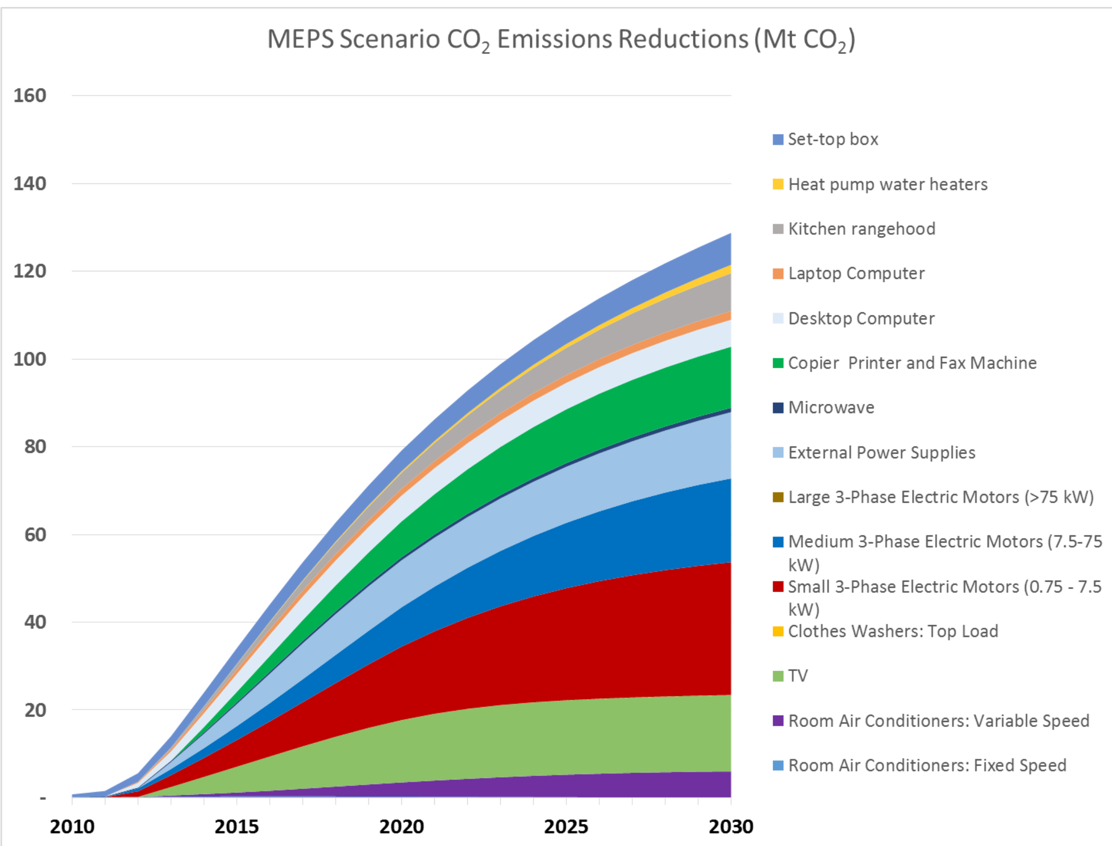

Figure 8. Annual CO_2 Emissions Reduction under MEPS Scenario (Baseline Minus MEPS Scenario)

3.2. BAT Scenario Savings

3.2.1. Potential Electricity Savings

Table 14 shows that in a BAT scenario in which MEPS for 11 selected products would reach the current international BAT levels of efficiency by 2015, the total cumulative reduction in electricity consumption by 2030 would reach 4817 TWh compared to the baseline scenario without new or revised MEPS after 2010. In 2030, annual electricity savings would be equivalent to the output of 100 1-GW typical coal-fired power plants.

Table 14. Annual Electricity Savings under BAT Scenario, in TWh (Baseline Minus BAT Scenario)

	2010	2015	2020	2025	2030	Cumulative
Room AC: Fixed Speed	0.1	1.0	1.3	0.9	0.3	17.4
Room AC: Variable Speed	0.0	2.0	12.4	21.9	27.3	261.4
TV	2.8	11.1	16.9	18.9	19.9	304.8
Clothes Washers: Front Load	0.0	3.5	24.9	46.1	61.1	550.4
CFLs	0.0	7.6	49.5	66.9	88.1	880.8
Refrigerators	20.3	25.5	29.3	31.1	32.4	589.8
Small Motors	0.0	7.7	30.9	54.7	70.4	672.1
Medium Motors	0.0	5.6	29.6	58.9	84.7	715.7
Large Motors	0.0	0.6	5.1	11.0	17.6	133.8
External Power Supplies	0.0	5.5	14.3	17.8	21.7	249.6
Distribution Transformers	0.6	2.7	16.4	35.6	58.7	441.6
Total	***23.7***	***72.8***	***230.5***	***363.9***	***482.1***	***4817.4***

Of the reduction from adopting international BAT efficiencies as the new MEPS for these 11 key products, the motors and CFL standards dominates the reduction potential as shown in Figure 9, accounting for 33% and 18% of the annual electricity savings potential in 2030, respectively. The large magnitude of savings from adopting BAT efficiency levels for CFLs are notable given that the newest MEPS achieved negligible electricity savings since the 2010 market-average baseline was already very high. This result suggests that the CFL standard could be tightened significantly, as there is still a very large efficiency gap between the current market average and most recent MEPS requirement and the international BAT levels. Despite having the second largest savings potential under the MEPS scenario, motors also have very large savings potential under the BAT scenario when compared to the MEPS scenario. This illustrates that motors are another product where there is still a large gap between the current MEPS level and the current international BAT level. Another big contributor under the BAT scenario is front-load clothes washers but not top-load clothes washers, which are already very efficient in the Chinese market and are expected to be phased out and replaced by top-load clothes washers over the next fifteen years. Televisions, external power supplies, refrigerators and variable-speed room air conditioners are other products with large BAT scenario savings potential.

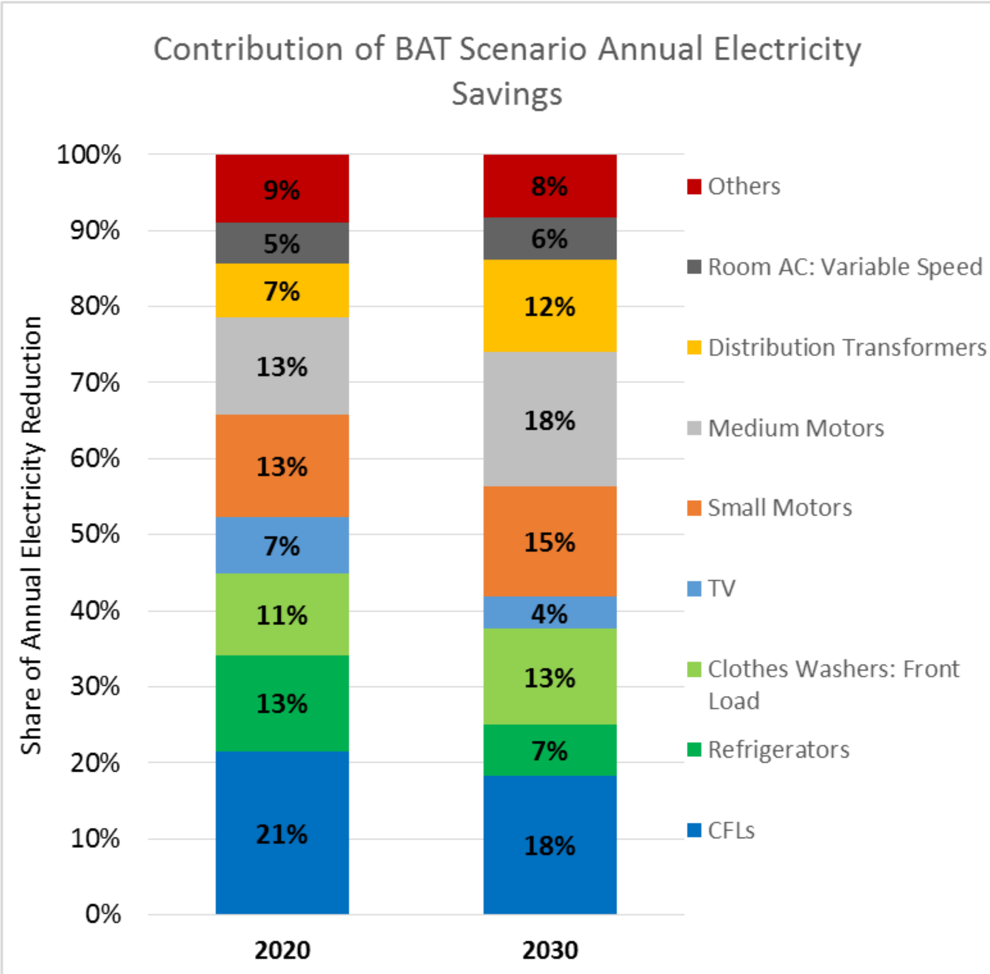

Figure 9. Contribution of BAT Annual Electricity Savings by Product

Note: Others include fixed-speed room ACs, external power supplies, and large motors

Figure 10 shows that by 2030, the annual electricity consumption for 10 selected products (excluding refrigerators since the MEPS has not been finalized at the time of analysis) in the MEPS scenario would reach 4444 TWh, consuming 92 TWh less than the Baseline Scenario. In contrast, annual electricity consumption in the BAT scenario would reach 4054 TWh in 2030, or additional savings of 492 TWh compared to the MEPS scenario. This suggests that adopting the international BAT efficiency levels for these 10 selected products could save more than five times the electricity saved from the newest MEPS adopted from 2010 to 2030. Table 15 shows that the largest untapped savings potential beyond current MEPS levels are in motors, CFLs, and distribution transformers.

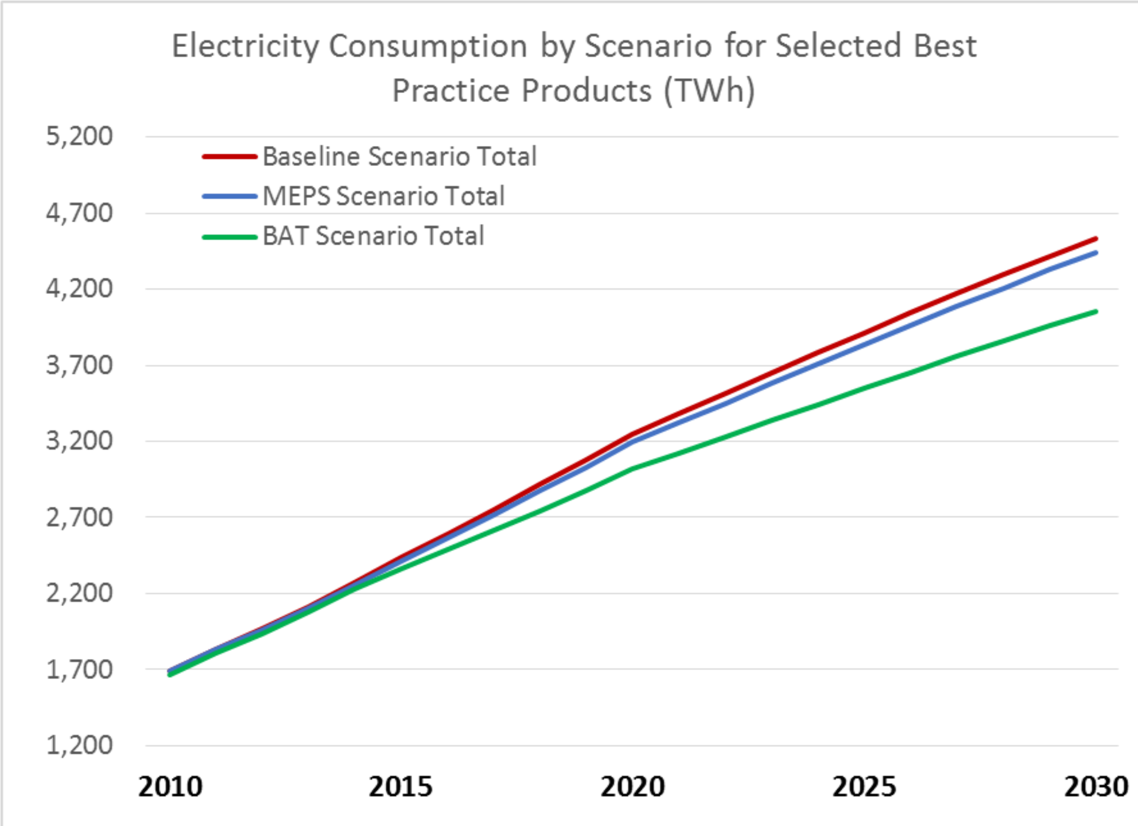

Figure 10. Comparison of Total Electricity Consumption for Selected BAT Products

Note: Y-axis not scaled to zero. Refrigerators excluded from this chart.

Table 15. Annual Electricity Savings Potential under BAT Scenario Beyond Current MEPS Levels, in TWh (MEPS Scenario Minus BAT Scenario)

	2010	2015	2020	2025	2030	Cumulative
Room AC: Fixed Speed	0.0	0.7	1.1	0.8	0.3	13.3
Room AC: Variable Speed	0.0	1.1	9.2	16.7	21.0	197.0
TV	2.8	5.5	2.9	1.7	1.8	69.0
Clothes Washers: Front Load	0.0	3.5	24.9	46.1	61.1	550.4
CFLs	0.0	7.6	49.5	66.9	88.1	880.8
Small Motors	0.0	1.8	14.4	28.8	38.8	338.8
Medium Motors	0.0	2.6	20.8	43.8	64.8	523.2
Large Motors	0.0	0.6	5.1	11.0	17.6	133.8
External Power Supplies	0.0	0.7	3.7	4.9	5.9	63.3
Distribution Transformers	0.0	1.9	15.3	34.6	57.9	422.7
Total	***2.8***	***26.0***	***146.9***	***255.2***	***357.3***	***3192.4***

Note: refrigerators savings are not included because MEPS levels have not been finalized.

3.2.2. Potential CO_2 Emissions Reductions

Over the period from 2010 to 2030, the electricity savings achieved from adopting BAT efficiency levels for the 11 selected products would translate into cumulative reduction of nearly 4.8 Bt CO_2 relative to the Baseline Scenario. As seen in Table 16 and Figure 11, annual CO_2 emissions reductions could grow from only 76 Mt CO_2 in 2015 to 462 Mt CO_2 in 2030 with the largest reduction potential coming from CFLs, motors and refrigerators.

Table 16. Annual CO_2 Emissions Reductions under BAT Scenario, in Mt CO_2 (Baseline Minus BAT Scenario)

	2010	2015	2020	2025	2030	Cumulative
Room Air Conditioners: Fixed Speed	0.1	1.0	1.4	0.9	0.3	17.6
Room Air Conditioners: Variable Speed	0.0	2.1	12.6	21.6	26.2	258.4
TV	3.0	11.6	17.2	18.6	19.1	306.1
Clothes Washers: Front Load	0.0	3.7	25.3	45.5	58.6	543.5
Refrigerators	21.8	26.7	29.7	30.7	31.0	597.0
CFLs	0.0	7.9	50.3	66.1	84.5	872.8
Small Motors	0.0	8.0	31.4	54.0	67.4	665.0
Medium Motors	0.0	5.9	30.1	58.1	81.2	706.3
Large Motors	0.0	0.7	5.2	10.9	16.9	131.8
External Power Supplies	0.0	5.7	14.5	17.6	20.8	248.4
Distribution Transformers	0.6	2.9	16.6	35.1	56.2	435.1
Total	***25.6***	***76.1***	***234.2***	***359.1***	***462.1***	***4782.0***

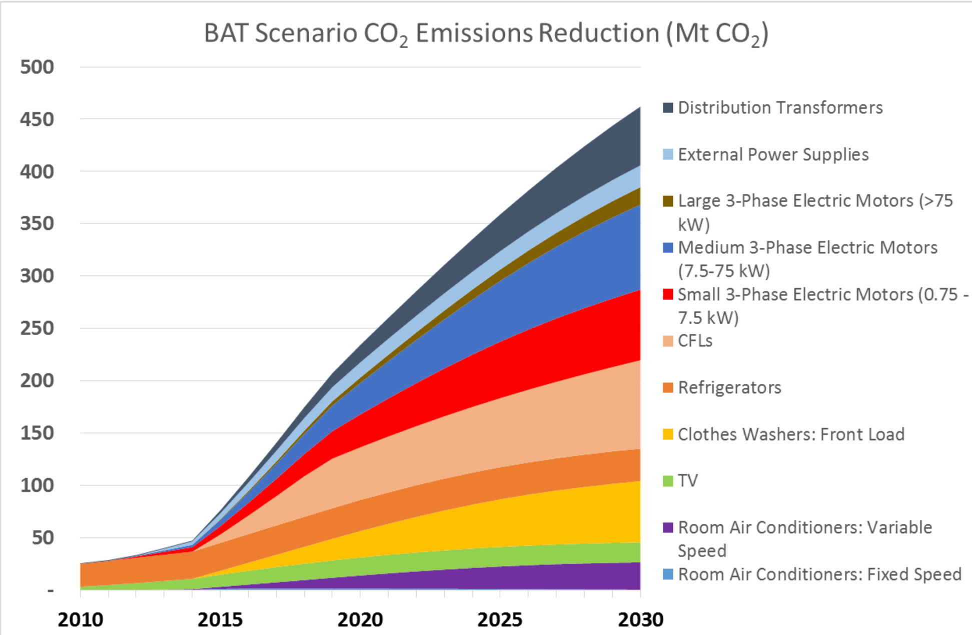

Figure 11. BAT Scenario CO_2 Emissions Reductions (Baseline minus BAT Scenario)

4. Key Findings and Implications

We find that of the 23 new or revised MEPS adopted by China between 2010 and 2013, electric motors and televisions have the largest energy and CO_2 reduction potential. Motors have significant improvement potential because it is a very energy-intensive type of equipment used by all industrial subsectors where overall efficiency is still relatively low. The revised 2012 MEPS helped raise the minimum efficiency of small and medium motors, resulting in energy savings potential of over 50 TWh annually in 2030 and 525 TWh cumulatively from 2010 to 2030. The full realization of this savings potential will depend on full enforcement of the motors MEPS, which has been more difficult to achieve not only in China, but also internationally. Televisions and external power supplies are two other products that had relatively large energy savings potential, likely the result of rapidly growing demand and sales as the incremental efficiency gain and UEC reduction is smaller. As two major consumer electronic products, the expected fast growing sales forecast for both televisions and external power supplies reflect consumer preferences and rapid technological changes in the consumer electronics market. Televisions have fast turnover with new television replacements outpacing retirements because of consumer preferences for newer technologies and features. The rapid improvement in LCD-LED backlighting for televisions and faster than expected market uptake of more efficient televisions – likely driven by the high efficiency appliance subsidy program - are reflected in market average efficiency outpacing the MEPS threshold in the 2013 revised MEPS despite only a three-year interval between MEPS revisions.

Of the 12 revised MEPS adopted between 2010 and 2013, some revised MEPS actually had limited or no impact on energy savings and CO_2 emissions reduction, including for CFLs, front-load clothes washers, fixed-speed room air conditioners, and distribution transformers. The long time lag of 10 years between the 2003 and the 2013 revised MEPS for CFLs, as well as quicker than expected market adoption of efficient CFL technologies as a result of the high efficiency lighting subsidies, may have contributed to a high sales-weighted market efficiency prior to implementation of the revised MEPS. This is likely also the case for front-load clothes washers and fixed-speed room air conditioners, which experienced a 9 and 6 years interval between MEPS revisions, respectively, and were both covered under the high efficiency appliance subsidy program. Nevertheless, the revised MEPS for clothes washers provided additional benefits beyond energy and CO_2 reductions in terms of additional MEPS requirements for better washing performance and lower water consumption. Distribution transformers also had a 7 year interval between MEPS revisions and were not covered by efficiency subsidy programs, but the markets for both oil-filled and dry-type transformers also moved quickly towards efficiency levels at or beyond the revised MEPS requirements. One possible explanation for this is that electric utilities, unlike average residential consumers, have a greater financial incentive to invest in more efficient distribution transformers because the losses directly impact their electricity sales profits.

For these revised MEPS, the market had overtaken target efficiency levels by the time of implementation likely because of market transformation that had occurred as a result of technological improvement, changing consumer preferences, the China Energy Label program, and notably the efficiency product subsidy programs implemented between 2009 and late 2012. For CFLs, front-load clothes washers, fixed-speed room air conditioners, and LCD-LED televisions, China represents a special case where more of the market transformation impact may be resulting from labeling programs and the large-scale national subsidy program than the MEPS program. The example of televisions provides some anecdotal evidence of manufacturers changing its supply line quickly by introducing more highly efficient models in anticipation of the revised MEPS and new subsidy thresholds for mid-2012. Unfortunately, it is difficult to differentiate between the different drivers of market transformation without more nuanced, disaggregated data collected over time. 2010 to 2013 also represent a unique time period in China because of the efficient rebate subsidy program, which makes it more difficult for MEPS revisions to anticipate the impact of the subsidy program. Nonetheless, improved coordination and data collection may be able to help capture some of these rapidly changing market dynamics and inform future MEPS revisions.

Although some of the revised MEPS had limited energy savings potential compared to the baseline, there is still very large remaining potential as indicated by the gap from the latest MEPS requirements and the current Chinese or international BAT levels for 10 selected products. Depending on the product, there is still untapped energy savings potential ranging from around 10% for medium and large motors, CFLs, and external power supplies to upwards of 40% savings potential for LCD-LED televisions, room air conditioners, and front-load clothes washers. The BAT scenario savings indicate that adopting all of these BAT efficiency levels for future MEPS could increase the energy and CO_2 emissions reductions by as much as four times, with cumulative reduction of over 3100 TWh beyond what would already be achieved by the revised MEPS from 2010 to 2030. Although this represents more of a technical savings potential rather than actual feasible savings potential, there are nevertheless several key areas of improvements that can help increase the total savings potential of future MEPS and reduce the gap between future MEPS thresholds and BAT efficiency levels, including:

1. Shorten the time lag between revisions so that revised MEPS can better reflect the latest market dynamics. If there is a long lag anticipated between revisions, greater effort to adopt more ambitious or stringent MEPS requirements may be needed because the market would likely have changed significantly since the previous MEPS was adopted.
2. Collect and utilize more detailed and up-to-date market data to help inform the development of revised MEPS requirements, particularly for products with a quickly changing market such as consumer electronics, and to provide more insight on market transformation that is occurring and the latest market changes in consumer preferences and technological improvements
3. Improve coordination between the proposed efficiency levels for revised MEPS, labeling thresholds and subsidy thresholds, such as by adopting more ambitious MEPS requirements if subsidies targeting highly efficient products (e.g., TV subsidy for TVs that were more efficient than Grade 1) are anticipated prior to or during the next revised MEPS cycle

5. Conclusion

This study found that the one-time accelerated adoption of 23 new and revised MEPS for 14 product categories between 2010 and 2013 as part of China's recent "One Hundred Standards" initiatives had significant impact on reducing appliance and equipment electricity consumption and energy-related CO_2

emissions. We found that 135 TWh could be saved annually from these 23 MEPS, essentially offsetting the equivalent of electricity supplied by more than 1 Three-Gorges Dam and 28 coal-fired power plants – both of which require significant upfront investment costs and have environmental consequences - *annually* by 2030. These savings are possible even when several products have already experienced market transformation with higher than expected market average efficiency that is close to or exceeded the revised MEPS requirements. Because these product markets had already overtaken new MEPS efficiency levels by the time of implementation, the revised MEPS did not have as large of an attributable impact as expected at the time of the standards development.

The limited or no impacts from the revised MEPS for CFLs, front-load clothes washers, fixed-speed room air conditioners, and distribution transformers suggest that understanding market dynamics are crucial to the development of effective and impactful MEPS. Properly characterizing the market dynamics related to MEPS development and revisions as well as other concurrent policy developments such as wide-ranging subsidy programs and emerging technological trends are needed when evaluating the market baseline and proposing new or revised MEPS efficiency thresholds. This is especially important for China, which sets its MEPS more incrementally and more frequently, than other countries such as the US which tends to significantly move the market with more stringent MEPS that are adopted over a longer time period.

More real-time, up-to-date market data can help capture rapidly changing market trends and help set relevant market baseline, but this type of data is currently difficult to acquire given the constrained financial and human resources for MEPS development in China. New analytical tools and more in-depth analysis for specific products such as televisions may help, as well as methodologies to further refine impact evaluations that can differentiate the market transformation impacts of multiple programs including MEPS, labeling and subsidy programs. For example, utilizing more detailed techno-economic analyses such as the engineering analysis, manufacturer mark-up economic analysis, and detailed consumer impact analysis supported by improved data collection to consistently evaluate proposed new or revised standards thresholds can help raise the stringency of future standards while still demonstrating cost-effectiveness. Alternatively, greater emphasis on future target values for standards or similar reach efficiency levels such as the China Top Runner designation can help incentivize manufacturers to transform their production lines prior to implementation of the revised MEPS. This approach has been successful with Japan’s Top Runner program, albeit Japan has a much more consolidated appliance and equipment manufacturing industry with far fewer manufacturers than China.

As a mandatory policy that can significantly affect the market with wide-ranging possible impacts, MEPS can still be a very effective tool in significantly moving the market efficiency, particularly for products where efficiency gains have been slow. Thus, improving the stringency of future MEPS is still key to capturing greater electricity savings and CO_2 emissions reductions from efficiency improvements and MEPS continue to be crucial tool for improving end-use product energy efficiency. There is still very large remaining potential for efficiency improvement for at least 11 major energy-consuming products as indicated by the gap between current MEPS levels and current international BAT efficiency levels.

Increasing the stringency of future MEPS towards these levels can achieve greater savings very cost-effectively and quickly.

Acknowledgement

We are very grateful to Kevin Mo of Energy Foundation China for funding this study. We also sincerely appreciate the valuable insights and feedback provided by various experts from the China National Institute of Standardization. We thank Virginie Letschert of the International Energy Studies Group and Jing Ke of the Energy Efficiency Standards Group at Lawrence Berkeley National Laboratory for their input to this study.

This project was supported by Energy Foundation China through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

References

Almeida, A., P. Fonseca, and P. Bertoldi. 2003. "Energy efficient motor systems in the industrial and in the services sectors in the European Union: characterization, potentials, barriers and policies." *Energy* 28: 673-690.

Appliance.Net. 2014. "Appliance lifespan in the home varies – when to replace." http://www.appliance.net/2007/home-appliance-life-span-102

Beijing Business News. 2014. "High Efficiency Rangehood Considerations: limited differentiation in efficiency (in Chinese)." March 6, 2014. http://tech.sina.com.cn/e/2014-03-06/08409216749.shtml

China Electronics Network. 2014. "Global TV retirement trend of less than 7 years for replacing traditional large CRT TV (in Chinese)." http://www.eccn.com/news_2012060407325011.htm

China Industry Research Network. 2014. "Future prospects of domestic kitchen rangehood gaining market share in high-end products (in Chinese)." September 25, 2014. http://www.chinairn.com/news/20140925/113754531.shtml

[CNAS] China National Accreditation Service for Conformity. 2014. "Contribution of High Efficiency Products to Improving Building Energy Efficiency." http://www.cnas.org.cn/rdzt/sjrkrzl2014/jbyj/2014/06/793982.shtml

[CNIS] China National Institute of Standardization. 2014. Personal Communication. October 22, 2014.

CNIS. Various Years (2011, 2012, 2013, 2014). "White Paper for the Energy Efficiency Status of China Energy-Use Products 2010, 2011, 2012, 2013." Beijing: China Standards Press.

[DOE] U.S. Department of Energy. 2013. "Energy Conservation Program: Energy Conservation Standards for Standby Mode and Off Mode for Microwave Ovens." https://www.federalregister.gov/articles/2013/06/17/2013-13535/energy-conservation-program-energy-conservation-standards-for-standby-mode-and-off-mode-for

[ERI] Energy Research Institute. 2014. Personal and email communication, November 6, 2014.

Evans C. 2014. "Benchmarking of Clothes Washers between the Chinese and European Markets." http://clasp.ngo/~/media/Files/SLDocuments/2014/2014-01_Benchmarking-of-Clothes-Washers-between-the-Chinese-and-European-Markets.pdf

Fang.com. 2014. "Air source heat pump and heat pump water heaters' lifetime." http://home.gz.fang.com/news/2011-03-02/4601222.htm

Fridley D., Lin J., Zhang G., Li A. and B. Wang. 2005. *Analysis of the Energy Efficiency Potential for External Power Supply End-Use Products*. Berkeley, California: Lawrence Berkeley National Laboratory. LBNL-58107

Gansu Jinchuan Solar Co. Ltd. 2013. "China Water Heating Industry Recent Developments and Future Forecast and Analysis." http://www.jinchuansolar.com/qydt/hydt/2013/09/25/1380096241745.html

Han, Jingyi, Arthur P.J. Mol and Yonglong Lu, 2010, "Solar water heaters in China: a new day dawning." *Energy Policy* 38: 383-391.

Hofman M. 2011. "Topten Product Criteria Paper on Washing Machines." http://www.come-on-labels.eu/download-library/product-criteria-paper-on-washing-machines

Letschert, V., M. McNeil, and N. Zhou, 2009. "Residential Electricity Demand in China –Can Efficiency Reverse the Growth?" In *Proceedings of the 5th International Conference on EEDAL 2009*. Berlin: German Energy Agency.

Letschert, V., Desroches L-B., Ke J., and M. McNeil. 2012. "Estimate of Technical Potential for MEPS in 13 Major World Economies." Berkeley, California: Lawrence Berkeley National Lab.

Letschert, V., Desroches L., Ke J. and M. McNeil. 2013. "Energy efficiency - How far can we raise the bar? Revealing the potential of best available technologies." *Energy* 59: 72-82.

Lexmark. 2014. "What is the ideal lifespan for your device?" http://www.lexmarknewsblog.com/what-is-the-ideal-life-span-for-your-devices/

Li, J., Zeng S., Hu B. and T. Zheng. 2013. "Market Analysis of China Energy Efficient Products." Available from: www.clasponline.org

Li, Junfeng and Runqing Hu, 2005, "Solar thermal in China: Overview and perspectives of the Chinese solar thermal market." *Refocus* 6 (5): 25-27.

McNeil, M., Bojda N., Ke J., Qin Y., de la Rue Can, S., Fridley D., Letschert V. and J. McMahon. 2011. "Business Case for Energy Efficiency in Support of Climate Change Mitigation, Economic and Societal Benefits in China." Berkeley, California: Lawrence Berkeley National Lab. LBNL-5031E.

McNeil, M. Letschert V., de la Rue du Can, S. and J. Ke. 2012. "Bottom-up Energy Analysis System – Methodology and Results." Berkeley, California: Lawrence Berkeley National Lab. http://superefficient.org/Tools/BUENAS

McNeil, M., Letschert V., de la Rue du Can, S. and J. Ke. 2013. "Bottom-up Energy Analysis System (BUENAS) – an international appliance efficiency policy tool. *Energy Efficiency* 6: 191-217.

[REN21] Renewable Energy Policy Network for the 21st Century. 2015. “Renewables 2015 Global Status Report.” http://www.ren21.net/status-of-renewables/global-status-report/

Park WY, Phadke A., Shah N., Letschert V. 2011. "TV energy consumption trends and energy-efficiency improvement options." LBNL-5024E. Wei H., Liu J. and B. Yang. 2014. “Cost-benefit comparison between domestic solar water heater (DSHW) and building integrated photovoltaic systems (BIPV) for households.” *Applied Energy* 126: 47-55.

SIRAC Air Conditioning Equipment Co. Ltd. 2015. “Products: Heat Pump Water Heater.” http://hpsirac.com/products/heat-pump-water-heater

Wei H, Liu J and B Yang. 2014. “Cost-benefit comparison between Domestic Solar Water Heater (DSHW) and Building Integrated Photovoltaic (BIPV) systems for households in urban China.” *Applied Energy* 126: 47-55.

Zhang X, You S, Xu W, Wang M, He T, and X Zheng. 2014. “Experimental investigation of the higher coefficient of thermal performance for water-in-glass evacuated tube solar water heaters in China.” *Energy Conversion and Management* 78: 386-392.

Zheng T., Hu B., Li J., and L. Zeng. 2013. “An Investigation of China’s Subsidy Program for Energy-saving Products.” *Proceedings of the 7th International Conference on Energy Efficiency in Domestic Appliances and Lighting*. Coimbra, Portugal.

Zheng X., Chu W., Qin P., Guo J., Yu Y., Song F. and Z. Chen. 2014. “Characteristics of residential energy consumption in China: findings from a household survey.” *Energy Policy* 75: 126-135.

Zhou N., Fridley D., McNeil M., Zheng N., Letschert V., Ke J., and Y. Saheb. 2011. “Analysis of Potential Energy Saving and CO_2 Emission Reduction of Home Appliances and Commercial Equipment in China.” *Energy Policy* 39: 4541-4550.