A Bottom-up Prospective Impact Evaluation of China's Accelerated Standards Development from 2010 to 2013

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Abstract

China first established mandatory minimum energy performance standards (MEPS) for appliances in 1989 and has since become one of the most active countries in adopting product standards. An unprecedented 21 standards were adopted by China from 2012 to 2013, compared to only 7 standards adopted from 2010 to 2011. This paper seeks to evaluate the total potential energy and CO_2 savings of China's 2010 to 2013 MEPS using bottom-up, ex-ante impact evaluation and scenario analysis. Using the latest actual and projected sales, market efficiency distribution, and retirement distributions data for 19 products, we developed 3 scenarios (baseline, MEPS and best available technology) of efficiency improvement by comparing pre- and post-MEPS efficiency criteria and current international best practice efficiency levels.

We find that the one-time adoption of the new or revised MEPS for 19 types of products could reduce cumulative electricity consumption by 1517 TWh and CO_2 emissions by over 1.5 gigatonnes of CO_2 between 2010 and 2030 compared with the baseline scenario. Some revised product MEPS for CFLs, front-load clothes washers, fixed-speed room AC and distribution transformers, have little or no impact because market transformation had already occurred faster than expected before the revised MEPS were implemented. This suggests that more data is needed to properly characterize market dynamics related to MEPS development and revisions in order to set an appropriate baseline and differentiate between market transformation impacts of market drivers and policies. The significant efficiency gap between the newest MEPS requirements and international best practice indicate that more aggressive standards revision can help achieve greater savings.

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. As of 2015, China had adopted 57 MEPS, covering 15 household appliances, 13 lighting products, 14 types of industrial equipment, 5 categories of office equipment and 10 types of commercial equipment. 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 and Standardization Administration of China. 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. As part of this initiative, an unprecedented total of 21 new and revised MEPS were developed by the China National Institute of Standardization (CNIS) and 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 number of products covered by its MEPS program by over 30%. 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. The ex-ante assessments conducted during the development of a new or revised MEPS also does not take into consideration actual market changes or sales. For example, the ex-ante assessment of a 2011 MEPS only considers market trends and actual sales prior to 2010 when the standard is developed while this study considers all available data and market trends through 2013.

A previous 2011 study (Zhou et al. 2011) evaluated the total potential impacts of China's standards and labels for 37 products that were implemented as of 2009, assuming continuous improvement of these standards over time. This study seeks to update that prospective evaluation of China's MEPS program by quantifying the additional potential energy and CO_2 reductions from the newest 23 standards that have been adopted since 2010. 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 global 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 product energy efficiency standard-setting under the 13th Five-Year Plan (2016-2020) period and beyond.

Methodology

This study uses a bottom-up energy end-use modeling framework for analyzing the expected change in appliance and equipment ownership, usage, and energy efficiency from the base year of 2010 through 2030. 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.

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 (McNeil et al. 2011). For other products, particularly industrial and commercial products, where saturation forecasts are not feasible, Chinese domestic sales forecasts are used to project future sales and to calculate the stock for a given year.

For each product, lifetime assumptions, historical and projected Chinese sales and stock data 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. 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 average lifetime. All of this data is used in shipments and diffusion rate calculations that make-up the stock turnover model. More details on the stock turnover modeling can be found in McNeil et al. 2011.

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 4 specific types of industrial equipment and 1 specific commercial product with limited scale of deployment. The 23 selected MEPS are grouped into 19 major products; the specific product categories included in this analysis are shown in Table 1.

Scenarios

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.

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. Due to limited data on the autonomous market and technological improvement trends of each individual product type, we do not attempt to account for autonomous efficiency change in the baseline scenario, which could result in over-estimated savings potential from MEPS. For this study, the baseline is set by calculating the UEC based on one of two levels: the reported 2010 market (e.g., sales-weighted) average efficiency of that product if sales-weighted efficiency data is available or the minimum efficiency requirement of the previous MEPS for products that were already covered by MEPS. For selected major household appliances that were covered by a previous MEPS, the preferred baseline efficiency level is set at the reported 2010 sales-weighted reported average efficiency level if this data is available 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 under-estimated market-average efficiency, and over-estimating the savings potential of the revised MEPS.

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.

BAT Scenario

The third scenario is the BAT scenario, which is only applicable to a subset of the key products that are most commonly used. These 11 products include room air conditioners (fixed- and variable-speed), clothes washers (front-load), refrigerators, CFL, televisions, external power supplies, and three-phase motors (three size categories) and distribution transformers. The BAT efficiencies are based on the latest technological trends and often represent the maximum achievable energy-efficient design from technologies that have been commercialized for product models that are comparable in scale and configuration to the Chinese MEPS products. By comparing the most recent MEPS levels to international BAT efficiencies, this scenario helps highlight the "efficiency gap" between current Chinese MEPS and the current BAT levels in the world and remaining potential for improving a given product's efficiency.

For each of the three scenarios, the specific efficiency criteria for each product are determined through technical analysis of the MEPS documents, literature review and online research of product-specific market efficiency trends, and discussions with Chinese experts from CNIS. A summary of the key efficiency assumptions are shown in Table 1 and more detailed discussion of the basis and references for each of these assumptions can be found in the full report on which this paper is based (Khanna et al. 2016). These efficiency criteria are then combined with data on the capacity and usage patterns such as average hours of active mode or standby mode power consumption and assumptions of a typical representative product derived mostly from the first China Residential Energy Consumption Survey by Renmin University (Zheng et al. 2014) or from Zhou et al. 2011. The subsequent calculated annual unit energy consumption for the three scenarios are shown in Table 1.

Table 1. Product Efficiency Assumptions for the Baseline, MEPS and BAT Scenarios

	MEPS Years	**Baseline Efficiency Criteria**	**Baseline UEC (kWh/unit /yr)**	**MEPS Efficiency Criteria**	**MEPS UEC (kWh/unit/ yr)**	**BAT UEC (kWh/unit/ yr)**
Fixed-speed Room AC	2004, 2010	2010 market average: 3.31 W/W	129	3.37	126	71
Variable-speed Room AC	2008, 2013	2010 market average: 3.95 W/W	108	4.41	96	58
LCD-LED TV	2010, 2013	2010 market average: EEI of 0.99	128	EEI of 1.3	95.3	92.3
Vertical Impeller/Top-load Clothes Washer	2004, 2013	2010 market average: 0.02 kWh/cycle/kg	26	0.0199 kWh/cycle/kg	25.9	N/A
Horizontal Drum/Front-load Clothes Washer	2004, 2013	2010 market average: 0.19 kWh/cycle/kg	247	0.19 kWh/cycle/kg	247	92
Microwave	2010	Standby mode: 1 W	74	Standby mode: 0.5 W	65	N/A
Copier/Printer/ Fax	2010, 2014	10.19 kWh/unit/week	530	40% improvement	389	N/A
Desktops	2012	N/A	250	N/A	225	N/A
Laptops	2012	N/A	70	N/A	63	N/A
Range hood	2013	Active mode: 200 W; Off-mode: 3W	62	Active mode: 33% improvement; Off-mode: 1.5 W	37	N/A
TV Set-top Box	2010	Active mode: 12 W; Standby-mode: 6W	60	Active mode: 10 W; Standby mode: 3W	34	N/A
Heat Pump Water Heater	2013	COP: 3.17	317	COP: 3.7	271	N/A
CFLs	2003, 2013	2010 market average: 55.1 lm/W	20.3	53 lm/W	21.1	N/A

Linear Fluorescent Lamps	2003, 2013	2010 market average: 53 lm/W	21.1	53 lm/W	21.1	N/A
External Power Supplies	2007, 2013	Active mode: 26 W/average unit; Standby mode: 0.75 W	80	Active mode: 24 W; Standby mode: 0.3W	77	76
Small Motors: 0.75 - 7.5 kW	2006, 2012	76.2% efficiency	2,750	81.40%	2,574	2,354
Medium Motors: 7.5 - 75 kW	2006, 2012	88.4% efficiency	44,000	89.80%	43,314	40,943
Large Motors: > 75 kW	2006, 2012	94.5% efficiency	770,000	94.50%	770,000	757,969
Distribution Transformers	2006, 2013	Below S10 (oil-filled); SC10 (dry-type)	Varies by capacity	S11 (oil-filled); SC11 (dry-type)	Varies by capacity	SH15

For each scenario, the total energy consumption of each appliance (measured in terms of electricity) is then calculated by the model using given assumptions about annual unit energy consumption, lifetime, and calculated stock. Since the only difference among the three scenarios for each product is the efficiency levels of appliances resulting from MEPS implementation and possible adoption of BAT efficiencies, the subsequent divergence in modeled energy consumption from the baseline scenario can be attributed to energy savings from different pace of efficiency improvements. 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 that emphasizes more renewable and nuclear power generation over coal-fired generation. We assume that by 2030, 27% of China's electricity generation will be from renewable power with additional 9% from nuclear power based on analysis conducted as part of the Reinventing Fire: China project (ERI, RMI, LBNL and Energy Foundation China, forthcoming).

Results and Discussion

The energy and CO_2 emissions results of this analysis are presented in two sections. The first section discusses the total electricity savings and CO_2 emissions reduction of the MEPS scenario relative to the baseline scenario for all 19 products. The second section focuses on the impacts of the BAT scenario for the subset of BAT products for which targets can be established using international BAT efficiency levels in order to highlight the remaining gap for improving efficiency beyond current MEPS levels.

MEPS Scenario Savings

We find that the one-time adoption of the 23 new or revised MEPS from 2010 to 2013 for the 19 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 2 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 2. 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
Small Motors (< 0.75 kW)	0.0	5.8	16.5	25.9	31.6	333.4
Medium Motors (0.75 – 75 kW)	0.0	3.0	8.8	15.1	19.9	192.5
Large Motors (>75 kW)	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***

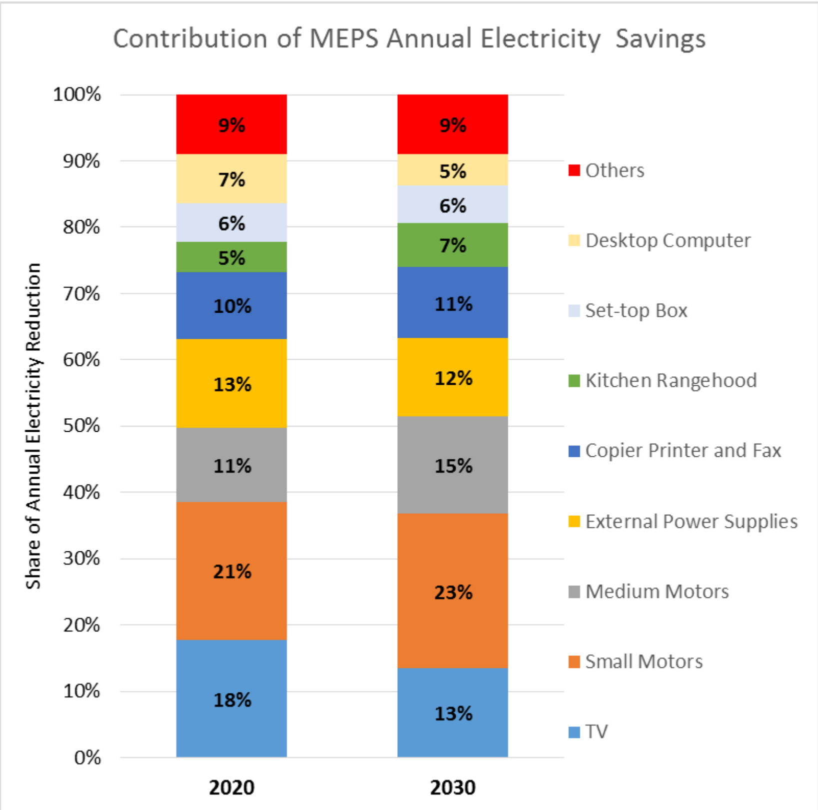

Figure 1. Contribution of MEPS Annual Electricity Savings by Product

As seen in Figure 1, 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 are still projected to hold relatively 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 could amount 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 projected electricity savings in 2030.

Error! Reference source not found. 2 shows that in 2030, annual electricity savings from the one-time implementation of these MEPS could equal the output of 28 1-GW typical coal-fired power plants[1] and 1.3 times the annual generation output of the Three Gorges Dam[2].

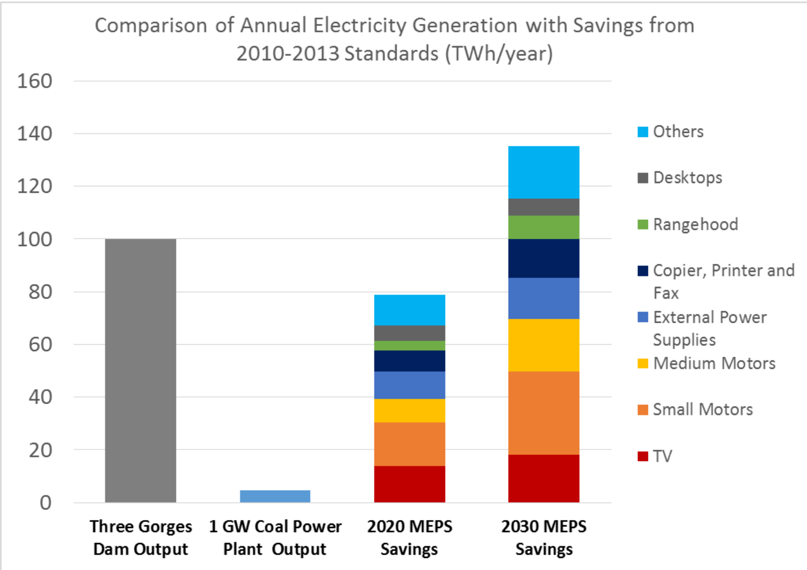

Figure 2. Comparison of MEPS Annual Electricity Savings projected for 2020 and 2030 with Supply-side Power Generation Output

This finding is similar but 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 projected to be 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 could 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

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1 Typical coal-fired power plants in China are assumed to have 38% generation efficiency and average capacity factor of 55%.

2 Three Gorges Dam has total installed capacity of 22.5 GW and we assume an average capacity factor of 50%.

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).

Over the period of 2010 through 2030, these projected electricity savings could 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 CO_2 as a result of the electricity savings achieved by the one-time adoption of new or revised MEPS between 2010 and 2013.

BAT Scenario Savings

Table 3 shows that in a BAT scenario in which MEPS for the 11 selected products are assumed to reach the current international BAT levels of efficiency by 2015, the total cumulative reduction in electricity consumption by 2030 could reach 4817 TWh compared to the baseline scenario without new or revised MEPS after 2010. In 2030, annual electricity savings could equal the output of 100 1-GW typical coal-fired power plants.

Table 3. 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 selected key products, the motors and CFL standards dominate the reduction potential, 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 efficiency 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 projected 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 front-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 3 shows that by 2030, the annual electricity consumption for 10 selected BAT products (excluding refrigerators since the MEPS has not been finalized at the time of analysis) in the MEPS scenario could reach 4444 TWh, consuming 92 TWh less than the Baseline Scenario. In contrast, annual electricity consumption in the BAT scenario could 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. The largest untapped savings potential beyond current MEPS levels are in motors, CFLs, and refrigerators.

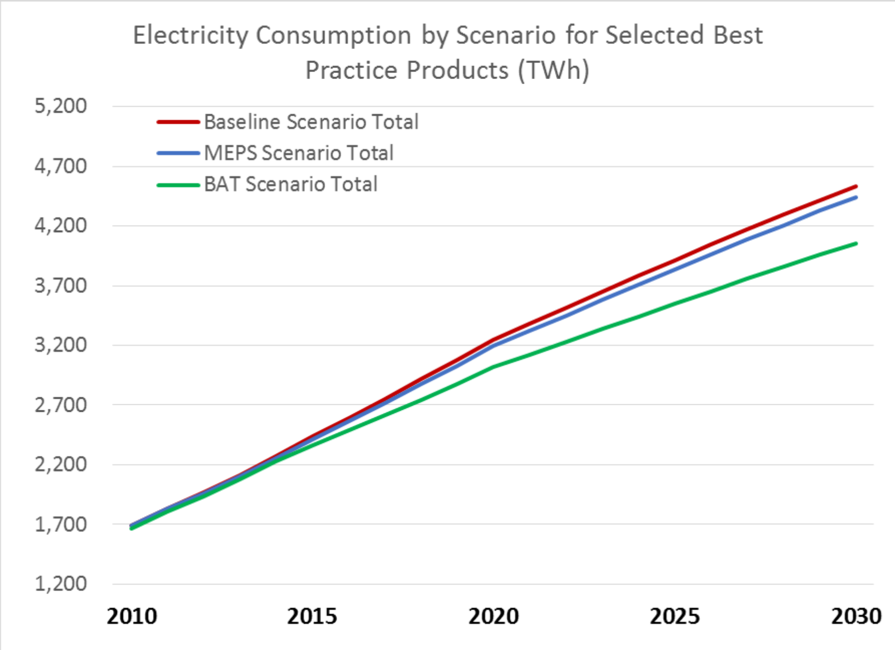

Figure 3. Comparison of Total Electricity Consumption for Selected BAT Products

Over the period from 2010 to 2030, the electricity savings achieved from adopting BAT efficiency levels for the 11 selected product groups could translate into cumulative reduction of nearly 4.8 Bt CO_2 relative to the Baseline Scenario. 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.

Key Findings and Policy 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 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 major consumer electronic and accessory, the expected fast growing sales forecast for both televisions and external power supplies, respectively, 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. At the same time, the average efficiency of LCD-LED televisions has improved significantly from 2010 to 2015 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). After the public announcement of the two-tiered subsidy thresholds levels for high efficiency televisions in May 2012, 81% of all LCD-LED television sales reached the most efficient China Energy Label Grade 1 efficiency level with EEI of 1.4 or higher and the least efficient Grade 3 models were virtually pushed out of the market with only 4% of total sales (Zheng et al. 2013). Another key driver for the market adoption of high efficiency televisions during this time is the substantial improvement in LED backlighting technology. As a result of both policy and technological progress, the LCD-LED television market transformed so quickly that the market average efficiency of LCD-LED televisions outpaced the revised 2013 MEPS threshold despite only a three-year interval between MEPS revisions. 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.

Of the 12 revised MEPS adopted between 2010 and 2013, some revised MEPS are projected to have 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. The long time lag between MEPS revisions and small incremental efficiency improvement between revisions could result in the efficiency of all models on the market quickly surpassing the MEPS level, rendering it ineffective. 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. For dry-type and oil-filled distribution transformers, the S9 class corresponding to the old 2006 MEPS efficiency were completed pushed out of the market by 2012. 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 (CNIS 2013). One possible explanation for this is that electric utilities, unlike average residential consumers, have a greater financial incentive as well as access to more financial capital 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 an example 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.

The limited or no impacts from the revised MEPS for CFLs, front-load clothes washers, fixed-speed room air conditioners, LCD-LED televisions and distribution transformers suggest that understanding market dynamics are crucial to developing MEPS that are set at a meaningful level to have market impacts. 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 that 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. It can also help policymakers identify a few specific product MEPS with greatest savings potential and prioritize their implementation and enforcement given limited resources. Alternatively, greater emphasis on future target values for standards or similar reach efficiency levels such as the China Energy Efficiency Top Runner designation of most efficient products can help incentivize manufacturers to transform their production lines prior to implementation of the revised MEPS.

Although some of the revised MEPS had limited energy savings potential compared to the baseline, there is still very large remaining technical 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 with China, such as by adopting more ambitious MEPS

requirements in anticipation of significant market changes if subsidies targeting highly efficient products (e.g., TV subsidy for TVs that were more efficient than Grade 1) are planned during the next revised MEPS cycle

Conclusions and Future Research

This study found that the one-time accelerated adoption of 23 new and revised MEPS for 18 product categories between 2010 and 2013 as part of China's recent "100 Energy Efficiency Standards" initiatives likely had significant impact on reducing appliance and equipment electricity consumption and energy-related CO_2 emissions based on our assumptions and analysis. 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 significantly more 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 a projected impact as expected at the time of the standards development.

Given the large number of MEPS adopted by China between 2010 and 2013 and the limited publicly available data on product sales and efficiency distribution, this study made a number of simplifying assumptions. For each product category, we picked one representative product type based on the most common size and technology configuration due to lack of model-specific sales and efficiency data. We assumed frozen baseline efficiency rather than autonomous efficiency improvement without product specific basis for assuming autonomous market and technological improvement, which could inflate the baseline energy consumption and over-estimate the MEPS savings potential. Similarly, the MEPS scenario uses the simplifying assumption of a one-time improvement in efficiency with the same unit energy consumption assumed for all products, when in reality different models may consume different – and possibly lower - energy consumption than the MEPS level. This could result in over-estimated savings potential for MEPS if products on the market are already highly efficient, or under-estimated savings potential if the MEPS drives continuous improvement in efficiency over time. Our study also did not consider other aspects of the new or revised MEPS, such as change in test methods, water consumption or other performance requirements for products such as clothes washer, which may bring additional benefits beyond our estimates. It also did not attempt to adjust the savings potential based on MEPS compliance, as previous pilot studies have found generally high compliance amongst most products, but actual savings are likely lower given our assumed 100% compliance for all products. These limitations suggest that while the projected total and product specific savings may change, the order of magnitude of the projected impact of the 23 MEPS and the relative scale of savings amongst different products, will most likely hold. Additional research and sensitivity analysis of key input parameters including projected sales growth, lifetime, usage patterns, compliance rates, and efficiency criteria can better bound the uncertainties associated with our projected savings. Collection of more nuanced product-specific sales and efficiency datasets over time can also help better disaggregate the energy and CO_2 reduction impacts of different programs including MEPS, labeling and subsidies.

Despite the limitations of this study, our analysis highlights key product MEPS that contributed the bulk of expected savings due to not only efficiency improvement, but also growing demand and usage. It also identified other product MEPS with limited impact due to faster than expected market transformation. Both of these findings highlights the importance of setting the MEPS level at a level representative of actual market trends, and the need for incorporating detailed up-to-date market data in energy efficiency standard-setting analysis. 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 energy and CO_2 reductions with lower costs and shorter time compared to the time and financial investment needed to expand the electricity supply.

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