technology-specific Long Range Energy Alternatives Planning (LEAP) model to evaluate the energy savings potential of eleven products in the scenarios of continuous improvement and accelerated improvement in China.[6] In 2011, the International Energy Agency (IEA) estimated that at least 3.7 exajoules (EJ) of energy per year could be saved by higher standards for residential appliances and equipment. Adoption and regularly revision to mandatory MEPS and labeling for appliances and equipment were recommended by the IEA, but commonly used evaluation methodologies were not clearly explained in that study. [7] Here, we consider the methodology used in Zhou et al. study is the best available model to determine energy savings resulting from mandatory standards. Zhou's work was focused on the potential energy savings estimated using projections. In this paper, we evaluate the "achieved" savings by energy efficiency standards implemented to date using historical data. The main intent is to appraise the contribution of energy efficiency standards within the larger policy framework.

Fundamental Methodology

In 1992, China published a national standard, Methods for Calculating and Evaluating the Economic Value of Electricity Saving Measures, to evaluate the benefit of both policy and technical measures that resulted in electricity savings (later revised in 2009).[8] It defines the calculation methods for electricity savings and economic value of electricity saving technologies. It also gives the economic assessment methods for investment in projects for electricity saving technologies.

The basic methodology of this standard is an aggregated method for individual product/working load consuming energy. The basic equation is:

$$\Delta A_C = \sum_{i=1}^{m} \left(a_{qi} - a_{hi}\right) Q_{hi} \qquad (1)$$

Here, ΔA_C is the electricity savings, a_{qi} is the electricity consumption of unit product *i* or work load *i* before the electricity saving technology is implemented, a_{hi} is the electricity consumption of unit product *i* or work load *i* after technologies implemented, Q_{hi} is the production of product *i*, and *m* is the total number of different products evaluated.

This method has been used to evaluate the energy savings of standards by using the annual sales of new products and the difference of energy consumption between products before and after the implementation of mandatory minimum efficiency standards. This is only a rough evaluation since it does not account for some important factors, such as separating out any business as usual improvements in energy efficiency absent of new standards. To simplify the evaluation, it also does not take into account changes in product usage due to behavior, size, or functional changes.

In 2010, a new bottom-up method was introduced by Lawrence Berkeley National Laboratory to evaluate the energy savings by energy efficiency standards for energy-using products.[5] This model is based on a scenario analysis of annual stock change for targeted products and those products' average energy intensities. The key factors that influence the annual stock include new sales and product lifetime. The average energy intensity depends on the energy efficiency, power, and usage of the product. Annual and cumulative energy savings can be evaluated and compared among different scenarios. The basic concept of the method is shown in the following figure.

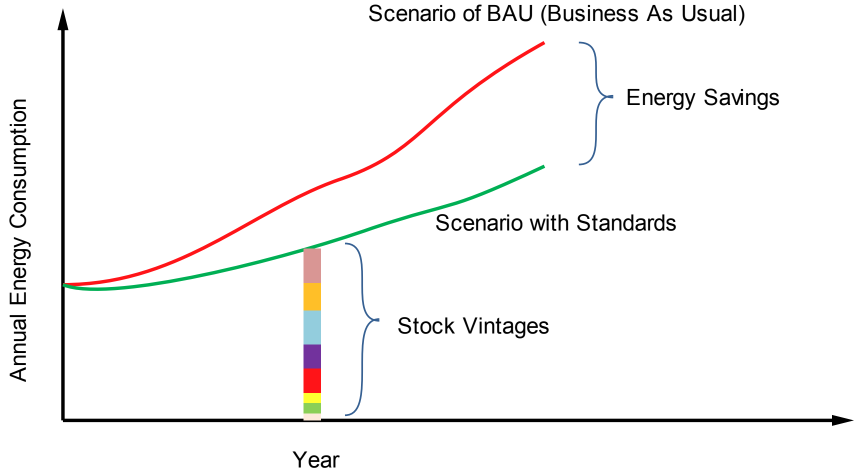

Figure 1. Framework of the Evaluation Methodology

Referring to LBNL's model, we simplify the method of evaluation to the following steps:

Step 1: Determination of scenarios for analysis. There should be at least two scenarios: a reference scenario (business as usual or BAU) and a comparison scenario (introduction of standards). Multiple scenarios can also be analyzed together.

Step 2: Evaluation of the annual sales of target product in different scenarios. The sales are calculated using historic sales data (which influences the retirement of old products) and new product sales. It is difficult to project how many new products will be bought because there are multiple drivers. Here, we simplify the assumptions and set a constant growth rate of sales for each category of products.

Step 3: Evaluation of the annual stock of the target product. Using previous stock, new sales, and retirement of the target products, the stock of year *i* can be calculated with the following equation:

$$\mathrm{Stock}_i = \mathrm{Stock}_{i-1} - \mathrm{Retirement} + \mathrm{Sales}_i \qquad (2)$$

Here, subscript *i* refers to the year evaluated. Retirement is defined as the total number of retired products sold from the first year analyzed to year *i*-1.

Step 4: Evaluation of the annual average energy consumption of the target product. In this step, the annual total energy consumption in a given year will be calculated by compiling the energy consumption of products in each stock vintage from the first year analyzed to the latest year:

$$\mathrm{Annual\ Total\ Energy\ Consumption} = \sum_{year} E_i \times \mathrm{Stock}_i \qquad (3)$$

E_i is the annual average energy consumption of the target product. It depends on the average energy efficiency and usage of the product. We assume that annual average energy efficiency will be influenced both by energy efficiency policy (such as mandatory standards) and technological progress. Some researchers content that the energy consumption of products can change over time. In this paper, we did not consider this effect because we have not found a convincing research result to prove it.

Step 5: Evaluation of annual energy savings by comparison of the energy consumption of different scenarios. As Figure 1 shows, the annual savings should be the difference of annual energy consumption between reference scenario and the scenario with standards.

Results of Evaluations

In 2011, we conducted the evaluation of energy savings for 2010 resulting from the introduction of new energy efficiency standards for six groups of key energy-using products in China. The evaluation results from 2009 to 2011 are summarized in the following table. The six groups of products accounted for an energy savings of 4.89 TWh in 2010, or about 0.8% of total energy consumption for those products.

Table 2. Evaluated Energy Savings in 2010 by Implementation of Energy Efficiency Standards

Products	**Year of Standards Effected**	**Estimated Energy Consumption in 2010**	**Evaluated Energy Savings in 2010 resulting from Energy Efficiency Standards**
Refrigerators	2008	76.4 TWh	1.2 TWh
Room air conditioners	2010	241 TWh	2.3 TWh
Electric water heaters	2008	33.1 TWh	0.11 TWh
Rice cookers	2008	40.1 TWh	0.38 TWh
Computer monitors	2008	5.5 TWh	0.4 TWh
Compact fluorescent lamps	2003	220.4 TWh	0.5 TWh
Total	-	616.5 TWh	4.89 TWh

As shown in table 2, energy savings of compact fluorescent lamps (CFLs) is very small compared to its annual energy consumption. The main reason is that the 2003 standard is already very outdated and has not yet reached full technical potential for energy savings. In this situation, the impact of energy efficiency standards on the average energy intensity of CFLs attenuates more quickly due to the shorter life-span of CFLs as compared with most household appliances. For this reason, we think it is important to continuously improve and revise energy efficiency standards.

The cost of development of energy efficiency standards in China is very low. The total budget of each standard including state finance and in-kind support from Energy Foundation is around USD 50,000. Energy efficiency standards may be a very cost-effective way to achieve energy savings in China if we do not consider the social costs (costs to manufacturers and consumers) and implementation costs (costs to administrations). The quantitative results of cost-effective evaluation cannot be concluded because studies of these social and implementation costs are not available yet.

Key Factors Impacting the Results of Evaluation

Data quality

Data quality is a big challenge to influencing the evaluation of energy efficiency standards in China. Most data used in this evaluation were based on survey reports or statistics data. The lack of historic data collection distorts the estimates of projected sales, stock, and shipments needed for evaluation. The United States has been performing a Residential Energy Consumption Survey (RECS) for more than 30 years, which helped to establish historic baselines on the energy consumption of appliances. Although China started implementing energy efficiency standards for appliances in 1989, historic data on sales, stock, and energy consumption of appliances has been largely lacking due to restricted resources and an immature survey system. Until now, China does not have a complete survey and statistics system to enable a comprehensive understanding of the use pattern of residential appliances. Data quality for the use and production of energy-using products is not high enough to support evaluation. Double counting and inconsistent results were found in most survey reports or statistics books.

Market Situation

China has experienced an unusually high speed of economic development in the past three decades. Therefore, the market often sees high fluctuations in sales and production. For instance, in 2007, 27 million sets of room air conditioners were sold in China, increasing to 35 million in 2009. Sales increased by almost 30% in just two years. A sharp increase in sales results in an enormous energy savings due to new energy efficiency standards, even though overall energy consumption is still rising quite rapidly. This distorted result may send the wrong signal to policy maker.

The market and energy efficiency of some products such as consumer electronics also change very quickly. In China, flat-screen TVs replaced cathode ray tube (CRT) TV's as the market leader in just three years. It is difficult to get good quality data for product categories that change so quickly. It is also difficult to set the BAU scenario and distinguish energy savings caused by standards as opposed to those caused by technology evolution in such a short time period.

Mixed Standard System

Energy efficiency standards of China include both mandatory efficiency requirements and a recommended performance index. How to evaluate the impact from a mixture standard system such as this is a noticeable barrier in the field of evaluation. The mandatory requirements and recommended performance index have different mechanisms to achieving energy savings. The performance index is more akin to the implementation of a labeling program or certification scheme.

In this paper, we only considered the effect of energy efficiency standards in phasing out low performance products that fail to meet the mandatory minimum requirements. For the performance index, we assumed it could be effective only when an energy label program or voluntary certification scheme was implemented along with the index. It would be a valuable for future evaluations to be able to separate the energy savings caused directly by minimum energy efficiency standards from the savings caused by energy labeling or certification schemes. Policy-makers are interested to know the distinct contributions of labeling programs and certification schemes.

Implementation Status
One premise of our evaluation is that the minimum energy efficiency standards of targeted products have been fully implemented, but in fact implementation can vary widely depending on the market situation. Lack of supervision and awareness often leads to poor implementation. Since 2009, various studies were carried out jointly by LBNL and CNIS to check product compliance of energy efficiency standards and energy labeling system. The preliminary conclusion was that compliance levels for energy efficiency standards in China were not as good as those in the EU or US markets. It should also be pointed out that the number of selected products and regions in these pilot studies were too limited to represent the whole picture.

The implementation level of energy efficiency standards is also difficult to quantify. Normally, market surveys or statistics will not focus on the compliance of certain products to certain standards. Additionally, considering the broad distribution of geographies and development levels in China, it is hard to get an exact idea of compliance at the national level. Next steps include disaggregating the evaluation not only by product categories but also by region to incorporate results of the pilot studies on compliance. This will provide a more precise picture of the impact of energy efficiency standards and demonstrate the importance of full implementation.

Conclusions

Since 1989, China has published 46 mandatory energy efficiency standards for appliances, industrial equipment, lighting product, office equipment, commercial equipment, and vehicles. Energy efficiency standards for energy-using products play an important role in China's policy framework to improve energy efficiency. In 2010, a new bottom-up method was introduced to evaluate the energy savings by energy efficiency standards for energy-using products. This model was based on a scenario analysis of the stock change and average energy efficiency of targeted products.

Standards that are effectively implemented can achieve large energy savings. In 2010, six groups of product (refrigerators, room air conditioners, electric water heaters, rice cookers, computer monitors and compact fluorescent lamps) produced a total annual energy savings of 4.89 TWh or around 0.8% of total energy consumption for those products. We find that the development and implementation costs for new standards are relatively low and that energy efficiency standards are a cost-effective way to achieve energy savings.

Some fundamental factors like data quality, market situation, mixed standards, and implementation status suggest areas for improvements in the evaluation methodology. In China, the quality of data is a big challenge to successful evaluation, and China's survey and statistics system needs to be improved. The unusual high rate of development in China's market causes some distortion in the real effects of energy efficiency policy and may give wrong signals to policymakers. As mentioned before, energy efficiency standard of China include a mandatory minimum efficiency requirement as well as a recommended performance index, and more attention needs to be paid to the evaluation of such mixed standard systems. One premise of this evaluation was that the standards were fully implemented for the targeted products. Yet, it is difficult to quantify the implementation status of energy efficiency standards. Considering the broad distribution of geography and development levels in China, future evaluations should disaggregate energy efficiency standards not only by products categories but also by regional features.

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