# Assessment of the Japanese Energy Efficiency Standards Program

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## ABSTRACT

Japanese energy efficiency standards program for appliances is a unique program which sets and revises mandatory standards based on the products of the highest energy efficiency in the market. This study assessed the cost-effectiveness of the standard settings for an air conditioner as a major residential appliance or typical example in the program. Based on analysis of empirical data, the net costs and effects from 1999 to 2040 were estimated. When applying a discount rate of 3%, the cost of abating $CO_2$ emissions realized through the considered standards was estimated to be -13,700 JPY/t $CO_2$. The sensitivity analysis, however, showed that the cost turns into positive at a discount rate of 26% or higher. The authors also revealed that the standards' "excellent" cost-effectiveness largely depends on that of the 1st standard setting, and the $CO_2$ abatement cost through the 2nd standard was estimated to be as high as 26,800 JPY/t $CO_2$. The results imply that the government is required to be careful about the possible economic burden imposed when considering introducing new, additional standards.

## KEYWORDS

*Energy policy, Energy efficiency, Standards, Cost-effectiveness, $CO_2$ abatement cost, Air conditioner.*

## INTRODUCTION

Energy efficiency standards have been introduced and developed in a number of countries since the 1960s [1] and have been regarded as one of the important policy measures for energy savings or related $CO_2$ emissions [2]. Geller *et al*. [3] examined several energy efficiency programs adopted in OECD countries to point out the effectiveness of standards programs in reducing energy consumption; however they had not assessed the relevant cost and cost-effectiveness. Meyers *et al*. [4] estimated the benefit/cost of the standards for major energy consuming appliances such as air conditioners and refrigerators in the U.S. residential sector for the period 1987-2050 to show their superiority in view of economics.

In Japan, energy efficiency standards had originally been introduced since 1980. However the former standards failed to induce sufficient improvement because they were seldom revised and were set mostly through negotiations with industries [5]. After the Kyoto Protocol was entered into and greenhouse gas reduction targets were established, a new type of mandatory standard setting program called "Top Runner Program" was established in 1999 to accelerate energy conservation efforts [6]. Under the program, standards are set based on the products of the highest energy efficiency ("Top Runner") on the market, and they need to be met by the manufacturers on weighted average basis.

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Starting with nine products in 1999, it has expanded to 26 products by 2013 and so far the standards have been met for all products [7], leading to the recognition that the program in general has been "successful" [5].

But on the other hand, neither its actual energy saving effects, incurred costs, nor cost-effectiveness are well known despite their importance in the program evaluations [8]. The literature which quantitatively assessed the program or standards settings is very limited. Kainou [9] analysed the cost-effectiveness of the standards program in its initial stage, showing that the cumulative benefits of more than tens of billions of JPY through the period 1999 to 2030 would be obtained by the settings of the standards for major energy consuming appliances such as air conditioners or refrigerators and concluded that the standards program in general should be viewed as a "quite excellent policy measure". However, a major shortcoming in their analysis procedure was that autonomous efficiency improvements of appliances in the market were disregarded. That is, they incorporated all of the improvements gained during the program into the effects of the program. Also, given a situation in which technological progress has been made and the recent standards set by the program have accordingly been revised to be more severe than those set in the initial stage, it is another challenge for us to review the cost-effectiveness based on the current situation.

The purpose of this study is to examine the cost-effectiveness of the standard settings for air conditioner as a major residential appliance or typical example by incorporating the latest statistics together with consideration of autonomous technical improvements for baseline cases.

## METHODOLOGY

### *Analysis of the economic impact of the program*

Nordqvist [8] discussed the principles for estimation of society's cost related to the standards program. The cost consists of the sum of the related actors' expenditures, subtracted by the value of avoided cost for energy use. Manufacturers need to invest substantial resources to comply with the requirement, which likely led to increase of product prices and borne by consumers as final cost [8]. However through the use of appliances with higher energy efficiency, the electricity cost to be paid by consumers reduces year after year. For the confirmation of manufacturer's compliance with the standards, which is another important aspect in the program, monitoring activities by the government should also be considered.

The costs/avoided costs of the standards set in the program were therefore supposed to consist of the following items:

- Avoided cost for electricity consumption by appliances with higher energy efficiency;
- Incremental production cost to meet the standards;
- Monitoring cost of government for the manufacturers' compliance.

Evaluating the impact of the standards needs estimations of energy consumptions or relevant costs for cases with/without the standards, and comparisons of those assumed cases. Also, those costs or the $CO_2$ emission reduction effects should basically be viewed in time series after the adoption of the standards. To comprehend such dynamics and have a discussion from a long-term perspective, we evaluated them through 1999 to 2040.

### *Key assumptions for analysis: the number of appliances*

The number of air conditioners of annual sales, retirement, and summation of their stocks are basic data, on which our evaluation relies. The historical sales volumes from

1965 to 2013 were collected from the industry association [10]. To calculate the number of retirement, probability distribution was assumed based on Weibull type distribution function. Its parameters were determined by fitting using least-squares method to a vast amount of cumulative survey data collected on actual lifetimes [11], where the average lifetime was estimated to be 15 years. As for the stocks in future, saturated numbers of air conditioners possessed per household, namely, 2.6 units per two-or-more-person household and 1.1 per one-person household [12, 13], were assumed. The number of total stocks was then obtained using estimated number of households for each category [14]. Annual sales from 2014 to 2040 were calculated forward from the above mentioned number of stocks.

### *Avoided cost for the electricity consumption*

Trend of energy efficiency of appliances. The standards for air conditioners were introduced in 1999 and there have been two phases or periods. The 1st (initial) standard was introduced in 1999 for the target year of 2004. After that, the 2nd (revised) was adopted in 2006 for the target year of 2010. Kimura [5] pointed out that the standards had a significant impact on improvements in energy efficiency of air conditioners. Figure 1 shows the trend of average energy efficiency of air conditioners sold in Japan from 1970 [15*†, 16].

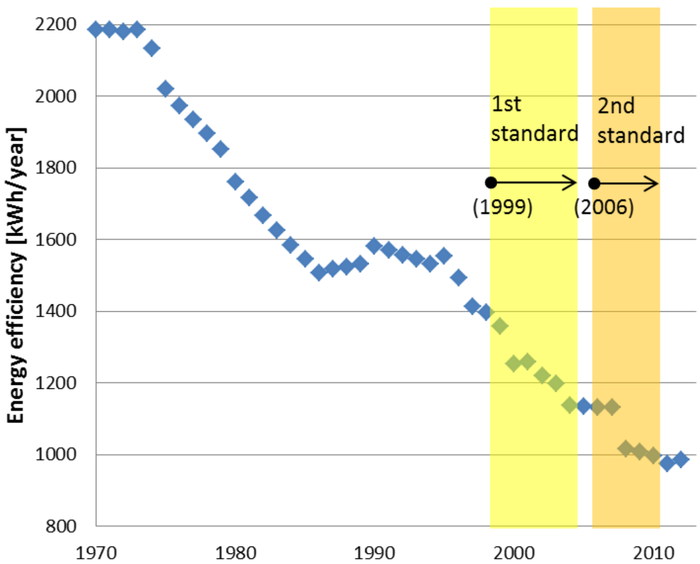


Figure 1. Trend of the average energy efficiency of air conditioners sold in Japan [15*†,16]

Air conditioners began to spread in the 1970s, and since then, their efficiency increased based on the technological improvements such as applications of inverter controls, better fans or heat exchangers, but the progress stagnated in the mid-1990s as can be seen in Figure 1. The introduction of the standards was considered to have accelerated their improvements. Table 1 shows annual rates of improvement in energy efficiency for the periods before, during and after each phase of the standard settings. We can more clearly see the transition of the progress in energy efficiency, which strongly suggests the impact of standards.

*† Energy efficiency indicator was converted from COP into kWh/year, based on typical usage patterns in accordance with the Japan Industrial Standard (JIS) [16]

Table 1. Annual rates of improvements in energy efficiency*‡ for periods before, during and after the standards periods (starting-target year)

| | Rate of annual improvement |
|---|---|
| Before 1st phase (assumed for 1988-1998) | 0.9% |
| During 1st phase (1999-2004) | 3.4% |
| After 1st/Before 2nd phase (-2005) | 0.2% |
| During 2nd phase (2006-2010) | 2.6% |
| After 2nd phase (2010-2013) | 0.1% |

Assumed impact on the progress in energy efficiency. As previously stated, not all of the improvement in energy efficiency is attributable to the effect of the standards. For the purpose of estimation of their effect, progress of baseline cases need to be defined. Mahlia *et al*. [17] referred to rates of average annual improvement in energy efficiency of appliances based on the prior/existing surveys in their analysis of the standards program. In this study, we adopted such simplified methods, referring basically to the observed average annual improvement rate before introduction of the standards to define the assumed trend in baseline cases. When considering the future progress in those cases, efficiency levels to be achieved were also taken into consideration from a technical point of view. It is pointed out that the achievements of technological developments for major energy consuming components in air conditioners such as compressors or fan motors, had almost reached saturation levels in 2006 [18], where average energy efficiency was approximately 1,000 kWh/year. Based on the above considerations, this analysis assumed the progress of energy efficiencies for appliances sold in each case. Figure 2 shows the assumed progresses in energy efficiency for appliances sold from 1998 to 2040, where '"Standards" case" represents case with 1st/2nd standards, "Baseline case (a)" without 1st/2nd standards, and "Baseline case (b)" with 1st and without 2nd standards.

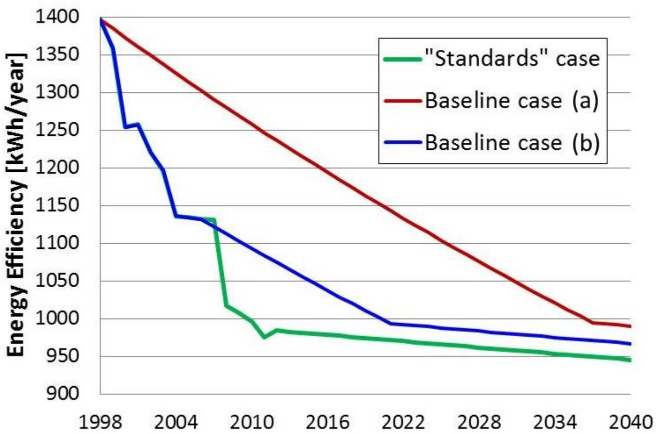


Figure 2. Progress in average energy efficiency of air conditioners in the assumed cases

*Estimated electricity consumption.* Electricity consumption in each case was calculated using the assumed efficiencies of the newly introduced and of stock appliances with their corresponding populations. Figure 3 shows the result of calculation on their stock basis from 1998 to 2040 for each case.

*‡ Annual rate of improvement in energy efficiency was defined as annual average percentage of decrease in kWh/year

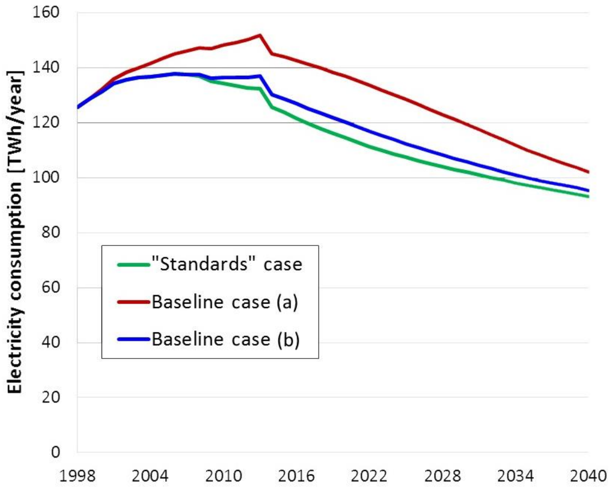


Figure 3. Estimated electricity consumption for air conditioners in the assumed cases

Effectiveness of the standards. In calculating the effects of the standard settings which corresponds to the amount of electricity savings, the electricity consumptions estimated for assumed cases were compared. The total effect of the standards is estimated by subtracting the electricity consumptions in "Standards" case from those in Baseline case (a). In the same manner, the effects of the 1$^{st}$ standard setting is estimated by subtracting the values in Baseline case (b) from those in Baseline case (a), and for the 2$^{nd}$ standard setting, values in "Standards" case were subtracted from those in Baseline case (b). From the Figure 3, we can notice that the effects obtained by the standards largely depend on that of the 1$^{st}$ standard setting, and by contrast, the effects of the 2$^{nd}$ standard setting are relatively small.

Based on the estimated amount of electricity savings, avoided costs of the standards were calculated by applying average electricity prices. The electricity prices in history in real terms were collected from the data record [19], and those in future were assumed to be kept at the level of 2012. Similarly, $CO_2$ reduction effect of the standards was estimated using $CO_2$ emission factors for electricity in history [20], and those in future were assumed to be kept at the level of 2012.

### *Incremental production cost*

Experience effects. The incremental production costs incurred by the standards were estimated through the observation on structural changes in the trend of the retail prices. In considering the basic transition of the prices, we referred to the ideas of experience effects within the corresponding industry. There is enormous empirical support in the world [21] for relationship between production costs and experience accumulated within industries, or in practice, decreasing trends in retail prices in real terms and cumulative sales volumes, which are often modelled by empirical experience curves.

Observation of the price trends. Figure 4 shows the historical relationship between the cumulative sales volume of air conditioners and average retail prices [22] in real terms for the period 1984 to 2011. Here logarithms of the values for each are shown for a clearer observation. We can see a progressive decrease in prices through cumulative sales from earlier periods, which agrees with general features mentioned above. However, we might see some transitions of the trends from the period around 1999 or a change from 2006 which correspond to the starting years of the standards.

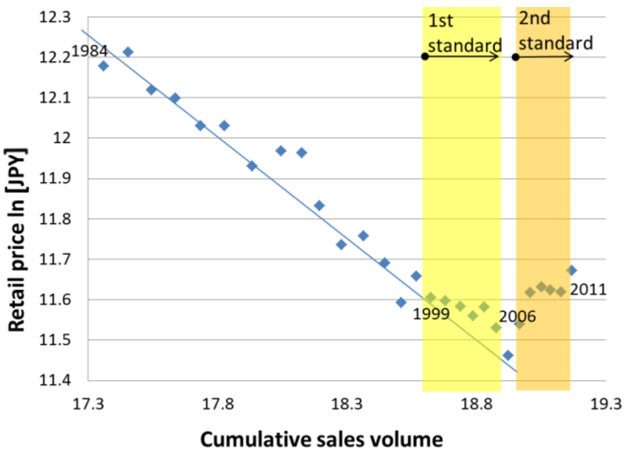


Figure 4. Observed relationship between the prices and cumulative sales (logarithms of the values are plotted)

Statistical analysis. For the purpose of examining the impact of the standards on the prices, and determining their magnitudes, a statistical verification approach was applied. We adopted an estimate formula based on a log-linear model incorporating the model of the experience curve together with irreversible dummy variables which correspond to the presence of the standards for the explanatory variables. The formula was given as follows:

$$\ln(P(t)) = \alpha + \beta_0 \times \ln\left(\sum_{s=1965}^{t} V(s)\right) + \beta_1 \times D_1(t) + \beta_2 \times D_2(t) + u(t) \qquad (1)$$

where $P(t)$ is price of appliance in real terms in year $t$, $V(s)$ is sales volume of appliance in year s, $D_1(t)$ and $D_2(t)$ are dummy variables corresponding to the adoption of the 1$^{st}$ standard or 2$^{nd}$ standard, taking the value 0 or 1 ($D_1(t) = 0$ for $t$ <1999, and equals 1 for $t$ ≥1999; $D_2(t) = 0$ for $t$ <2006, and equals 1 for $t$ ≥2006) to indicate absence or presence of the standards, $\alpha$, $\beta_0$, $\beta_1$,and $\beta_2$ are coefficients to be estimated, and $u(t)$ is the error term in the regression.

Using the available set of empirical data of the period 1984 to 2011, the coefficients in equation (1) were estimated and their statistical significance was confirmed. The results are shown on Table 2.

Table 2. Results of parameter estimates for the incremental cost incurred by the standards

| Term | Estimated coefficients | t-value |
|---|---|---|
| Cumulative production volume: $\beta_0$ | -0.480$^*$ | -11.9 |
| 1$^{st}$ standard dummy: $\beta_1$ | 0.010 | 0.25 |
| 2$^{nd}$ standard dummy: $\beta_2$ | 0.213$^*$ | 6.65 |
| Constant term: $\alpha$ | 20.56$^*$ | 28.2 |
| Explanatory power: $R^2$ [adjusted $R^2$] | 0.969 [0.938] | |

The asterisks ($^*$) indicate statistical significance at 1% level.

We see from Table 2 that the explanatory power of the model is very high and its coefficients except for that of the 1$^{st}$ standard dummy were statistically significant. Using the results above, we had quantitative discussions on the incremental production costs by the adoption of the standards. As for the impact of the 1st standard on prices, although some changes might have occurred in reality, they were regarded as insignificant here in view of statistics. That does not contradict the arguments about the level of the 1st standards perceived by the industry or changes in prices of air conditioners [23]. On the other hand, the impacts of the 2nd standard on prices were found statistically significant. The incremental cost per unit was estimated by comparison of the obtained $P(t)$ values with and without the 2nd standard in equation (1). The calculated percentage to the price of the appliance was 19%, and it corresponds to 21,051 JPY in 2010 for example. Using the assumed annual sales volumes to 2040, the future trend of additional prices were calculated in the same manner. The sum of incremental costs was then obtained from those prices and sales.

### *Monitoring activity by the government/their cost*

Monitoring and compliance. Monitoring activities for and manufacturers' compliance with the standards are important factors which influence the standards' effectiveness. While some of standards programs in the world are not functioning well because of insufficient levels of compliance or governance [24], those in Japan is considered to work very well [5]. In their process, when the target year arrives, the manufacturers are required to submit a report on their sales and the energy efficiency of their products, and the government evaluates their compliance.

Monitoring costs. This study considered the costs for those processes. Here, manufacturer's relevant costs incurred for testing or reporting activities for the adopted standards are considered to be reflected in the prices of products mentioned above. Therefore, we focused on the monitoring activities by the government. According to the Ministry in charge of the program, four officials cover the activities for 21 corresponding products in 2008 [25]. The monitoring costs per one appliance were calculated using those figures with the level of salaries paid for them. Their salary levels were assumed as average of government officials whose figures in history were obtained from [26] and those for future were assumed constant at the level of 2012.

## RESULTS

This section presents the results of our analyses for the period through 1999 to 2040. Here, the additional costs on the appliances paid annually in their average were calculated based on the average lifetime of air conditioners (15 years) with an assumed discount rate of 3%.

### *Economic impact of the standards*

Figure 5 shows the estimated incremental cost/avoided cost of the standards through 1999 to 2040.

The estimated avoided cost increases from the start of the standards as the new products conforming to the standards spread and replace the old models with relatively low energy efficiencies. It reaches a peak at approximately 600 billion JPY in around 2020, followed by continuous decrease with the first cycles of replacement coming to their ends and the improvement rates in energy efficiency slowing down. The additional cost for appliances annually paid increases over the average lifetime from the introduction of the 2nd standard until it reaches the peak in 2021, followed by gradual decrease with the sales volume decreasing. The monitoring costs by the government are, as visualized in Figure 5, negligible quantities. The avoided cost is larger than the incremental cost all through the considered period. The cumulative net costs are obtained as shown in Figure 6. They keep decreasing from the start to reach at the cost of -10,420 or the benefit of 10,420 billion JPY in 2040.

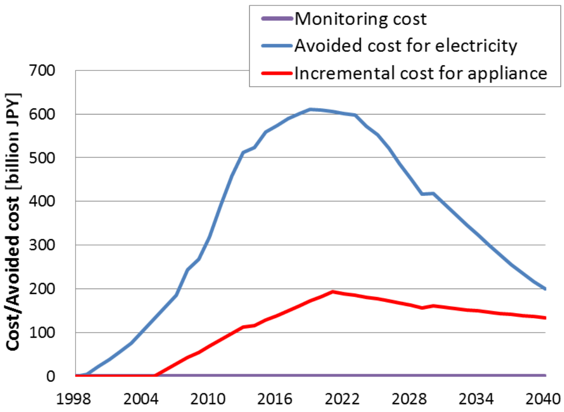


Figure 5. Estimated incremental cost/avoided cost through the standards (discount rate: 3%)

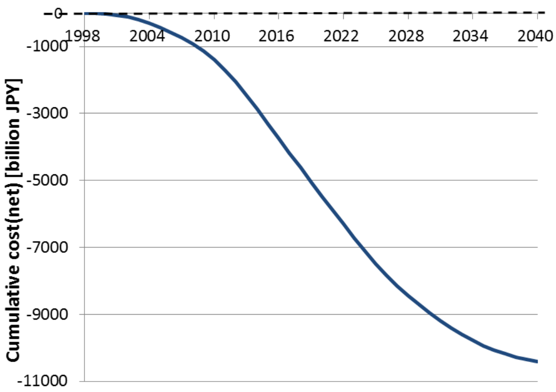


Figure 6. Estimated cumulative net cost through the standards (discount rate: 3%)

### *Cost-effectiveness of the standards*

Figure 7 shows the cumulative $CO_2$ reduction effects estimated to 2040. They keep increasing from the start of the standards to reach 330 Mt $CO_2$ in 2040 which is approximately twice of the amount of annual emission from the residential sector in Japan in 2010.

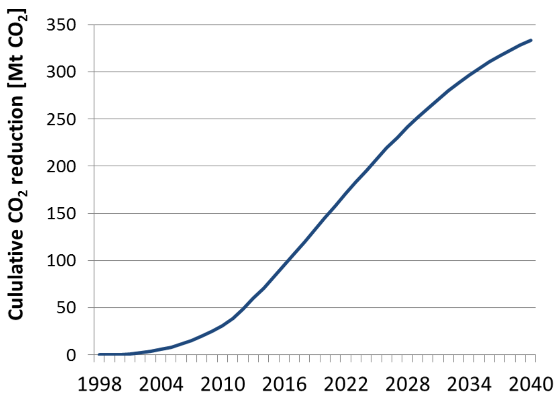


Figure 7. Estimated cumulative $CO_2$ reduction effect through the standards

Using the estimated net costs and $CO_2$ reduction effects, $CO_2$ abatement costs of the standards in JPY per t $CO_2$ was calculated as shown in Figure 8.

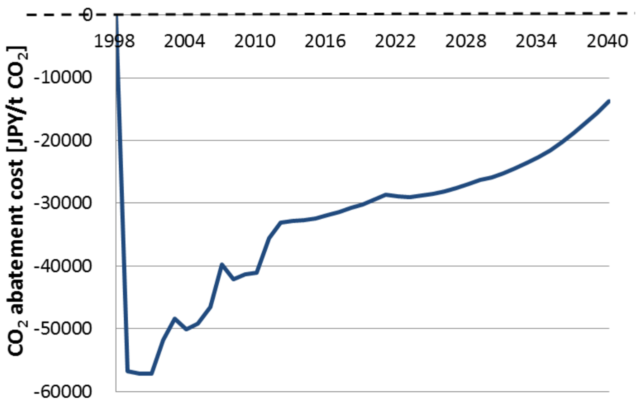


Figure 8. Estimated $CO_2$ abatement cost through the standards (discount rate: 3%)

Reflected from the net cost mentioned above, the estimated $CO_2$ abatement cost realized through the standards was negative within these periods, and it was -13,700 JPY/t $CO_2$ in 2040. This means the standards reduces significant amounts of $CO_2$ emission, producing net economic benefits at the same time.

***Sensitivity analysis***

The estimated economic impact by the standards is dependent on the discount rate applied in the calculation. As the assumed discount rate rises, corresponding net costs estimated increase accordingly. Figure 9 shows the result of the sensitivity analysis in terms of influence of applied discount rates on the $CO_2$ abatement costs.

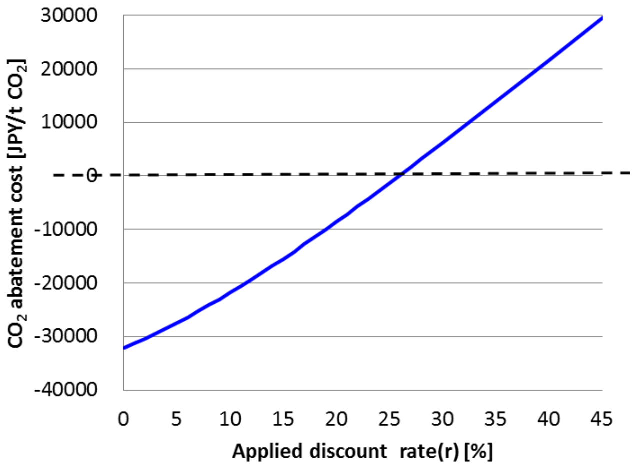


Figure 9. Discount rate dependence of the estimated $CO_2$ abatement cost

It can be clearly seen that the estimated $CO_2$ abatement cost increases when a higher discount rate is applied. Its value turns from negative into positive at 26% or higher.

In real economic activity, high discount rates (implicit discount rate) for consumers' choice of appliances are usually observed. The discount rates are affected by not only interest rate but also by depreciation rate and opportunity costs for searching. For example, the observed discount rates for air conditioners in the U.S. were from 5% to as high as 89% [27]. Wada *et al*. [28] summarizes the averaged discount rate for air conditioners were about 24%. When considering those discount rates found in the previous studies, the $CO_2$ abatement cost estimated in this study is not necessarily negative and could be positive.

This implies that examination of the cost of the standard settings requires careful consideration on the influence of the discount rate applied, and their results should also be viewed as such.

## DISCUSSION

Although the estimated net cost of the standards at a discount rate of 3% was negative to reduce significant amount of $CO_2$ emissions, the results are greatly reflected by the fact that the 1$^{st}$ standard setting involved little cost and their energy saving effect in contrast was relatively large. Figure 10 shows the costs only of the 2$^{nd}$ standard.

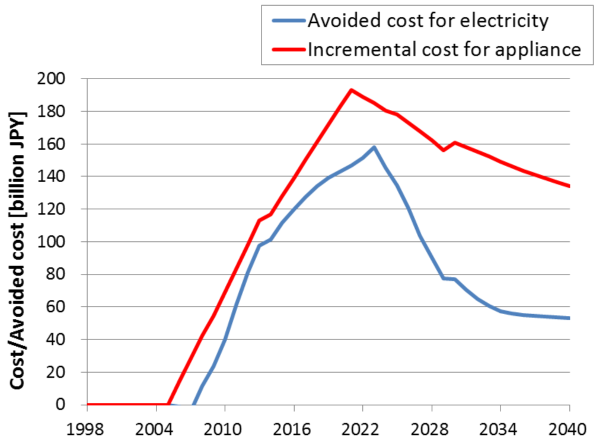


Figure 10. Estimated incremental cost/avoided cost by the 2$^{nd}$ standards (discount rate: 3%)

It can be seen from Figure 10 that the incremental cost of the 2$^{nd}$ standard was larger than the avoided costs for all through the considered period, which leads to considerable amount of net additional cost of it. On top of that, as previously mentioned and can be seen in Figure 3, the energy saving effect by the 2$^{nd}$ standard was relatively small. Both of these facts substantially raise the $CO_2$ abatement cost. Figure 11 shows the estimated $CO_2$ abatement cost of the 2$^{nd}$ standard. As indicated in Figure 11, it has a considerably high value through the considered period and is 26,800 JPY/t $CO_2$ in 2040.

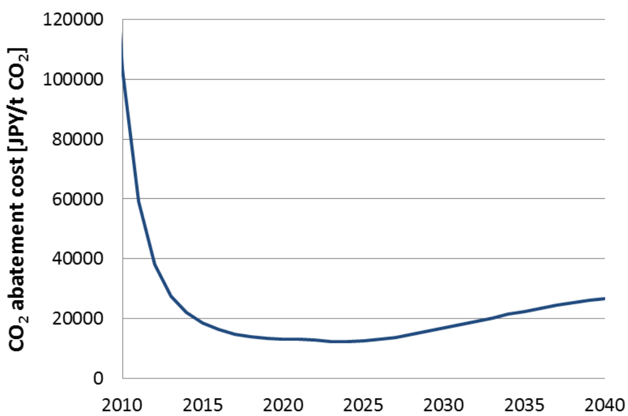


Figure 11. $CO_2$ abatement cost of the 2$^{nd}$ standards (discount rate: 3%)

The Japanese government mentions that introduction of "the 3rd standard" for air conditioners needs to be considered [7]. Undoubtedly, improving energy efficiencies of appliances is important for us to save energy resources or to reduce $CO_2$ emissions, besides, from a simple technical point of view, introducing the new standards would not be impossible on the ground that the highest energy efficiencies of air conditioners on the market have been still improving since 2010 until nowadays [16]. However they are required to carefully consider its possible impact on the economy as well as its effectiveness. Considering the cost-effectiveness of the 2nd standard shown above together with the recent situation in Japan in which technical development of components are almost reaching saturation levels, introducing "the 3rd standard" would impose a considerable burden on the economy.

## CONCLUSION

This study assessed the cost-effectiveness of the Japanese energy efficiency standards for air conditioners. The $CO_2$ reduction effect estimated through 2040 was 330 Mt $CO_2$. When applying a discount rate of 3%, $CO_2$ abatement cost realized through the standards was estimated to be negative value of -13,700 JPY/t $CO_2$, suggesting its certain excellence as an energy efficiency policy measure, which supports the view shown by the previous research [9]. According to the result of the sensitivity analysis, however, the net cost turns from negative into positive at a discount rate of 26% or higher. The results also revealed that the "excellent" cost-effectiveness of the standards largely depends on that of the 1st standard, and that the estimated $CO_2$ abatement cost of the 2nd standard was considerably high value of 26,800 JPY/t $CO_2$ in 2040.

Policy implications obtained from those results are that considered standards could be a highly cost-effective measure if they would be introduced in stages or countries where energy efficiencies of appliances are still relatively low; meanwhile, in a situation where those efficiencies are so high as at present in Japan, adoption of the additional standards could quite possibly involve considerable amount of costs to be shouldered by the consumers, even though certain energy savings or $CO_2$ reductions would be expected by them.The Japanese government, who is looking for the possibility of introducing "the 3rd standard" for air conditioners, is required to be careful about the possible economic burden imposed by it.

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