Behavior Change and Driving Forces to Save Electricity in the Electricity Crisis in Japan

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Abstract

Japan experienced an unprecedented electricity crisis in the summer of 2011 because of the earthquake and tsunami, along with the accompanying nuclear power plant shutdown. In response to this emergency, the government of Japan set electricity conservation targets of 15% for July through September. As a result, demand for electricity was curbed substantially, avoiding power outages. In this study we conduct an ex-post evaluation focusing on the electricity-saving efforts in the residential sector, by conducting interviews with a focus group interview of 20 people and a questionnaire survey of 3,000 households. The result shows that 10% saving was achieved on average after the weather normalization adjustment. It is estimated that about 40% of the reduction in electricity use resulted from conservation of electricity used for air-conditioning. Moreover, we elaborate on the roles of incentives in changing consumer behaviors. It is revealed that while social norms played an important role in raising consciousness of electricity conservation, they tended to lead to electricity conservation through self-control on air-conditioning, lighting, and other uses and in some aspects these effects are difficult to maintain. Provision of information is effective for the purpose of planned electricity conservation, which can take firm root. Finally, we tested the degree to which people were conscious of peak electricity hours and how they acted on information provided about peak electricity conservation.

1. Introduction

Due to the impacts of the March 11th, 2011 earthquake and tsunami, along with the accompanying nuclear power plant shutdown, there were concerns about a short supply of electricity in East Japan during the summer 2011. In response to this emergency, the government of Japan set electricity conservation targets of 15% for July through September. Regulations were applied to businesses with contracts for 500 kW or more of peak electricity demand, requiring 15% reductions in use of electricity vs. the 2010 level, and households were encouraged via the mass media and other means to conserve electricity (International Energy Agency, 2011; Ministry of Economic, Trade and Economy, 2011a). As a result, demand for electricity was curbed substantially, avoiding power outages (Ministry of Economic, Trade and Economy, 2011b)[1]. As there are concerns that Japan could face nationwide electricity shortages in the future, it would be desirable to shift to electricity conservation that reduces the impact on social and economic activities as much as possible.

Accordingly, this paper reviews the experiences of electricity conservation during summer 2011 in households served by Tokyo Electric Power Co. (TEPCO), Japan's largest power company[2]. Japan experienced another electricity crisis in 2004 due to the nuclear power shutdown (International

1 Huge efforts were also taken to save electricity in the spring 2011 shortly after the earthquake as well (Hirayama, 2011). In addition to seasonal difference in air-conditioning load, the situation in the spring is characterized by greater urgency and the implementation of rolling blackout due to the lack of time to launch a campaign. People and society were actually enforced to experience inconvenience for about two weeks.

2 Similar studies were conducted in other countries. For instance, Bender et al (2002) elaborated the role of mass media campaign in the California 2001 electricity crisis.

Energy Agency, 2005), but the supply-demand gap at that time was relatively small compared to that of 2011. In the summer 2011, people became more conscious of saving energy not only in the east Japan but also in the west Japan where the situation was not very serious. For example, households reduced peak demand by 4% in the service area of KEPCO, the largest utility in the west Japan. Nevertheless, efforts in the east Japan were outstanding, which resulted in the peak reduction of 11% in TEPCO's area (Ministry of Economic, Trade and Economy, 2011b). Section 2 summarizes the methodology of our surveys. Section 3 elucidates electricity conservation rates and identifies electricity conservation measures that were highly effective. Section 4 discusses the characteristics of driving forces for conserving electricity and of behaviors taken, as well as the potential for continuing them. Section 5 discusses the degree to which peak reductions of electricity were understood. And Section 6 summarizes the key findings.

2. Survey outline

To ascertain the state of electricity conservation in households, we conducted surveys using interviews and questionnaires (Nishio and Ofuji 2012). The overall survey flow is shown in Fig. 1. We first qualitatively identified a diverse range of conditions through group interviews and then conducted a questionnaire-based survey.

Firstly, we conducted our interviews in late October 2011 in the form of a focused group interview, with five members per group. Four interview sessions were conducted. Next, a large-scale questionnaire-based survey was conducted in November 2011 with respondents participating via the Web. In order to avoid sample bias, we set a goal for data collection as follows: (1) the ratio of males to females is 1:1, and (2) the region share and the rate of single-person households are given based on the statistics. The number of valid respondents was 2,970. 68% of them were the head of household and the remaining 32% were spouse. The average age of respondents was 52 years old. The average size of households was 2.2 persons and single-person households accounted for 35% of respondents. 45% live in detached house, while the remaining 55% live in multifamily house. We asked respondents to prepare their electricity bills and to report the amount used in each month of July through September for 2010 and 2011. The reduction rate of electricity for three months from 2010 to 2011 was 15.5%, which was nearly equal to the statistics of 15.4% (Note that both are figures before weather condition adjustment). This comparison indicates that self-reported data obtained in this survey is enough to represent population.

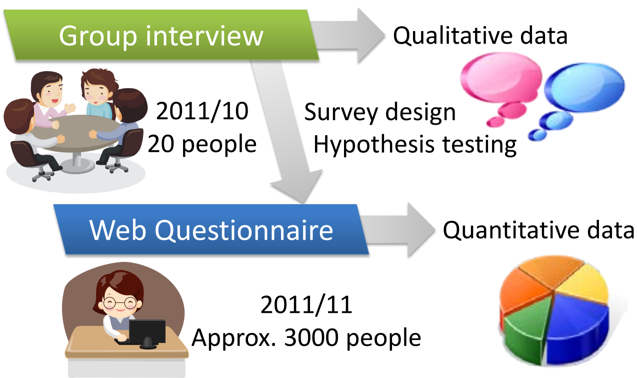

Figure 1. Survey outline

3. Electricity conservation rates and conservation measures

In this section we describe overall electricity conservation rates and how these rates were apportioned by household. Furthermore, we identify electricity conservation measures that were highly effective.

The amount of electricity used in the months July through September in 2010 and 2011 and how they were distributed are shown in Fig. 2. While use of electricity averaged 382 kWh/month in summer 2010, this figure had fallen substantially to 323 kWh/month in summer 2011 (a 15% reduction). However, the fact that 2010 had high air-conditioning demand due to record-setting heat could be one factor behind this result. For this reason, we employed regression analysis to adjust the use of electricity for weather conditions (cooling degree days). As shown in Fig. 3, the electricity conservation rate for July through September after adjusting for weather conditions averaged 10.5 percent. The share of households achieving electricity savings of 15% or more reached 32 percent.

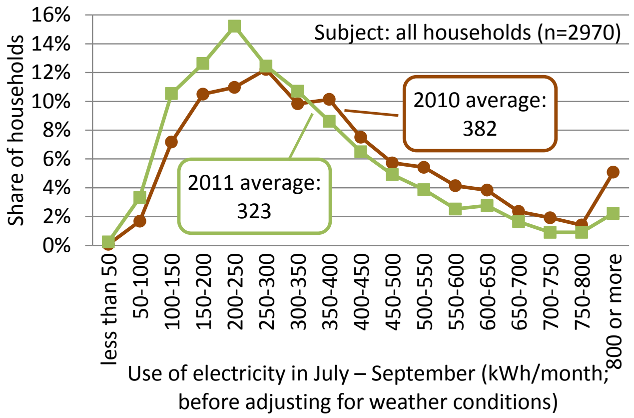

Figure 2. Electricity consumption in 2010 and 2011

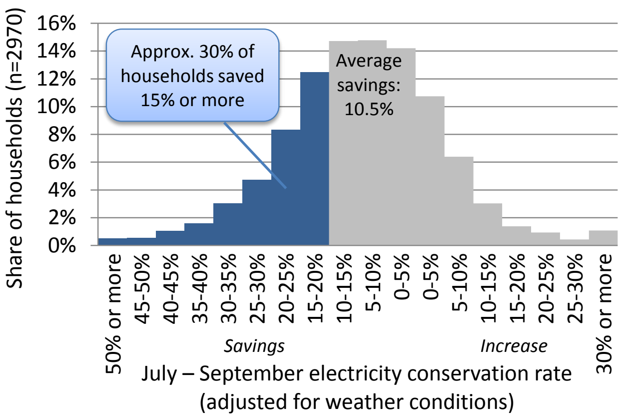

Figure 3. Electricity conservation rate

Next, we used multiple linear regression analysis to verify statistically the contribution of each electricity conservation measure to the electricity conservation rate adjusted for weather conditions (Fig. 4). We identified as possible explanatory variables a total of 47 electricity conservation measures from air-conditioners, refrigerators, televisions, lighting, and other appliances. In concrete, the air-conditioner temperature settings is defined as the difference in degree Celsius, the refrigerator temperature setting is also defined as the difference in levels (1: high, 2: middle, and 3: low), and other 45 variables are defined as dummy variables (1: implementation, and 0: non-implementation). After the above regression analysis, the overall electricity conservation effects of each measure (as shown later in Fig.7) are derived by multiplying the conservation effect when implemented (coefficient estimates from the regression analysis; as shown later in Fig.6) by the implementation rate (average of explanatory variables; as shown later in Fig.5).

Fig. 5 shows the main electricity conservation measures that had high rates of implementation by the survey respondents. Reducing the time air-conditioners were used had the highest implementation rate. Next came adjusting temperature settings, with the average temperature setting rising by 1.1 Celsius degrees (or 2.0 Fahrenheit degrees). The third most commonly implemented measure was that of reducing the time lights were turned on.

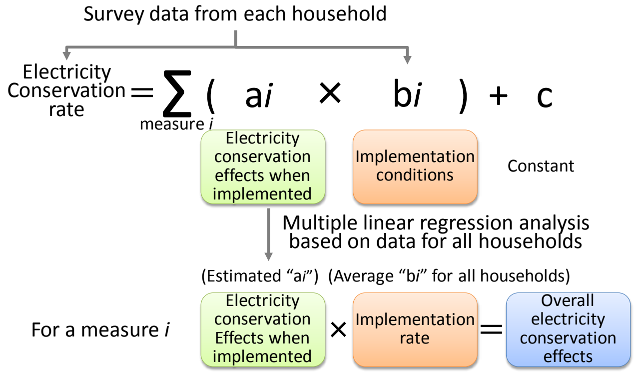

Figure 4. Methodology of estimating electricity conservation effects

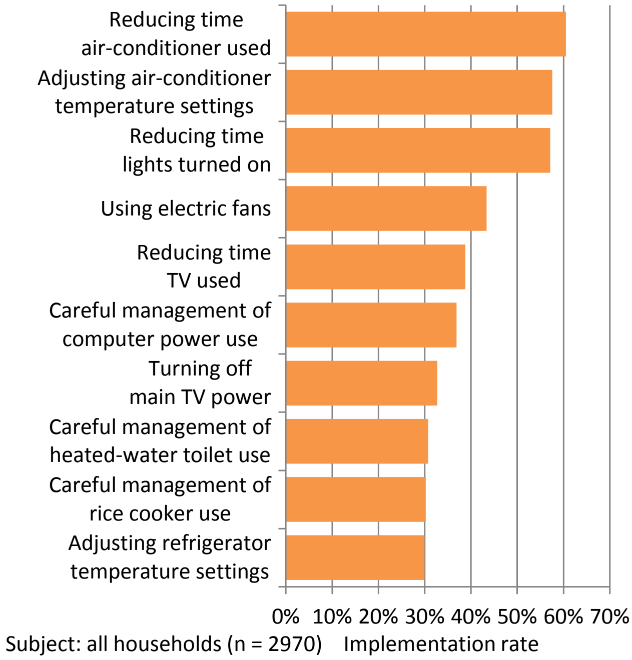

Figure 5. Main electricity conservation measures having high rates of implementation

Fig. 6 shows the main electricity conservation measures that had high conservation effects when implemented. These are the results of estimation using multiple linear regression analysis, and they are statistically significant. The figure also shows the 95% confidence interval. For example, the figure shows that reducing the number of refrigerators reduced the volume of electricity a household used by roughly 10% on average. Since of course, the number of households with a reducible number of refrigerators is very small, this measure had a low implementation rate of 0.7%. Other measures with high levels of effects if implemented were switching to a new energy-efficient refrigerator, with conservation effect of 10.4%, and switching to a new energy-efficient air-conditioner, with an effect of 6.7%.

Fig. 7 shows the main electricity conservation measures that had high effects overall, taking into consideration their implementation rates and their electricity conservation effects when implemented. The most effective measure was that of reducing the time air-conditioners were used, which resulted in a 2.6% savings overall. The second most effective action was that of adjusting air-conditioner temperature settings, which resulted in savings of 0.7%, and the third was reducing the time lights were turned on, with a 0.6% effect. Other measures reliably generating results were those involving changing settings such as refrigerator temperature and TV brightness and being sure to turn off the power to rice cookers. Summarizing the effects of these individual measures by use of electricity shows that the effects of electricity conservation related to air-conditioning use accounted for the largest share, at roughly 40% of overall results.

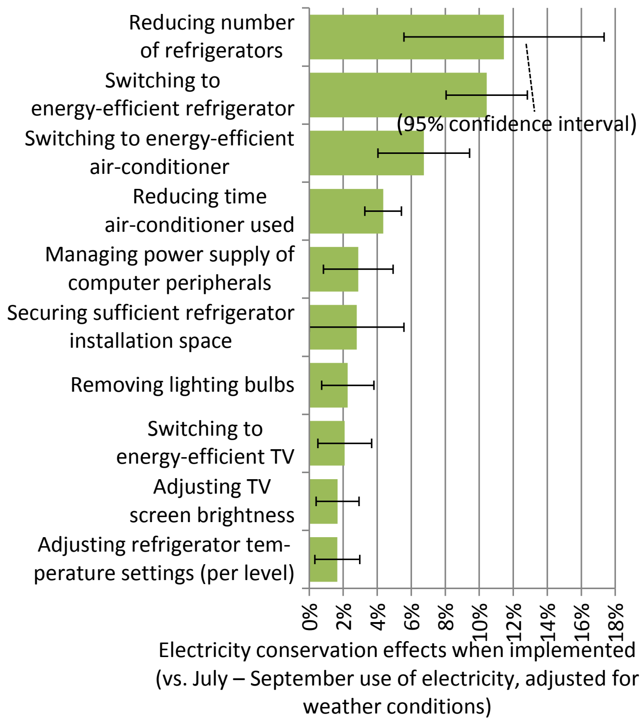

Figure 6. Main electricity conservation measures with high conservation effects when implemented

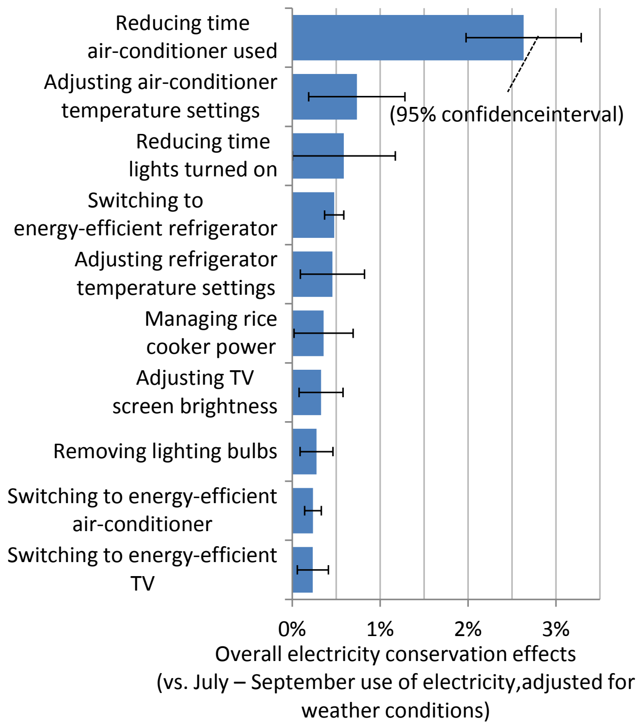

Figure 7. Main electricity conservation measures with high overall effects

4. Electricity conservation motives and potential for continuation

Appropriate incentive design is one of the most important interests in electricity-conservation and energy-efficiency policy. Results of our interviews show that subjects were motivated to conserve electricity by a wide variety of impetuses, ranging from a sense of responsibility to contribute to society to individual economizing. It was also pointed out that while some of electricity conservation took place through patience (people suffered thorough inconvenient and/or uncomfortable life in the summer), others were the result of ingenuity (people realized opportunities to save electricity easily). In this way, it is expected that types of behavior and their sustainability will vary by motive.

We designed a questionnaire based on the above hypothesis and used it to verify quantitatively the mechanism between motive and response. All data used in this Section are from the results of having subjects answer questions by choosing from the five answers “Agree,” “Somewhat agree,” “Not sure,” “Somewhat disagree,” and “Disagree.” While we will leave out the details here, we analyzed these data through factor analysis and covariance structure analysis. Applying factor analysis to the answers to 11 questions resulted in the identification of three main motivational groups: normative incentives, informational incentives, and economic incentives. We examined the causal relationship between these groups and responses to three questions on electricity-conservation efforts, by applying covariance structure analysis. The directions of the arrows in Fig. 8 indicate the causal relations, while the coefficients above the arrows show the strength of these causal relationships. These results showed that at higher-level efforts normative incentives had the highest level of motivation (0.43). The contributions of economic and informational incentives roughly were identical (0.25 and 0.22 respectively).

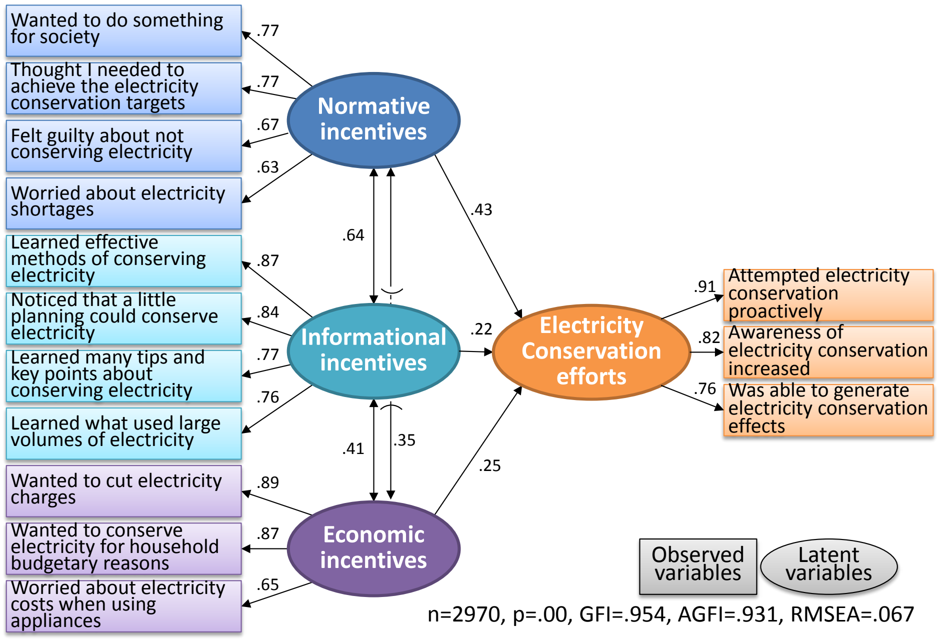

Figure 8. Causal relationship between incentives and electricity-conservation efforts

In looking at the types of electricity conservation behaviors, we identified two factors of patience and ingenuity from data on eight other questions. We used covariance structure analysis (also known as Structural Equation Modeling) to examine whether motives inspired subjects to patience or ingenuity and made them want to continue their efforts. Fig. 9 depicts the causal relationship between each pair of factors and each coefficient.

Before considering the overall structure, it would aid in understanding to first explain the relationships between latent variables (circled in the figure). While ingenuity increases the potential for continuation, patience has the opposite effect. Tracing these even further backward, while ingenuity is underpinned by informational incentives, the presence of normative incentives is an important factor behind patience.

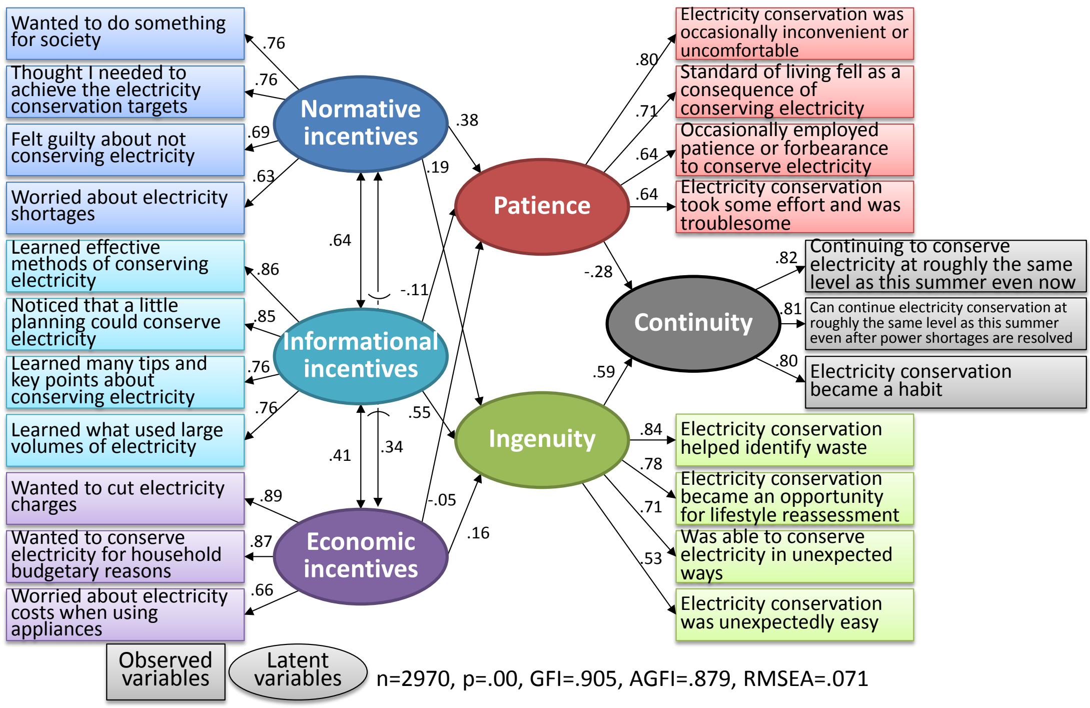

Figure 9. Incentives, types of efforts and continuity

Informational incentives made the largest contribution to continuity. Since informational incentives greatly encouraged ingenuity and also moderated the degree of patience (i.e., led to positive effects as a result of negative effects negating each other[3]), it contributed to increasing continuity in particular. At the same time, in general it was difficult for normative incentives, which led to results through underpinning an awareness of electricity conservation, to lead to continuity because they included a large element of electricity conservation through patience. Fig. 10 compares the contribution of each motive to continuity.

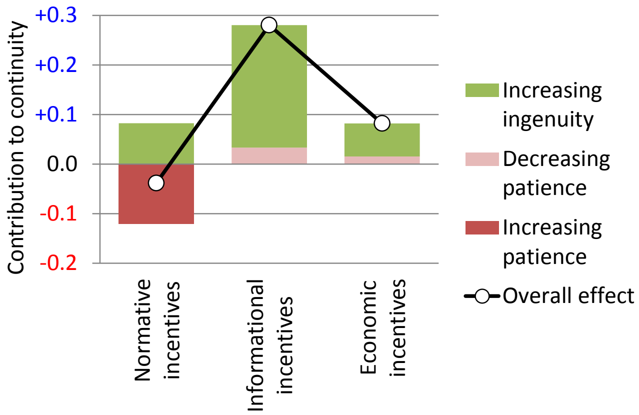

Figure 10. Incentives and continuity

5. Toward promotion of peak electricity conservation

TEPCO summer electricity demand grows particularly high on weekday afternoons (especially around 1:00 – 4:00 pm) when air-conditioning demand increases. For this reason, the Japanese government set demand control targets for the 9:00 am – 8:00 pm period weekdays from July 1 through September 9. At nights and on weekends and holidays the government called for conserving electricity to a reasonable extent. As a result, demand was curbed substantially throughout the entire period. While demand is interpreted to be stable if it is no more than 90% of peak supply capacity, a look at actual data on electricity usage rates shows that there was a relatively large margin available in the afternoon hours (Fig. 11). On most days the rate fell below 80% after 8:00 pm, and for a long period during the nighttime hours it remained in the 50% range.

It would be desirable in the future to orient electricity conservation efforts in the direction of avoiding, as much as possible, conservation that impacts people and feels burdensome to them outside the hours when the electricity supply is tight, while steadfastly maintaining superior energy conservation measures. To get suggestions on how to do so, we tested the degree to which subjects were conscious of peak electricity hours and how they received information about peak electricity conservation.

3 In the SEM analysis, total effects are calculated by summing the effects between two variables. For example, the total effect of "normative incentives" on "continuity" is {0.38*(-0.28)+0.19*0.59}=0.04, while that of "informational incentives" on "continuity" is {(-0.11)*(-0.28)+0.55*0.59}=0.28 (the underlined relationship is explained in the text).

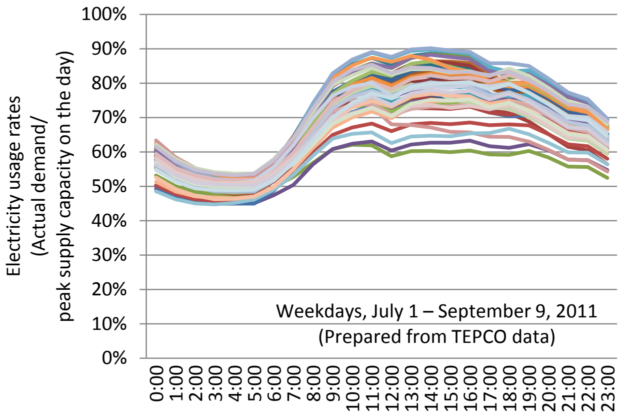

Figure 11. Actual electricity usage rates

Focus on peak hours

Roughly 80% of subjects were conscious of electricity conservation at nights and on weekends and holidays as well (Fig. 12). In contrast, only about 20% were not conscious of electricity conservation at nights and about 10% were not conscious of conservation on weekends and holidays.

When those who reported being conscious of electricity conservation at nights too were asked the reasons why, the most common answers were to "save money" and it "had become a habit" (Fig. 13). Such reasons are not dependent on time of day. At the same time, the second most common answer was "it could contribute to resolution of the power shortages," and subjects also answered "it could contribute to the recovery of the areas affected by the earthquake and tsunami." While such reasons of norm consciousness definitely underpinned electricity conservation in the summer, in light of the nighttime electricity supply and demand conditions at the time these cannot necessarily be said to be desired answers, and as such it can be said that there remains room for improvement in provision of information on peak electricity conservation.

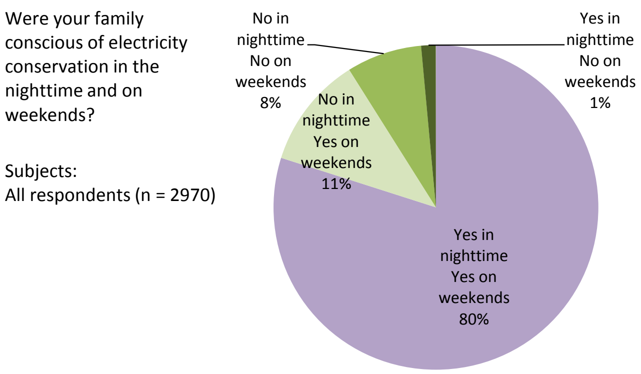

Figure 12. Conscious of electricity conservation at nights and on weekends

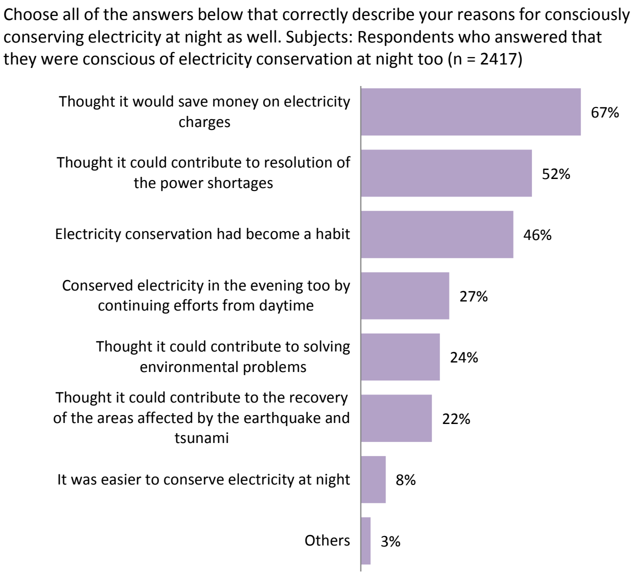

Figure 13. Reasons of being conscious of electricity conservation at nights

The interview subjects included many people who made efforts to conserve electricity at nights and on weekends. Some of them continued conserving electricity out of an electricity-conservation consciousness, even though they knew that there was more than enough supply at those times. At the same time, others acted based on the normative motive of desiring to do what they could, without being very conscious of demand and supply conditions. Among such people, many commented that they would not have conserved electricity so much if they had known that there was enough electricity.

- *"I made the same efforts on weekends and holidays as well, thinking more about electricity charges than conservation. While probably I would not have felt very guilty for using the air-conditioner at night, I would feel guilty for using it too much."*
- *"The only thing one can do to conserve electricity late at night is to conserve electricity used for air-conditioning, because I do not watch TV or eat meals at night."*

Still, some people consciously tried to conserve peak electricity based on an understating that there was relative margin between demand and supply at nighttime. However, as shown by the fact that such people accounted for only about 20% of subjects in Fig. 12, people of this type were a minority among interview subjects.

- *"Since I had heard that electricity use peaked in the afternoon, thinking that the peak hours were over in the morning or after 8:00 at night I cranked up the air-conditioning to kind of enjoy the coolness. Just cooling down once is enough, while it would be a little tough to feel hot all day and night. Since I don't remember hearing much about conserving electricity on weekends and holidays, we used it as usual, without being very conscious of conservation."*
- *"While previously I did the laundry after my husband had left for work, this summer I decided to do it as soon as I got up in the morning to avoid the peak hours. I decided to use the dishwasher at night, since the peak time for dishes that need washing is after dinner and I wanted to avoid the peak hours of use of electricity."*

One method of increasing awareness of peak electricity conservation is that of providing information on electricity demand and supply conditions for the current day and the day before. In summer 2011, TEPCO provided forecasts of electricity demand and supply[4], and television broadcasters as well as Yahoo! provided their own forecasts. More than 90% of subjects reported seeing such information "often" or "sometimes" (Fig. 14), and as such it can be said that there was broad awareness of the existence of information on electricity demand and supply.

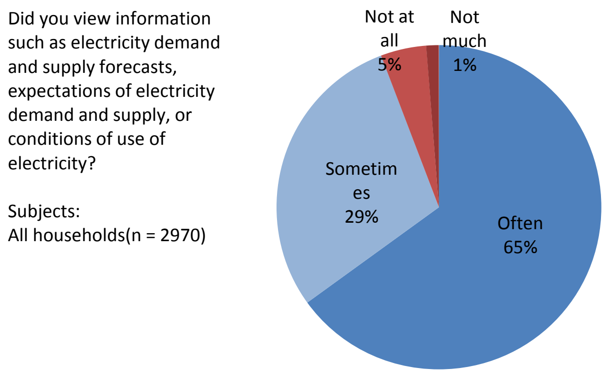

Figure 14. Contact with electricity forecasts

However, did contact with information on electricity demand and supply bring about changes in behavior? There are two possible responses for subjects (Type A and B).

Type A subjects reported viewing such information but said that demand and supply conditions did not either relax or increase their consciousness of electricity conservation. Their stance was that

4 See the TEPCO website (http://www.tepco.co.jp.cache.yimg.jp/en/forecast/html/index-e.html). For your information, links to other power companies' website are at http://www.meti.go.jp/setsuden/electricity.html (in Japanese). Korea also experienced electricity shortages in 2011 and information of electricity demand is being updated at http://www.powersave.or.kr/main/main.aspx (in Korean).

they already were doing what they could, so that they did not have much of a response to information on electricity demand and supply conditions in summer 2011.

- *"While I viewed that information, my response was something like, 'Is that so?' I was not much affected by the information, neither feeling relieved when the figures were low nor feeling I had to try harder when they were high."*
- *"I never felt that I could relax because the figures were low. I felt nothing more than that today would be all right."*

On the other hand, Type B subjects were those who changed their consciousness of electricity conservation based on an understanding of the demand and supply conditions seen in such information. These subjects showed variation in their electricity conservation behavior, as they judged that conservation was not so necessary at nights and on weekends and holidays.

- *"I always watch the news in the morning. They broadcast forecasts of electricity demand and supply during the news, and sometimes I felt a little more comfortable thinking that things probably would be all right when it was not such a hot day. Watching the electricity forecasts each day, I got a sense that the peak hours were the hot hours in the afternoon and right before dinnertime when people were preparing meals, and so I was conscious of those hours. At nighttime and on weekends I used electricity as usual without being very conscious of conservation."*
- *"Since the percentage of electric capacity in use falls to about 50% at night, I thought that I did not have to try hard at night."*

Thus, while the presence of information on electricity conservation hours and electricity demand and supply was well-known, such information was not incorporated into some people's lives as clear indicators for use in decision-making, while for others, a consciousness of conservation of electricity permeated through daytime, nighttime, and weekends and holidays. This can be considered positive in that it led to major controls on demand throughout the summer and helped avoid large-scale power failures. Nevertheless, there is room for improvement in promoting electricity conservation consciousness toward peak hours while lessening the burden of conservation at nights and on weekends and holidays through improved methods of providing information.

One good example of informative program is a "Flex Alert" introduced in the state of California in the United States (Flex Your Power, 2012). The Flex Alert is an urgent call when immediate conservation is needed, and its key point is to convey simple messages on three measures to be followed when it is issued: (1) turn off all unnecessary lights, (2) use appliances after 7 pm, and (3) set air conditioner to at least 78 degrees Fahrenheit (or 26 degrees Celsius). Some of TV commercials were made with a sense of humor. Looking back at Japan in 2011, it must be noted that such an approach was not socially acceptable to normative atmosphere and public criticism of electric power industry. Normative approach aiming to encourage society to take as many measures as possible was the only realistic way in the unprecedented and unpredictable crisis, and accordingly curtailed demand day and night. However, in the future, there are many things we can learn from the concept of Flex Alert to encourage consumers to take effective measures during peak hours.

Focus on peak load

One possible method is to focus on loads that cause peak demand to occur and ensuring widespread understanding of measures to conserve electricity in regard to such loads. For example, during summer peak hours, air-conditioning accounts for about one-half of power consumption in the household sector, and measures targeting this share of demand are very important. For this reason, we asked in our questionnaire, "What share do you think air-conditioning accounts for in electric power consumption by households in the area as a whole during peak power usage in the summer?" According to the answers to this question (Fig. 15), about 60% of subjects thought the answer was smaller than the actual figure of 50 percent.

We then asked those who gave an answer of less than 50% and those who answered “don’t know” the following question: “Actually, it is said that demand for air-conditioning use rises around 2:00 pm when the temperature increases, accounting for about 50% of the electricity consumed by households in the entire Kanto region. Do you think that if you knew this you would have been more conscious of conserving electricity used in air-conditioning on weekday afternoons?” The results showed that about one-half of respondents answered in the affirmative (Fig. 16).

Of course, in conserving electricity used for air-conditioning there also is a need to raise awareness about heatstroke, and careful consideration must be given to the reliability of electricity conservation effects with regard to the important subject of intensely hot days as well. Still, these results suggest that consciousness of conserving electricity used for air-conditioning does increase with provision of better information.

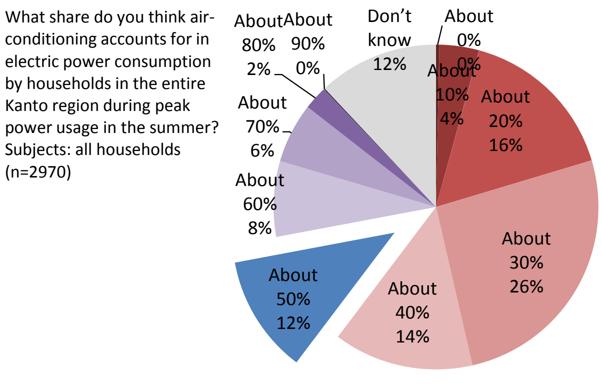

Figure 15. Impressions on the share of air-conditioners

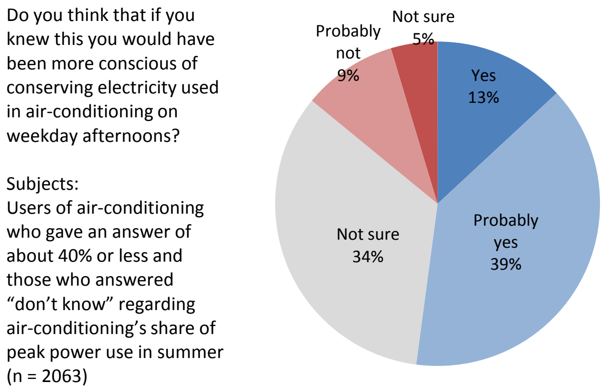

Figure 16. Possible effects by information on air-conditioners

6. Conclusions

In this study we examined the state of household electricity consumption during the summer 2011 electricity shortages in East Japan. The key findings from this study were the following:

- After excluding the effects of weather conditions, the amount of electricity used in July through September 2011 decreased by 10% on average from the previous year. About 30% of households achieved electricity conservation of 15% or more. About 40% of the reduction in electricity use resulted from conservation of electricity used for air-conditioning, with reductions in the time air-conditioning was used accounting for just under 3 percent of the total energy savings during the studied period. Other main measures taken that had large effects included reducing the times lights were turned on and adjusting settings such as air-conditioner and refrigerator temperatures and television brightness.
- Driving forces for electricity conservation were (1) normative motives aiming to contribute to resolution of the electricity shortage, (2) informational motives such as tips and expertise, and (3) economic motives intending to reduce electricity charges. While social norms played an important role in raising consciousness of electricity conservation, they tended to lead to electricity conservation through self-control on air-conditioning, lighting, and other uses and in some aspects these effects are difficult to continue. Provision of information is effective for purposes of planned electricity conservation, which can take firm root more easily.
- While some people switched electricity conservation behavior being conscious of the time of day, the majority remained conscious of conservation at nights and on weekends and holidays as well. While some reasons cited for doing so were to save money and because conservation had become a habit, many subjects tried hard to conserve electricity based on a norm consciousness,

and some commented that if they had known that there was more than enough supply of electricity at such times they would not have tried so hard. It would be worthwhile to study ways of providing easily understandable information emphasizing peak hours and peak load in order to move toward electricity conservation that would have less impact on people's lives and would require lower expenditures.

There is no guarantee cooperative behaviors driven by norms will be maintained in the long run. Therefore, the provision of information becomes more important. As this study indicated, information is a useful tool to change behavior and its impact is expected to continue. Although much progress was made in 2011, there remains room to increase implementation rates of each measure. Also, it is worth considering ways to encourage consumers to take effective measures during peak hours.

Further studies are needed to understand consumer behavior and to identify more effective interventions in case of electricity crisis. Retention of electricity saving is one of the most important topics, and it is also beneficial to monitor how people are motivated to save electricity. With regard to the latter point, one methodology is to ask the same set of questions indicated in Fig.8 for comparison, or in a simpler way, to pick up key questions with high coefficient, for instance, "wanted to do something for society," "learned effective methods of conserving electricity," "wanted to cut electricity charges, " and "attempted electricity conservation proactively." Another critical issue is to reveal to what extent measures are able to be taken at the very peak of electricity demand during hottest weather. The result implies potential to raise awareness of effective use of air-conditioners. However, in case where there is little potential for additional voluntary actions, it is necessary to further promote measures day and night.

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