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Households Hold Key to Resolving Power Shortage

Demand control based on price mechanism and smart grids

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Summary

- Based on our understanding that rationing through planned outages and power-use restrictions is a resource allocation that results in serious economic and social harm, we examine the efficacy of balancing supply and demand through the price mechanism. We focus mainly on the household sector. Because it is hard to exercise control over electricity demand in this sector, it will be key to alleviating Japan's electricity shortages.

- It has been said that the price elasticity of electricity demand is intuitively fairly low, but there is insufficient research focusing on the demand side. In this report, we estimated an electricity demand function in terms of electricity prices and found short-term elasticity was –0.47 and long-term elasticity –1.48 for the household sector. Our conclusion is that it is possible, and indeed desirable, to rebuild the electricity system by putting the price mechanism to work so as to boost efficiency in balancing supply and demand. The new system is expected to help gauge which economic actors truly need electricity at what times of day, while the conventional one is incapable of extracting such information.

- However, the price mechanism is not a panacea. Building smart grids and deploying smart meters and other two-way communication enabled control devices should complement efforts to balance supply and demand through pricing. This perspective has been the subject of surprisingly little discussion elsewhere.

- Experiments and experiences in the US of the price-based demand response (controlling electricity demand using the price mechanism) show that demand is reduced more efficiently when smart devices are used. Attention-worthy demonstration trials are also underway in Japan in places like Kitakyushu. These should amass valuable data and research findings concerning the potential for controlling supply and demand using the price mechanism and smart devices when deploying renewable energy on a mass scale.

1. Pros and Cons of Power-Use Restrictions and Planned Outages

Planned outages and power-use restrictions are emergency measures

Japan's supply of electricity is shrouded in uncertainty due to nuclear power plant shutdowns and other factors. As a result, people have pointed to the need for measures to address the power situation from both the demand side and the supply side. The planned outages in spring 2011 and the power-use restrictions in summer 2011 were measures that were taken during a time of crisis. However, the mandatory restrictions imposed by the power companies and the government probably caused economic losses by ignoring the freely made (economically rational) choices of economic actors.

Electricity rationing has resulted in inefficient and unfair allocation of resources

When a production line is shut down—even at a predetermined time—due to a power outage, in many cases there is a noticeable decline in productivity around the time of shutdown. Power-use restrictions impose supply-chain adjustment costs as companies are forced to shift production times. Shifting production to Saturdays has apparently upset people's lives, as some have been unable to look after or spend time with their children because these changes are not coordinated with schools.

Electricity demand rising as economy recovers

But above all else, in the midst of unprecedented crisis, Japan was able to avoid sudden widespread power outages. Nevertheless, there are concerns that the sense of crisis is waning now that the country has gotten through the summer power supply shortfall thanks to energy saving measures. Electricity demand will trend higher as the economy gets back on track and economic growth begins to pick up steam. For the time being, electricity consumption will probably rise as reconstruction after the Great East Japan Earthquake moves into high gear. While there will probably be some energy saving innovations over the long term, increases in output will mean increases in the volume of power used unless there are changes in manufacturing technology. The need to ensure a stable power supply has certainly not diminished.

Limits to what can be accomplished from the supply side

Meanwhile, it takes time to build power plants, so it is hard to immediately increase the supply of electricity. While it is pragmatic to address the problem created by the shutdown of nuclear power plants by maximizing the use of existing thermal power plants, there are limits to this. Furthermore, there is the problem of increased emissions of CO2, a greenhouse gas. Although renewable energy shows growing promise from the standpoint of reducing CO2 emissions, there are problems nonetheless, such as the small amount of power generated and the uncertainty of such supplies. Furthermore, passing on the rising cost of fuels used in thermal power generation and the acquisition costs of renewable energy in the form of electricity prices could put a damper on economic activity. Japan is approaching the limit of what can be accomplished to address the power problem from the supply side alone.

Turning the focus to household electricity demand

Therefore, we would like to turn the focus to the often overlooked demand side of the equation, especially household electricity demand, and look at making the supply-demand system more efficient through market mechanisms and new investment. Specifically, we propose implementing price mechanisms as well as smart meter and smart grid technology as quickly as possible in order to directly and indirectly exercise control over home electricity demand.

Ensuring efficient electricity supply system by controlling electricity demand, including home electricity usage

Electricity demand from large users like corporations can be controlled in a pinch through policy mechanisms. But, controlling demand from homes (small users) must be left up to each household, so it is far from certain whether this demand can be reliably reduced. Japan's electricity system is organized to follow fluctuations in demand. Therefore, the power companies have more than sufficient generation and transmission facilities to ensure a stable supply of electricity even at peak demand times, and this is one factor that makes electricity prices higher.[1] If control could be exercised over electricity demand—including home usage—generating costs could be held down and it would be possible to ensure an efficient supply system without putting too much of a burden on the entire economy.

2. Price Mechanism Promotes Efficiency

2.1 Benefits of the price mechanism

Conventional price mechanism in Japan

Supply adjusted to match electricity demand

Because technology for storing power at reasonable cost has not yet been developed and it is impossible to keep electricity "in stock" for future use, electricity supply must always match demand. As a result, supply is modified to match changes in demand mainly by adjusting operating rates at power plants.

Pricing structure based on electricity demand already exists

There is already a mechanism for tweaking electricity demand. For example, when the volume of electricity consumed rises, the per-kWh electricity rate also rises. Price structures vary slightly by power company but "meter-rate lighting B plan," a billing system for ordinary residential use (10A-60A) offered by Tokyo Electric Power and other electric power companies, contains both an ampere-based fixed price component (for Tokyo Electric Power customers at 30 amps the charge is Y819 per month) and a meter charge that depends on the volume of electricity actually used.[2] In the case of Tokyo Electric Power, the per-kWh price is Y17.87/kWh up to 120 kWh/month, Y22.86/kWh for 120-300 kWh/month, and Y24.13/kWh for more than 300 kWh/month (Chart 1). In other words, it is a three-tier price system where electricity charges increase in three stages as the volume of electricity used rises.[3]

Rational to lower prices when demand is lower and to raise them when demand is higher

A variety of other price options aimed at flattening electricity demand are available to households and industry. There are plans that lower prices during nighttime hours when usage is low and plans that raise prices for industrial customers during summer months when usage is high.

Is the current price structure contributing to electricity saving efforts?

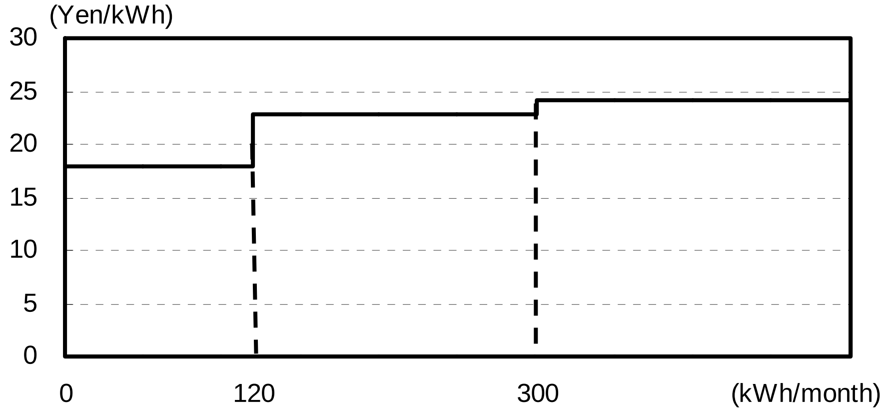
Nevertheless, under Tokyo Electric Power's three-tier price system, the per-kWh rate difference between the second and third tier is only Y1.27, so it is unclear how much this structure is helping to curb electricity consumption. We wonder how many households realize that they are paying some kind of penalty when they consume more electricity in a given month.

Today's meters impossible to fine-tune consumption depending on time of day

With the electricity meter commonly used in homes today it is only possible to calculate month-to-month differences in usage and it is impossible to assign different electricity prices for shorter increments of time, such as by the hour. Furthermore, although electricity charges fluctuate due to changes in fuel costs, they do not change in accordance with supply-demand conditions. Later in this report we will discuss smart meters and other communications enabled equipment as well as smart grid technology. This kind of infrastructure will be necessary if power consumption is to be more precisely regulated through pricing.

1. Hatta, Tatsuo (2004), "*Denryoku kyososhijo no kihon kozo*" (Basic structure of a competitive electricity market). In Hatta, Tatsuo and Makoto Tanaka (Eds.), "*Denryoku jiyu ka no keizai gaku*" (Liberalizing electricity markets: an economic analysis), Chapter 1, Toyo Keizai Shinpo-sha (in Japanese).
2. In the meter-rate lighting A plan, a billing system for ordinary residential use in Kansai, Chugoku, and Shikoku power company areas, there are no ampere-based fixed prices, and bills basically depend on volume of electricity used, with a minimum charge—beyond the minimum (up to the first 11-15 kWh per month), the per-kWh price increases in three stages. Okinawa Power Company has a similar price system. In general, power companies nationwide have price structures where the per-kWh electricity price rises when volume of electricity used increases.
3. Solar surcharges and fuel price adjustment costs are also taken into account for calculating electricity bills.

Home Use Electricity Price (Tokyo Electric Power's Case) Chart 1



Source: Tokyo Electric Power; compiled by DIR.

Benefits of price mechanism capable of adjusting supply and demand

Pricing as a way to eliminate electricity supply-demand gap

System planning must incorporate a variety of mechanisms in order to match electricity supply and demand. However, artificial rationing when the relationship between supply and demand is broken is a problem, as we have already discussed. For the efficient distribution of resources, there must be a working price mechanism that restores the balance of supply and demand. For example, it goes without saying that there should be a mechanism that causes electricity prices to rise when supply of electricity is tight, encouraging users to adopt energy saving measures and thereby holding down electricity consumption. By the same token, there should be a mechanism that provides an incentive for increasing supply, such as electricity from independent power producers (IPP) and others on the supply side to be purchased at higher prices. Meanwhile, there should be a mechanism that restores the balance of supply and demand by lowering prices when the supply and demand balance is looser. A scheme that allows the pricing mechanism to work when there is excess supply will become increasingly important if distribution of power generated from wind power and solar power becomes more prevalent in the future.

Scheme under which electricity can be consumed as needed

It makes sense to use the price mechanism to adjust supply and demand because the need for electricity varies from company to company and from household to household depending on respective circumstances. Generally, a stable supply of electricity is essential for places like hospitals and semiconductor foundries, but at the same time there is also unnecessary demand for electricity, such as excessive street lighting and lighting in unoccupied rooms. It is impossible for outsiders to grasp how much electricity a particular user truly needs. Therefore, in order to extract information that is hidden from the outside about the strength of electricity demand it is necessary to get each user to signal whether that electricity is truly needed by making electricity charges overt.

Using "prices" to extract user-side information

In other words, users that want a consistently stable supply of electricity will continue to consume electricity even if the price is somewhat higher, but those that are wastefully consuming electricity will have an incentive to reduce consumption if they are able to see how their electricity charges are rising. Thus, voluntary consumer behavior is more likely to result in the efficient use of electricity than rationing by the government or by the power companies. Imposing preemptory rolling blackouts by region and uniform power-use restrictions by company size to differentiate usage volume is both arbitrary and inefficient since it ignores the preferences of economic actors with respect to demand for power, and ultimately it is harmful to economic welfare. In contrast, if electricity prices are lowered when capacity exceeds demand, it could spur demand for electricity during those times and seasons.

Price mechanisms used in power markets in some Northern European countries and the US

Electricity is traded using a price mechanism in some places in Northern Europe and the US where electricity markets have been deregulated, and various ideas have been incorporated into the designs of these markets. For example, long-term contracts for electricity are a way to lock in future quantities and prices in advance. Furthermore, day-ahead and intraday markets have been established so that power generators and large users can close the gap between long-term contract volumes and actual power needs.[4] These devices are used to strike a balance between supply and demand by curbing extreme volatility in electricity prices while still allowing the price mechanism to work.[5]

2.2 Price mechanism and smart grid technology

Problems accompanying the price mechanism

Will price mechanisms work well in Japan?

Merely deregulating and allowing the market to function is certainly not enough. Price mechanisms have problems, too. If the electricity supply and demand condition is constantly regulated only in real-time, both power generators and consumers would be exposed to large fluctuations in price, and it would be hard to draw up electricity supply or usage plans. The aforementioned schemes that are used in some places in Northern Europe and the US provide some guidance as to how to avoid such problems. Nevertheless, it is debatable whether schemes that work in a relatively small market would also work well in Japan, which is a large market.

Bringing about a well-functioned price mechanism would be fairly expensive

Designing and maintaining a well-formed market system in order for the price mechanism to function well would probably be fairly expensive. For example, in a real-time market where electricity trading takes place just ahead of time, if supply and demand is out of balance the body that ultimately regulates supply and demand will ask some generators to quickly bring power online and, if this is impossible, it may ask some large users to stop using power. Because it takes time to get generating facilities ready to begin operating (warming up boilers), power generators must always be on standby to quickly bring generating capacity online, and this is fairly costly in terms of fuel expenses and labor costs.

Smart grid technology complementing price mechanism

Smart grid and smart meters

In our view, smart grid technology will be essential for building an efficient electricity system. While there is no clear definition of the term “smart grid,” it generally refers to an electricity network in which suppliers and users can exchange information with each other by taking advantage of information technology and communication capabilities. Smart grid supplier-side and user-side data is transmitted using two-way communications enabled devices, such as smart meters. Smart meters make it possible to take advantage of more detailed information, such as energy consumption per unit of time. Combining this with smart grid technology would make it possible for users who are connected to the electricity network to share surplus electric power with each other and for people to remotely operate electrical equipment in homes and offices so that they can directly control electricity usage. Detailed electricity consumption data is essential for setting electricity prices.

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4. See Hatta (2004) for information about the Northern Europe example.
5. It is generally understood that the partial deregulation of electricity prices led to the oft-cited example of the 2001 California blackouts. As wholesale electricity prices were deregulated, while retail prices remained fixed, wholesale prices rose faster than retail prices when the market was tight and excess demand did not disappear.

Difficulties accompanying renewable energy

Smart grid technology will be essential for bringing about a low-carbon society in which renewable energy is deployed on a large scale. The amount of electricity generated by renewable energy sources like solar or wind power varies greatly depending on the weather, so deployment on a large scale would cause many problems in the power grid. Electricity has to respond to demand that fluctuates from moment to moment. Frequency is held constant by maintaining a balance between supply and demand, and this is accomplished by ensuring that there is a certain amount of electricity from balancing power sources (thermal power, pumped-storage hydropower and other sources, which are capable of maintaining output to a certain level). However, if renewable energy with highly volatile output is deployed on a large scale, electricity from balancing power sources could be insufficient, making it impossible to maintain a constant frequency (Quadrant 1 in Chart 2). Furthermore, supply could exceed demand if a large amount of electricity is generated from renewable energy sources when demand is low (such as on a holiday), resulting in surplus electric power (Quadrant 2 in Chart 2). According to one report, if the amount of electricity from wind power grows to account for more than 5% of Japan's power, it would become difficult to maintain the balance of supply and demand because of insufficient electricity from balancing power sources.[6] Furthermore, it has been estimated that deploying more than 10 million kW of solar power capacity would result in a surplus of electricity.[7] For now, these sorts of power grid problems are restricting the amount of renewable energy that can be deployed.

Smart grids will help lower the cost of renewable energy deployment

These problems could be resolved by installing large storage batteries, but this would be fairly costly. If the demand side could be controlled through the use of smart grid technology as the output from renewable energy fluctuates, it would be possible to keep supply and demand in balance with minimal storage batteries and balancing power sources, making it possible to deploy more renewable energy while holding down electricity prices (quadrants 3 and 4 in Chart 2).

Smart grid and price mechanism synergies

While not directly related to the topic of this report—adjusting supply and demand through prices—smart meters and smart grids are valuable infrastructure for controlling electricity supply and demand conditions. By combining this infrastructure with price information, it should be possible to realize an even more advanced electricity system. As we mentioned earlier, although we are focusing on the price mechanism, it is not a panacea. Being prepared for those times when it is necessary to ask power companies to suddenly generate more power represents a cost (a cost that increases marginally just before consumption). If that cost is too high, then it is basically reasonable to use smart grid technology to adjust same-day supply and demand.

Smart grid technology complements price mechanism

In practice, it would be possible to shut down electricity supply to electrical devices that are connected to a smart grid when a steep increase in electricity prices is expected. If power companies offered contracts with lower electricity prices on

6. Ministry of Economy, Trade and Industry, "*Heisei 22 nendo shin-enerugi-to donyu sokushin kiso chosa jigyo (furyoku enerugi no donyu kanoryo ni kansuru chosa) chosa hokokusho*" (FY2010 basic research project on the promotion of new energy deployment [wind energy feasibility volume study] research report), May 2011 (in Japanese). The report projects that wind power capacity to be connected to the grid is about 5% of overall installed generation capacity, excluding Tokyo, Chubu, and Kansai electric power companies (companies that have not set limits on wind power capacity to be connected). The report assumes that wind power capacity to be connected to the grid would be 10.18 million kW nationwide, if wind power capacity vs. overall capacity is also 5% for the three companies.

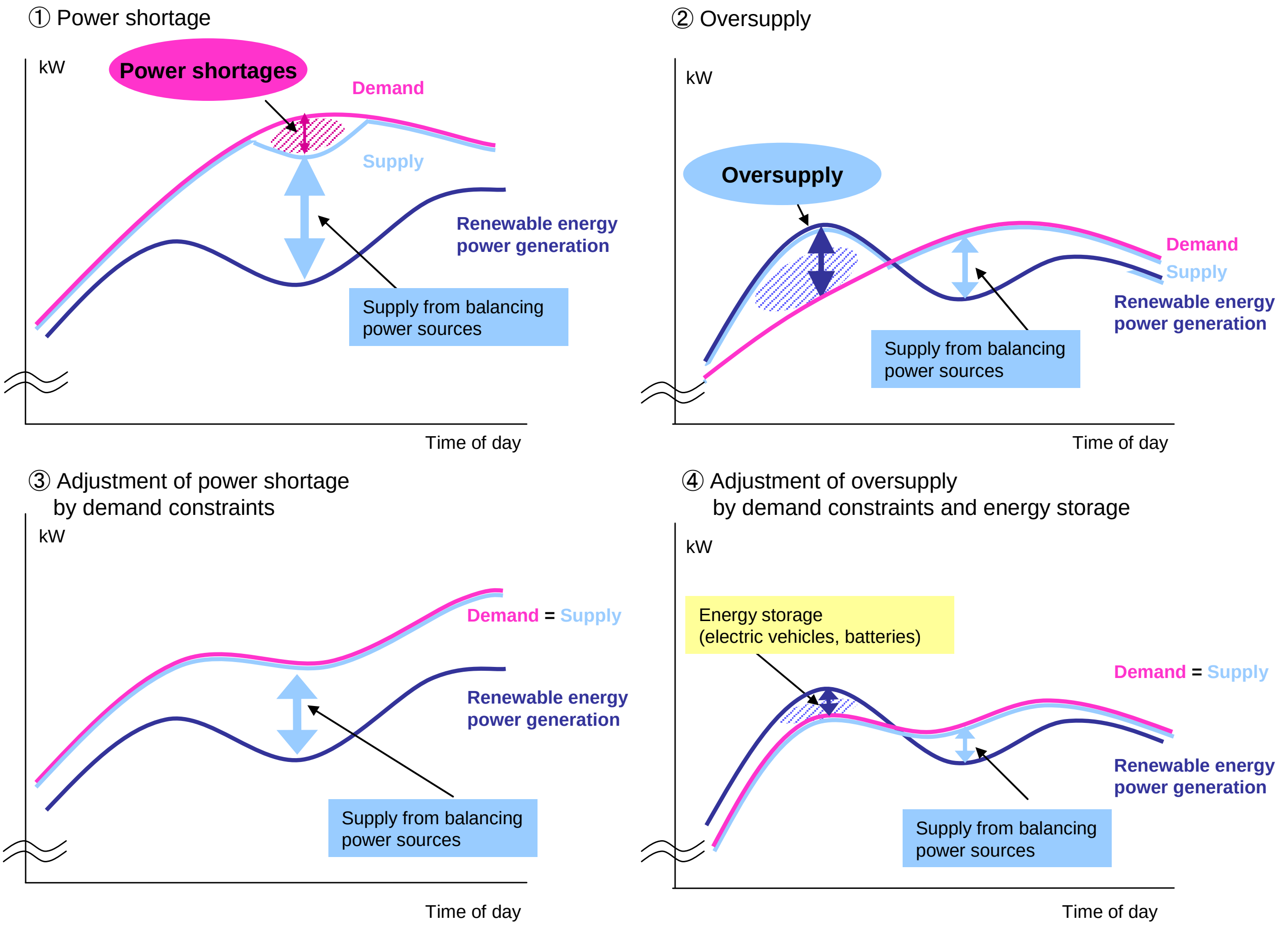
7. Study Group on the Scheme for Next-Generation Power Transmission and Distribution Networks, "*Tei-tanso-shakai jitsugen no tame no jisedai sohaiden nettowaku kochiku ni mukete: Jisedai sohaiden nettowaku kenkyukai hokokusho*" (Towards building next-generation power transmission and distribution networks for a low-carbon society: study group on the scheme for next-generation power transmission and distribution networks report), April 2010 (in Japanese). It should be noted that the assumption regarding nuclear power plants was as of 2010, and therefore calculation results will change if the composition of electricity sources changes based on the national energy plan that is currently under review.

the condition that power supply was subject to such restrictions, allowing them to curb household power consumption at peak times, it would be possible to build an efficient electricity system in which the price mechanism and smart grid technology complemented each other. This kind of contract would restrict use with the user's consent, which would be clearly preferable from an economic welfare perspective to uniformly and unilaterally controlling use through planned outages and power-use restrictions.

Building a system all households feel benefits

We think that many households would be interested in paying for a service that would use advanced technology to automatically curb electricity consumption when prices increase in response to an increase in electricity demand. As shown by the cases that we will present in Section 4 of this report, we think that equipment that controls demand for power along with changing prices has substantial benefits. From this perspective, smart grid technology can be seen as important power infrastructure that helps make up for weaknesses of the price mechanism.

Power Supply-Demand and Renewable Energy Generation **Chart 2**



Source: Compiled by DIR.

3. Will Japanese Electricity Demand Respond to Prices?

3.1 Household power consumption trends and debate on price elasticity

Is the price elasticity of demand for power zero?

Based on the above discussion, it is apparent that an important question is whether electricity demand in Japan will respond to changes in electricity prices. If demand is inelastic (if price elasticity is zero), the price mechanism will not work no matter how much prices are changed, and it will be impossible to alter user behavior. Or, if there is little price elasticity, electricity prices would have to be hiked substantially in order to suppress demand. One could draw the conclusion that depending on the level of elasticity, instead of adopting a flexible price structure, it might be better if the power companies kept supplying electricity to match user needs.

Is there enough proof to support the hypothesis that there is little or no price elasticity?

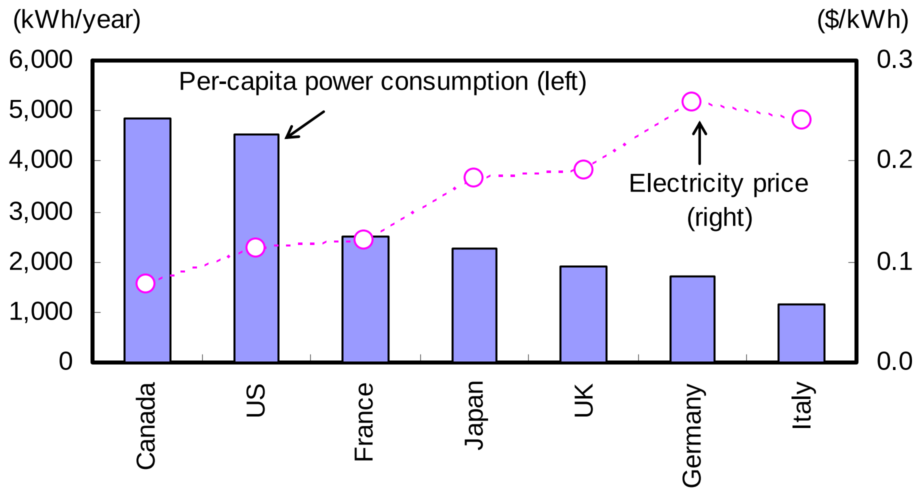
It has long been asserted that electricity demand is inelastic, or only slightly elastic, when it comes to responding to changes in prices. But in fact, this does not seem to be the result of any quantitative analysis. Akiyama and Hosoe (2008) point out that the price elasticities actually used in analyses were 0.1, 0.01, or even zero, and largely relied on a priori assumptions that were based on the analysts' intuition.[8] Because electricity policy has been supply-centric, little importance has been attached to price elasticity (which gauges demand-side behavior), and this is why there is scant empirical analysis.

Previous research does not show zero price elasticity

Even so, looking at the results of previous research, which itself is very scant, none of the empirical evidence shows a price elasticity of zero. In other words, it is possible to curb electricity demand by using the price mechanism. When Akiyama and Hosoe (2008) estimated industrial and commercial electricity demand functions by region and measured price elasticity, they found that it ranged from –0.10 to –0.30 in the short term and –0.13 to –0.55 in the long term, and it tended to be higher in rural areas than in urban areas (we will discuss short-term and long-term elasticity later in this report). Additionally, the Cabinet Office (2007) has measured an elasticity of –0.37 for the entire nation.[9]

Furthermore, international comparisons suggest that household electricity demand may well be responsive to changes in electricity prices. Chart 3.1 shows per-capita household electricity consumption and electricity prices (purchasing power parity basis) for the G7 countries. It indicates that there is a slight tendency for per-capita electricity consumption to be lower in countries where electricity rates are higher.

Home Use Electricity Price and Per-capita Power Consumption Chart 3.1



Source: IEA/OECD, IMF, country data; compiled by DIR.
Note: 2008 data; per-capita power consumption = aggregate home use power consumption / population; electricity price: purchasing power parity.

8. Akiyama, Shuichi and Nobuhiro Hosoe, "*Denryoku juyo kansu no chiiki betsu suitei*" (Electricity demand function estimates by region), Central Research Institute of Electric Power Industry, "Socio-Economic Research No. 56," February 2008 (in Japanese). In the quoted passage, elasticity is not shown as a negative figure as the absolute value is used. However, the actual value is negative.
9. Cabinet Office, "*Kisei kaikaku no keizai koka: Riyosha no meritto no bunseki (kaitei shisan) 2007 nenban*," (Economic effects of regulatory reform: analysis of user benefits (revised estimates) 2007 edition), "*Seisaku koka bunseki repoto*" (Policy effect analysis report), March 2007 (in Japanese).

Our measurement of household price elasticity

In this report we present our own measure of electricity demand price elasticity. Our estimates are for the household sector because it is the focus of this report. There is little previous research on household price elasticity,[10] but it is mainly household electricity demand that must be curbed in the future by using smart grid technology.

3.2 Estimating price elasticity

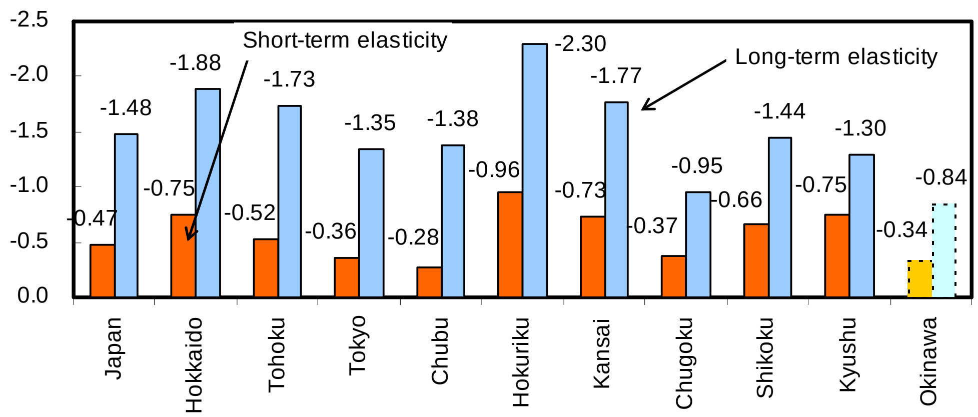
Estimating electricity demand function by region

Electricity demand varies depending on a variety of influences. In this report, we measure price elasticity after estimating a demand function in terms of four factors (explanatory variables) that influence electricity demand (dependent variable). The four explanatory variables are (1) income, (2) electricity prices, (3) temperature (extent to which heating and cooling equipment is used), and (4) electricity demand the previous year. The estimation period is 1986 to 2010. Bearing in mind that income levels and weather conditions vary greatly from region to region, we compiled our estimates by electric power company operating region, using these as the panel data for each prefectural capital location (See "Appendix" for measurement method and estimation results).

Nationwide short-term price elasticity = –0.47

The estimation results are shown in Chart 3.2. The leftmost bar in the chart represents Japan's nationwide short-term (one year) price elasticity, which is –0.47. In other words, if there is no change in any other factors, a 1% rise in electricity prices reduces electricity demand by 0.47 percentage points. Based on this relationship, to reduce electricity demand by 15% during peak periods, as was the case in July and August 2011, electricity prices would have to be increased about 30% (= 15% / 0.47) during such times. However, because electricity demand could conceivably be even higher than expected depending on summer temperatures, it is probably necessary to raise electricity prices even higher (enough to keep demand from exceeding supply).

Elasticity of Electricity Price vs. Power Demand by Power Company Service Area **Chart 3.2**



Source: Ministry of Internal Affairs and Communications; Japan Meteorological Agency; compiled by DIR.
Note: Long-term elasticity: elasticity that accounts not only for demand change for current year but also factoring in expected change in following years. Significance in the case of Okinawa was less than 10%.

Long-term price elasticity = –1.48

Nationwide long-term price elasticity is –1.48. We estimated electricity demand assuming that it is affected by demand the previous year. Thus, if electricity prices

10. One example of this limited previous research is Tanishita, Masayoshi, "*Setai denryoku juyoryo no kakaku danryokusei no chiiki betsu suitei*" (Estimation of regional price elasticities of household electricity demand), Journal of Japan Society of Energy and Resources, September 2009 (in Japanese). The measure results for short-term elasticity (–0.5 to –0.9) and long-term elasticity (–1.0 to –2.7) were close to our own results.

change for a given year, some of the effects will be seen the following year, and again the year after that, and indefinitely thereafter, thereby influencing future electricity demand. Long-term price elasticity gauges the total effect. “Long term” refers to a period of about five years, and long-term price elasticity, calculated from the prior year’s electricity demand coefficient (0.68), is about three times as great as short-term elasticity.[11]

Substantial regional differences in price elasticity

There are substantial regional differences in price elasticity. Excluding Okinawa (statistically insignificant), short-term price elasticity ranges from –0.28 to –0.96, and long-term price elasticity from –0.95 to –2.30. Price elasticity is roughly 3.5 times greater in Hokuriku (–0.96) than in Chubu (–0.28). This suggests that it might be counterproductive to think of price elasticity as uniform throughout the country and it might be necessary to draw up more finely targeted policies. The regional disparities in elasticity may be a reflection of differences in household size and price structure. Looking at the estimation results presented by Akiyama and Hosoe (2008), household price elasticity is higher than industrial price elasticity in every region, which is consistent with the estimation results produced by Tanishita (2009).

Need for an open mind when it comes to elasticity

It is important to pay a certain amount of attention to the fact that price elasticity varies depending on factors like the measurement method that is used. Hoshino (2010),[12] a researcher who has authored a survey of the empirical research, including overseas cases, points out that price elasticity estimation results trace a range depending on type of estimation model and data. We are also well aware that the elasticities calculated in this report are not the final word.

Encouraging price-consciousness in the home is a valid perspective for rebuilding electricity system

Even so, we want to emphasize that the price mechanism will function because there is plenty of price elasticity in electricity consumption, and therefore, there must be an effort to generate the research needed to uncover the degree of price changes that would be necessary to balance supply and demand. Our estimate suggests that there is greater price elasticity in the household sector than in the industrial sector. As we discussed earlier, under the status quo, household sector demand is not being gauged in real time and electricity usage has continued to increase. In our view, making the household sector more price-conscious is a valid perspective from which to view the rebuilding of Japan’s electricity system.

4. Case Studies: US and Japan

4.1 Types of price-based demand response

Electricity consumption and price data necessary for price-based demand response

Exercising control over demand-side electricity consumption using a price mechanism is called “price-based demand response” (or sometimes “dynamic pricing”). In this section, in order to provide a more concrete picture of price-based demand response, we will present some examples of trials that have sought to put the price mechanism to work.[13] When presented with a higher price, a consumer could conceivably (1) do nothing (accept the higher rate), (2) suspend electricity use (shift use to a different time), or (3) reduce electricity use (for example, adjust

11. If short-term price elasticity is α, and the coefficient of real electricity consumption the previous year is β, then from $0 < \beta < 1$ and the infinite geometric series formula, long-term price elasticity is $\alpha / (1 - \beta)$. Using a β of 0.68 in this report, cumulative elasticity five years after price change accounts for some 90% of long-term elasticity.
12. Hoshino, Yuko, “*Enerugi juyo no choki kakaku danryokusei: Seisaku bunseki ni mochiiru baai no ryuiten*” (Long-term price elasticity of energy demand: What should we keep in mind when applying it to policy analyses?), Central Research Institute of Electric Power Industry, CRIEPI Research Report, May 2010 (in Japanese).
13. As a background material for section 4. Case Studies: US and Japan, we used Hattori, Toru and Naoki Toda, “*Beikoku ni okeru kateiyo demando resuponsu puroguramu no genjo to tenbo: Pairotto puroguramu no hyoka to honkaku donyu ni okeru kadai*” (Demand response programs for residential customers in the United States—evaluation of the pilot programs and the issues in practice), Central Research Institute of Electric Power Industry, CRIEPI Research Report, March 2010 (in Japanese).

the temperature of an air conditioner). When implementing a demand response system, a critical point is that all users must be able to access data about electricity consumption and electricity prices.

TOU already offered in Japan

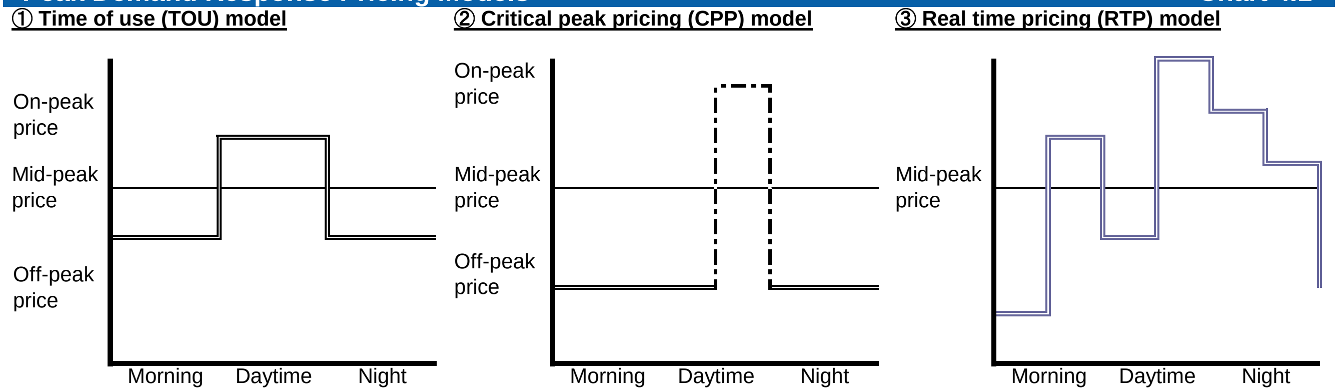
As shown in Chart 4.1, price-based demand response schemes can be broadly divided into three categories: (1) time of use (TOU), (2) critical peak pricing (CPP), and (3) real-time pricing (RTP).

(1) TOU: Prices are established by season and/or time of day. Users apply in advance. Japanese power companies are already offering TOU programs to household customers: Tokyo Electric Power calls it "Otokuna Night," Tohoku Electric Power, "Tokutoku Power Night," and Kansai Electric Power, "Happy e Time."

(2) CPP: Higher prices are established for just a few hours on peak day pricing event days. The number of such days in a year is limited to a number that is set in advance (12 days, 9 to 15 days, etc) and the higher price applies to only certain hours (noon to 4:00 PM, 2:00-5:00 PM, etc). In most cases, users are notified of such days 24 hours in advance.

(3) RTP: Prices are established for each hour of the day, referring to a day ahead market (energy market for the following day or 24 hours in advance of a given time in any day). If further adjustment is needed on a given day, pricing is made based on price and consumption data obtained from smart meters or some other two-way communication devices.

Peak Demand Response Pricing Models **Chart 4.1**



Source: Compiled by DIR.
Note: In addition to models 1 to 3 above, there is a model combining TOU and CPP.

Objective of TOU and CPP is to respond when supplies are tight, while RTP is to balance supply and demand

Chart 4.2 lays out the objectives and responses used under each type of program. The main objective of TOU and CPP programs is to address those times when supply is tight, which is the main topic of this report. On the other hand, the main objective of RTP is to balance overall supply and demand, and it should be particularly useful when suppliers have deployed renewable energy with volatile output.

Smart meters not needed for TOU

Users who choose TOU can avoid paying higher prices by not using electricity, or using less electricity, during those predetermined times when prices are higher. For evening hours or when they are not at home, they can also set timers to automatically use electricity during times when prices are lower. Therefore, a smart meter or other two-way communication device is not required.

Smart meters a necessity for CPP

Users who choose CPP can use the same methods as those who choose TOU to avoid higher prices if they are at home because they are notified of peak day pricing event days in advance. However, a smart device (smart meter, smart thermostat) that automatically controls electricity usage based on information received from the electricity provider is needed in order to automatically respond to such events.

RTP requires both smart meters and smart grid

It would be hard for a user who has chosen RTP to manually respond to electricity prices that fluctuate from moment to moment. Therefore, there must be an environment (a smart grid) that allows real-time access to supply and demand information (price information) through technology such as smart meters and home energy management systems (HEMS). If household appliances, light fixtures, and other devices can work with a smart meter, users are able to automatically curb usage in the order they choose.

Demand Response Pricing: Objectives and Household Responses **Chart 4.2**

<table>
<tr><th rowspan="3"></th><th rowspan="3">Pricing by demand category</th><th colspan="3">Purposes</th><th colspan="2">Household responses</th></tr>
<tr><th colspan="2">Reducing peak demand, shifting peak</th><th rowspan="2">Can overall community supply-demand be balanced?</th><th rowspan="2">Manual control</th><th rowspan="2">Control system</th></tr>
<tr><th>Can an expected demand increase be ironed out?</th><th>Can an unexpected tight supply situation be resolved?</th></tr>
<tr><td>① TOU</td><td>Fixed</td><td>Yes</td><td>No</td><td>No</td><td rowspan="2">・Electricity not used
・Shift usage hours
・Reduce electricity consumption</td><td>Home appliance timers</td></tr>
<tr><td>② CPP</td><td>Fixed</td><td>Yes</td><td>Yes</td><td>No</td><td>Smart meters + smart home appliances</td></tr>
<tr><td>③ RTP</td><td>Not fixed</td><td>Yes</td><td>Yes
（Flattening out of demand to reduce possibility of creating demand peak)</td><td>Yes</td><td>Hard to control</td><td>・Smart meters + smart home appliances
・Home energy management system</td></tr>
</table>

Source: Compiled by DIR.

4.2 Case studies of effects of price-based demand response in Japan and the US

California CPP

Like TOU, users can manually adjust usage under a CPP program. In the case of California's Pacific Gas & Electric (PG&E), there is a service for small and medium-sized enterprises in which electricity-using devices are controlled automatically.[14] Users who enroll in this service connect their central air conditioning systems or heat pump to SmartAC™ (a smart thermostat or smart switch).[15] When energy demand is high, the SmartAC™ is activated by PG&E and electricity consumption is reduced by controlling the connected equipment. PG&E says that most of the customers it has surveyed do not notice that the system has been activated. The utility has also taken steps to avoid compromising customer convenience. For example, customers can contact PG&E by telephone or via the Internet to specify days on which the SmartAC™ should not be activated, without penalty.

Pilot program shows that using a control device reduces peak time usage more

In 2008-09 a pilot program involving about 900 households was conducted in Washington DC to determine how much difference smart control devices make in reducing peak demand with CPP.[16] The program installed free smart meters, which record electricity consumption on an hourly basis and send that data wirelessly to a billing vendor, in the homes of the pilot participants. The smart meters had LCD displays so that the users could read their electricity consumption. Free smart thermostats were also installed in about one-third of the homes that had central air

14. http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/sac/
15. A thermostat is a device that adjusts the temperature by, for example, adjusting the temperature of an air conditioning unit or by turning it on and off. A switch simply turns the unit on and off.
16. http://www.powercentsdc.org/

conditioning or heating systems. The pilot results showed that while participants without a smart thermostat reduced consumption by 29%, those with a smart thermostat reduced consumption by an even greater 49%. This is one example of the effectiveness of control devices that work without human intervention.

RTP using smart devices also showed a certain reduction in consumption

The same Washington DC pilot program also tested RTP. Here, RTP was called "Hourly Pricing" (HP), and the scheme tested setting prices referring to a day ahead market (market for 24 hours in advance of a given time in any day). Prices were posted on a website and could also be obtained by making a toll-free telephone call. When prices were high, participants were notified via voicemail, e-mail, or a text message. Prices were also displayed on a smart thermostat that could also automatically reduce the electricity used by air conditioners. HP participants who used a smart thermostat reduced consumption during peak times by 10%, which was less than for CPP participants. However, the final report for the pilot program says that this lower reduction can be explained by the fact that average market electricity prices were fairly low during the pilot period because of lower crude oil prices and weak industrial activity in the wake of the Lehman Shock, and, furthermore, due to the fact that the "high prices" for HP were not as high as those for CPP. Therefore, off-peak prices may have affected the outcome.

The results of this US pilot program show that users will take action if prices are raised when the market is tight. They also show that direct control using smart devices may be a valid way to effectively regulate demand. Japan should also think of ways to optimize demand for electricity by bringing the price mechanism and smart devices together.

Potential of using price-based demand response in the mass deployment of renewable energy in the demonstration trial stage

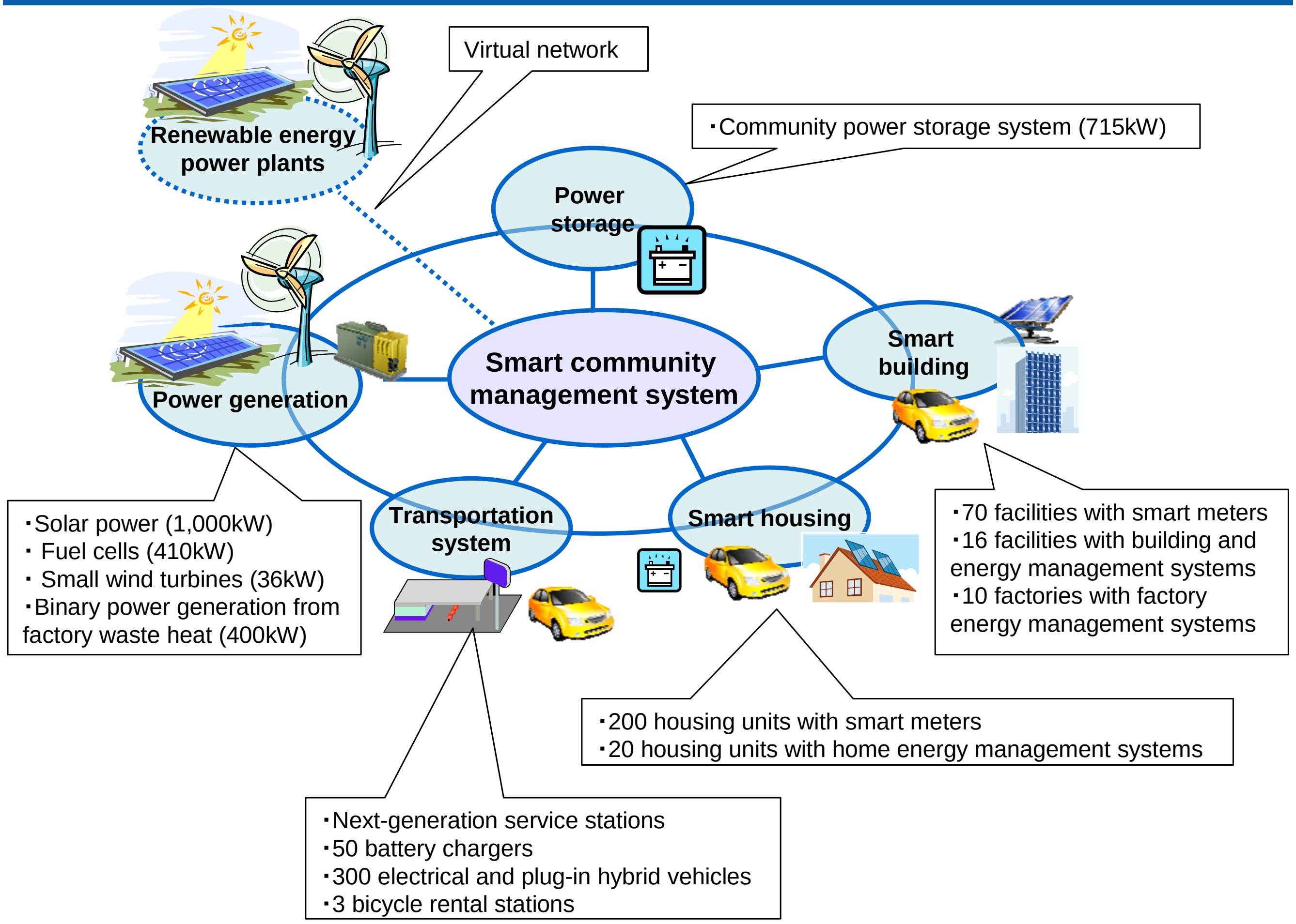
As Japan looks towards becoming a low-carbon society, a trial is currently underway to see how well price-based demand response will work when renewable energy is deployed on a large scale. Part of the Kitakyushu Smart Community Creation Project[17] is a demonstration of how to stabilize a power system by controlling demand when deploying renewable energy on a mass scale (Chart 4.3).

The trial is being conducted in the Higashida district of Kitakyushu city, to which Nippon Steel is delivering electricity from its Higashida cogeneration plant as a "special supplier." In this trial, the 21,000 kW of electricity from the Higashida cogeneration plant will serve as the backbone power source, while solar power, fuel cells, small wind power turbines, and binary power generation from factory waste heat will also be deployed in an effort to raise the proportion of power from new energy technologies to 10%. On the demand side, smart meters are being installed in 200 homes and 70 businesses, laying the foundation to guide demand through dynamic pricing, in which electricity rates vary depending on the time of day (indirect control). It will also be possible to directly control household appliances and building equipment according to the supply-demand situation through connected HEMS or building energy management systems (BEMS). The project will also seek to strike an optimal supply-demand balance by using storage capacity, including electric vehicles or local electricity storage systems. The plan is to develop and deploy the smart meters in FY11, introduce dynamic pricing in FY12, and begin an incentive program (awarding eco points for cooperating with efforts to stabilize the electricity system) in FY13. Depending on the results, the intention is to demonstrate the extent to which it is possible to maintain the quality of the electricity system while expanding the proportion of renewable energy by virtually adding large-scale wind farms and "mega solar" power generation outside the demonstration area.

17. Five-year (2010 onwards) demonstration projects are underway in four areas of Japan. The cities of Kitakyushu, Yokohama, Toyota, and Keihanna have been designated as "Next-generation energy and social system demonstration areas." The Kitakyushu project is a testbed for variable electricity charges.

Because this demonstration is being conducted in a locality that gets its electricity from a "special supplier," electricity prices can be adjusted to follow a number of different patterns. This means that it will be possible to demonstrate how users respond, and this is the most important feature of this demonstration. This demonstration trial should produce data that will be extremely useful for bringing about a low-carbon society that revolves around renewable energy, and therefore we will be closely watching how it unfolds.

Energy Management System: Aug 2011 Kitakyushu Smart Community Creation Project Master Plan
Chart 4.3



Source: Kitakyushu Smart Community Council; compiled by DIR.

Conclusion

Based on our understanding that the key to resolving power shortages lies in the household sector, in this report we have argued that electricity usage should be optimized by putting the price mechanism to work. We have also explained that if smart grids are developed and smart meters and other smart control devices are deployed as renewable energy is being deployed on a mass scale, these will complement the price-driven supply and demand mechanism. The key points of this report can be summarized as follows.

Firstly, rationing through planned outages and power-use restrictions are ways of allocating resources that result in substantial economic and social harm. In order to ensure a stable supply of electricity it is necessary to build an efficient supply-demand system that takes advantage of the price mechanism, and this should particularly focus on the household sector because this is the area in which it is hardest to exercise policy control over electricity consumption.

When it comes to using the price mechanism, there are existing electricity price structures under which prices rise marginally depending on volume consumed, but it is unclear how much they contribute to power conservation. There must be a mechanism for matching supply and demand. This can be accomplished by installing smart meters that can be used to precisely gauge real electricity needs (which have been hard to measure so far) and people's preferences from price information.

While there will probably be some objections that the price elasticity of electricity demand is fairly low, there is insufficient research focusing on the demand side. In this report, based on our estimated electricity demand function, we arrived at a short-term elasticity of –0.47 and a long-term elasticity of –1.48 for the household sector. Making the household sector more price-conscious with respect to electricity is a valid perspective from which to view the rebuilding of Japan's electricity system.

However, the price mechanism is not a panacea, and we see it has having a mutually complementary relationship with technology like smart meters, smart devices, and smart grids. Based on the results of price-based demand response experiences in the US, demand reductions are achieved more efficiently when smart devices are used. Attention-worthy demonstration trials are also underway in Japan in places like Kitakyushu. These should amass valuable data and research findings concerning the potential for controlling supply and demand using the price mechanism and smart devices when deploying renewable energy on a mass scale.

Appendix: Estimates of Price Elasticity for Household Electricity Demand

In order to understand how much household electricity demand declines when electricity prices rise, it is necessary to measure changes in demand purely due to changes in price by removing various non-price factors that influence electricity demand. In other words, it is necessary to estimate the household electricity demand function.

Using Akiyama and Hosoe (2008) and Tanishita (2009) as references, we estimate the household electricity demand function for region *i* (nationwide and respective power company operating area, Appendix Chart 1) as follows:

$$\ln(QE_{i,t}) = \alpha_i + \beta_i \cdot \ln(Y_{i,t}) + \gamma_i \cdot \ln(PE_{i,t}) + \delta_i \cdot \ln(QE_{i,t-1}) + \varepsilon_i \cdot \ln(HD_{i,t}) + \phi_i \cdot \ln(CD_{i,t})$$

where, QE : real electricity consumption value, Y : real consumption expenditure (proxy variable for disposable income), PE : real electricity price, HD : heating degree day, CD : cooling degree day.

Using 1986-2010 as our estimation window, we aggregated the data for households with two or more occupants living in the capital cities of Japan's 47 prefectures into panels by region. Due to data limitations, we used consumption expenditures as a proxy variable for disposable income (*Y*). If the changes in average propensity to consume are gradual, they should not have any substantial effect on the estimation results even if consumption expenditures are used in lieu of disposable income. In fact, when we looked at those working households with two or more occupants for which disposable income data is available, we found that there was only the slightest difference in price elasticity when we derived our estimates using disposable income as the explanatory variable and when we used consumption expenditures. Next, we converted consumption expenditures and the yen value of electricity consumption into per-capita figures by dividing them by the number of household members, and used CPI (excluding imputed rent for owner-occupied dwellings) as the deflator. Finally, "heating degree days" represents the calendar year aggregate of the number of degrees by which temperature is below 14 centigrade, for days on which the average temperature is below 14 centigrade. By the same token, "cooling degree days" represents the calendar year aggregate of the number of degrees by which temperature is above 24 centigrade, for days on which the average temperature is above 24 centigrade.

Power Company Service Areas — **Appendix Chart 1**

Power company	Prefectural capitals in power company service area							
Hokkaido	Sapporo							
Tohoku	Aomori	Morioka	Sendai	Akita	Yamagata	Fukushima	Niigata	
Tokyo	Utsunomiya	Maebashi	Saitama	Chiba	Tokyo	Yokohama	Mito	Kofu
Chubu	Nagano	Gifu	Nagoya	Tsu	Shizuoka			
Hokuriku	Toyama	Kanazawa	Fukui					
Kansai	Otsu	Kyoto	Osaka	Kobe	Nara	Wakayama		
Chugoku	Tottori	Matsue	Okayama	Hiroshima	Yamaguchi			
Shikoku	Tokushima	Takamatsu	Matsuyama	Kochi				
Kyushu	Fukuoka	Saga	Nagasaki	Kumamoto	Oita	Miyazaki	Kagoshima	
Okinawa	Naha							

Source: Compiled by DIR.

The estimation results are presented in Appendix Chart 2. Short-term price elasticity is the coefficient of "real electricity prices" in this table, and the nationwide figure is –0.47. Long-term price elasticity appears in the bottom row of the table. There are few regions in which the coefficient of heating degree days is statistically significant, but significant results were obtained for most other explanatory variable coefficients (statistically significant coefficients are marked by asterisks). We believe that heating degree days is insignificant because many homes use heating equipment that does not use electricity, such as kerosene and gas heaters. In contrast, cooling degree days is significant in almost all but the colder regions because on hot days cooling equipment that runs on electricity is mainly used.

Estimation Results of Household Sector Power Demand **Appendix Chart 2**

		Japan	Power company service area									
			Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu	Okinawa
Constant term	Coefficient	-1.18***	-	-	-2.98***	-	-	-2.06***	-1.82**	-1.91***	-1.98***	-4.32***
Real consumption expenditure		0.31***	0.16	0.15***	0.42***	0.09**	0.06	0.28***	0.39***	0.35***	0.45***	0.55**
Real electricity price		-0.47***	-0.75**	-0.52***	-0.36***	-0.28***	-0.96***	-0.73***	-0.37***	-0.66***	-0.75***	-0.34
Power consumption value (1-yr previous)		0.68***	0.60***	0.70***	0.74***	0.80***	0.58***	0.58***	0.61***	0.54***	0.42***	0.60***
Heating degree day		0.01	0.03	0.00	0.10***	0.00	0.13**	0.13**	0.01	0.09*	0.06	0.00
Cooling degree day		0.01***	0.00	0.00	0.05***	0.02	0.02	0.11***	0.07***	0.08***	0.08***	0.31***
R2		0.94	0.96	0.95	0.95	0.94	0.95	0.94	0.90	0.96	0.95	0.95
DW		2.34	1.98	2.34	2.42	2.37	2.37	2.08	2.01	2.29	2.09	2.35
Long-term price elasticity		-1.48	-1.88	-1.73	-1.35	-1.38	-2.30	-1.77	-0.95	-1.44	-1.30	-0.84

Source: Ministry of Internal Affairs and Communications; Japan Meteorological Agency; compiled by DIR.

Notes: 1) Estimated based on quantitative analysis of panel data (fixed or random effect models depending on Hausman test results) for households with more than one person in prefectural capitals by power company area over the 1986-2010 period, with logarithmic variables. *, **, and *** denote significance of 10%, 5%, and 1%, respectively.

2) Real consumption expenditure and power consumption value: per-capita basis (household figures divided by number of household members); consumption expenditures and electricity prices: deflated by CPI (excl. imputed rent); electricity prices: CPI basis.

3) Heating (cooling) degree day: sum of temperature differences from 14 (24) centigrade for days when average temperature is below 14 (above 24) centigrade.