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Effect of the installation of natural-gas fuel-based on-site technologies on grid power in terms of investment and operation costs

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ABSTRACT

Since the Great East Japan Earthquake, the experience of the Fukushima Daiichi nuclear accident and the need for blackouts to avoid power shortages has caused the Japanese government to reconsider the most suitable combination (best mix) of energy sources. The improvement of the so-called “3E+S” conditions, namely, economy, environment, energy security, and safety, is required for the energy system of each country. The installation of gas systems, such as on-site combined heat and power (CHP), fuel cells, and gas air-conditioning (gas engine-driven heat pumps and absorption chillers), can contribute to this improvement. An evaluation of the whole energy system as a whole, including the gas and grid power systems, will offer significant information to the gas industry and facilitate governmental discussions.

Furthermore, with effect from 2016, deregulation has been planned for all sectors of the electric power industry in Japan. In the near future, gas companies will not only retail natural gas, but also electricity. Therefore, following deregulation, the gas companies will need to evaluate the whole energy system, including the gas and grid power systems, in order to establish and utilize their most appropriate energy supply combination.

Based on these circumstances, we evaluated the effect of installing the gas systems on grid power in terms of investment and operation costs by using the Electric Load Curve Estimation Model and the Grid Power Supply Simulation Model. For this purpose, it was necessary to calculate the hourly electric load curves of grid power both with and without the gas systems. However, as gas systems vary widely according to each sector, e.g. residential, commercial, and industrial, it was necessary to calculate separate load curves before combining the results to estimate a total load curve.

Although a large number of studies have been performed on the hourly electric load curve of an individual customer, little is known about the total hourly electric load curve of an area or of various sectors. Hence, in this study, we developed the Electric Load Curve Estimation Model, which can be used to calculate both individual and total hourly electric load curves. This data was subsequently input into the Grid Power Supply Simulation Model, which enabled us to calculate the investment and operation costs for electricity supply. Accordingly, the costs with and without the gas systems could then be compared.

Following on from this, a case study focusing on the Tokyo metropolitan area was performed. Results indicate that including gas systems, alongside other energy sources, can limit total investment and operation costs. In particular, on-site CHP can be economically competitive where nuclear power plants are out of service. Overall, these results suggest that an energy supply system that includes gas systems is more economically efficient than those that rely on grid power only.

1. Introduction

Since the Great East Japan Earthquake, the experience of the Fukushima Daiichi nuclear accident and the need for blackouts to avoid power shortages has caused the Japanese government to reconsider the most suitable combination (best mix) of energy sources. The improvement of the so-called "3E+S" conditions, namely, economy, environment, energy security, and safety, is required for an energy system. The installation of gas systems such as on-site combined heat and power (CHP), fuel cells, and gas air-conditioning (gas engine-driven heat pumps and absorption chillers), can contribute to this improvement. An evaluation of the whole energy system, including the gas and grid power systems, will offer significant information to the gas industry and facilitate governmental discussions.

Furthermore, deregulation has been planned for all sectors of the electric power industry in Japan with effect from 2016. In the near future, gas companies will not only retail natural gas, but also electricity. Following deregulation, the gas companies will need to evaluate the whole energy system, including the gas and grid power systems, in order to establish and utilize their most appropriate energy supply combination.

Based on these circumstances, we evaluated the effect of installing the gas systems on grid power in terms of investment and operation costs by using the Electric Load Curve Estimation Model and the Grid Power Supply Simulation Model. A case study was then performed, focusing on the Tokyo metropolitan area in 2020.

2. Methodology

In this study, we estimated total electric load curves before and after installing the gas systems and then calculated power generation costs for grid power using these load curves. The reduction of the power generation costs due to installing the gas systems was then evaluated by determining the hourly electric load curves of grid power, both before and after installing the gas systems. However, as gas systems vary widely according to each associated sector, e.g. residential, commercial, and industrial, it was necessary to calculate separate load curves for before combining the results to estimate a total load curve.

Although a large number of studies have been performed on the hourly electric load curve of an individual customer, little is known about the total hourly electric load curve of an area or of various sectors. Hence, in this study, we developed the Electric Load Curve Estimation Model that can be used to calculate both individual and total hourly electric load curves. This data was subsequently input into the Grid Power Supply Simulation Model, which enabled us to calculate the investment and operation costs for electricity supply. Accordingly, the costs with and without the gas systems could then be compared.

2.1 Electric Load Curve Estimation Model

2.1.1 Model Summary

We developed the Electric Load Curve Model to estimate hourly electric load curves for the demands of each sector in 2020 by using a bottom-up approach. Using this model, the effect of each measure, including the installation of the gas systems on total electric demands, was assessed. The major parameters were the number of households, the total floor area of commercial buildings, and temperature.

The target sectors of this model were residential, commercial, and industrial. Sixteen household types were identified within the residential sector and 11 commercial uses exist within the commercial sector. The transport sector is also important for estimating electric demand in future because the number of electric vehicles (EVs) will continue to increase. However, as the number of EVs has high uncertainty for 2020, the transport sector was out of scope for this model.

Figure 1 shows the flow for the Electric Load Curve Model, where the total hourly electric load curve of Tokyo Electric Co. in 2010 was used [1]. The electric demands of the residential and commercial sectors were estimated by the previously mentioned bottom-up approach. In contrast, an estimate of the electric demands in the industrial sector is more challenging because the electric load curve is strongly dependent on each user. Therefore, we defined the electric demand for this sector as the difference between the total demand and the sum of the residential and commercial demands.

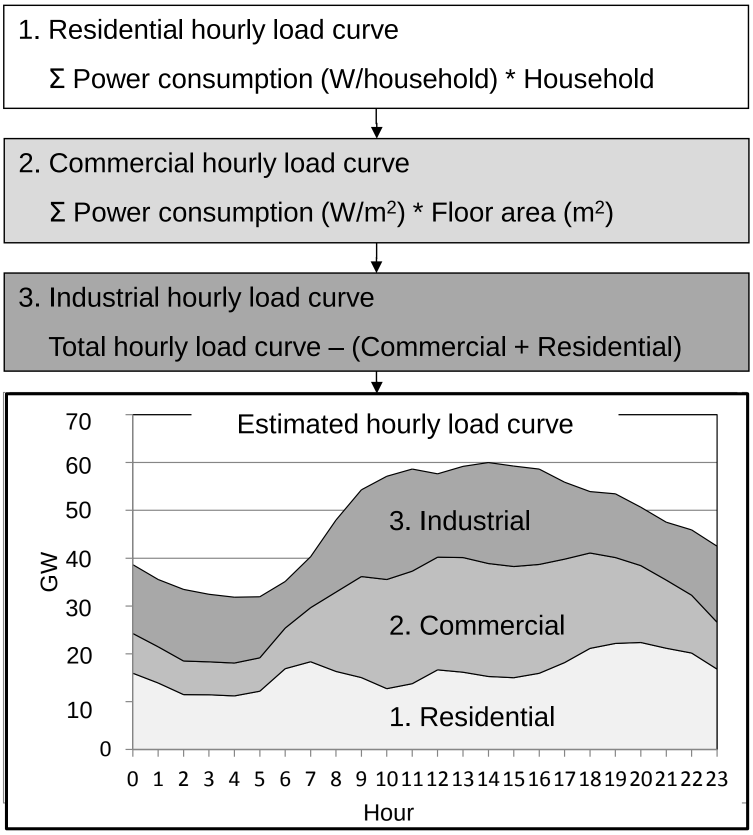

Fig. 1. Flow for the Electric Load Curve Model

2.1.2 Residential Sector Estimation

In this study, hourly load curves for the residential sector were estimated using statistics for life patterns because there were very few measured load curves. Data reported by NHK Broadcasting Culture Research Institute [2] was used, which included Japanese hourly life patterns such as cooking, watching TV, sleeping, etc.

Life patterns were initially converted to usage patterns for household electric appliances, and then to electric load curves. For example, watching television corresponds to the power consumption of a television. The power consumption for 16 household types [W/household] was estimated as "one-person," "couple-only," "couple-and-children," and so on. Data on the number of households was obtained from the National Institute of Population and Social Security Research [3].

The power consumption for the residential sector in this model was modified by comparing the calculation results, annual electric consumption data [4] and previous studies [5]. For example, Figure 2 shows the modified total load curve for the residential sector.

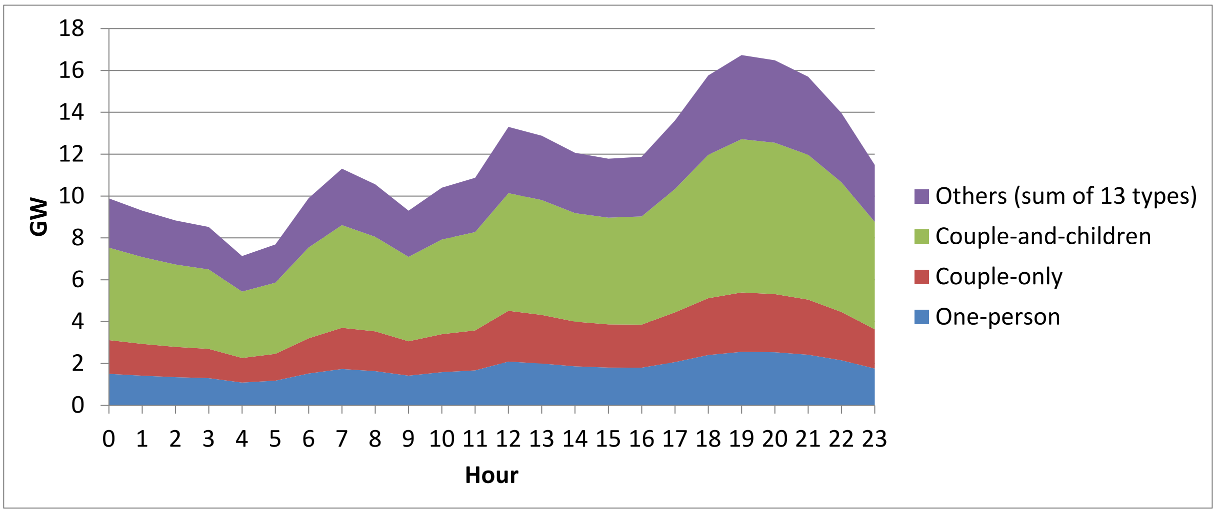

Fig. 2. Total load curve for the residential sector (weekdays in summer)

2.1.3 Commercial Sector Estimation

Estimated load curves for the commercial sector were based on data from various users. The hourly power consumption per floor area [W/m^2] was defined for each type of commercial use, which was then used to estimate the total demand in this sector.

The commercial sector consisted of 11 types of use, e.g., large offices, small offices, stores, supermarkets, convenience stores, hospitals, hotels, schools, welfare facilities for the aged, restaurants, and others. The power consumption was composed of (1) cooling, (2) heating, and (3) power and lighting for each type. We used the total floor area of the commercial buildings in the service area of Tokyo Electric Co. based on estimate provided by Agency for Natural Resources and Energy of Japan [5].

The power consumption for this sector was modified by comparing the calculation results, annual electric consumption data [4], and previous studies [5]. For example, Figures 3 and 4 show the modified power consumption and the modified total load curve for the commercial sector.

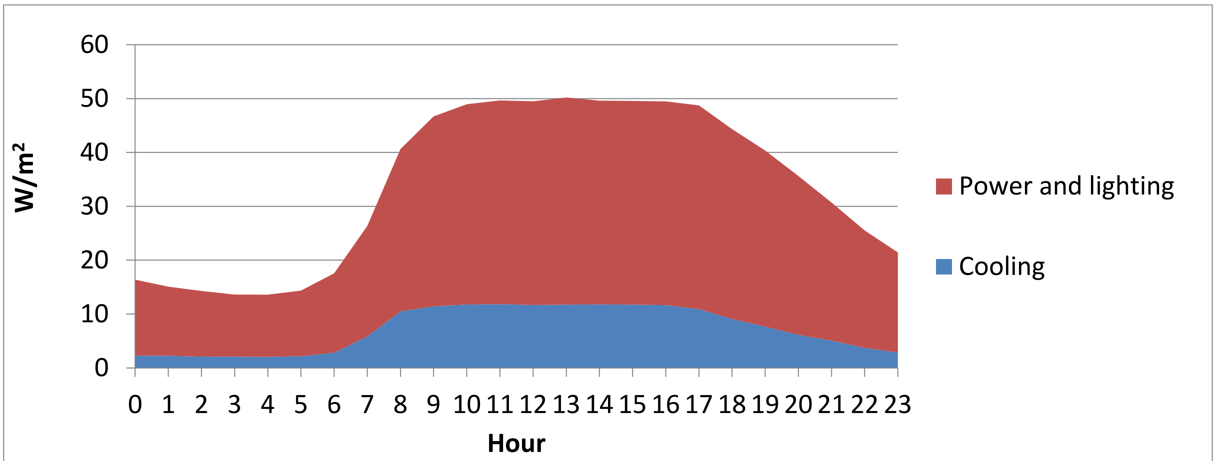

Fig. 3. The power consumption for “large offices” (weekdays in summer)

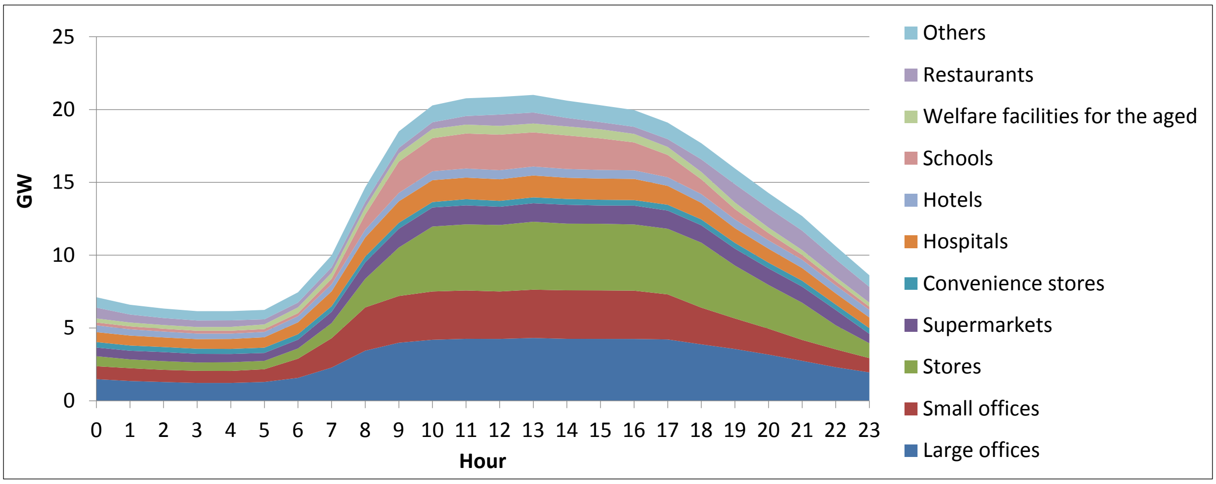

Fig. 4. The total load curve for the commercial sector (weekdays in summer)

3. Results and Discussion

Initially the load curve of the “couple-and-children” in the residential sector was verified using existing load survey data. Then the Electric Load Curve Estimation Model was used to evaluate the hourly electric load curves for two cases. One was the “reference case” and the other was the “gas systems installation case.” The two load curves were compared in order to determine the reduction of demand for grid power (kW) due to the installation of the gas systems.

Finally, we used the total hourly electric load curves as the input data for the Grid Power Supply Simulation Model, which enabled us to calculate the investment and operation costs for the electricity supply. We subsequently compared these costs before and after installing the gas systems, and calculated a cost reduction for the grid power generation. If the cost reduction is larger than the investment and operation costs for the gas systems, the energy supply system including the gas systems will be more economical than grid power only.

3.1 Verification of the Load Curve in Residential Sector

Measured data for 50 “couple-and-children” type households were obtained and used to confirm the validity of the estimates based on life patterns. Figure 5 shows a comparison between the estimated values and the measured data.

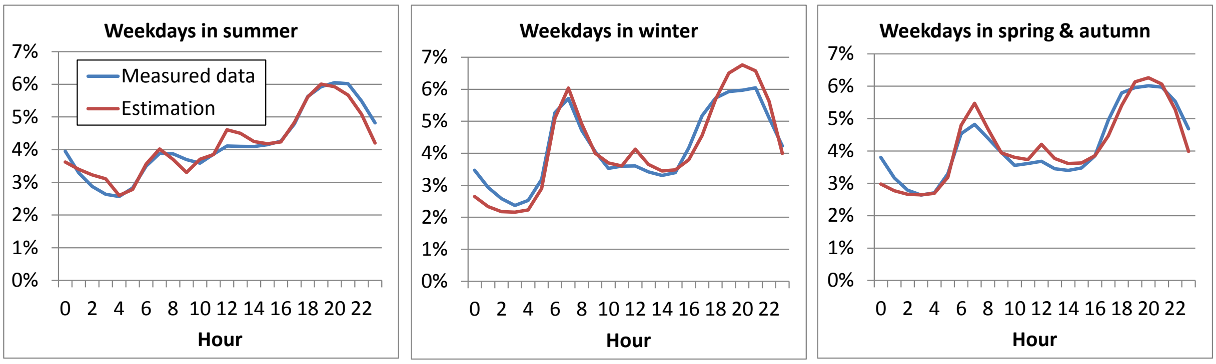

Fig. 5. Estimates and measured data for “couple-and-children” (weekdays)

As shown in Figure 5, the estimated values were in good agreement with the measured data; therefore, we are confident that the model accurately reproduces load curves based on the life patterns. However, there is some deviation between the curves, for example, the estimation showed a tendency to have a larger peak in the daytime. Future investigations will examine the at-home rate at lunchtime and the actual use of household appliances, etc. The estimation also highlighted differences between nighttime demands during winter, spring, and autumn, indicating a need to scrutinize the use of heating appliances.

During this study, the "couple-and-children" type household among 16 types was verified. More detailed verification will be carried out once various load curves have been measured, such as the "one-person" type household.

3.2 Effect of Demand Reduction for Grid Power

3.2.1 Estimation for the Load Curves with and without Gas System

This study compared the load curves before and after installing the gas systems. Initially the load curve was estimated without the gas systems for 2020, which is known as the “reference case.” The load curve with the gas systems was then determined. For the “reference case,” a power-saving effect of -4.3% was assumed, in accordance with the data of power saving in 2012 [6].

In the “gas systems installation case,” the gas systems were installed in addition to power-saving factors. The installed gas systems were assumed to be residential fuel cells, on-site CHP, and gas air conditioning. As the operation pattern of gas systems varies a great deal, the operation and load curves were simulated sector by sector.

For the residential sector, a load curve was evaluated after the installation of fuel cells, using an in-house household energy simulation model. With regard to the commercial sector, a load curve was determined after the installation of CHP and gas air conditioning, using an in-house commercial energy simulation model. As previously discussed, a detailed load curve was not assumed for the industrial sector. Therefore, a load curve was evaluated after the installation of CHP, on the assumption of a daily start and stop operation from 8:00 to 21:00.

The number of gas systems installed in the Tokyo metropolitan area was based on “The Tokyo Gas Group’s Vision for Energy and the Future” [7], as shown in Table 1. This vision shows 300,000 units for residential fuel cells, 4 million kW for CHP, and 5.7 million refrigeration tons (RT) for gas air conditioning in 2020.

Table 1. The number of gas systems installed

	2011	2020
Residential fuel cell (stock)	9,000 units	300,000 units
On-site CHP (stock)	1.5 million kW	4.0 million kW
Gas air conditioning (stock)	4.0 million RT	5.7 million RT

3.2.2 Evaluation Results

Figure 6 shows the estimated load curves on a peak day as an example. These results indicate a 2.8 GW demand reduction by the gas systems at 14:00 when the maximum power demand generally occurs. In contrast, the demand reduction is decreased at nighttime. We confirmed that this trend is mainly due to the daily start and stop operation for CHP in commercial and industrial sectors.

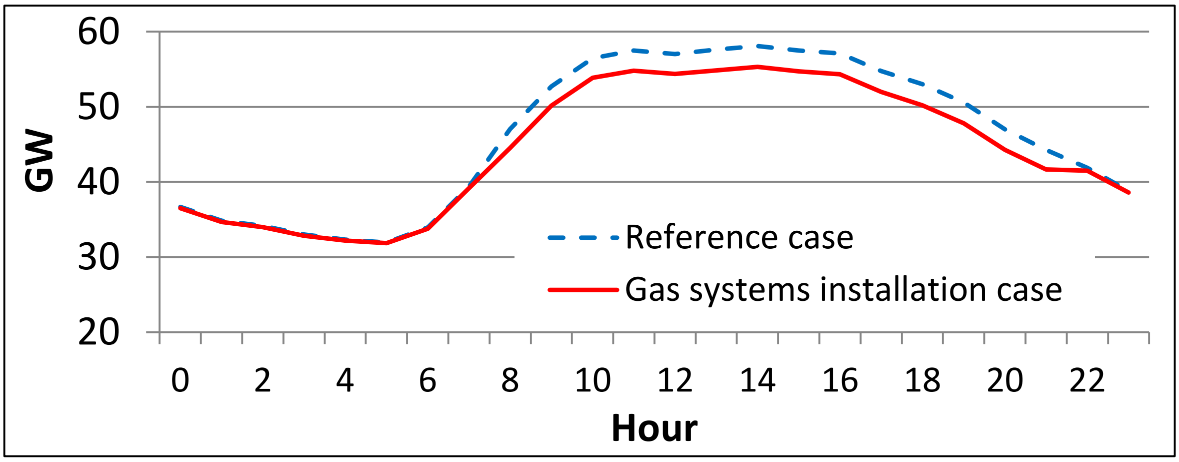

Fig. 6. The estimated load curves in a peak day

3.3 Cost Reduction for Grid Power due to the Installation of Gas Systems

3.3.1 Calculation of Power Generation Costs for Grid Power

In Japan, nuclear power plants were shut down following the earthquake in 2011. Therefore, we assumed two scenarios for grid power generation. The first is a “nuclear 80% operation scenario” where nuclear power plants operate at 80% of their capacity. The second is a “nuclear non-working scenario” where all the nuclear power plants are out of service.

Table 2 shows other premises for the simulation. We used fuel prices estimated by International Energy Agency [8]

Table 2. Premises for the simulation

	Premises
Currency exchange rate	85 JPY/USD
Crude oil price	683 USD/kl
LNG price	651 USD/t

3.3.2 Evaluation Results

Figure 7 and 8 show the cost reduction for grid power due to the installation of the gas systems in each scenario. We calculated the average hourly reduction of power generation costs for weekdays, Saturdays, and holidays in each season. Figure 7 and 8 indicate that the cost reduction is larger during a period of high demand.

When attention was focused on a weekday of the “nuclear non-working scenario,” our results were 218 USD/MWh for summer, 215 USD/MWh for winter, and 211 USD/MWh for spring and autumn. In addition, the cost reduction was 221 USD/MWh for a peak day. These reductions were caused by mainly CHP, residential fuel cells, and gas air conditioning.

On the other hand, the Energy and Environment Council reported that the power generation cost was 174 USD/MWh for CHP with daily start and stop operation and 60% waste heat utilization [8]. We compared this power generation cost for CHP with the cost reduction for grid power due to the installation of the gas systems.

As a result, it was clear that the energy supply system including the gas systems was more economically efficient than those consisting of only grid power for “nuclear non-working scenario.” In addition, this system was also more economically efficient on weekdays and Saturdays for the “nuclear 80% operation scenario.”

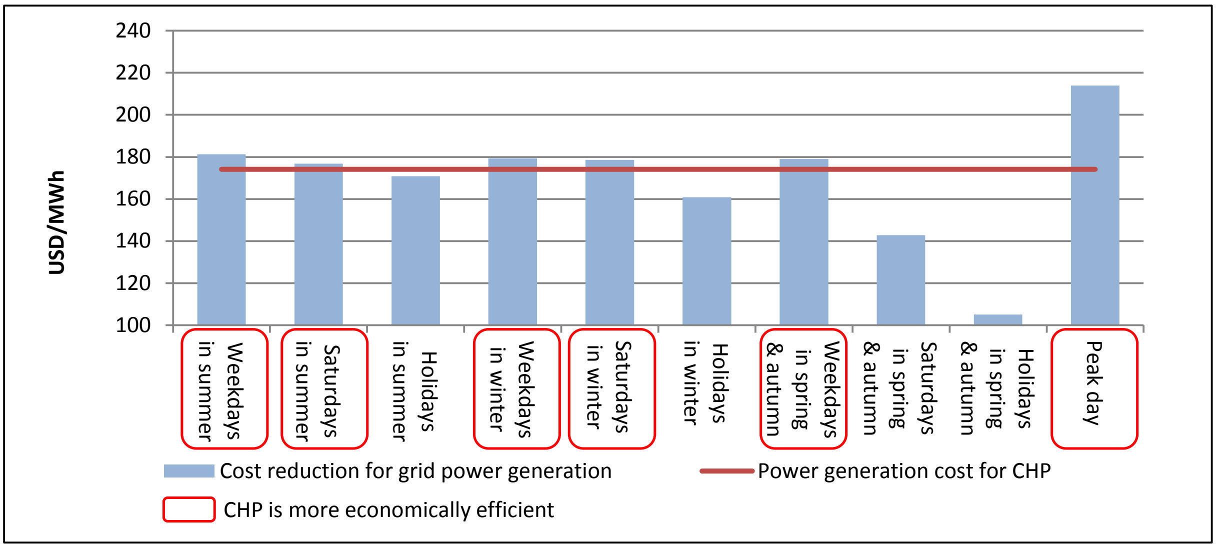

Fig. 7. Cost reduction for grid power due to the installation of gas systems (nuclear 80% operation scenario)

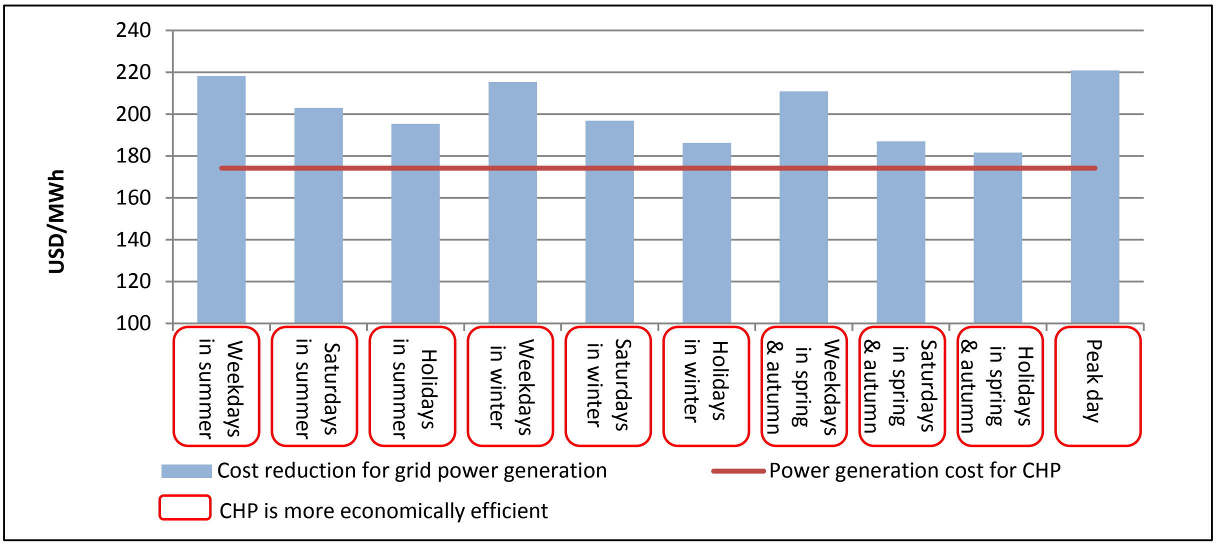

Fig. 8. The cost reduction for grid power due to the installation of gas systems (nuclear non-working scenario)

4. Conclusions

In this study, the effect of reducing the grid power demand (kW) and cost reductions (USD/MWh) due to the installation of the gas systems was evaluated. For this purpose, the Electric Load Curve Estimation Model was developed, which can be used to calculate the hourly electric load curves for each sector and the total electric load curves. We subsequently used the total electric load curves as the input data for the Grid Power Supply Simulation Model, which enabled us to calculate the investment and operation costs for electricity supply. Thus, we could compare these costs before and after installing the gas systems.

Following on from this, a case study focusing on the Tokyo metropolitan area, was performed. Results indicate that including gas systems, alongside other energy sources, can limit total investment and operation costs. In particular, on-site CHP can be economically competitive where nuclear power plants are out of service. Overall, these results suggest that an energy supply system that includes gas systems is more economically efficient than those that rely on grid power only. Therefore, an evaluation of the whole energy system will offer significant information for governmental discussions.

When energy supplies are deregulated in Japan, proposals for the optimal system, including both gas and grid power systems, will become increasingly important. Under such circumstances, gas companies will need to develop an integrated model for analyzing gas and electricity.

5. References

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