Case Study: Smart Community Demonstration Project in Speyer, Germany

1. Introduction

A smart community demonstration utilizing technologies of Japanese companies was conducted in Germany, where the introduction of renewable energy and environmentally advanced technologies are already progressively implemented. In this country, the renewable energy targets to cover 80 percent of the domestic electricity supply by 2050 in line with the energy transition policy "Energiewende."

This demonstration project, conducted from 2015 to 2017 in the historical city “Speyer” which is located on the banks of the beautiful Rhine river, was carried out as one of the "Smart Community International Demonstration Projects" of NEDO, and was implemented by a consortium consisting of NTT DOCOMO, NTT Facilities, Hitachi Chemical, and Hitachi Information and Communications Engineering under the cooperation of the city of Speyer, a municipal public service company Stadtwerke Speyer (hereinafter referred to as SWS), the public housing company GEWO Wohnen GmbH. The Japanese companies have developed and constructed a system that maximizes the self-consumption rate of electricity generated by rooftop photovoltaic (PV) panels through the integration of various technologies such as storage batteries, heat pumps (HP), and ICT which controls electricity consumption. The aim of the system is to help further introduction of renewable energy into households, and to present the potential for new business models to companies such as Stadtwerke in Germany.

For this demonstration, the city of Speyer, NEDO and SWS signed MOU (Memorandum of Understanding). For Type A project, NTT DOCOMO and NTT Facilities signed ID (Implementation Document) with SWS and GEWO, and for Type B project, Hitachi Chemical and Hitachi Information and Communications Engineering signed ID with SWS and GEWO (Figure 1).

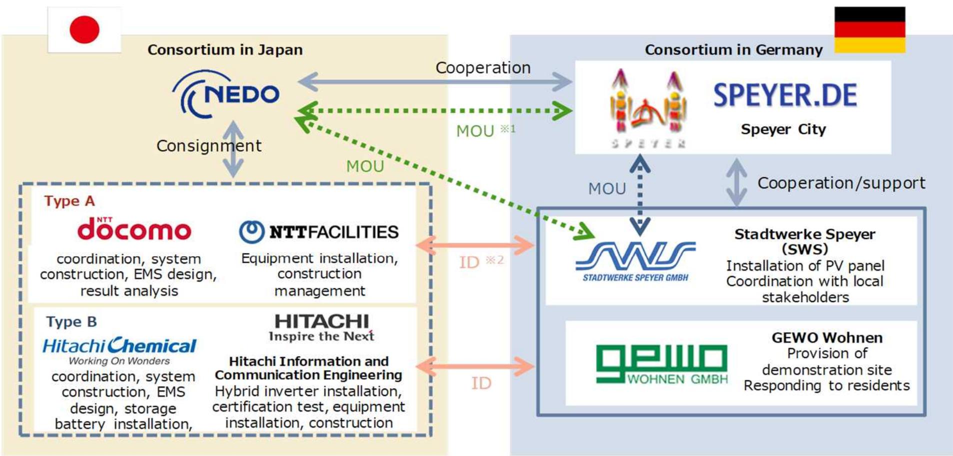
This case study summarizes the implications for smart community technologies in Japan and the potential social contribution of the demonstration project.

2. Background of Initiatives

In Germany, with the enactment of the Renewable Energy Law (EEG) in April 2000, a feed-in tariff (FIT) scheme for renewable energy began in earnest, and that has driven the introduction of PV power generation systems exponentially. Initially, whole PV generation for residential use was mainly sold to the grids based on FIT price, but as PV generation costs decreased, FIT prices fell below the actual electricity tariff rates in 2012. Therefore, instead of selling all the electricity generated at home to the grid, the interest of customers is shifting toward saving electricity charges by raising the self-consumption rate.

In addition, for Stadtwerkes, the following concerns are emerging: First, they cannot use FIT system as an appealing point to their customers when introducing PV power generation facilities, because they cannot make enough profit by selling power using the FIT scheme anymore. Second, the increasing reverse power flow from PV power generation is raising the costs of maintenance of system facilities and network expansion. Thus, it is an important issue for both consumers and power utilities to maximize the self-consumption rate of PV power generation.

Japan has accumulated excellent battery storage, heat pump for hot water supply, and information communications technologies. We could meet the needs for generation and consumption of heat and electricity in Germany by combining these technologies. This demonstration project casted the ideas into shape. In this demonstration, the effectiveness of Japanese advanced technologies and a potential business model were successfully verified in Germany where the introduction of distributed energy resources are much more progressed and, because of that, some “advanced” problems are already visualized. It provides numerous suggestions to consider the future of Japanese energy policy and the development of renewable energy-related businesses.



※1 MOU: Memorandum of Understanding
※2 ID: Implementation Document

Figure 1 Demonstration System

3. Outline of the demonstration project in of Speyer

The following is a summary of this demonstration project, and the activities in the city of Speyer where the demonstration was conducted.

3.1. Efforts in the city of Speyer

The city of Speyer, located in southwestern Germany along the Rhine River, has about 50,000 people. Although it is a relatively small city, it has a long and important history; Speyer was developed as a trading and financial hub and flourished as one of the most important location during the era of Holy Roman Empire around the 10th century. Speyer Cathedral, known as the final resting place of seven Roman emperors, is the second item in Germany registered as well-known World Heritage. The city also impresses the world because of its active efforts to introduce renewable energy. Speyer has positioned itself as a leader in the implementation of Energiewende and aims to produce renewable energy in order to cover 100% of electricity consumption by 2030 and 100% of heat consumption by 2040.

The municipal- or state-owned corporations in the form of "Stadtwerke" have significant presence in the power retail and distribution market in Germany. As of 2019, there are more than 1,400 Stadtwerkes in Germany, and many of them function as the largest electricity distributors for their local energy market. SWS, the company jointly conducted this demonstration project, is also a Stadtwerke, run by the city of Speyer, and the company accounts for more than 90% of the electricity market and more than 80% of the gas market in the city of Speyer. GEWO, a public housing corporation, owns 2700 apartments and 400 detached houses in the city and provides housing to about 8000 people, which is about 16 % of the city's population. Such cooperation among public utilities has been actively developed in Speyer. In 2000, The city of Speyer, SWS and GEWO jointly established a joint venture called TDG (Technical Services Company in English) to provide power and heat supply services for houses and buildings using renewable energy. SWS installed PV panels on the rooftops of buildings owned by GEWO, and developed power and heat supply businesses using solar thermal and biomass combined heat and power (CHP) facilities jointly constructed with TDG.

3.2. Outline of Initiatives

The largest challenge for the city of Speyer aiming at 100% of renewable energy was to improve "self-consumption rate". In order to realize this, the power and heat supply system consisted of HEMS (Home Energy Management System), storage batteries and heat pumps was constructed in the project. The self-consumption rate will be improved by considering various factors such as weather, demand, electricity price, and by optimally controlling the storage battery and heat pump. In this demonstration, the following two types of demonstration sites were selected, and the demonstration was conducted mainly based on the following themes (Figure 2);

Type A: Self-consumption model for detached houses

Verification of the effect of the self-consumption rate improvement by demonstration systems

Storage battery control linked to electric power market price (Experiment assuming that electricity wholesale price fluctuates in conjunction with market prices)

Review of business models

Type B：Self-consumption model for apartment buildings

Verification of the effect of the self-consumption rate improvement by demonstration systems

Comparison and analysis of two control Modes (including the experiment assuming that electricity wholesale price fluctuate in conjunction with market prices)

Cost reducing efforts by hybrid inverter

Review of business models

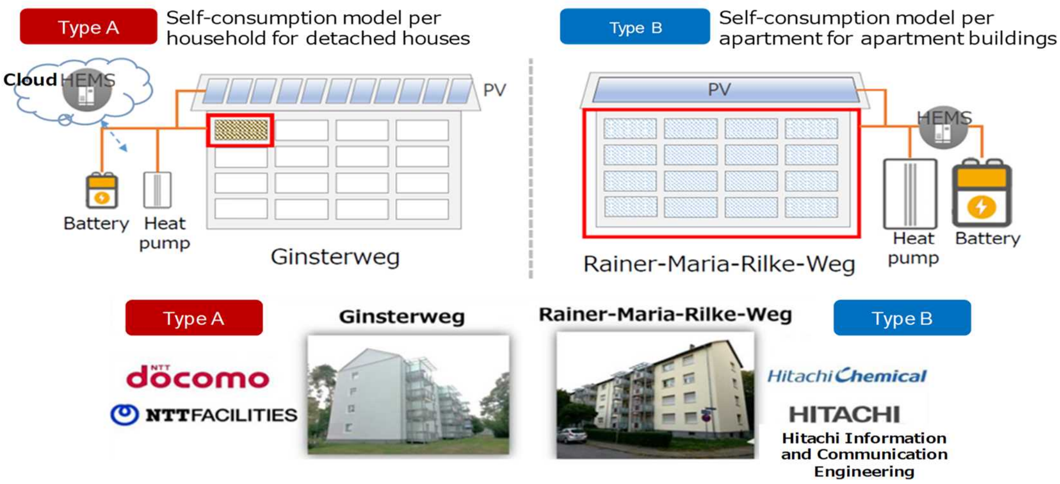


Figure 2 Outline of this demonstration

The Type A demonstration was conducted by NTT DOCOMO and NTT Facilities, and Type B was conducted by Hitachi Chemical and Hitachi Information & Telecommunication Engineering. The German companies were responsible for selection of the demonstration site, contact and response to the residents, and installation of PV panels, while the Japanese companies were responsible for operation of the demonstration, system development, installation of facilities, and effect analysis.

4. Construction of demonstration systems

The systems built for the project is described below.

4.1. Type A (household unit model) system design

In Type A, the self-consumption model for “detached houses” was supposed to be verified, but since there were some difficulties to find appropriate detached houses, the demonstration was conducted in an apartment building. Therefore, the system was constructed in each of the 16 apartments in order to set up virtual detached houses (Left on Figure 2).In addition, equipment such as storage batteries and heat pumps that cannot be installed in each apartments was placed in a container called “Energy Center”, and they were set in the neighborhood of the apartment building.

HEMS was established as the core of the system; there are two HEMS, a cloud HEMS (remotely controlled from Japan through the internet) which formulates a management control plan for multiple households, and a local HEMS (set up in each household) which controls the equipment of each household(Figure 3). The advantages of separately installing these two HEMS is that (1) it can reduce the size of the HEMS equipment installed in a household for easier installation, and reduce the cost of the equipment, and that (2) it can makes it easy to manage the increased number of users in the future by integrating functions that require high performance, such as creating forecasts and controlling plans, into the cloud HEMS.

The cloud HEMS combines the equipment information of each household collected from the local HEMS and the weather information from the weather information service. The forecast data are the following.

- PV power generation (Hourly)
- Home power consumption (Hourly)
- Home heat consumption (Hourly)

Based on these data, it formulates the control plan for the storage battery and the heat pump each hour. Heat pumps are designed to supply heat from the hot water storage tank based on the prediction of heat consumption in the house, and to utilize boiler as a backup when the heat supply from the heat pump is insufficient. For battery storages, in order to maximize the financial merit, it hourly calculates the recommended amount of storage/discharge based on PV power generation and power consumption forecasts and sends instructions of charge/discharge control for 24 hours a day. The local HEMS receives control plans from the cloud HEMS and communicates to the storage batteries and heat pumps. In this way, the "self-consumption" of PV power generation was maximized by executing daily prediction and control.

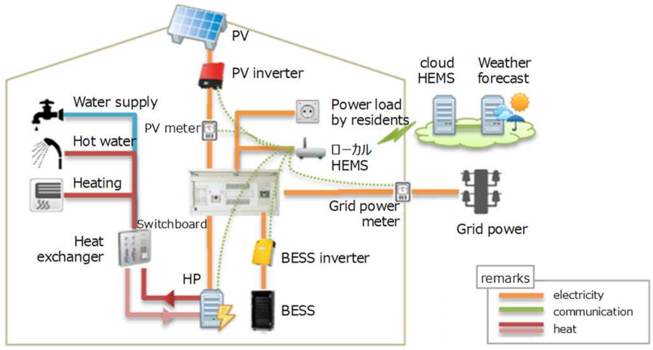


Figure 3　Model image for a detached house for local production and local consumption (Type A)

4.2. Type B (Self-Consumption model for each building)

In Type B, the system control is performed per building, assuming a system for housing complex (e.g. apartment buildings). Based on this concept, storage batteries, heat pumps, inverters were installed, and a power supply control system for the entire building by HEMS were introduced (Figure 4). The heat pump only supplied heat for heating system in the rooms, because the water heaters for hot water supply, which required some construction work in each apartment, could not be changed. The HEMS was divided into LTC (Long term control) and STC (Short term control). The LTC was installed in the SWS server, and the STC was installed in the Energy Center. The LTC collects information of the entire building from the sensors and combines with weather information from weather forecast services and perform prediction and control in the building. The STC receives the control plan from the LTC and controls the batteries and heat pump. In addition, a remote monitoring function which complains with General Data Protection Regulation by the European Union (EU) has been installed so that the status of these operations can be monitored in Japan.

In Type B, HEMS were designed for 2 operation control modes: "

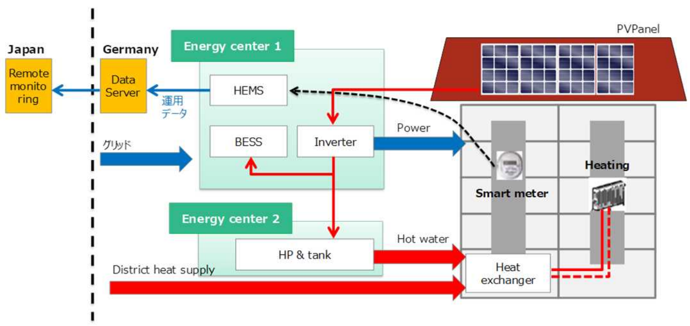


Figure 4　Model image for a housing complex for local production and local consumption (Type B)

Maximum self-consumption control (SCMC)" mode and "Energy cost minimization control mode (ECMC)." SCMC mode promotes the operation of the storage battery and the heat pump when there is surplus in generated power. It also controls the battery to discharge electricity from storage battery and suppress power from PV purchase when power is insufficient. In the "ECMC" mode, under the assumption that the electricity price fluctuates according to the power supply and demand situation (in actual situation in Germany, electricity price is fixed), the electric power is purchased in bulk when its rate is cheaper, and the electric power is sold when its rate is higher, and the electric power can be supplied from the battery storage when its rate is higher. Heat pumps are controlled to function when they seem to be able to reduce electricity fee (for example, when generated power from PV is excessed and heat consumption is large). It aims at keeping the cost low, and efficiently using the power generated by the PV panel.

5. Introduction and installation of system

In the Type A demonstration, Sony's storage batteries (Fortelion), Daikin Industries' heat pumps (Altherma), SMA's PV inverter, and storage battery inverter were installed in addition to the HEMS which NTT DOCOMO (especially developed for this demonstration). In the Type B demonstration, storage batteries made by Hitachi Chemical, a hybrid inverter made by Hitachi Information and Communication Engineering, heat pumps made by Daikin Industries and FEFU's PV inverter were introduced. Manufacturing of energy center container was outsourced to Koncar in Croatia, and software manufacturing was outsourced to Robotina in Slovenia.

In order to reduce the fire risk of the storage batteries installed in the Energy Center are regarded as equipment containing fire, the local Fire Department and SWS repeatedly had discussions. Germany does not have a clear fire-fighting standard for lithium-ion batteries (LIB), but fire departments requires to install fire-fighting equipment that automatically extinguishes fires if it occurs in LIB. Therefore, NTT Facilities and Hitachi Chemical took the lead to determine the specifications of fire-fighting equipment after obtaining the cooperation of external consultants specializing in fire-fighting equipment to formulate the fire prevention concept (Figure 5).

Since the demonstration facility is to be installed in a residential area, the environmental standard for noise was applied, and it required that the noise on the outer wall of the apartment building at night should be less than 45 [dB]. Therefore, measures such as installing a hood in the outdoor unit of the heat pump and installing a noise-absorbing material near the intake port were taken (Figure 6). In addition, smart meters such as a watt-hour meter, a thermo-hygrometer (Type A only), and a calorimeter, and communication equipment were installed in the common area of the apartment building(Type A only) and the Energy Center, and temperature and humidity sensors, a calorimeter, and communication equipment were installed in each unit of apartment.

Since resident's presence is essential for the installation of equipment in residential space, the work schedule was adjusted by posting the notice at the entrance of the apartment building and informing each household by sending a letter and making a phone call in advance (Figure 7).

Figure 5 Installation of fire extinguishing gas cylinders, communication equipment to fire stations, fire information control systems (FIBS), and water injection ports

Figure 6 Installation of noise insulation equipment and silencers outside the Energy Center

Figure 7 Posting of work schedule at the entrance of the

6. Data acquisition and evaluation of demonstration effects

Through this demonstration, power consumption and heat consumption per minute were obtained over 21 months. By analyzing the obtained actual data and various prediction data, the results obtained in the demonstration were compared with the assumed values in the absence of the demonstration system about the self-consumption of PV power generation, the volume of reverse flow to electrical system, gas usage of gas-fired boiler and heat usage. The effects of the introduction of the demonstration system were also evaluated. The results of type A and type B data analysis are summarized below.

6.1. The result of Type A demonstration

In Type A, the demonstration was mainly evaluated from the following three viewpoints.

- Verification of the effect of the demonstration system to improve the self-consumption rate
- Storage battery control linked to power market price
- Review business model

① Verification of the effect of the demonstration system to improve the self-consumption rate

Comparing the self-consumption rate when PV power generation is used alone, and when the demonstration system is used with a storage battery and heat pump, the self-consumption rate of households with PV was 25.6% on average, while that of households with the demonstration system was 63.8%. As a result, the self-consumption rate was improved by about 40 points. Among the households in this demonstration, the highest self-consumption rate is 77.8%, and the lowest self-consumption rate is 53.4%, showing 28.9 to 44.7 points improvement in the self-consumption rate (Figure 8).

Reviewing by season, the self-consumption rate in winter (November to February when PV generation is relatively low) was approximately 40% to 60% for PV alone without the demonstration system, while it was approximately 100% for PV with the demonstration system. On the other hand, the self-consumption rate in summer (July to September when PV generation is relatively high) was approximately 20% for PV alone, and 50% to 80% for the system installed. By time zone, the improvement effect of the self-consumption rate was high a few hours before the peak of PV power generation, but it was found that the improvement effect was limited after the peak of PV power generation due to a fully charged battery. In addition, comparing the self-consumption rate of each household with the amount of reduction by large and small households, the self-consumption rate in a year was 44% to 78%, showing a difference of more than 30 points depending on the amount of power consumption. As shown in Figure 8 below, the self-consumption rate of households with an annual power consumption of 2347 kWh was 78%, while that of households with an annual power consumption of 925 kWh was only 44%.

In addition, as a result of obtaining data by setting the storage battery capacity at 2.4 kWh, 4.8 kWh, and 6.0 kWh, it was found that the self-consumption rate with any storage battery capacity was nearly 100% for 6 months from September to February, and the operation rate of the storage battery was low. In Germany, PV capacity and storage battery

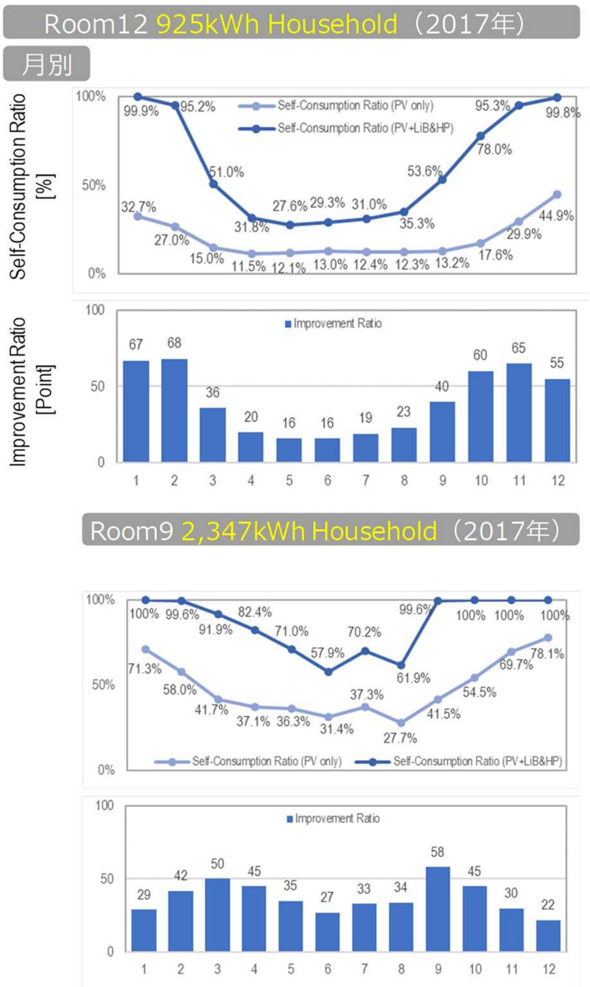


Figure 8 Trends in the rate of self-consumption in households with different power consumption

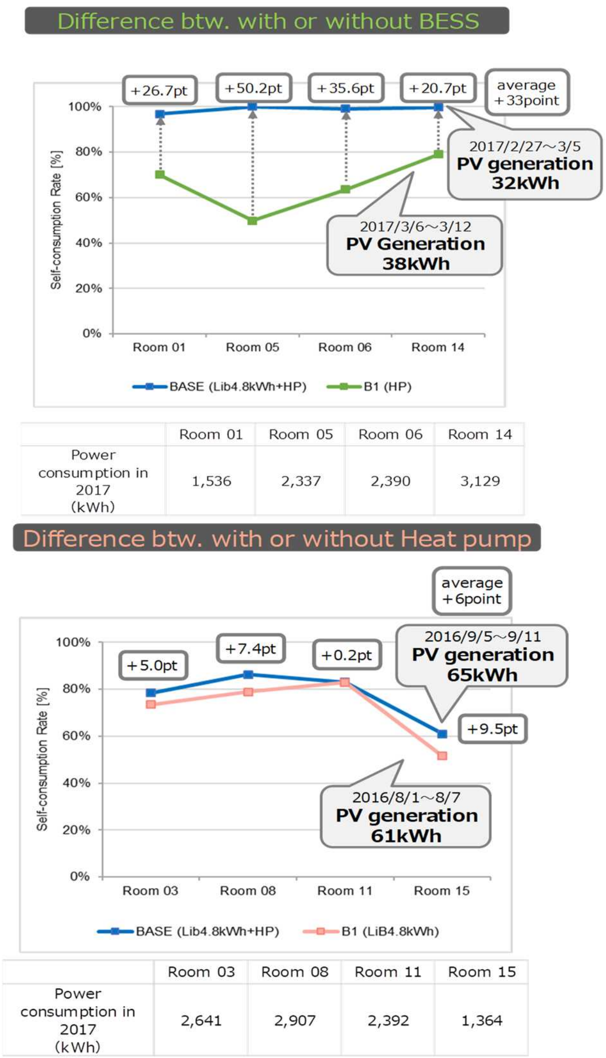


Figure 9 Changes in self-consumption rate due to the presence or absence of storage batteries and heat pumps

capacity are generally regarded as the same value (For example, if the PV is 5 kWp, the battery capacity is also 5 kWh.). However, as a result of demonstration, it was concluded that the difference in PV power generation is large depending on the season in Germany, and it is better to appropriately set the storage battery capacity according to the PV capacity.

As a result of data acquisition every week by changing the presence/absence of the storage battery capacity and that of the heat pump, the self-consumption rate increased by more than 33 points on average when the storage battery capacity was present, but the boost effect was limited when the heat pump was present (Figure 9).

This is probably due to the fact that the PV power generation could not be used for the heat pump before the storage battery because the heat pump was shared in the building, although it was supposed to increase the self-consumption rate by operating the heat pump at the peak of the PV power generation.

② Demonstration results based on the assumption that electricity prices are linked to market prices

In order to improve the added value of the HEMS in the future, in addition to the control of self-consumption operation, an empirical analysis of battery control was conducted to optimize the economy in accordance with market prices.

As a result, it was confirmed that this demonstration system functions to charge at lower rates and discharge at higher rates can be linked to the market in order to maximize the economic effect (Figure 10).

By this control, the battery can be charged by the grid power system when the market price is reasonable so that the battery can be effectively used even when PV power generation is low, and the economic benefit can be improved. For example, the results from the business model suggest that the self-consumption system owned by an electric power retail company such as Stadtwerke, can be used to minimize the procurement price and obtain the source of economic benefits.

③ Review business model

In addition to this technical verification, the feasibility of the deployment of this demonstration system in Germany and the business model were also examined.

In this demonstration, it is assumed that the system operator Stadtwerke (SWS in this demonstration) owns PV panels, storage batteries, heat pumps, and other equipment, and installs them into the homes of consumers as a model (Figure 11).

Under this model, Stadtwerke will cover the cost of purchasing and installing the equipment. However, by operating the system through HEMS, not only profit can be optimized by charges from consumers and selling power to transmission companies, but also new business possibilities such as building a virtual power plant (VPP) using the equipment installed in many homes of consumers can be examined. From the consumer's viewpoint, renewable energy can be introduced without covering the initial and operation cost, and electricity can be used at a lower and more stable price. GEWO, which owns properties, can also expect revenue from rooftop space rental business and an increase in customers due to the improved image of the properties.

As a result of the analysis, it was estimated that if the storage battery

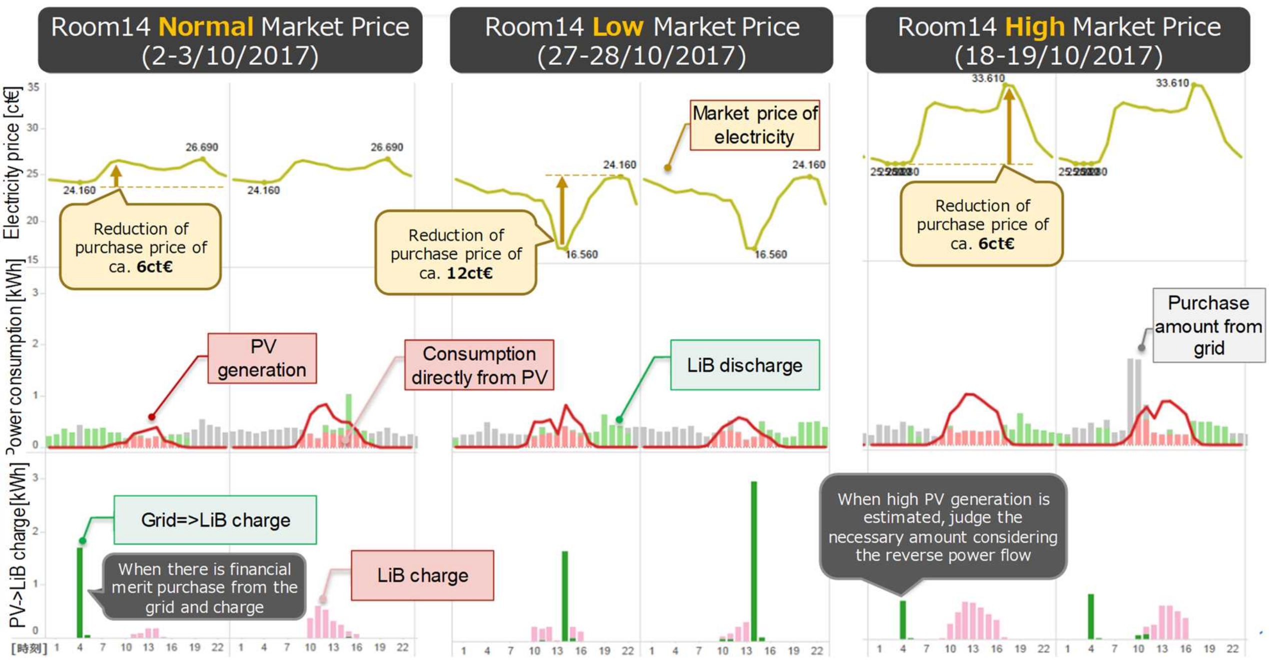


Figure 10 Effect of procurement price reduction through battery control according to market price level

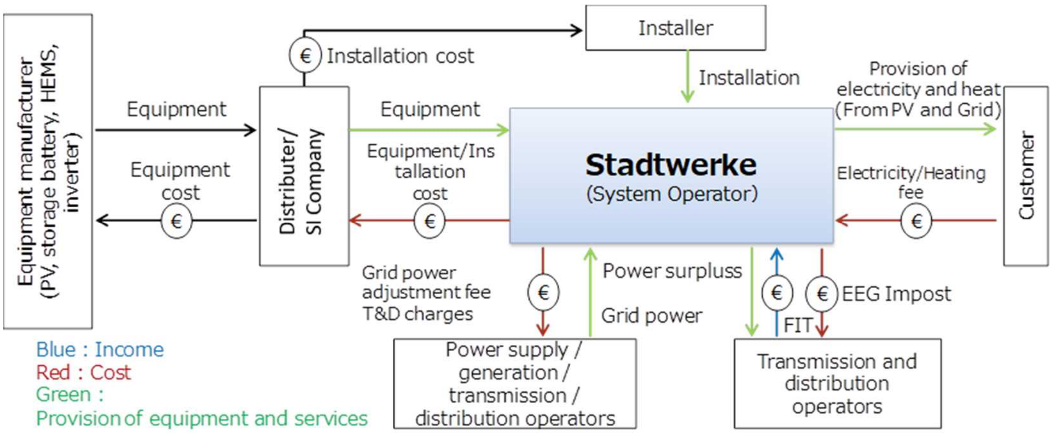
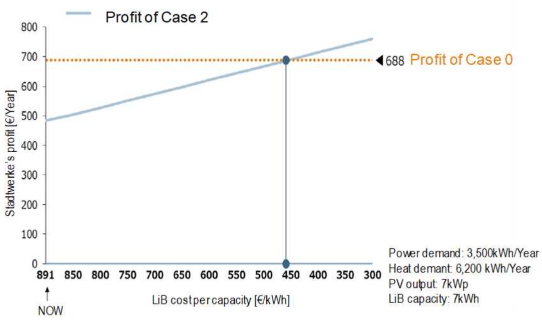


Figure 11 Relationship diagram of the Stadtwerke model

cost is reduced to 450 EUR/ kWh, and the PV panel and the storage battery are owned and installed by Stadtwerke, the profitability will be higher than using them without the equipment. For households with high electricity demand (Electricity demand: 4,800 kWh/year, PV output: 10 kWp), profits can be secured by reducing battery costs from the current level of 891.5 EUR/ kWh to 800 EUR/ kWh. It also showed that the payback period for the PV + battery system would be 13 to 19 years if it is introduced in 2020, and 10 to 12 years if it is introduced in 2030. The payback period for the PV +battery + HP and PV + battery + HP + HEMS systems is approximately 15 to 30 years, and it is difficult to collect the investment in a short period (Figure 12).



No	Condition	Business start in		
		2020	2025	2030
1	PV	9~11	7~9	6~8
2	PV + Battery	13~19	11~14	10~12
3	PV + Battery + HP	15~29	12~26	10~13
4	PV + Battery + HP + HEMS	15~29	12~26	10~13

Figure 12 Break-Even point for battery prices and Payout time

6.2. The result of Type B demonstration

In Type B, verification was mainly evaluated from the following four viewpoints.

Effect of the demonstration system to improve the self-consumption and self-sufficiency rate

Comparative analysis of effects of two control modes

Cost reduction effect of hybrid inverter

Review business model

Effect of the demonstration system to improve the self-consumption and self-sufficiency rate

During a year from January to December 2017, in the case this demonstration system using a storage battery and a heat pump was introduced, the self-consumption rate, which represents the percentage of energy generated by PV that was consumed in the house, was 88% (yearly), and the effect of the introduction of the system on the improvement of the self-consumption rate was 34% (Figure 13). The heat pump was used only for heating, but in the case the heat pump was used for hot water supply such as showers, the self-consumption rate could be improved to 93% by using surplus power in summer based on the assumption of in-house heat consumption data of Type A. In particular, the highest self-consumption rate was recorded in winter, reaching almost 100% between September and April. On the other hand, in June, it marked the lowest level (67%).

In addition, the "self-sufficiency ratio", which represents the ratio of PV power generation and discharge from storage batteries to the total power consumption of housing complexes, was 69% annual average. The self-sufficiency rate was 51% at the maximum in September, and an average annual self-sufficiency rate was 27% (Figure 14).

Furthermore, by introducing this demonstration system with a storage battery, it was confirmed that the system power purchase cost can be reduced compared with PV alone, because the system can be positively charged when the electricity price is low, and the power purchase at night can be suppressed by discharging at night when the electricity price is high. Specifically, while the annual electricity cost reduction for PV alone was 3,976 EUR, the effect of the introduction of the improvement system of self-consumption rate was 6,580 EUR. It showed the reduction effect was 1.66 times.

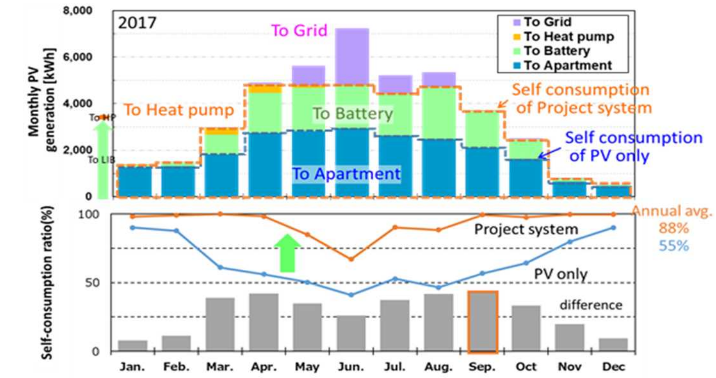


Figure 13 Improvement in self-consumption rate

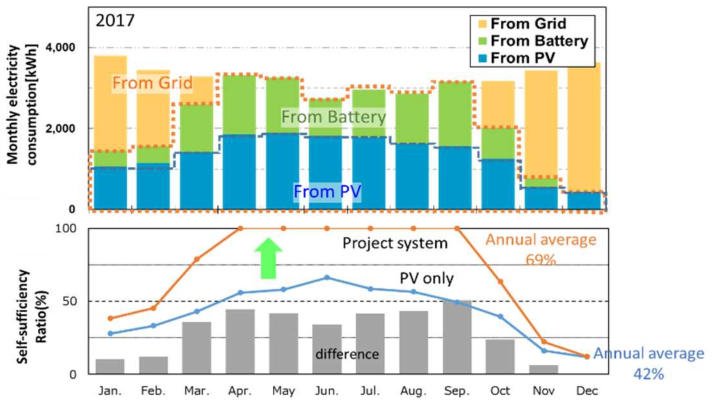


Figure 14 Effects of the self-sufficiency rate

① Comparative Analysis of Effects of Two Control Modes

As described in the previous chapter, in the demonstration of Type B, there were 2 operation control modes: "Maximum self-consumption control mode (SCMC)", in which the operation of storage batteries and heat pumps was encouraged when surplus power was generated, and electricity was discharged from the storage batteries to control power purchase when power was insufficient, and another mode is "Energy cost minimization control mode (ECMC)", in which electricity is purchased at a low rate, and sold at a high rate, and controlled so that it can be supplied from the battery to home at high rate (Table 1).

Data were collected for each mode. In the SCMC mode, control is performed to reduce power sales (reverse flow) to the maximum extent. In the ECMC mode, a control plan (Battery charging/discharging and HP operation patterns) is established based on predicted data of PV power generation, power and heat consumption, and procurement costs for power purchase, power sales, and heat purchase up to 4 days in advance. Under the SCMC mode system, when surplus power is generated in the summer, the heat pump operates, resulting in a decrease in power sales and a deterioration in cost performance. However, on the assumption that the consumption of hot water is also supplied by the heat pump, another calculation using Type A data showed that the source of hot water supply was switched from gas to district heat supply (District heating system: DHS), and the cost advantage is improved.

Considering that the cost merit under the SCMC mode was minus 203

Table 1: Arrangement of Two Operation Control Modes

Item	Maximum self-consumption control mode(SCMC)	Energy cost minimization control mode(ECMC)
Purpose	minimization of reverse flow	Minimization of power and thermal energy costs
Control Policy	Charge/discharge and HP operation patterns are determined according to power shortage or surplus power. a) When surplus power is generated : Only battery charge is switched, and battery charge + HP operation is switched according to the surplus power and SOC of the battery. b) When power is purchased: Discharge from the storage battery to suppress power purchase.	Charge/discharge and HP operation patterns are determined from the amount of shortage or surplus of power and heat calculated from the prediction so that cost of purchased and sold electricity, and purchased heat are minimized. a) Purchase electricity: Purchase electricity in bulk when electricity is reasonable. b) Sell electricity:Sell electricity in bulk when electricity is sold at high prices. c) Purchase heat：HP runs to provide power when its price is high.
Battery	Minimization of grid electricity trading	Charging and discharging are controlled so that electricity is purchased at a low rate and sold at a high rate
Heat pump	Start HP when surplus power is high, regardless of heat consumption	Start HP when there is surplus power and heat, and hot water generated by HP is consumed.

EUR, it can be said that the cost merit by changing the control mode is 548 EUR. Assuming that hot water consumption was also supplied from heat pumps as well as the case in SCMC mode, it was confirmed that the cost advantage also increased under the ECMC mode.

In addition, the cost advantage of ECMC mode was improved under the imaginary situation where the electricity price fluctuates, because electricity was purchased in bulk on the 1st day when electricity price was low in winter. The improvement effect of cost advantage per year is calculated to be about 345 Euros compared to the case without HP (Figure 15). Considering that the cost merit under the control mode of maximizing the self-consumption rate was minus 203 EUR, it can be said that the cost merit by changing the control mode is 548 EUR (because minus turns into positive merit).

	fixed price period	variable price period
Maximum self-consumption control mode (SCMC)	Sales of electricity decreased due to operation of HP with surplus electricity in summer, resulting in a deterioration in cost advantage.	
Energy cost minimization control mode (ECMC)	Almost the same cost advantage as without HP to reduce unnecessary HP operations	The cost advantage is improved because electricity is purchased in bulk when electricity price is lower on the first day during the winter.

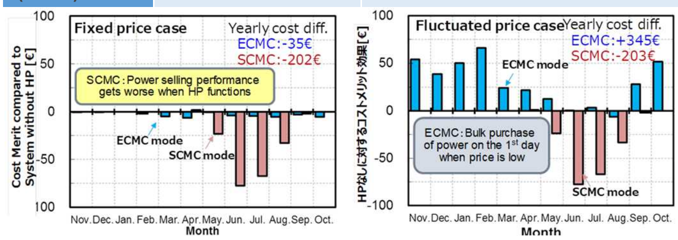


Figure 15：Comparison of cost advantage of HP by control modes (Heat: for heating purposes only)

③ Cost reduction effect of hybrid inverter

In Type B, as the 2nd stage of the demonstration, the data between October 2016 and March 2018 were also obtained in the case of installing a hybrid inverter. The hybrid inverter is a combination of a PV inverter and a storage battery inverter, and it has 2 DC input circuits (DC voltage converter) and 1 AC output circuit (DC AC converter). One of the DC input circuits is for PV power generation control and the other is for storage battery charge/discharge control. Thus, the electric power obtained by the photovoltaic power generation can be effectively charged to the storage battery by skipping the electric power conversion process and lowing the electric power loss (Figure 16).

In this study, it was verified whether the hybrid inverter shows the superiority of energy efficiency compared with the conventional configuration using PV inverter and storage battery inverter introduced in the energy center of the demonstration site.

Energy efficiency is defined as the ratio of the amount of electricity that the inverter could ultimately output to the grid, i.e., the amount of electricity that could be consumed by households (including surplus electricity once stored in storage batteries), to the amount of PV power generated.

Data were collected and analyzed 4 times in February, May, August, and November using the conventional inverter and hybrid inverter under the same conditions. As a result, the power conversion efficiency from PV with the hybrid inverter was improved by up to 11.1% compared with the conventional inverter, and the cost reduction equivalent to the purchased power was estimated to be EUR283 per year (Figure 17).

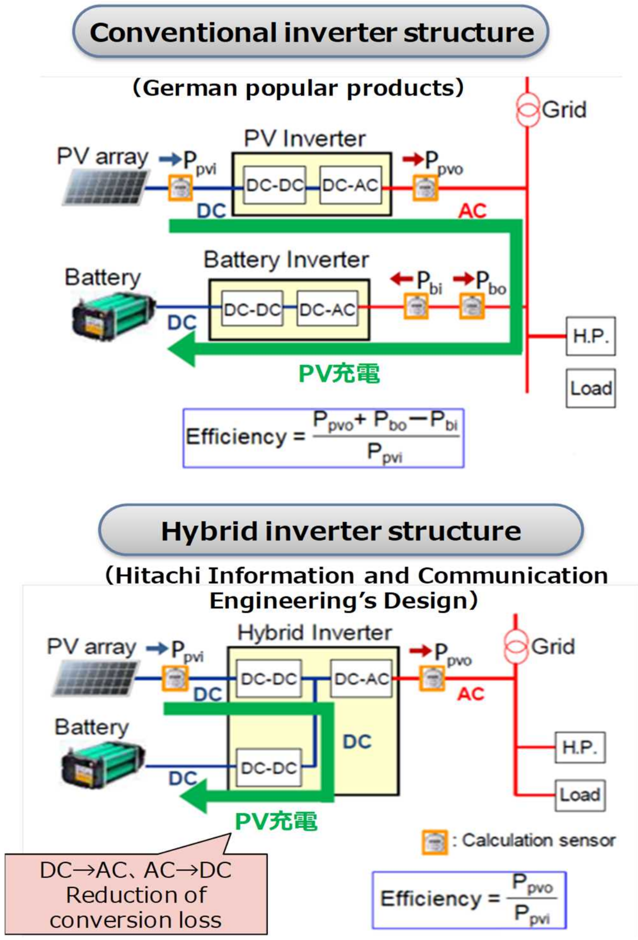


Figure 16: Structure of Conventional Inverter and Hybrid Inverter

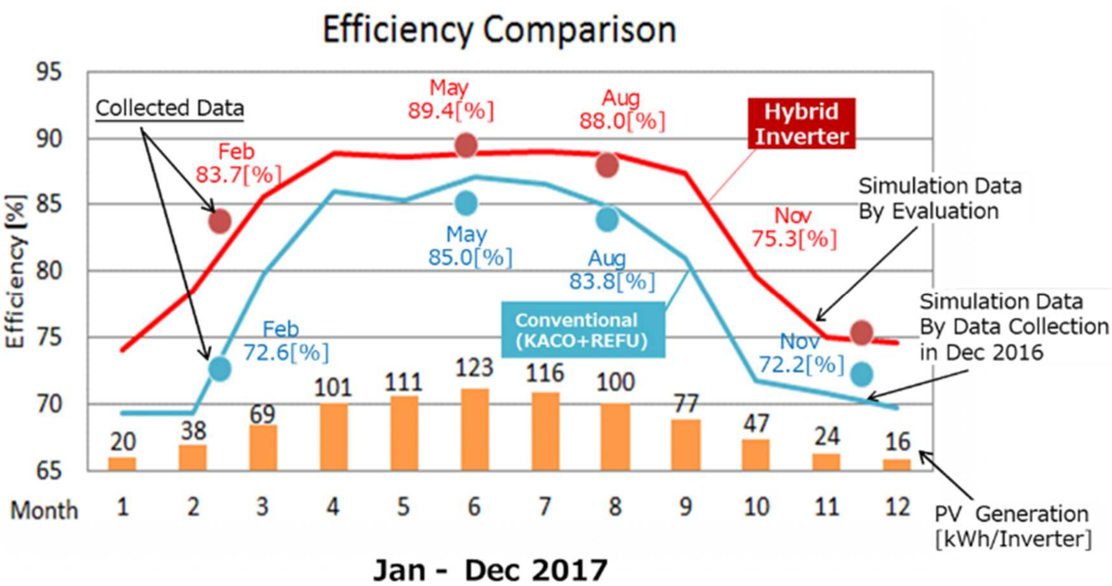


Figure 17: Cost reduction effect by hybrid inverter

④ Review business model

This section presents the results of reviewing the type B business model. A business model was examined assuming that the system operator Stadtwerke (SWS in this demonstration) owns PV panels, storage batteries, heat pumps, and other equipment, and installs them in the homes of consumers as well as Type A.

In Type B, it is assumed that a storage battery, a storage battery inverter, and HEMS will be installed in the housing complex for 16 households used in the demonstration project. Assuming household power consumption of approximately 40,000 kWh per year and PV outputs of 45 kWp and 30 kWp, respectively, and the storage battery capacity was set at 10 kWh/house/day × 16 houses × 1 day = 160 kWh. If the storage battery capacity was approximately 30 to 45 kWh, the self-sufficiency rate would increase along with the storage battery capacity, but if the self-sufficiency rate exceeded approximately 45 kWh, the payback period for the self-sufficiency rate would be extended and the cost advantage of the storage battery would decrease (Figure 19). It results in taking 8 to 10 years to earn a profit on the investments in the shortest run in the case of using PV output of 30 kWh and storage capacity of 30kWh. As the battery life is 15 years, it is evaluated that the investment is expected to be paid off before the battery reaches the end of its life (Figure 18).

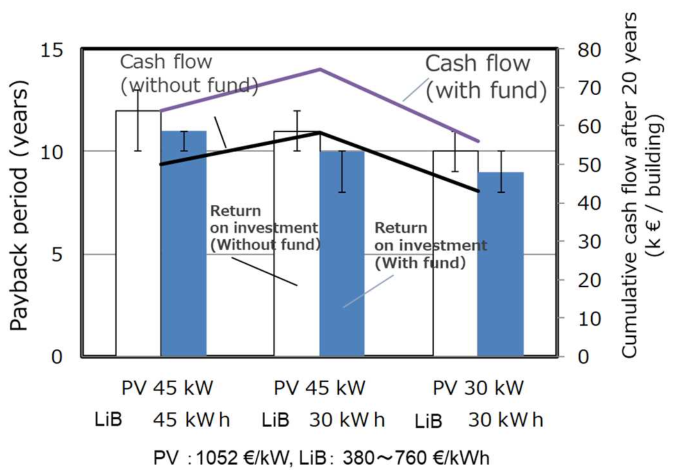


Figure 18: Estimate of the payback period

6.3. Summary of the demonstration

In this way, we were able to prove that various effects can be expected by introducing this demonstration system from the data confirmed in the demonstration of Type A for detached houses and Type B for apartment buildings. Main results are as follows.

- **Improvement in the rate of self-consumption** : approximately 40% for Type A and approximately 34% for Type B.
- **Possibility of storage battery control linked to market price of electric power** : It was confirmed that economic optimization linked with market price could be carried out in addition to control of self-consumption operation by control of storage battery.
- **Effectiveness of the energy cost minimization control mode** : It was proved that cost advantage can be improved by purchasing electricity on a day when electricity price is low.
- **Efficiency of hybrid inverter** : It was shown that the efficiency of power conversion from PV will be higher than that of conventional inverters and it enables cost reduction.

Furthermore, the following CO2 reduction effects were confirmed by introducing this demonstration system.

Type A: 580.7 kg-CO2 / year per household
Type B: 11,235kg-CO2 / year per building
(Observation data from January to December 2017)

When introducing a system that could have the effects mentioned above, the project examined a business model in which a power transmission and distribution company such as Stadtwerke became a system operator and installed equipment in the homes of consumers. The project also achieved significant results in indicating profitability and the exact number of years it would take to recover the investment.

～ Key Findings ～

The introduction of a comprehensive private power generation system and consumption system including advanced HEMS in the demonstration project was relatively new attempt even in Germany. Thus, we were able to obtain various notices and lessons by observing the installation of the implementation and demonstration results. The main points are described from the following three viewpoints.

① Realization of a “local production and consumption of electricity” model that attracts more attention in the post-FIT phase
② Japanese technology that holds the key to local production and consumption of electricity
③ What Japan learns from Stadtwerke’s model

① Realization of a “local production and consumption of electricity” model that attracts more attention in the post-FIT phase

Germany, which has set a goal of 80% renewable energy supply in 2050, is facing the moment of “grid parity” as power generation equipment costs fall. For this reason, Stadtwerkes are no longer able to earn profits from a simple business models such as selling electricity using the FIT system. However, while this issue was clarified, the concept of "Local production and consumption of electricity" and " Prosuming (In this case, it refers to the self-consumption of generated electricity or the sale of generated electricity to other users.)" is attracting attention as a new incentive.

The realization of high economic efficiency is essential to promote the private consumption of electricity. In this demonstration, the system of maximizing self-consumption rate using a storage battery, heat pump, and HEMS is considered to be more effective by controlling multiple number of buildings at once time than by controlling on a single house or building basis. For example, in the demonstration of Type A, since it is controlled on a household basis, it is difficult to predict the behavior pattern of each person in the household on an hourly basis, and it is impossible to predict it accurately. It is more efficient to control on some household basis. This is also the case for Type B, and an electricity supply model covering several buildings is superior to power generation and control per building in terms of economies of scale and efficiency. In addition, the following are some of the advantages of a system in which multiple number of buildings are managed together.

The equipment cost can be reduced by the integration of the control system and the consolidation of constructions.

The reverse flow from the storage battery of the house can be supplied to other houses so that the electric power can be interchanged.

Power distribution companies are also likely to benefit from avoiding the congestion of distribution lines and penalty for imbalance charges

In this way, the value of using renewable energy is expected to increase further by promoting local production and consumption of electricity utilizing the technologies used in this demonstration project. In Germany, end of the FIT scheme has reaffirmed the importance of self-consumption, and lower battery and module prices caused the reduction of initial costs. What is required to the policy makers from now on is to promote the economic effectiveness and importance of realizing “local production and consumption of electricity”.

However, there remain some institutional challenges in realizing a power generation and supply system that connects multiple number of buildings. One of them is network tariff. Under German law, it is necessary to use grid system line to exchange electricity between different buildings, and accordingly network tariffs and electricity tax must be paid. For example, if one household delivers electricity to a shared storage battery in the community and then the same household receives electricity from that battery, there will be a double electricity tax imposed. SWS and other German utilities also have a strong desire to develop local production and consumption of electricity on an area basis, but institutional reforms will be essential to support that. In Japan, discussions on network tariffs are currently underway. Given that the " local production and consumption of electricity" is expected to become widespread as a new solution after the end of the FIT system, it is necessary for Japan to consider a system that will not hinder it.

② Japanese technology that holds the key to local production for local consumption of electricity

The comprehensive system combining HEMS, heat pump, storage battery and other equipment used in this demonstration was an important technology and concept for realizing the "local production and consumption of electricity" described above. Germany already had a power supply business combining with a battery, heat pump, and PV, but the effort to maximize self-consumption by utilizing a highly accurate HEMS control system seemed to be new intention even in Germany. Mr. Bühring, the president of SWS, who was deeply involved in this demonstration project, says that the high-performance heat pump made in Japan and the detailed control system by HEMS implicated the possibility of new business for SWS.

Furthermore, the successful experience of this demonstration project will provide a great clue to the "sector coupling technologies" that will be a key of German energy policy in the future. In other words, it will provide a mechanism in making the best use of renewable energy power by linking different sectors such as power, heat, and transport.

Thus, Japanese technology and quality may play a role in the movement of local production and consumption of electricity in Germany. However, in order to develop infrastructure and operate businesses in Germany, it is necessary to deal with the systems and customs which are different from those in Japan.

One of the examples is the regulation on the protection of personal information in Germany. The regulations on the protection of personal information are very strict in Germany, and it took about six months to start the demonstration project because various procedures. In order to ease the process, they made various efforts such as holding briefing sessions to raise the likelihood of residents signing the Data processing agreement.

Also, as mentioned above, it seems to have been difficult to meet German safety standards and noise standards. The most impactful problem is that German laws and regulations do not mention the fire-extinguishing systems for installing lithium-ion batteries, even though it is necessary to obtain permission from the local fire department to install such systems in homes. As a result, the companies which handled the issue spent more time and money than expected for the examination since they had to hire local consultants to formulate the requirements of fire-fighting equipment based on the risk assessment.

It was reaffirmed that responding to local regulations and customs requires not only flexible responses on the site, but also close cooperation with local contractors and partner companies.

③ What Japan learns from the Stadtwerke model

A "Stadtwerke business model" which can be seen in Germany, is that municipally owned companies play a major role in supplying electricity in a region, has been attracting attention in Japan in recent years. In order to realize local production and consumption of electricity, close cooperation between not only electric power companies but also between municipal governments and residents is essential. Although Stadtwerke is funded by a municipality, it is a privately-operated company that has the advantage of being able to make quick and rational decisions and to manage its business with the latest technology taking risks.

According to Mr. Bühring, president of SWS, the biggest strength of

Stadtwerke is "trust by the citizens". As Stadtwerkes locate close to the citizens, they can operate an optimal and safe distributed energy system that meets local conditions and demand. In addition, a management stance that pursues public interests creates a synergistic effect with the city's environmental policy. In Japan, the liberalization of retail electricity service in 2016 allowed local governments to join the electricity retail business. A new power company owned by a municipality may become an important player in promoting the introduction of renewable energy and local production and consumption of electricity in the future. In the form of trinity management among SWS, GEWO and the city of Speyer would be ideal for promoting "Prosuming " on a local basis, and Japan has many lessons to learn from this.

At the same time, it is necessary to pay attention to the problems faced by local governments' management systems in examining Stadtwerke's business model. The main issues of the Stadtwerke's model could be ① difficulty in taking advantage of economies of scale, ② regional gaps in funding and know-how level, ③ duplication of capital investment across the whole country. Therefore, it is important not only to share experiences and best practices between municipalities and Stadtwerke, but also to pursue economies of scale by sharing facilities and electricity itself.

In Berlin, the capital of Germany, there is an organization called the Association of Municipal Companies (VKU) which is the proxy of over 1,400 Stadtwerkes in Germany. The association also hopes that the concept of "Prosuming" will support its energy transition policies, and in order to disseminate the concept throughout Germany, the association shares Stadtwerke's achievements and challenges in each region and makes policy recommendations to the federal government. The existence of the Stadtwerke association is significant to facilitate communication between the plan-implementing side (Stadtwerke) and the policy-making side, and to promote cooperation between regions.

The results of these activities are becoming visualized in actual business. For example, in 2008, with the cooperation of this association, 37 of Stadtwerke in Germany jointly established a gas power plant called "Trianel" and started joint operation. Taking advantage of Stadtwerke's community-based characteristics, it is expected that cooperation between regions, and between business fields (e.g. IT services and water/waste treatment services) will boost its growth in the future.

It will be important for Japan to consider the solutions on the issues that Germany is currently facing, and to pay attention to Stadtwerkes' experience in order to develop electric power business led by local governments in the future. It should also be noted that the reason why Stadtwerke in Germany has won the trust of local residents as a community-based company is that the company not only supplies electricity, but also provides a wide range of services required for welfare in community such as water supply, development of local infrastructure, and waste collection. Among electricity retailers managed by municipality, which are currently developing in Japan, only a few are engaged in comprehensive community service. Under such circumstances, the key to the future development of the "Japanese version of Stadtwerke " will be the development of its strengths as a business operator on a local government scale and cooperation with the local community.

7. Conclusion

We have organized the implementation plans, results, and "Key Findings "of the two types of projects to maximize self-consumption in this demonstration. The Japanese consortium, the city of Speyer, SWS, and GEWO worked together and made a successful demonstration result that would contribute to the city's renewable energy policy.

Renewable energy power generation systems including advanced EMS control, heat pumps, and storage batteries, are not yet widely used for households. However, if the prices of storage batteries and heat pumps decline, control by region/area becomes possible, and services such as VPP (Virtual Power Plant) becomes available, the business feasibility would increase significantly. It is also essential to reform the tax system, network tariffs, and other relevant regulations. The fact that such institutional issues have been highlighted was also one of the important results of this demonstration project. We strongly hope that the knowledge, learning and potential issues gained from this demonstration will be widely shared in the world where the maximization of the self-consumption rate of renewable energy becomes a major theme of environmental energy policy. Finally, Mr. Bühring, one of the main players and initiators of this demonstration project, expressed his gratitude to those involved in the demonstration and commented on the outlook of the business in Germany.

Comment by Mr. Wolfgang Bühring, President of SWS

In this demonstration, we wanted to verify the effectiveness of " Prosuming " by using PV power technology for residential use, and to prove that it can contribute to future sector-coupling technologies and an expansion of the renewable energy business. I have been involved in the efforts to introduce renewable energy since I became president. I believe that the continued cooperation among SWS, GEWO, and the city toward the same goal was a success factor in the city's energy policy and enabled us to conduct this demonstration in Speyer.

When I heard about this demonstration for the first time, I wanted to introduce it to Speyer. I promoted the potential of Speyer in the meeting with NEDO. In particular, I emphasized that Speyer, a historical city, has something in common with "Nara" in Japan, has close ties with its government, and is comparable to other large cities in terms of flexibility and stability as a small city. As a result, we were able to present the potential value and benefits for Germany to promote renewable energy by demonstrating the feasibility of an "energy self-consumption model" which can generate and consume electricity making full use of the high-performance HEMS using unique and advanced technologies of Japanese companies.

In the process of building the system, I saw that Japanese companies had difficulties under the German regulations. There were not many examples of lithium-ion batteries being introduced for households in Germany, and it was necessary to prove safety and install fire-fighting equipment to introduce them in those days. However, I was impressed by how quickly and appropriately Japanese companies responded to the issue. When there was a discussion about the safety of Lithium batteries, I was very encouraged by what a member of the Japanese companies said, "We are confident in the safety of Japanese batteries. I'm not afraid of sleeping on this battery every night"

In this demonstration, I realized that it is necessary to increase the self-consumption rate on a region basis by connecting networks with many households and sharing electricity rather than realizing the self-consumption system on a household basis. Although the distribution network is an important backbone for distributed power supply system in a region, the grid usage fee is currently charged on a pay-for-use (kWh) basis and it is not suitable for this demonstration model. We believe it is necessary to reform this system by making it capacity-based on a flat-rate system. Now that the demonstration has been completed, SWS aims to standardize "Plug and Play (A service that automatically controls home appliances, storage batteries and HP by turning it on without complicated settings)" as the next step. If we introduce and standardize advanced control systems such as the HEMS used in this demonstration, we will be able to increase efficiency. We also believe that linking the HEMS to market prices and utilizing the electricity generated by each household in balancing markets will be able to create new businesses that generate profits.

I am confident that the results in this demonstration project collaborating with NEDO, Japanese companies, their employees, and us gave a strong impetus to many stakeholders inside and outside the industry. The results of this demonstration have become widely known through symposiums organized by the Stadtwerke association and presentations by the energy advisory committees of the state governments, and I am confident that this leads to the revitalization of renewable energy projects by municipally owned companies in the other areas outside Speyer. We have received several requests for lectures from Congress and the Ministry of the Environment, and we plan to report this demonstration project. These activities will be effective in the process to realize the "sector coupling" that is essential to German energy conversion policy. In this way, my goal is for Speyer to become a trendsetter in environmental and energy policies throughout Germany and a role model for other "Stadtwerke" to implement advanced projects.

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