COMPARING PURSUITS OF 100% RENEWABLE ENERGY BY GERMANY AND CALIFORNIA, AND FUTURE OF POWER SYSTEM

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INTRODUCTION

Germany, which boasts the world's fourth largest GDP, and California, a US state with the world's fifth largest economy in terms of GDP, are both striving to realize a carbon-zero society, and are stepping up their efforts to achieve the goal of having 100% of their electricity needs met by renewable energy (RE). Having set a 2050 target of cuttings its greenhouse gas emissions by 80%-95% compared to 1990 levels, Germany is moving forward with major energy transformation policies. In September 2018, California passed a landmark State Bill (SB100), whose purpose is to achieve 100% RE by 2045. Although Germany and California have the common target of 100% RE, they cannot be treated as the same because of the different situations faced by the two and the difference in geographical conditions. For example, Germany neighbors nine countries and has an electric power grid that is interconnected with those of its neighbors. On the other hand, California has the Pacific Ocean to its west and the Sierra Nevada mountain range to its east. Its power grid is substantially less connected than Germany's. In this report, the RE policies and current situations of both Germany and California are compared and analyzed, and solutions to problems related to achieving 100% RE and what can be expected in a world of 100% RE are discussed.

OVERVIEW OF RE POLICIES AND THE CURRENT SITUATION

Germany

Germany passed its current Renewable Energy Sources Act first in 2000 and has been promoting RE. Following the Fukushima Daiichi Nuclear Power Plant accident in 2011, the country introduced transformative energy policies, centered on a roadmap for nuclear phaseout by 2022 and increase of RE's share in the power mix to 80% by 2050. It has since approved the Climate Action Plan 2050 in response to the Paris Agreement, promoting RE through government policies. RE's weight in the power generation mix has grown year by year as that of nuclear power has declined, and in 2018, RE accounted for 40% of power generated. Because the initial target of 35% by 2020 was achieved earlier than planned, Germany's federal government is exploring the possibility of raising the 2030 target from 50% to 65%. By comparing it to Japan's 2030 target of RE accounting for 22%–24% of its energy mix, which is outlined in its Basic Energy Plan, it is easily understood how high Germany's target is. There are also reports that it would be possible for Germany to reach 100% RE by 2050.

In addition, early in the morning of January 1, 2018, and at midday on May 1, 2018, albeit temporarily, Germany covered almost all of its domestic demand with RE, an unprecedented situation in history. This partly owed to the fact that both days were holidays with low power demand, but given that this was achieved when the country's RE ratio was only 40% of total power, similar situations where RE meets almost all domestic demand will increase as its share of the energy mix grows.

California

Since 2006, California has stipulated the RE percentage of retail electricity sales, and mandates its achievement by power utilities. That percentage has been revised as it was determined appropriate and realistic. In the SB100, which was signed into state law in September 2018, while a target RE percentage in 2020 was maintained at 48%, it stipulates the target of 75% in 2030, and 100% in 2045.[1] As of 2017, RE accounts for 44% of electric power, and it is considered certain that the 2020 target will be achieved. SB100 was successfully passed in California partly because RE is viewed as a technology that will exponentially evolve, just like semiconductors, and various innovations are anticipated to take place in the next 10–20 years.

There are about 60 power utilities in California, and the grid operators, such as transmission system operators (TSO) and independent system operators (ISO), coordinate power supply and demand within the state, just like Germany. However, Los Angeles, the largest city in California, has an independent city-operated power bureau, which purchases cheap out-of-state power using DC transmission, and there is no integrated approach to operation as a state. As a rule, however, SB100 applies to all power utilities in the state.

In 2017, 292 TWh of electric power was supplied by California, slightly greater than that provided by Tokyo Electric Power Company (TEPCO). This was a decrease from the 301 TWh supplied in 2012. Even some experts mistakenly attribute the decline to weak demand due to a stagnant economy. In fact, however, power demand is rising as a result of economic and population growth. The decline was related to California's energy policies. California is promoting local production and local consumption of electric power through general household rooftop photovoltaic (PV) panels[2]. Since PV panels are not counted as either an RE power source or any other power source, they make it look like the power supply has contracted. California is moving forward with the shift to RE from both upstream and downstream by reducing the share of fossil-fuel derived power from power companies and promoting residential PV, respectively.

COMPARISON: GERMANY VS. CALIFORNIA

The following table summarizes electric power–related data for Germany and California. In this report, several noteworthy aspects are pinpointed. The main difference between Germany and California is that Germany has an advanced power grid interconnected with surrounding countries. Located in the center of continental Europe, its mesh network power grid is connected to those of nine neighboring countries. Power interchange with neighbors, therefore, is easy for Germany. It can flexibly trade power in increments of 15 minutes on European electric power exchanges, and there is active trading in the market. On the other hand, California is located on the west coast and neighbors only three states and Mexico. Its transmission infrastructure that connects with other states is undeveloped, and the scale of market for trading electric power with neighboring states is small. In 2017, Germany traded a total of 110 TWh of electric power with neighboring countries, exporting 80 TWh and importing 30 TWh. However, California's power trade is basically a fixed trade based on long-term purchase agreements, and almost all trading was imports (about 86 TWh). Because it is difficult for California to flexibly collaborate with neighboring states and countries in this field, it needs to solve its energy problems through a local production and local consumption approach.

[1] The state laws gives figures that do not include the 15% generated from large-scale hydroelectric plants. But in this report, it was included so that comparisons could be made with Germany. It stipulates that once RE accounts for 75% of power, CO_2-free power sources other than RE sources can be taken into account.

[2] The amount generated by general household PV panels reached about 7GW at the end of 2017. The requirement that new homes be equipped with PV panels starting in 2020 was decided upon in December 2018.

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Table: Comparison of Germany and California

				Germany	California
Basic data	Population (million)			82.70	39.50
	Area (1,000 km^2)			357	424
	Population density (people/km^2)			232	93
	GDP (trillion US$)			3.77 (No. 1 in Europe)	2.7 (No. 1 in US)
	Per-capita GDP (US$)			45,600	68,000
RE targets	As percentage of final consumption*			2020: 35% 2030: 50% 2040: 65% 2050: 80%	2020: 48% 2030: 75% 2045: 100%
Power generated and breakdown	Total power generated (TWh)			655	292
	Share	Coal and brown coal		37%	4%
		Nuclear		12%	9%
		Natural gas		13%	34%
		RE		33%	44%
			Solar	6%	10%
			Wind	16% (offshore wind, 3%)	9%
			Biomass	7%	2%
			Hydro	3%	18% (small-scale, 3%)
			Geothermal	0%	4%
		Other		5%	9%
Electric power imports and exports	Exports (TWh)			80	0
	Imports (TWh)			30	86
Electric power consumption by sector	Industry			49%	25%
	Commercial			27%	42%
	Home			24%	33%

Notes: Figures are for 2017. Euro converted to US$ using 1.15 US$/Euro. The California state law gives percentages that do not include large-scale hydroelectric power (15%), but this was added here to make comparison with Germany possible.

Source: Created by authors using data from OECD, Federal Statistical Office of Germany, German Association of Energy and Water Industries, United States Census Bureau, etc.

There are also differences in demand peaks attributed to the difference in their respective industrial structures. A breakdown of Germany's electric power demand shows that 49% is for industrial use, 27% for commercial use, and 24% for domestic use. Factories of heavy industries, such as automobile, machinery, and chemicals, operate during the day; therefore, peak demand occurs in the early afternoon. On the other hand, a breakdown of California's power demand shows that 25% is for industrial use, 42% for commercial use, and 33% for domestic use, revealing smaller demand for industrial purposes than in Germany. This is because California has a small manufacturing sector, and the state's main industries are entertainment (Hollywood, etc.), IT, and other soft industries. Accordingly, peak demand occurs not during the day but at evening, when workers start to use power after they get home.

Issues Facing Germany and Their Solutions — Reinforcing Its Interconnected Grid

In terms of international comparison, it can be said that Germany possesses a robust power grid. That said, there is a need to reinforce the power grid even further so that electricity generated in Northern Germany, where there are a lot of wind power facilities, can be sent to Southern Germany, the main area of demand because of the concentration of industries (the "north-south grid"). In order to prevent the amount of power generated from exceeding the grid's transmission capacity, TSOs issue power utilities redispatch orders to adjust their levels of power generation. Recently, these orders have become a problem. For example, on windy days, TSOs will coordinate power generation so that power generated does not exceed the transmission capacity of the north-south grid by ordering power utilities in Northern Germany to reduce power generation while ordering power utilities in Southern Germany to increase power generation. The Federal Network Agency for Electricity, Gas, Telecommunication, Post and Railway is warning that the cost of redispatch orders is growing yearly. If wind power installation capacity grows from the current level of approximately 50 GW to about 100 GW by 2030, this will amplify the demand-supply imbalance between Northern and Southern Germany. The country aims to handle it through a ten-year network development plan to reinforce the grid, which also includes addressing the problem of redispatch orders.

The European Union (EU) has a long history of working to create a single market, which can be traced back to the days of the European Economic Community (EEC), and efforts to create a single market for the energy sector are moving forward. Countries outside the EU have also floated the idea of connecting their power grids cross-country, but there has been almost no progress due to the conflicts of interest of each country. "Easier said than done", indeed. It can probably be argued that the promotion of the interconnected power grid was only possible, precisely because it was the EU, which touts the basic principle of a single market. The development of offshore wind power is currently underway in both the North Sea and Baltic Sea, and it will be necessary to make the power grids even more interconnected in order to share power with neighboring countries. Plans to lay a submarine transmission cable between Germany and Norway are moving forward. It is envisioned that excess wind power from Germany will be sent to Norway, where it will be stored using pumped-hydro storage plants, and then when there is strong demand in Germany, electricity will be generated in Norwegian plants and sent back to Germany. German electricity exports are trending upward, and Germany is probably developing its power grid in preparation for becoming a major electricity exporter as RE grows.

Issues Facing California and Their Solutions—Pursuing Local Production and Local Consumption

Unlike Germany, California's power grid is not strongly interconnected. In California, where peak demand does not occur during the day, it is impossible to offset demand with PVs, even though California is blessed with good day light conditions. This means flexible power generation and energy storage are indispensable to shift peak demand. The leading technology for doing this is electric energy storage. California was the first in the world to pass a law that requires power utilities to have a certain amount of energy storage capacity. Looking ahead to the 2030s when RE will account for 70% of electric power, however, this kind of storage alone will be insufficient, and there is a need to collaborate with parties outside the power industry. In particular, in order to respond to the major issue of stabilizing frequencies when there is excess power, the greatest hope is to make use of electric vehicle (EV) batteries, which can be flexibly charged and discharged. In 2017, there were 370,000 EVs in California, which accounted for 1.2% of all vehicles in the state. They consumed less than 1% of total power that year. But, under the Zero Emission Vehicle (ZEV) regulation,[3] the state has set a target of 5 million EVs in use by 2030. At that point, EVs will account for 5%–10% of total electric power consumption, an amount that cannot be ignored. If EV batteries are looked as an electric energy storage, 5 million EVs would be able to store an amount of electricity equivalent to several pumped hydro-storage plants. EV batteries can be charged during the day when there is excess power and then charging can be stopped and reversely send the power to power consumers (i.e. the grid, buildings, etc.), when there is a shortage of electric power. As such, EV batteries will, without a doubt, play a major role in balancing frequencies. There will probably be an incremental evolution of

[3] Regulation that requires a certain percentage of a car manufacturer's sales volume be ZEVs.

such solutions. At first, EV charge control technology, which has a minor impact on existing power facilities, will develop, and then buildings will be powered by energy provided by EV batteries, and finally comes the solution to send power from EV batteries back to the grid, which can be accessed in the whole system again.

It is also forecast that greater use will be made of wireless charging in the 2030s, and there will be seamless coordination with automated vehicles. It will be possible to automatically charge and discharge vehicle batteries in a planned manner using artificial intelligence (AI). For example, a dynamic charging technology will put into practical use. Dynamic charging refers to automatically charging vehicles at the optimal time based on forecast electricity rates, which differ at night. Furthermore, EV charging will be scheduled so that the remaining charge on batteries does not vary much, which can help solve the problem of EV battery performance deteriorating due to repeated charging and discharging. When this type of service spreads, EV charging is expected to play a certain role in local consumption.

Furthermore, all new homes built after 2020 will be required to have PV panels. Local production at the individual level of the home is only natural, and it may go as far as the normalization of zero-cost operation of home appliances, such as dishwashers, water heaters, HVAC equipment, by operating them when there are negative prices (see next section). In a connected society equipped with IoT and AI, it would probably not be difficult to realize these types of uses.

Common Problems and Solutions — Negative Prices and Curtailed Electricity

Negative prices and an increase in curtailed electricity are two problems that both Germany and California face. Negative prices refer to a situation where the price of electricity turns negative in the power exchange market. When the supply of electric power temporarily exceeds demand, affected by the supply from weather-dependent RE, power companies with traditional power generation facilities, such as coal-fired powered plants, are forced to take some action, because of policies that give RE priority access to the power grid. They choose to continue to generate power and pay consumers in the power exchange market for accepting their excess electricity (negative price) when this is less expensive than shutting down and restarting power plants. In recent years, negative prices have been occurring with greater frequency. In 2017, in Germany, on the European Power Exchange's SPOT day-ahead market, a negative price for electricity occurred for a total of 146 hours during a 24-day period, and 185 hours over a 34-day period in the intraday market.[4] In California as well, there was a negative price for electricity for 114 hours in the day-ahead market, and about 5% of 15-minute trades in the same-day market were at a negative price. It is expected that as the amount of RE grows, negative prices will continue to frequently arise for the time being. In the long run, however, traditional power generation will gradually decline as markets come to rely solely on RE, and at some point of this transition, rules related to various issues such as setting electric power prices in the power market will be revised.

When grid transmission capacity is exceeded, even RE cannot be transmitted, and the electric power is curtailed. The amount of curtailed electricity is also increasing. In 2017, 5.5 TWh of power went curtailed in Germany (a year-on-year increase of 50%). The majority of it was wind power. In California as well, 401 GWh of RE went curtailed in 2017 (a year-on-year increase of 30%). More than 90% of that was from PV panels. This creates a necessity to store energy generated during the day. Under these conditions, it is vital to develop new mechanisms to make effective use of curtailed electricity. From the CSR perspective, for example, a credit system, in which companies that use RE are recognized as environment-friendly companies and rewarded with credits, is currently spreading in countries throughout the world. If the use of RE becomes more common, an alternative mechanism may possibly be established in which companies that effectively and flexibly utilize curtailed electricity are rewarded with new credits as companies that contribute to an electric power security system. Because a safe supply of electric power is of the utmost importance, excess electric power is now curtailed. This type of new credit mechanism would not only transform the current state of things, but also accelerate the use of curtailed electricity.

4 The average negative price in 2017 was ▲2.65 Euro cents.

FUTURE OUTLOOK

As discussed above, in order to solve their respective issues, Germany will probably primarily work to reinforce its power grid, which is connected both within the country and to other countries, and California will pursue a local production and local consumption model. Against this backdrop, in recent years, Germany and California have been regularly holding joint conferences related to decarbonization of their energy and transportation industries, sharing information on issues they face and solutions they have developed, and examining solutions to common issues, such as negative prices.

In general, the current system is still driven by power generators through adjusting supply to always meet demand, but it is expected that as we approach 100% RE societies, there will more instances when supply exceeds demand. This could lead to a paradigm shift in an electric power system in which demand is "generated" in a timely manner to match the supply of RE-derived power. For power supply systems based on RE, which is highly variable, the most dangerous situation is when supply falls short of demand. Therefore, it will be important to secure more than the current level of excess supply capacity ("reserve supply") so that electric power can be traded on spot markets, etc.. In the meantime, it is expected that as RE's share in the power mix increases and power generated by RE sources approaches total demand, it will become difficult for power companies to secure stable profits, and they could refrain from making capital expenditures. To that end, in California, if RE comes to account for more than 75% of total supply (2030 target), the use of other CO_2-free power sources other than RE will be permitted. For example, technological innovations may make thermal power stations with carbon capture and storage (CCS) equipment or small-scale nuclear power plants alternative options for commercial power sources. If that happens, changes may be made to the fee system for reserve supplies as well. Instead of just charging a fee proportional to the amount of power used (kWh), a scheme to recover investment costs from the fixed monthly basic fee, as the cost of contributing to a stabilized power system, could be introduced.

In a world where RE accounts for a large share of the power mix, power consumers should be able to dynamically change the amount of electricity consumption, which will probably make it necessary for them to adopt flexible purchasing methods. In addition, new technologies to be developed by 2030s, such as AI and IoT, and the utilization of new credits may open up potentials for a wide range of applications in various industries. For example, in hotels and other commercial facilities, it could be possible to employ a system in which electric power is consumed at the most appropriate time, transformed into different heat sources such as hot water and refrigeration, stored, and then used when necessary, thereby reducing total costs. Similar efforts are possible in the manufacturing industries, too. Smart factories envisioned in Germany's Industry 4.0 will probably make it possible to undertake flexible production where production volume is automatically adjusted in a timely manner to match the cost of electricity. In addition, in the chemical manufacturing industry, research is being conducted on synthesizing ammonia directly from water and nitrogen using an electrical reaction. This ammonia could then be used to make fertilizer for the agriculture industry. Since water and nitrogen are basically cost-free, the cost of producing fertilizer in this way would be close to zero if excess electric power sold at a negative price[5] could be used. The same goes to artificial photosynthesis in which organic compounds are made from water, CO_2, and electric power. If the CO_2 emission trading market gets more activated, this could be one way to consume the purchased CO_2. When combined with the power generated through biomass, which is considered CO_2 neutral, it could represent the ultimate zero emissions. In the transportation field, where the introduction of electrification is moving forward, it would be only natural to use that excess electric power to charge EVs. Not only in the automobile sector, but also in ships and other modes of transportation, various services based on almost zero cost electricity would be born.

In this way, in a world of 100% RE where "supply > demand" is the norm, a totally new electric power system that generates demand in a timely manner to match changes in supply will probably be seen. Under the environment that the cost of electric power is effectively zero, there will be enormous possibilities for the utilization of excess power in the manufacturing, agriculture, and transportation sectors, and beyond.

[5] When the cost of generating electricity is zero or negative, only transmission costs, taxes, etc. are charged.

Main Reference Material

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