An Analysis of PV and Battery Installations Connecting the Commercial and Household Sectors in Japan

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Abstract

Recently, the progress of information and communication technology (ICT) in fields such as cloud computing and bidirectional communication has been astonishing. Battery systems such as lithium ion, sodium-sulfur (NAS) and redox flow batteries have also made great progress. This study analyzes photovoltaic (PV) cell and battery installations connecting the commercial and household sectors under various capacity conditions. It also discusses present problems and suggested future measures.

The government-mandated high purchase prices of PV power via the feed-in tariff (FIT) system has created a unique environment with significant distortions in terms of PV and battery buying decisions. Subsequently, some companies and individuals buy PVs and batteries as a form of capital investment. The need to more carefully consider a desirable and sustainable feed-in tariff (FIT) system such as solar power is underscored in this paper.

A cost reduction is essential to enable more PVs and batteries to become connected to the commercial and household sectors. For this, a reduction in cost of various batteries could play a crucial role. Thus, innovations in battery technology will be highly desired from now on.

Many people try to pursue the goal of "energy independence" and not use any outside electricity from power companies ("absolute zero" target). But the realization of this target has so far been elusive. Instead of a strict target, a balance between purchased electricity and sold PV electricity ("nearly net zero" target) should be pursued.

Key words: PV, battery design, greenhouse gas measures, smart communities, FIT and zero emission strategies

Contents

Introduction

In 2015, the Japanese Government has set a new target to reduce greenhouse gases (GHGs) by 26% from their 2013 emission levels by 2030 in their Intended Nationally Determined Contributions (INDC) statement. Japanese GHGs emissions in 2017 were 8.4% down from their 2013 level, but 1.6% up from the 1990 Kyoto Protocol level [1]. In the long-run, the continuous increases in GHGs emission in the commercial and household sectors have largely contributed to overall GHGs increases in Japan.

The Paris Agreement was finally adopted at the COP24 convention which was held at Katowice in Poland in December 2018. The full-scale countermeasures of the Paris Agreement will take effect from 2020. Japan must also intensify its basic GHGs reduction measures in the long-run, because already in recent summits it committed to a 50% (or 80%) reduction of GHGs by 2050.

Great progress has been made in recent years in ICT in fields ranging from cloud computing to bidirectional communication. Moreover, substantial progress has also been made in electric batteries, evinced by the rise of lithium ion batteries, NAS batteries and redox flow batteries.

This study analyzes PV and battery installations in commercial and household sectors under various capacity conditions. It also highlights some current problems and future measures needed to insure adequate eco-friendly electricity is available.

Methods

This study utilizes six economic simulations, comparing various costs of installing PVs and batteries in the commercial and household sectors to the power grid. The average electricity demand pattern in the commercial and household sectors was estimated based on a 2012 METI survey report [2], some 2014 EDMC survey data [3] and the 2013 Cogeneration Comprehensive Manual [4]. We also surveyed past and present conditions of PVs and batteries based on NEDO and METI reports [5, 6]. The average daily pattern of solar power output was also estimated using the 2006 NEDO Sunshine Database [7].

In the economic simulation of this study, the household sector was assumed to consist of 1,000 households. If each household installed a 4kW PV on their roof, the maximum PV capacity was assumed to be 4,000 kW for this sector. The total floor area for the commercial sector was assumed to be 25,000 m^2. Hypothetically, commercial sector PVs would be installed on building roofs or open spaces. Electricity generation rates were calculated during daylight, intermediate and midnight time periods in both the commercial and household sectors.

The economic analysis is based on a calculation of a simple payback period in which the total equipment investment costs (with subsidies deducted) is divided by annual net profits. Moreover, annual net profits are calculated by subtracting the cost of purchased electricity as well as the revenues obtained by selling PV electricity by through a FIT. In this simulation, as an extreme example, a starting point in which no electricity was purchased from any outside power was first ascertained ("absolute zero" scenario). That starting point amounts to the PV Maximum Case (vi), in which the PV capacity is 44,000 kW and the battery capacity is 20,000 kWh.

The following simulations were also made: Case (i): with a PV capacity of zero and battery capacity of zero, Case (ii): with a PV capacity zero and battery capacity of 20,000 kWh, Case (iii): with a PV capacity of 8,000 kW and a battery capacity of zero, Case (iv): with a PV capacity of 8,000 kW and a battery capacity of 20,000 kWh and Case (v): with a PV capacity of 44,000 kW and a battery capacity of zero. In Case (iv), the electricity purchased from an outside power company is balanced with the surplus PV electricity sold to that company. Therefore, this case is described as an "nearly net zero" scenario rather than a "absolute zero" scenario.

Results

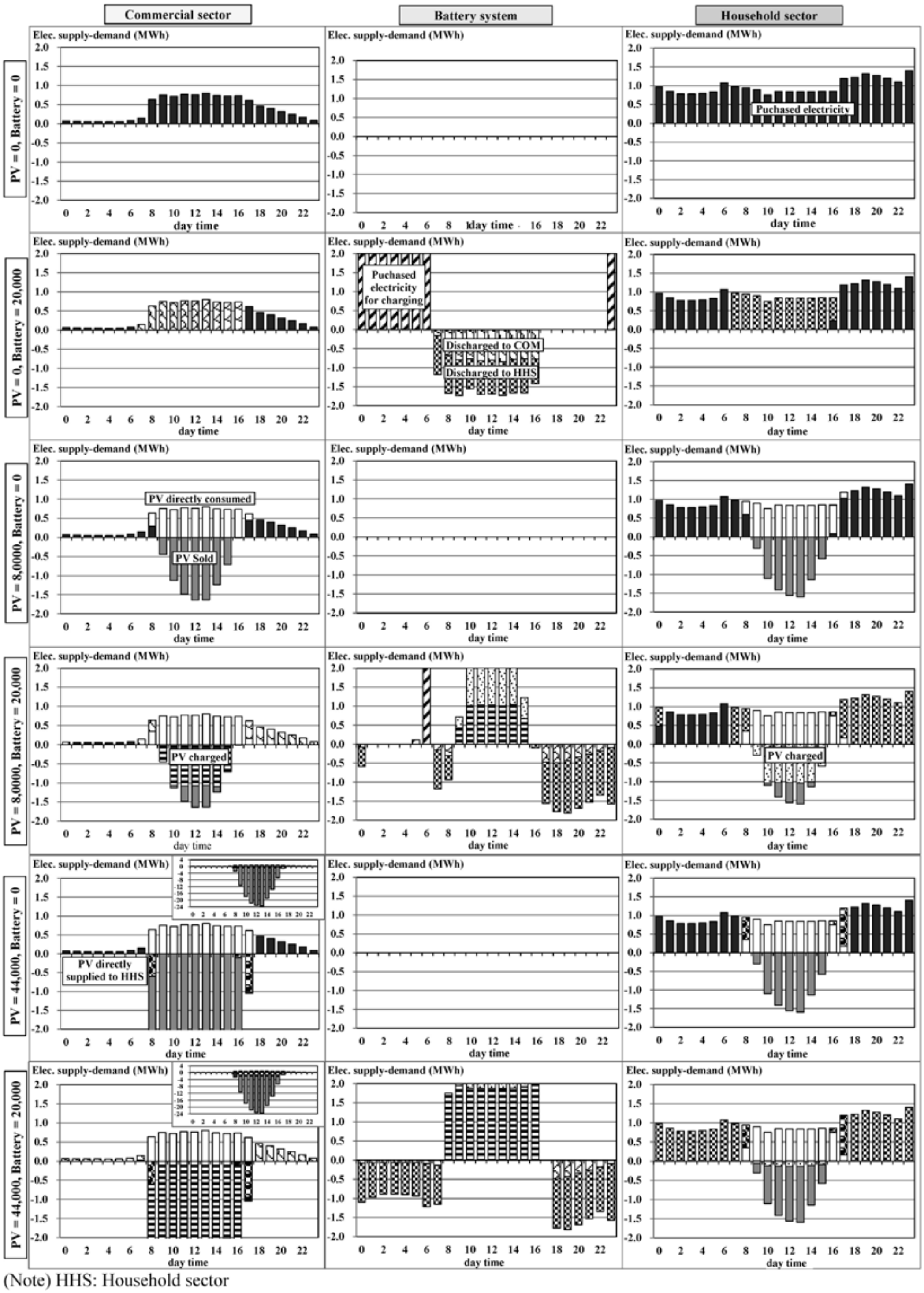
(1) Electricity supply and demand patterns in cases analyzed in this study

The electricity supply and demand patterns for both the commercial and household sectors and the battery systems for Cases (i) to (vi) are shown in Fig. 1, which shows typical supply-demand patterns for January in Japan. Fig. 2 shows the same supply-demand patterns for July in Japan and Fig. 3 is based on simulations of October in Japan. The first top part of all three figures shows the electricity supply and demand patterns of Case (i), with a PV capacity of zero and a battery capacity of zero. In this case, all the electric demands for both sectors are supplied by the electricity purchased from an outside power company.

The seond row of Figs. 1-3 show the electricity supply and demand patterns for Case (ii), with a PV capacity of zero and a battery capacity of 20,000 kWh. In this case, cheap electricity at midnight is purchased and charged to the battery, then discharged to the commercial and household sectors during the daylight hours. The electricity consumed at night is also purchased from an outside power company.

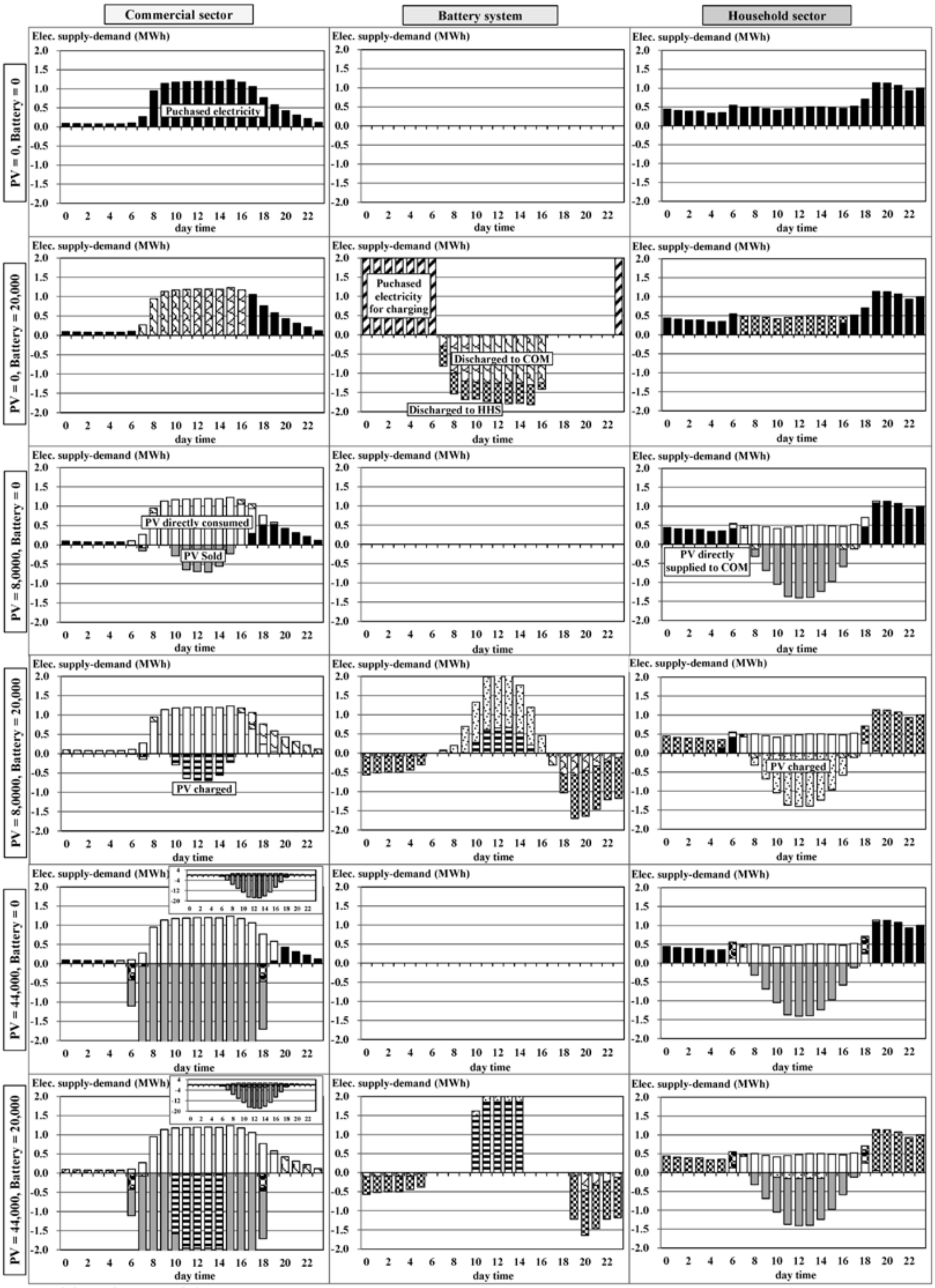
The third row of Figs. 1-3 shows the electricity supply and demand patterns for Case (iii), with a PV capacity of 8,000 kW (4,000 kW from the commercial sector and 4,000 kW from the household sector) and battery capacity of zero. In this case, the electricity consumed during the daylight hours is directly supplied by the PVs and the surplus PV electricity is then sold to an outside power company by using a FIT system. In this case, the electricity consumed at night is also purchased from an outside power company, as in Case (ii).

The forth row of Figs. 1-3 shows the electricity supply and demand patterns for Case (iv), in which the PV



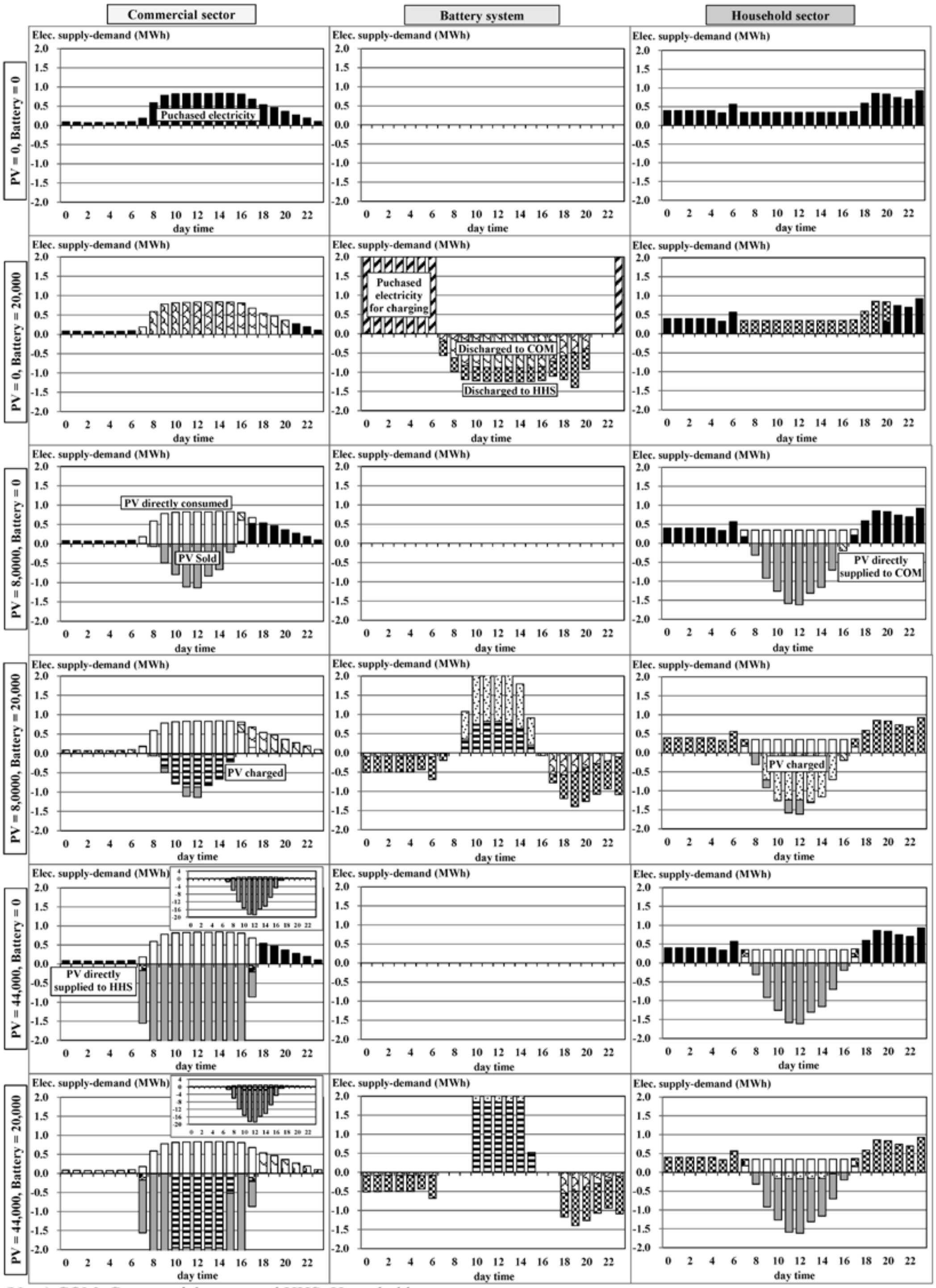
(Note) HHS: Household sector

Fig. 1 Changes in Electricity Supply Patterns in January in Japan by Installing PVs and Batteries



(Note) COM: Commercial sector

Fig. 2 Changes in Electricity Supply Patterns in July in Japan by Installing PVs and Batteries



(Note) COM: Commercial sector and HHS: Household sector

Fig. 3　Changes in Electricity Supply Pattern in October in Japan by Installing PVs and Batteries capacity is 8,000 kW and battery capacity is 20,000 kWh. In this case, the PV electricity generated is charged into batteries during the daylight hours. Moreover, the PV electricity is directly supplied to the commercial and household sectors during the day. In this case, the small remaining surplus of PV electricity is also sold to an outside company, as in Case (iii). The electricity charged into the battery is discharged to the commercial and household sectors at night. Depending on the season or month, the small shortage of electricity at night is covered by electricity purchased from an outside power company. In this case, the PV electricity sold and the electricity purchased from the outside power company are both small and they nearly balanced each other. Hence, Case (iv) can be called a “nearly net zero” scenario.

The fifth row of Figs. 1-3 shows the electricity supply and demand patterns for Case (v), with a PV capacity 44,000 kW (40,000 kW for the commercial sector and 4,000 kW for the household sector) and a battery capacity of zero. In this case, of course, the electricity consumed during the day is all supplied from the installed PV. The enormously large surplus PV electricity can be sold to an outside power company by using a FIT system. In this case, the electricity consumed at night is also purchased from that power company, as in Cases (ii) and (iv).

The bottom row of Figs. 1-3 shows the electricity supply and demand patterns for Case (vi), with a PV generating capacity of 44,000 kW and battery capacity of 20,000 kWh. In this case, the electricity consumed during the daylight hours is also all supplied from the PVs installed, as in Case (v). In addition, the PV electricity generated is also charged into the batteries during the day. The very large remaining large surplus of PV electricity is also sold to an outside power company by using a FIT system, as in the previous case. In this scenario, no electricity is purchased from an outside power company. Hence, Case (vi) can be described as an “absolute zero” scenario.

Based on the seasonal comparison of Figs. 1-3, the following specific characteristics are apparent:

a) As shown in Fig. 1, during the winter season (January), the electricity demand increases both in the commercial and household sectors. In particular, the household electricity demand is high throughout the day compared to other seasons. Commercial sector electricity demands are high mainly during the daylight hours. Only in Case (vi), is there no electricity purchased from any outside power company.

b) As shown in Fig. 2, during the summer season (July), electricity demands are high in both the commercial and household sectors. Commercial sector electricity demands notably peak during the daylight hours. Household sector electricity demands peak from the evening until midnight. Case (vi), in which no electricity is purchased from an outside power company, is almost realized in Case (iv), when the demand for outside electricity is nearly nil.

c) As Fig. 3 shows, in autumn (October), both commercial and household electricity demands are low compared to winter and summer demands. In addition to Case (vi), during this month no outside electricity is purchased in Case (iv).

d) PV installation plays a powerful role on covering the demand for electricity during the daylight directly in the commercial sector. PV installation also plays a limited role on covering the demand for electricity during the daylight in the household sector. However, the combination of PVs and batteries is significant in meeting the household sector electricity demands.

(2) Changes in annual electricity supply and demand balances by cases

Figure 4 shows the annual electricity demand and supply balances for both sectors across six hyopthetical scenarios with PVs and batteries. Case (i) represents the base case with no PVs and no batteries. In such a case, all electricity must be purchased electricity from an outside power company. In Case (ii) with no PVs and a 20,000 kWh battery capacity, more than half of the eletricity demand is covered through batteries, which are charged by puchasing cheap electricity at night from an outside power company.

In Case (iii), with PVs generating 8,000 kWh but no batteries, almost half of the needed electricity is supplied by PV-generated electricity, but the surplus of PV electricity (almost half of the PV electricity generated) is sold to an outside power company due to the lack of any storage batteries. Also in Case (v), with a 44,000 kWh PV capacity but no batteries, more than half of the needed electricity is suppplied by the PV

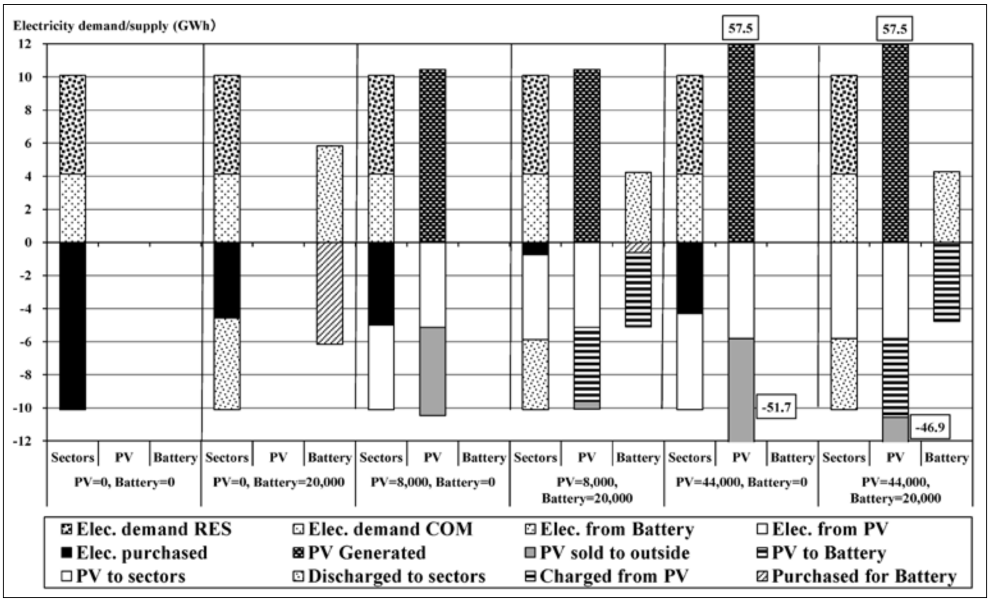


Fig. 4 Annual electricity demand and supply balances in six scenarios by sector from PVs and batteries

electricity generated, but the enormously large remaining surplus of PV electricity is sold to an outside power company due to the same lack of batteries. In Cases: (ii), (iii) and (v), almost half of the electricity demand is finally covered by electricity purchased from an outside power company.

Unlike the three cases mentioned above, in Case (iv), with PVs generating 8,000 kWh and batteries storing 20,000 kWh, almost half of the electricity demand is firstly supplied by the PV electricity generated as in Case (iii). Moreover, almost all of the remaining PV electricity is charged into the batteries during the daytime and then subsequently discharged into the power grid at night. Only a small remaining surplus of PV electricity is finally sold to an outside power company. Also, a small part of the needed electricity is obtained by purchasing electricity from an outside power company. The small portion of PV electricity sold by FIT nearly offsets the small portion of electricity purchased from outside. Hence, we can classify Case (iv) as an example of "net zero" scenario.

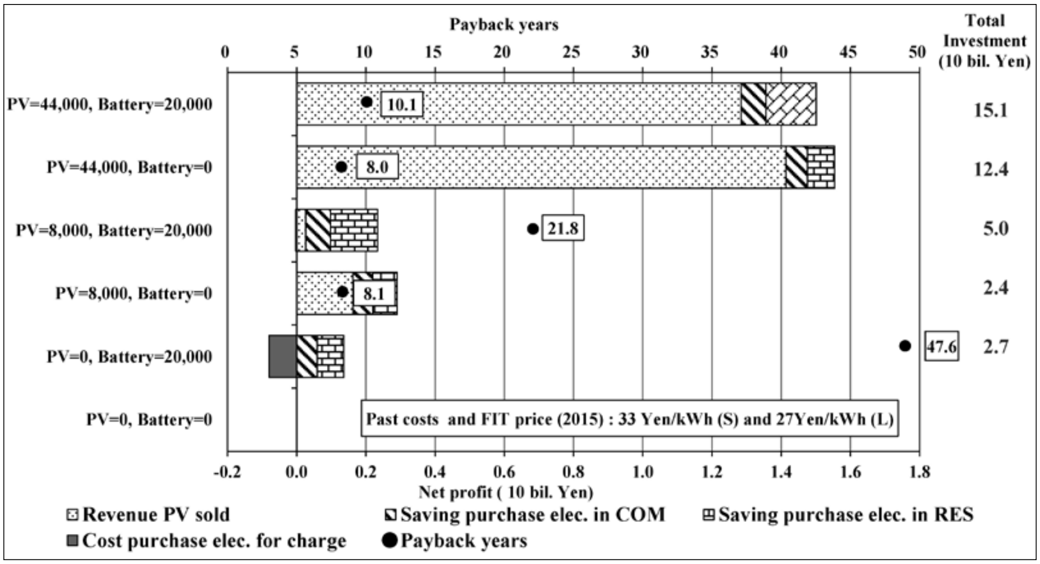
As in Case (iv) discussed above, in Case (vi), with PVs producing 44,000 kWh and batteries producing 20,000 kWh, almost half of the electricity demand is also met by the PV-generated electricity and the remaining demand is covered by electricity discharged from the batteries which are charged from PV electricity during daylight. As in Case (v), thanks to the large number of PVs installed the substantial remaining PV electricity is sold to an outside power company. In this case, there is no purchased electricity from that power company. Therefore, Case (vi) can be aptly called an "absolute zero" scenario.

(3) Changes in economics of PV and battery installation by cases

Figure 5 offers an analysis of the net profits and the payback periods for the total investments based on past costs and FIT purchase price conditions in 2015. In these simulations, based on a 2015 preceding study [8], PV costs were assumed to be 350,000 Yen/kW for home use (small residential scale) and 300,000 Yen/kW for the mega solar use (large industrial scale). Battery costs were also assumed to be 200,000 Yen/kWh. FIT purchase prices were assumed to be 33 Yen/kWh for the household sector and 27 Yen/kWh for the commercial sector.

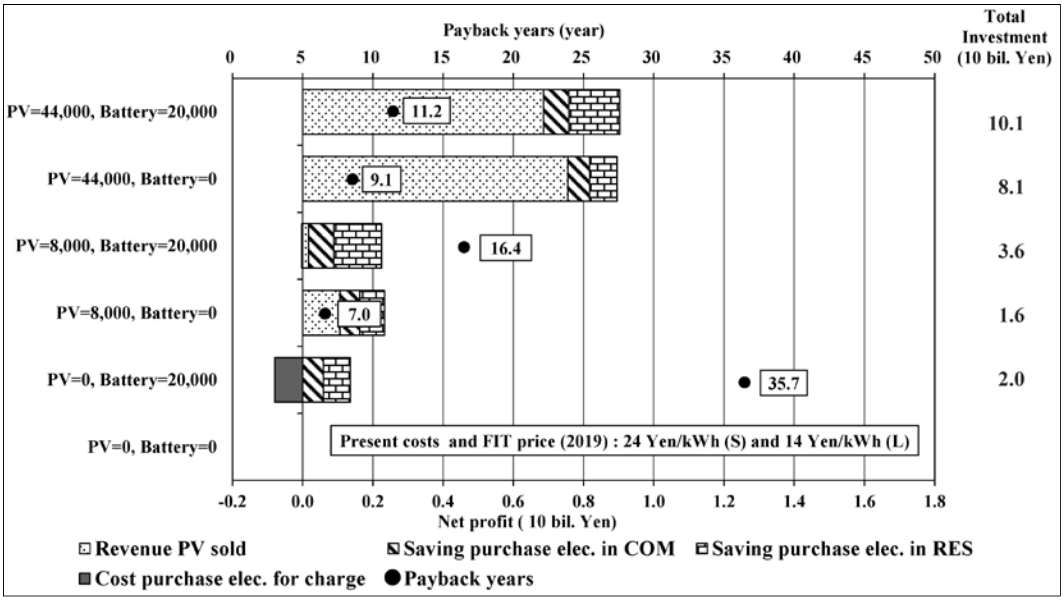
Figure 6 analyizes the net profits and the payback periods for the total investments based on current 2019 cost and FIT purchase price conditions. In these simulations, based on 2017 survey results [9], the cost of PVs was assumed to be 250,000 Yen/kW for the small scale residential use and 200,000 Yen/kW for large scale mega solar industrial use. Battery costs were estimated to be 150,000 Yen/kWh. FIT purchase prices were assumed to be 24 Yen/kWh for the household sector and 14 Yen/kWh for the commercial sector. Early in 2019, new FIT purchase prices for the commercial sector were announced by METI [10].

As Fig. 5 indicates, under 2015 conditions, the payback period for the total investments was about ten years or less for these three cases: Case (iii), which generated 8,000 kW through PVs but lacked batteries,



(Note) The capacity explanation from bottom to top in the left side corresponds to from Case (i) to Case(vi), respectively.

Fig. 5 An analysis of the net profits and payback periods for the total investments (based on 2015 costs and FIT purchase price conditions)



(Note) The capacity explanation from bottom to top in the left side corresponds to from Case (i) to Case(vi), respectively.

Fig. 6 An analysis of the net profits and payback periods for the total investments (based on 2019 costs and FIT purchase price conditions)

Case (v), which produced 44,000 kW through PVs but again had no batteries and Case (vi), which was endowed with a 44,000 kW PV generating capacity and 20,000 kWh battery storage capacity.

In the following two scenarios the payback period for the total investments remained high due to the high cost of batteries: in Case (ii), with no PVs but a 20,000 kWh battery storage capacity, and in Case (iv): PV 8,000 kW and battery 20,000 kWh (“net zero”).

As shown in Fig. 6, under current 2019 conditions, the payback period for the total investments in Case (ii) with no PVs but a 20,000 kWh battery storage capacity improved from 47.6 years (2015) to 35.7 years (2019). Moreover, the payback period for Case (iv) with a 8,000 kW PV generating capacity and a 20,000 kWh battery storage capacity also improved from 21.8 years (2015) to 16.4 years (2019) mainly due to a reduction in cost of batteries. A PV cost reduction also helped shorten the payback period.

Also as shown in Fig. 6, the payback period for the total investments in Case (iii) with 8,000 kW PVs and no batteries improved slightly from 8.1 years (2015) to 7.0 years (2019) mainly due to a PV cost reduction. On the contrary, the payback period for the total investments in Case (v) with 44,000 kW PVs and no batteries slightly worsened from 8.0 (2015) to 9.1 years (2019). Furthermore, the payback period for Case (vi) with 44,000 kW PVs and 20,000 kWh batteries lengthened a bit as well from 10.1 years (2015) to 11.2 years (2019) mainly due to decreased FIT purchase prices of PV electricity.

(4) Cost and performance changes in the capacities of installed PVs and batteries

In the preceding section, a simple payback period (payback years) was obtained for five different scenarios ranging from Case (ii) to Case (vi) and the costs of each case was analyzed. This section considers cost changes (as measured by the simple payback period) and performance (as measured by the ratio of purchased electricity, ratio of sold PV electricity and the ratio of net purchased electricity) by changing the battery or PV capacity step by step.

First, Figure 7 shows changes in the simple payback periods for the three ratios discussed above by varying the battery capacity from 0 kWh to 20,000 kWh every 2,000 kWh. The PV capacity in this simulation is fixed at 4,000 kW for both the household and commercial sectors.

Without batteries, the ratio of purchased electricity from an outside power company reaches almost 50% and the ratio of PV electricity sold slightly exceeds 50%. Moreover, the ratio of net purchased electricity is -3.5% and the simple payback period is 7.0 years. As battery capacity increases, both the ratio of purchased electricity and the ratio of PV electricity sold are gradually reduced.

With a battery capacity of 20,000 kWh, both ratios finally decline to slightly less than 10% and the ratio of net purchased electricity becomes +1.1%. This condition could be called an “nearly net zero” scenario. However, the simple payback period increases steadily the battery capacity increases and finally reaches

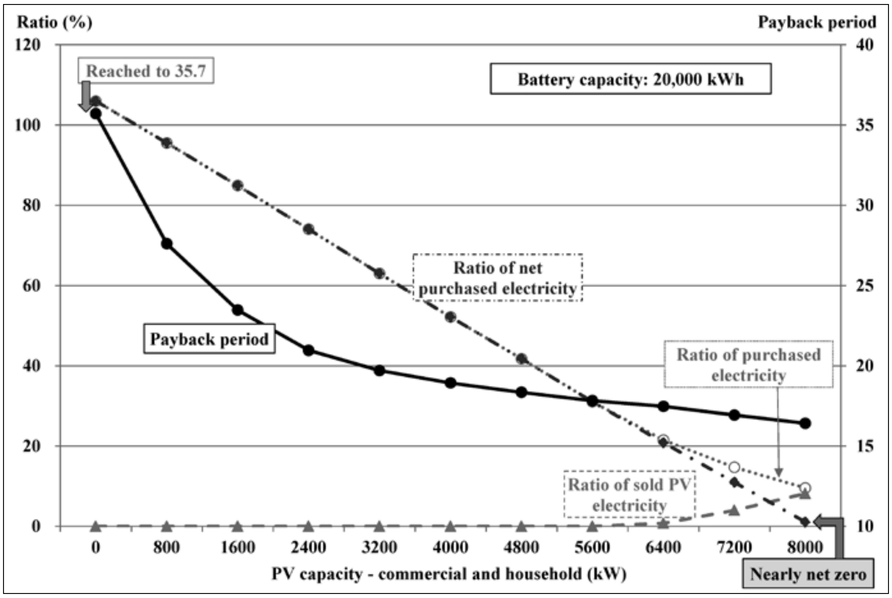


Fig. 7　Changes in cost and performance with varied battery capacity
(PV capacity fixed at commercial 4,000 kW and household 4,000 kW)

16.4 years when the battery capacity is 20,000 kWh. From the perspective of installation bodies, one crucial problem is a reduction of revenue due to an increase in battery capacity.

Second, Figure 8 shows changes in the simple payback period and three ratios already discussed above by varying the PV capacity in the commercial sector from 4,000 kW to 40,000 kW at 4,000 kW increments. The PV capacity for the household sector was fixed at 4,000 kW and the battery capacity was fixed at 20,000 kWh.

With a commercial PV capacity of 4,000 kW in a “nearly net zero” scenario, the ratio of purchased electricity from an outside power company and the ratio of PV electricity sold was less than 10%, as discussed in the preceding paragraph. At this point, the ratio of net purchased electricity was +1.1% and the simple payback period was 16.4 years, as also discussed above. As the commercial PV capacity increases from 4,000 kW to 40,000 kW, the ratio of sold PV electricity drastically rises from 8.2% to 81.6% and in the commercial sector, the ratio of net purchased electricity also drastically falls from +1,1% to -464.5% due to the enormous increase in PV electricity sold to an outside power company.

As the commercial PV capacity increases from 4,000 kW to 40,000 kW, the ratio of purchased electricity continues to fall from 9.5% until finally reaching 0.0% (an “absolute zero” scenario) when the commercial PV capacity is 40,000 kW. In light of the fact that the ratio of purchased electricity is already at 2.0% when the commercial PV capacity is 12,000 kW, it is clear that an additional PV installation to reach an “absolute zero” scenario would not be cost efficient.

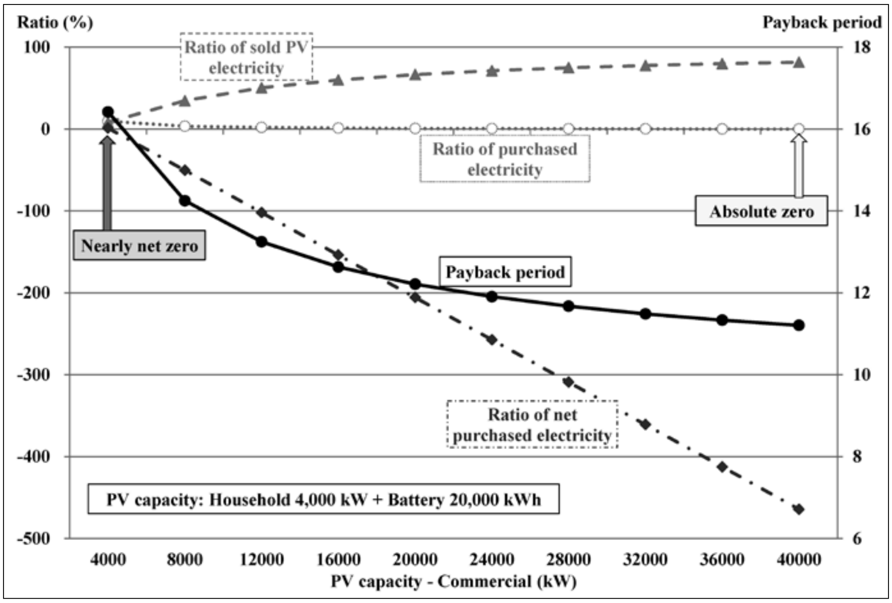


Fig. 8　Changes in cost and performance with varied commercial PV capacity
(household PV capacity fixed at 4,000 kW and battery capacity at 20,000 kWh)

The simple payback period also significantly decreases from 16.4 years to 13.2 years when the commercial PV capacity increases from 4,000 kW to 12,000 kW. However, even though the commercial PV capacity increases to 40,000 kW after then, the simple payback period gradually decreases to 11.2 years. From this viewpoint, it is also clear that installing more PVs to reach an "absolute zero" scenario would not be a cost effective decision.

Third, Figure 9 shows changes in simple payback period and three ratios by varying the PV capacity in both the commercial and household sectors from 0 kW to 4,000 kW at 800 kW increments. The battery capacity is fixed at 20,000 kWh.

As the PV capacity in both commercial and household sectors decreases from 8,000 kW to zero, the ratio of PV electricity sold falls from 8.2 % to zero promptly because of adequate battery capacity. Moreover, the ratio of purchased electricity to the ratio of net purchased electricity sharply increased from under 10% to 106%.

The simple payback period gradually increased from 16.4 years to 19.7 years, while the PV capacity in both sectors decreased from 8,000 kW to 3,200 kW. However, after that point, the simple payback period rose rapidly and reached to 35.7 years when the PV capacity was zero. This data makes it clear that battery costs have a crucial impact on overall expenses.

Fourth, Figure 10 shows changes in simple payback period and three ratios by varying the PV capacity in both of the commercial and household sectors from 0 kW to 4,000 kW every 400 kW, respectively. The battery capacity is assumed to be zero (0 kWh, no battery).

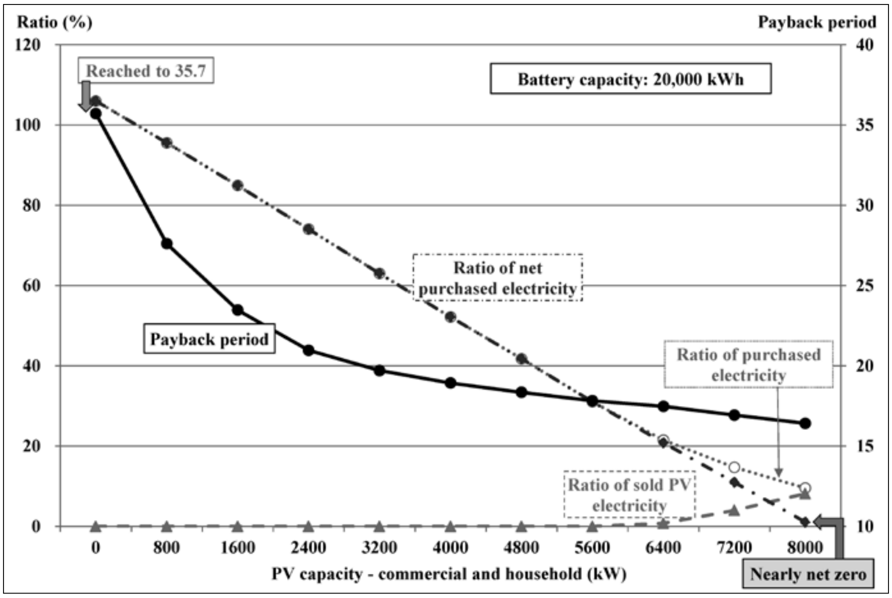


Fig. 9 Changes in cost and performance by with varied commercial and household PV capacity (battery capacity fixed at 20,000 kWh)

Different from the case of battery 20,000 kWh, the ratio of purchased electricity remains at about 50% even if the PV capacity in both sectors reaches to 8,000 kW and the ratio of sold PV electricity also increased to about 50% at the PV capacity 8,000 kW because of no battery. Because of balancing between purchased electricity (about 50%) and sold PV electricity (about 50%), the ratio of net purchased electricity reaches to -3.5% at the PV capacity 8,000 kW.

This situation may be called as a "quasi nearly net zero" case. However, this situation is quite different from the "nerly net zero" case shown in Fig. 9, because the ratio of purchased electricity and the ratio of sold PV electricity reach to less than 10% in the "almost zero" case.

Acoording to the results obtained on the costs of installing PVs and batteries intallation from the preceding subsections (3) and (4), the following points can be summarized:

a) A reduction in battery costs is crucial for the effective use of PVs and batteries in both the commercial and household sectors.
b) A reduction in PV costs is also important for the same reasons.
c) The lowering of FIT purchase prices has had a bad influence on the effective use of PVs and batteries in the commercial and household sectors.
d) However, any overly favorable FIT purchase prices would result in a kind of distortion regarding the effective use of PVs and batteries in the commercial and household sectors.

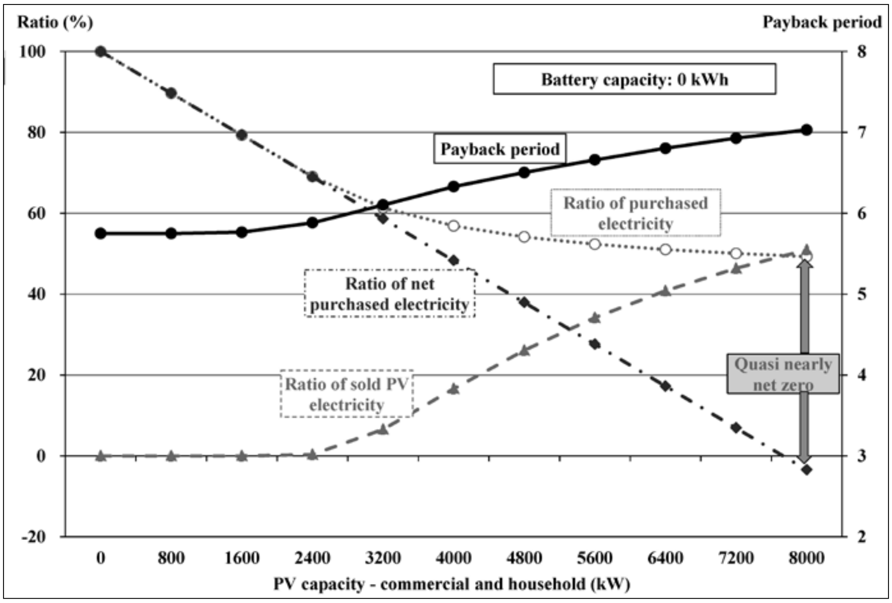


Fig. 10 Changes in cost and performance with varied commercial and household PV capacity (no battery, 0 kWh)

Concluding remarks

In Japan a special environment created by favorable purchase prices of PV electricity through a FIT system has introduced quite a large market distortion. This has prompted many businesses and households to invest in installing PVs and batteries. We need to reconsider what sort of FIT system would be desirable and sustainable. Special attention needs to be given to solar energy if Japan is to achieve healthy expansions of renewable energies.

Cost reductions are necessary to achieve greater PV and battery installation rates in both the commercial and household sectors. In particular, a cost reduction of various battery types is likely to play a crucial role. The need to earnestly engage in battery technology innovations is underscored.

Some business and residences seek to achieve an "absolute zero" purchased electricity scenario. However, the data from this study suggests that is not actually a cost effective measure. Instead of such a strict target, a process of the balancing the PV-generated electricity that is then sold to a power company with electricity bought from a power company in a "net zero" scenario should be pursued.

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