# An Economical Analysis on the Installation of Photovoltaic Cell (PV) and Battery in the Residential Sector

by

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## Abstract

Recently, the progress of ICT such as cloud computing and bidirectional communication system is quite remarkable. The battery system such as lithium ion, NAS and redox flow batteries is also being made a great progress. Therefore, in this study, we would like to analyze the PV (Photovoltaic cell) and battery installation connecting the commercial and residential (household) sectors under various capacity conditions. We also would like to discuss the present problems and future subjects of this activity.

The special environment brought by the much preferable purchased price of PV electricity by FIT makes quite large distortion to the decision making of investments for the installation of PV and battery. We need to reconsider desirable and sustainable FIT system, particularly to solar, more carefully.

For the installation of PV and battery connecting the commercial and residential (household) sectors, the cost reduction will be quite essential. Of these, especially, the cost reduction of various batteries would play a crucial role. Thus, technology innovation of battery will be desired earnestly from now on.

The “absolutely zero” purchased electricity at any time is often pursued as an achievable target. But the realization of this target is not reasonable. Instead of this strict target, the balancing between the purchased electricity and the sold PV electricity (“net zero”) would be pursued.

## Introduction

Japanese Government has determined the new target of GHGs reduction to achieve 26% reduction from the emission level in 2013 up to 2030 as Japanese INDC (Intended Nationally Determined Contributions). We have not been able to fix the concreate reduction measures to achieve this target yet. However, in the long-run, Japan must intensify her reduction measures basically, because she already committed 50% (or 80%) reduction of GHGs in 2050 through the past several Summits. In addition, the Paris Agreement will move to the execution stage from 2020 after COP24.

The GHGs emissions of Japan in 2017 recorded to the 8.2% down from the 2013 level but the 15% up from the 1990 level (the base year level of Kyoto Protocol) [1]. Because of the East Japan great earthquake and Fukushima nuclear accident in 2011, the thermal power generations was increased sharply instead of nuclear power generations. In addition, the continuous increases in GHGs emission in the residential sector have been significantly contributed to the whole GHGs increases in Japan through the long period.

In recent years, the developments of ICT (information and communication technologies) such as cloud computing and bidirectional communication system are quite remarkable. The battery system such as lithium ion battery, NAS battery and redox flow battery has also been made a great progress. Therefore, in this study, we would like to analyze the installation of PV (Photovoltaic cell) and battery in the residential sector under various conditions. We also would like to discuss the present problems and future subjects of this reduction measure.

## Methods

In this study, we made economics simulations on the installation of PV and battery connecting the commercial and residential sectors. The average electricity demand pattern in the commercial and household sectors and the average daily pattern of solar power output were adopted from the previous study [2]. We also made a cost survey on PV and battery on the basis of various domestic and overseas reports [3, 4].

The following simulations: (i) PV capacity zero and battery capacity zero, (ii) PV capacity 8,000 kW and battery capacity zero, (iii) PV capacity 44,000 kW and battery capacity zero, (iv) PV capacity zero and battery capacity 20,000 kWh, (v) PV capacity 8,000 kW and battery capacity 20,000 kWh ("net zero" case) and (vi) PV capacity 44,000 kW and battery capacity 20,000 kWh ("absolutely zero" case) were made. The economics was judged from the simple payback years obtained by dividing the total investment of necessary equipment by the annual net profit.

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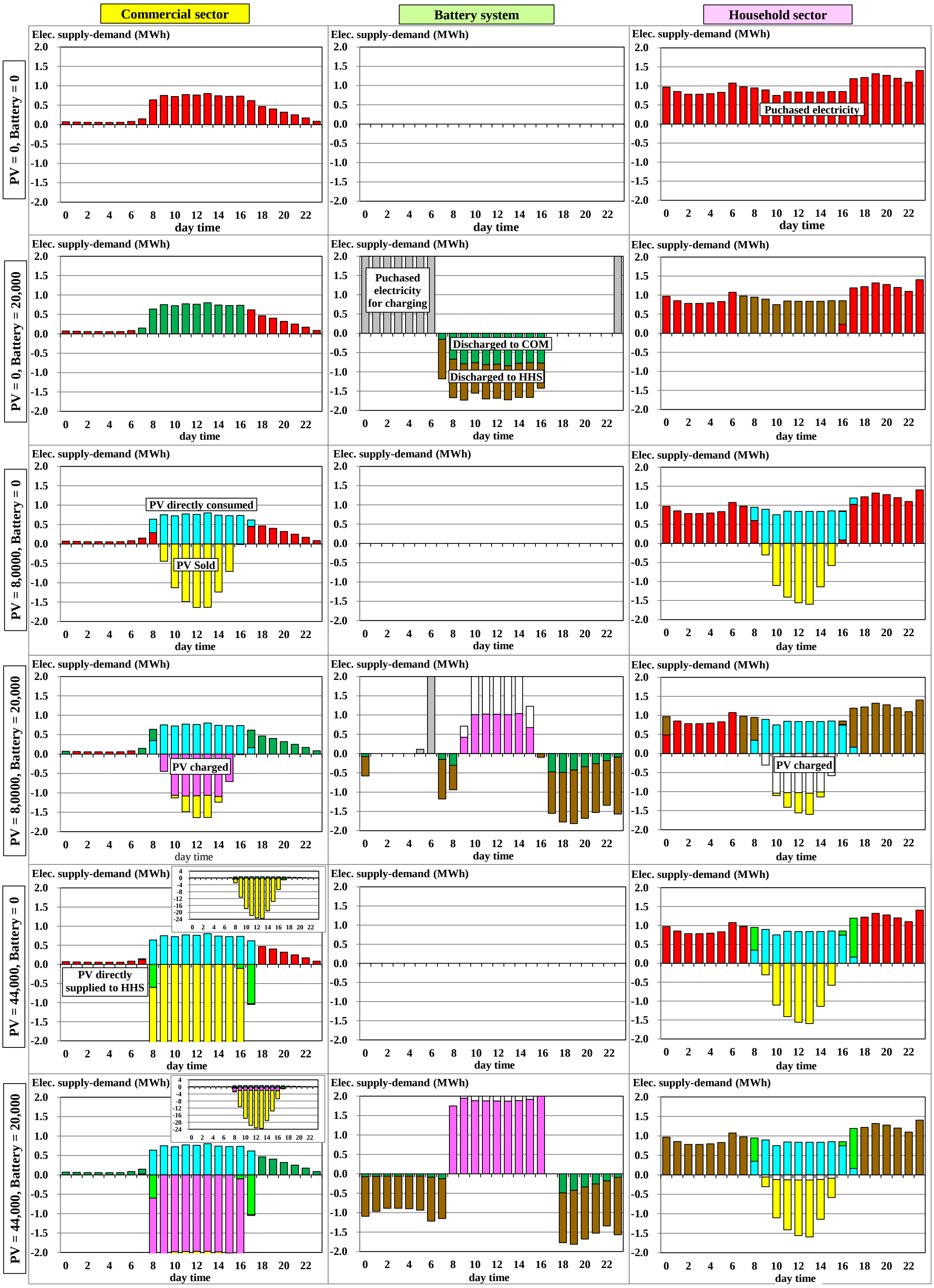
## Results

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

The electricity supply and demand patterns of the commercial and household (residential) sectors and the battery system on Cases (i) to (vi) are shown in Fig. 1 (only the winter season: January). The electricity suppy and demand patterns mentioned above were checked for every month from January through December. Only the supply and demand patterns in January is shown in Fig. 1. The first (top) shelf of three figures shows the electricity supply and demand pattern of Case (i): PV capacity zero and battery capacity zero. In this case, all the electricity demands in both sectors are supplied by the electricity purchased from the power company outside.



(Note) HHS: Household sector

Fig. 1 Changes in Electricity Supply Pattern in Winter Season (January) by the Installation of PV and Battery

The second shelf of Fig. 1 shows the electricity supply and demand pattern of Case (ii): PV capacity zero and battery capacity 20,000 kWh. In this case, the cheap electricity in the midnight is purchased and charged to the battery, and discharged to the commercial and household sectors in the daylight. The electricity consumed in the night is also purchased from the outside power company.

The third shelf of Fig. 1 shows the electricity supply and demand pattern of Case (iii): PV capacity 8,000 kW (commercial sector 4,000 kW and household sector 4,000 kW) and battery capacity zero. In this case, the electricity consumed in the daylight is directly supplied by PV and the surplus PV electricity is sold to the outside power company by using the FIT system. In this case, the electricity consumed in the night is also purchased from the outside power company, as well as Case (ii).

The forth shelf of Fig. 1 shows the electricity supply and demand pattern of Case (iv): PV capacity 8,000 kW and battery capacity 20,000 kWh. In this case, the PV electricity generated charged in to the battery in the daylight in addition the PV electricity is directly supplied to the commercial and household sectors in the daylight. In this case, the small remaining surplus of PV electricity is also sold the outside company as well as Case (iii). The electricity charged into the battery is discharged to the commercial and household sectors in the night. The small shortage of electricity in the night is finally covered by the electricity purchased from the outside power company depending on the season (or month). In this case, the PV electricity sold and the electricity purchased from the outside power company are both small and are almost balanced mutually. Thus, the Case (iv) is recognized as “net zero.”

The fifth shelf of Fig. 1 shows the electricity supply and demand pattern of Case (v): PV capacity 44,000 kW (commercial sector 40,000 kW and household sector 4,000 kW) and battery capacity zero. In this case, of course, the electricity consumed in the daylight is all supplied from the PV installed. The enormously large surplus PV electricity is sold to the outside power company by using the FIT system. In this case, the electricity consumed in the night is also purchased from the outside power company, as well as Cases (ii) and (iv).

The last (bottom) shelf of Fig. 1 shows the electricity supply and demand pattern of Case (vi): PV capacity 44,000 kW and battery capacity 20,000 kWh. In this case, the electricity consumed in the daylight is also all supplied from the PV installed as well as Case (v). In addition, the PV electricity generated is also charged into the battery in the daylight. The still remaining enormously large surplus PV electricity is also sold to the outside power company by using the FIT system as well as Case (v). In this case, there is no electricity purchased from the outside power company. Thus, Case (vi) is recognized as “absolutely zero.”

Based on the seasonal comparison we can easily point out the following specific characteristics.

a) In the winter season (January), the electricity demand increases both in the commercial and household sectors. Especially, the electricity demand in the household sector increases throughout the day, as compared with other season. The electricity demand in the commercial sector increases mainly in the daylight. In the Case (vi) only, the electricity purchased from the outside power company becomes zero.

b) In the summer season (July), the electricity demand also increases both in the commercial and household sectors. Especially, the electricity demand in the commercial sector increases largely in the daylight. The electricity demand in the household sector increases mainly from the evening to the mid night. In the Case (vi), the electricity purchased from the outside power company also becomes zero and in the Case (iv), the electricity purchased from the outside power company becomes almost zero.

c) In the intermediate season (October), the electricity demand decreases both in the commercial and household sectors, compared with the winter and summer seasons. Not only in the Case (vi) but also in the Case (iv), the electricity purchased from the outside power company becomes zero.

d) The PV installation plays a powerful role on covering the electricity demand in the daylight of the commercial sector directly. The PV installation also plays a certain role on covering the electricity demand in the daylight of the household sector directly. However, the combination of PV and battery plays a crucial role on covering the electricity demand in the night of the household sector.

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

Figure 2 shows the annual electricity demand and supply balances in sectors, PV and battery. The base case is Case (i): PV zero and battery zero. In this case, all electricity demand in residential (household) and commercial sectors is supplied by the purchased electricity from the power company outside. In Case(ii): PV zero and battery 20,000 kWh, more than half of the elcericity demand is covered by the electricity supply from the battery which is charged by the puchase of cheap electricity in the night from the power company outside.

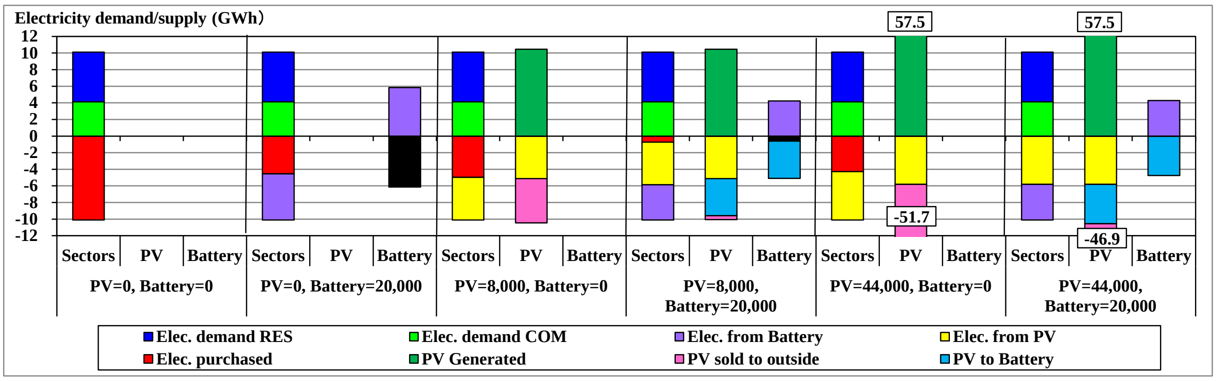


Fig. 2 Annual electricity demand and supply balances in sectors, PV and battery

In Case (iii): PV 8,000 kWh and battery zero, almost half of the electricity demand is supplied by the PV electricity generated, but the surplus of PV electricity (almost half of PV electricity generated) is sold to the power company outside because of no battery. Also in Case (v): PV 44,000 kWh and battery zero, more than half of the electricity demand is covered by the PV electricity generated, but the enormously large remaining surplus of PV electricity is sold to the power company outside also because of no battery. In Cases: (ii), (iii) and (v), almost half of the electricity demand is finally covered by the purchased electricity from the power company outside.

Different from the three cases mentioned above, in Case (iv): PV 8,000 kWh and battery 20,000 kWh, almost half of the electricity demand is firstly supplied by the PV electricity generated as well as Case (iii).

Almost all of the remaining PV electricity is charged into the battery and then is discharged to the electricity demand in the night. Only the small remaining surplus of PV electricity is finally sold to the power company outside. The quite small part of the electricity demand is fulfilled by the purchase of electricity from the power company outside. The small part of PV electricity sold by FIT is almost well-balanced with the small part of electricity purchased from outside. Therefore, we can recognize Case (iv) as an example of “net zero” state.

As well as Case (iv) discussed avobe, in Case (vi): PV 44,000 kWh and battery 20,000 kWh, almost half of the electricity demand is also firstly supplied by the PV electricity generated and all the remaining electricity demand is covered by the electricity discharged from the battery which is stored by charging PV electricity in the daylight. The still enormously large remaining PV electricity due to the huge PV capacity installed is sold to the power company outside as well as Case (v). In this case, there is no purchased electricity from the power company outside at all. Therefore, we can recognize Case (vi) as an example of “absolutely zero” state.

### (3) Economics of PV and battery installation by cases at present cost conditions

Figure 3 shows the components of net profits and the payback period to total investment under the present cost and FIT purchased price conditions during 2018 and 2019. In this simulation, based on the survey results in this study [9], the cost of PV is assumed to be 250,000 Yen/kW for the house use (small scale) and 200,000 Yen/kW for the mega solar use (large scale). The cost of battery is also assumed to be 150,000 Yen/kWh. The FIT (Feed in tariff) purchase price is assumed to be 24 Yen/kWh for the residential (household) sector and to be 14 Yen/kWh for the commercial sector. Entering 2019, the FIT purchased price in the commercial sector has just announced by METI [10].

As shown in Fig. 3, under the present conditions in 2019, the payback period of total investment in Case (ii): PV zero and battery 20,000 kWh is improved to 35.7 years and the payback period in Case (iv) : PV 8,000 kW and battery 20,000 kWh (“net zero”) is also improved to 16.4 years mainly due to the cost reduction of battery as compared with a few years ago. The recent cost reduction of PV also influences the latter improvement of the payback period.

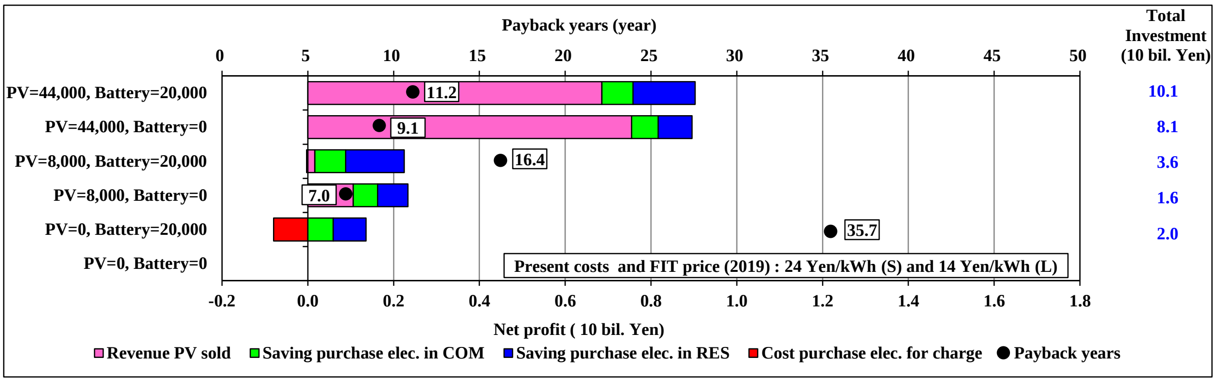


Fig. 3 Components of net profits and payback period of total investment with present cost and FIT purchased price conditions (in 2018~2019)

Also as shown in Fig. 3, the payback period of total investment in Case (iii): PV 8,000 kW and battery zero is slightly improved to 7.0 years mainly due to the cost reduction of PV. On the contrary, the payback period of total investment in Case (v): PV 44,000 kW and battery zero is slightly worsened to 9.1 years and the payback period in Case (vi): PV 44,000 kW and battery 20,000 kWh ("absolutely zero") is also slightly worsened to 11.2 years maily due to the lowering of FIT purchase prices to PV electricity.

## (4) Economics of PV and battery installation by cases at future cost conditions

The results in Fig.4 are obtained by the present costs of PV and battery and the lowest FIT purchased price of 7 Yen/kWh which is competitive at the power generation cost level. The payback years to total investment in the above-mentioned three cases (ii), (iii) and (vi) change to higher than or around 10 years because of the lowering of preferable FIT price.

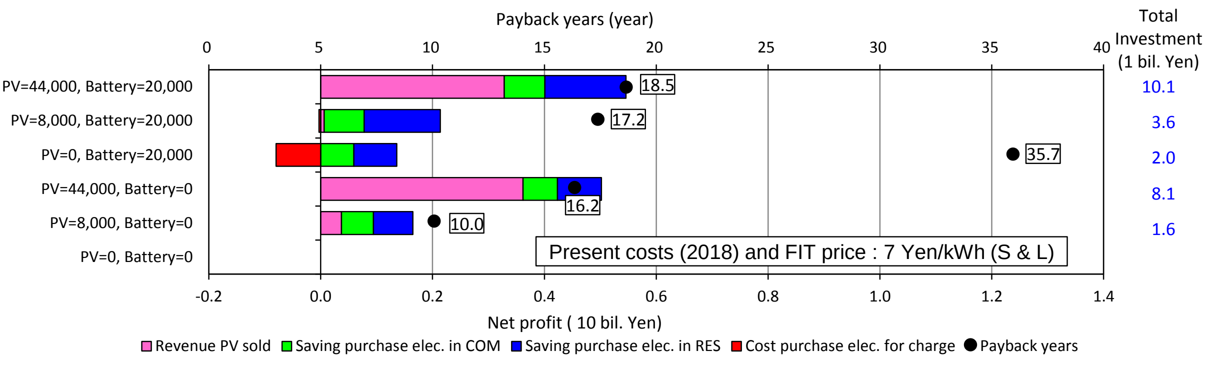


Fig. 4 Components of net profits and payback period of total investment
With the lowering of FIT purchased price to 7 Yen/kWh

The results in Fig. 5 are estimated by the expected lowest costs of PV and battery in the near future and the FIT purchased price of 7 Yen/kWh. The payback years to total investment in all of the cases (ii) – (vi) change to lower than 10 years because of the lowering of PV and battery cost.

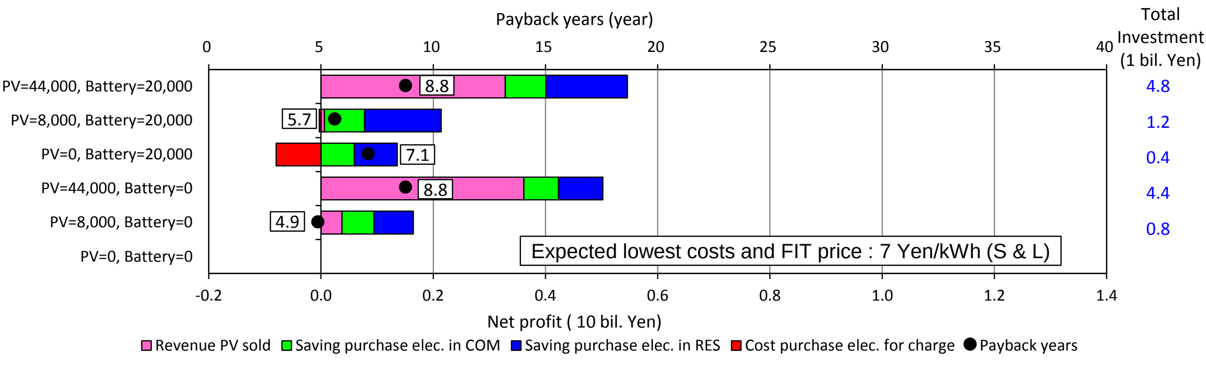


Fig. 5 Components of net profits and payback period of total investment with the FIT purchased price of 7 Yen/kWh and the expected future cost conditions

Acoording to the obtained results on the economics of PV and battery installation, we can point out the following issues.

a) The reduction of battery cost is quite crucial for the effective use of PV and battery in the commercial and residential (household) sectors.

b) The reduction of PV cost is also important for the purpose mentioned above.

c) The lowering of FIT purchase price has a bad influence on the effective use of PV and battery in the commercial and residential (household) sectors.

d) However, too preferable FIT purchase price bring a kind of distortion on the effective use of PV and battery in the commercial and residential (household) sectors.

### (5) Changes of payback period and performance by PV and Battery capacity changes

Figure 6 shows changes of payback period and supply performance (the ratio of purchased electricity, the ratio of sold PV electricity and the ratio of net purchased electricity) by battery capacity changes from 0 to 20,000 kWh under the PV capacity fixed at 8,000 kW (4,000 kW in the commercial sector and 4,000 kW in the household sector).

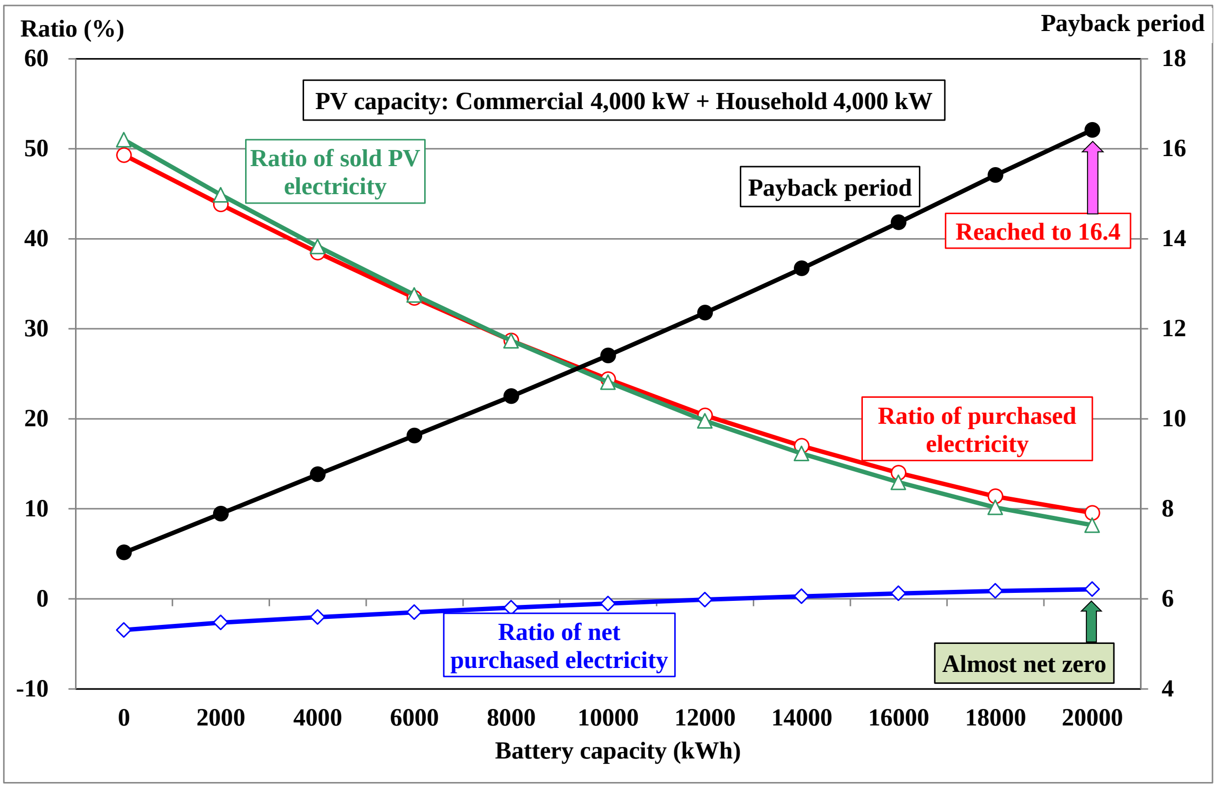


Fig. 6　Changes of payback period and performance by battery capacity changes

The payback period increased from 7.0 to 16.4 by changing the battery capacity from 0 to 20,000 kWh. The ratio of purchased electricity and the ratio of sold PV electricity both decreased from about 50% to about 10%. Therefore, the ratio of net purchased electricity reached to almost net zero at the battery capacity of 20,000 kWh.

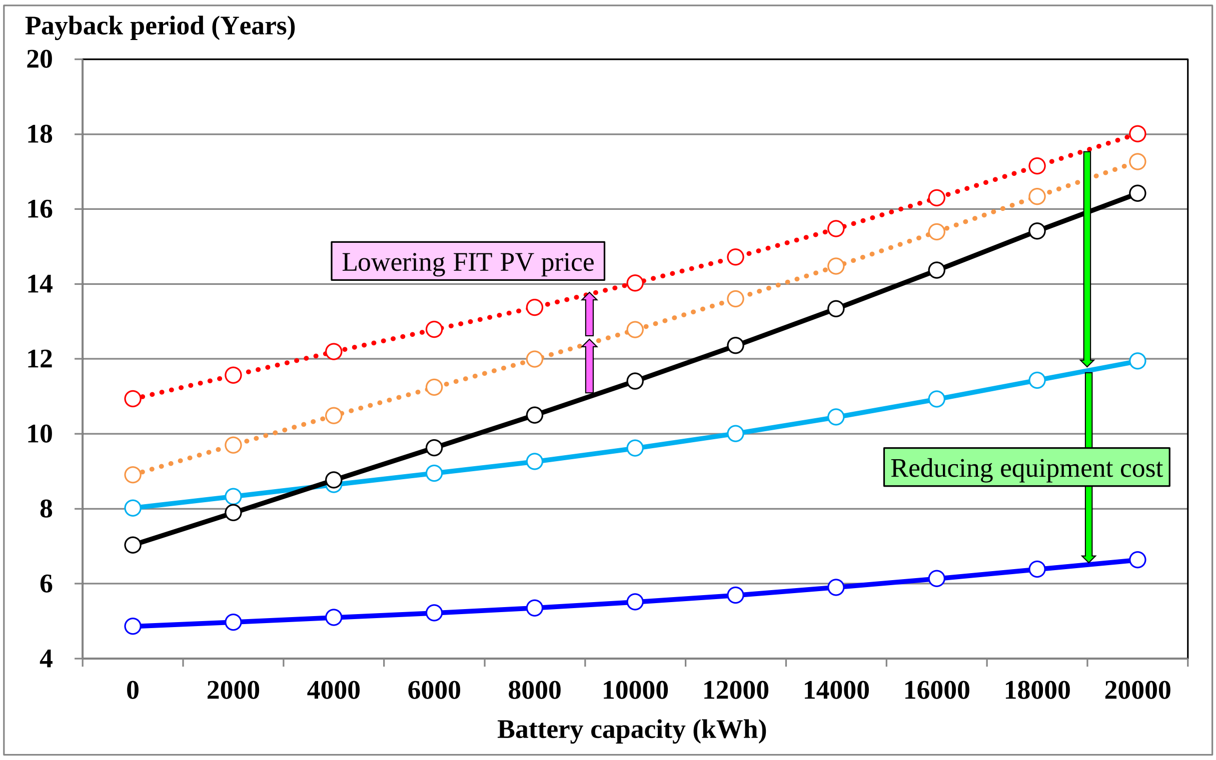


Fig. 7 Changes of payback period by lowering FIT PV price and reducing equipment cost (battery capacity change case)

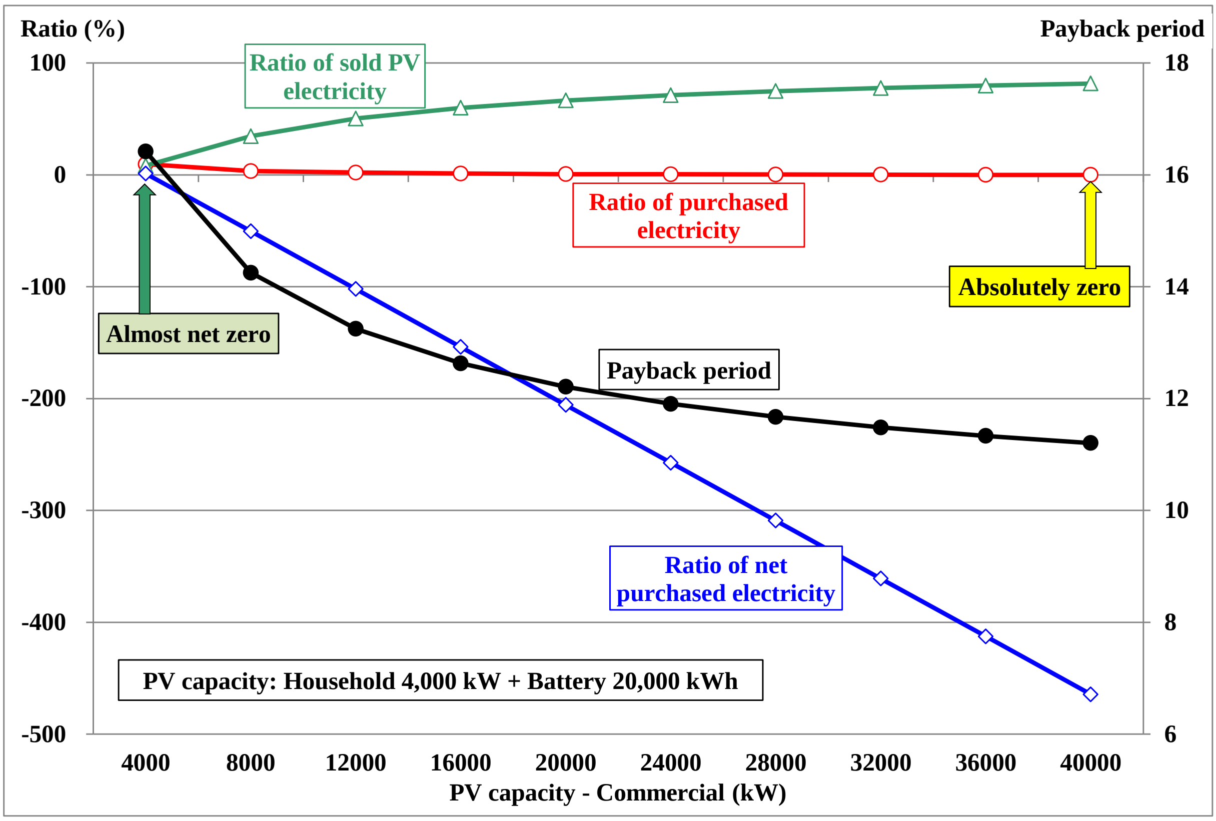


Fig. 8 Changes of payback period and performance by PV capacity changes from 4,000 to 40,000 kWh in the commercial sector

As shown in Fig. 7, the payback period increased because of lowering FIT PV price from 24 Yen/kWh (small) and 14 Yen/kWh (large) at present to 7 Yen/kWh expected for small and large both in the future via 14 Yen/kWh (small) and 10 Yen/kWh (large) also expected in the intermediate. On the other hand, if the installation costs of PV and battery are reduced to the lowest level expected in the future through the intermediate level also expected, the payback periods are improved largely as shown in Fig. 7.

Considering these results, it is recognized that the cost reduction of PV and battery would play a crucial role on the smart functions connecting between the commercial and household sectors.

Figure 8 shows changes of payback period and supply performance by PV capacity changes from 4,000 to 40,000 kW in the commercial sector under the battery capacity fixed at 20,000 kWh and the PV capacity fixed at 4,000 kW in the household sector.

As shown in Fig. 8, the payback period reduced (improved) from 16.4 to 11.2 by changing the PV capacity from 4,000 to 40,000 kWh. The ratio of sold PV electricity increased sharply from almost 10% to about 80% owing to the huge PV installation. Because of the sharp increasing of PV sold to the outside power company, the ratio of net purchased electricity also drastically changed from almost 0% to about -80%. Finally, the ratio of net purchased electricity reached to absolutely zero at the PV capacity of 40,000 kW.

If we consider changing from “almost net zero” to “absolutely zero,” as shown in Fig. 8, we can easily conclude that the realization of “absolutely zero” would be quite difficult. Instead of this strict target, the balancing between the purchased electricity and the sold PV electricity (“net zero”) would be pursued.

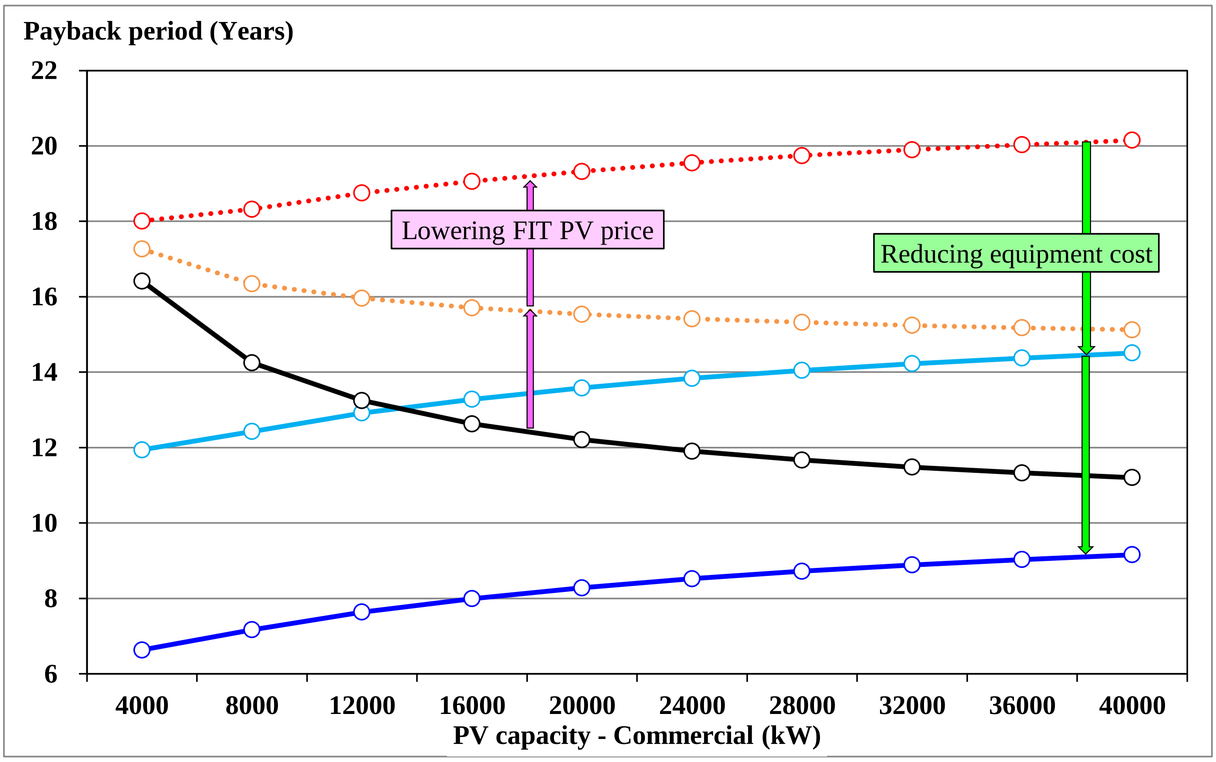


Fig. 9 Changes of payback period by lowering FIT PV price and reducing equipment cost (PV capacity change case)

As shown in Fig. 9, the payback period increased because of lowering FIT PV price from the level at present to the future expected level via the intermediate expected level. If FIT PV price is lowered to 7 Yen/kWh, the changes on payback period by increasing PV capacity switched from a decreasing direction to an increasing direction. On the other hand, if the installation costs of PV and battery are reduced to the lowest level expected in the future, the payback periods are improved largely as shown in Fig. 9.

## Conclusions

First, the special environment brought by the much preferable purchased price of PV electricity by FIT makes quite large distortion to the decision making of investments for the installation of PV and battery. We need to reconsider more reasonable and sustainable FIT system, particularly to PV, more carefully.

Second, for the installation of PV and battery connecting the commercial and household sectors, the cost reduction of PV and battery will be quite essential. Of these, especially, the cost reduction of various batteries would play a crucial role. Thus, technology innovation of battery will be desired earnestly.

Third, the “absolutely zero” purchased electricity at any time is often pursued as an achievable target. But the realization of this target is difficult. Instead of this strict target, the balancing between the small purchased electricity and the small sold PV electricity (“net zero”) would be pursued.

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