Community-based Allocation of Renewable Energy: Case Study on Energy Efficiency through Appropriate Scale of a Residential-community-based Photovoltaic System

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Summary

This paper studies about the community-based allocation of renewable energy which aims to provide alternative solution to efficient use of renewable energy. Most of the renewable energy sources such as the sun and wind are intermittent by nature. In case of residential buildings, the timings of energy demand and photovoltaic energy supply are not parallelly matched. Among many current solutions for the aforementioned issues include the use of battery storage, hybrid energy generation system, and the demand side response. However, this paper deals with those issues with the idea of strategically matching various energy demand patterns available within a community under a community-based energy system. Based on this load-balancing or demand-matching idea, a case study on residential-community-based photovoltaic systems with and without battery storage was done by using simulation. The main target was to find out the appropriate scale of the community-based system so that the generated renewable energy can be consumed efficiently within the residential community. In the simulation, actual data of energy demand and photovoltaic energy supply were used and a main assumption was made that when the scale of community becomes larger, the overall photovoltaic energy generation decreases due to the difference in weather condition. The simulation results showed that (1) in general the efficiency of the system becomes better when the scale of community increases; and (2) the addition of community-based battery storage is more economic than individual battery storage and can enhance the efficiency of the system. In conclusion, a community-based energy system is potential to improve the efficient use of renewable energy but further enhancement to the system is needed to achieve practical energy savings.

Keywords: community, energy allocation, renewable energy, photovoltaic energy, battery storage

1. Introduction

1.1 Background

Energy is one of our most indispensable resources and yet the energy security is one of the major problems nowadays that is always linked to the carbon emission and the global warming. As almost one-third of the total annual energy is consumed by buildings, and more than half of it is by residential buildings, it is important to improve the energy consumption of residential buildings. Recently, many countries are encouraging the residential-building owners to install renewable energy generation system to their homes, for examples the solar thermal and photovoltaic (PV) panels, wind turbines and geothermal heat pumps. However, most of the renewable energies are highly dependent on the weather conditions, for instance the solar energy system only works when the sun is available and becomes idle during the night time. This kind of intermittency problem of the renewable energy generation has been one of the many hurdles that prevent the development and growth of off-grid buildings. Among the well-known solutions to manage the intermittency of the renewable energy are the provision of operational and capacity reserve, energy storage, distributed generation, demand side response and interconnection with other grids [1], all of which are the important elements of the smart grid.

The smart grid enables two-way communication not only between the end-users and the grid operators but also among the end-users themselves. Currently this two-way communication is used by the grid operators to implement the demand side response program but in the future when the automation of the smart grid becomes more robust the two-way communication can be used by the end-users and among the end-users themselves to develop off-grid community. A standalone off-grid house still needs back-up energy storage in case of continuous days of bad weather. An off-grid community is better than a standalone off-grid house by having more buildings and hence more energy demand patterns which play a significant role in load balancing or demand matching. Having more energy demands (more buildings) has been found out to be able to make load balancing more efficient [2] and this opens the opportunity to improve energy efficiency and also maximize energy savings. As Friedman [3] stated that the building electric load is believed to have the potential to maximize energy savings with the smart grid.

1.2 Community-based allocation of renewable energy

Compared to many researches related to building energy, integrating buildings with the smart grid is relatively a new research topic and the relevant literature is growing but still limited. This paper looks into a community-based allocation of renewable energy. Just like any other energy system, the community-based energy allocation also faces the difficulty to make full use of the renewable energy supply without selling the surplus energy back to the currently outdated and overburdened power grid which can cause problems like transmission and distribution bottlenecks and power reliability and quality [3]. Battery storage is a helpful solution but people are holding back the usage of battery because of its current high cost. One of the good literatures about battery storage and on-grid building is done by Mulder *et al*. [4] which proposed methods to determine the optimal size of battery storage for on-grid house with PV panels. Considering the potential benefits a community has over a single building, this paper covers a case study about finding out the effect of the scale of community on the efficiency of the community-based allocation of renewable energy.

2. Case study

2.1 Objectives

It is believed that community-based allocation of energy is capable to provide more advantages than a standalone energy system because of the flexibility of load balancing. A case study was carried out to find out how the efficiency of community-based allocation of renewable energy changes under different scales of community. Similar to the study of Mulder *et al.* [4], the energy allocation efficiency in this study was also measured by the amount of buying and selling of electric energy from and to the power grid and it is better if the buying and selling of electric energy are small because the buying of fossil-fuel-based electric energy costs more in terms of economy and environmental impacts and the selling of surplus renewable energy also requires upgrade of current power grid infrastructure to support the extra loading or else grid instability may happen. The effect of integrating battery storage into the community-based allocation of energy was tested as well.

2.2 Methodology

2.2.1 Scope of case study

In this case study, the community-based allocation of renewable energy was set up in a residential community which only consisted of japanese detached houses. The residential community of detached houses were made up by eight types of detached houses with properties as shown in the *Table 1*. The information and energy monitoring data of these detached houses were obtained from a published source and these actual energy demands were used in the simulation. Only one renewable energy generation was available in the residential community and it was the photovoltaic (PV) energy and the installation of the PV panels was considered to be on the rooftop only.

Table 1 Properties of detached houses used in the simulation

House ID	Location	Completed Year	Total Floor Area (m^2)	Structure	Energy Source for Different Usage (E:Electric G:Gas)			
					Hot Water (Bath)	Hot Water (Kitchen)	Cooking	Heating
K01	Saitama	2002	92	Wood	E	E	E	E
K02	Tokyo	2001	106	Wood	E	E	E	E
K03	Tokyo	2002	105	Wood	G	G	G	E
K04	Saitama	2001	90	Wood	G	G	G	E
K05	Chiba	2002	132	Wood	E	E	E	E
K06	Chiba	2002	108	Wood	G	G	G	E
K07	Kanagawa	2000	240	ALC	G	G	G	E & G
K08	Gunma	1968	113	Wood	E	E	E	E

The objectives of this case study were achieved by performing simulation with the Microsoft Excel. The simulation was simplified to the state that was deemed by the author to be good enough to test the objectives of this case study.

2.2.2 Data treatment

The energy demand of the eight detached houses was monitored into eight usages: lighting, heating and cooling, hot water, kitchen, refrigerator, household chores, entertainment and others. The eight demand usages were sorted into direct current (DC) load and alternating current (AC) load as shown in *Table 2*, after considering the availability of DC and AC appliances in the current market.

Table 2 Load type of demand usage

Load Type	Demand Usage
DC load	Lighting, Refrigerator, Entertainment, 50% of other
AC load	Heating or Cooling, Hot Water, Kitchen, Household Chores, 50% of other

The community-based allocation of PV energy was simulated in two cases in which one was a residential-community-based PV system with battery storage and another without battery storage. As the main objective was to study the energy allocation efficiency under different scales of community, not to find out the effect of integrating battery storage in the community-based PV system, and therefore different simulation conditions which are explained later were applied to the two cases and both cases were not for direct comparison to each another.

In case of the PV energy generation, the simulation used actual PV output data of a 10kW crystalline-silicon PV system in Japan. In total, 36 sets of data (3 sets for each month in 3 weather conditions: sunny, cloudy and rainy) with each data set representing one day of PV output monitored at one-minute interval was obtained and they were treated into 12 sets of data (each data set for each month by taking average weather condition) with each data set representing one day of PV output data processed at one-hour interval. The PV energy generation from the PV panels installed on the rooftop was simulated based on this treated data.

2.2.3 Simulation conditions and constraints

PV energy is generated only when the sun is available and hence the community-based allocation of PV energy must consider this factor to reduce the buying and selling of electric energy with the power grid. The PV panels output DC electric energy and it is the most efficient to use the PV energy directly with DC appliances instead of converting it into AC which incurs energy loss. The residential community was simulated to be installed with maximum area of PV panels that was constrained by the available roof area and the roof area of each type of detached house was taken as half of the total floor area of the detached house. Under such condition, the generated PV energy was known to be insufficient to supply all DC and AC loads but more than enough if only DC load was supplied and as a result, the electric loads supplied by the PV energy for two cases of residential community were different as shown in the *Table 3*.

Table 3 Electric loads supplied by PV energy for two cases of community

Case	Coverage of Electrical Loads
Without battery storage	DC loads and AC loads excluding hot-water use
With battery storage	DC loads

For the case of community-based PV system without battery storage, everything except the AC hot-water use was supplied by the PV energy because making hot water by converting DC into AC involves energy loss and a lot more buying of grid power would be required as the energy used for making hot water is the highest portion of the total energy consumption of a Japanese residential building. On the other hand, when battery storage is integrated into the system, any surplus PV energy at any time of the day can be stored and discharged for usage if there is any PV energy insufficiency especially during the night time when PV energy generation is unavailable. As the PV energy is the most efficient to be consumed as DC, in this study all the PV energy was made to be consumed with DC appliances through the use of battery storage even though the charging and discharging of battery storage also involves energy loss and the loss was slightly higher than DC-to-AC conversion loss. In the simulation, the efficiency of DC-to-AC conversion was taken as 90% and the overall battery efficiency was 85%.

The main objective was to see how different scales of community affects the efficiency of the community-based allocation of PV energy and this study looked at that in a macroscopic way by taking the weather factor as the main constraint to PV energy generation. When the scale of community increases, the community area also increases and the weather condition experienced over different parts of the community starts to be different. This situation was simplified into an assumed relationship between the coefficient of weather factor against the community area as shown in *Figure 1* in which the coefficient is 1.0 when the community area is still small enough that the weather condition experienced over the whole community and the PV energy generation are almost the same and the coefficient starts to decrease as the community area gets larger and the PV energy generation becomes different from one area to another within the community. This effect was assumed to

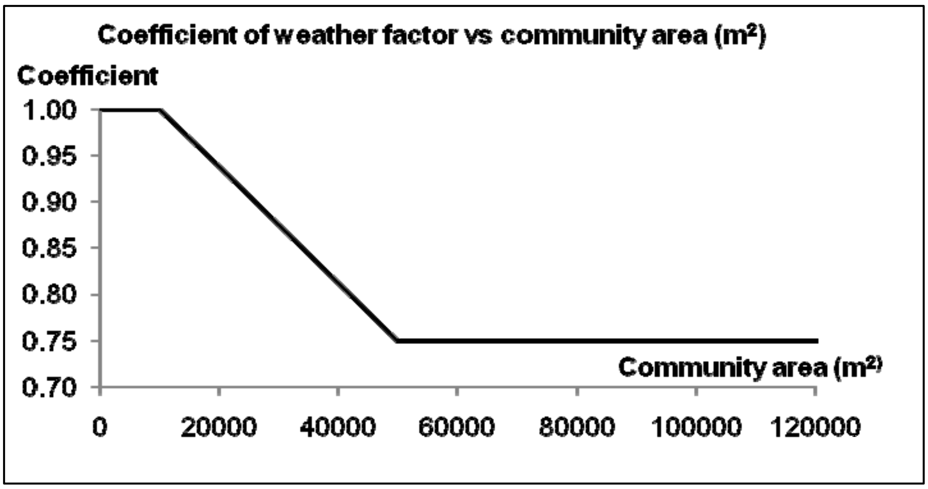

Figure 1 Assumed relationship between coefficient of weather factor against the community area

converge at the coefficient value of 0.75.

In the simulation, the built-in solver tool of the Microsoft Excel was used to find out a residential community which was optimized to certain conditions for each case. In terms of the optimization conditions, the optimized residential community must minimize the surplus PV energy for the case without battery storage and the electric deficit (buying of grid power) for the case with battery storage. Due to different simulation conditions, the composition of the optimized residential community for two cases was different as well. Another constraint here was that the energy consumption of the detached houses of the residential community followed a normal distribution.

Once the residential community was optimized, the energy allocation efficiency of two cases was respectively indicated by the surplus PV energy for the case without battery storage and the electric deficit for the case with battery storage. After that, the simulation (searching for the optimized residential community) was repeated for different scales of community to obtain the corresponding energy allocation efficiency for two cases.

2.3 Results and discussion

The *Figure 2* shows the simulation results for the two cases. In total eight iterations of simulation with different scales of community were carried out and they are represented by the dots in the graphs for the two cases. For the community-based allocation of PV energy without battery storage, the residential community should consume all the generated PV energy and reduce the selling of surplus PV energy back to the power grid. The simulation result shows that when the scale of community increases, the PV surplus becomes decreased and this indicates that the allocation of PV energy in a larger residential community can efficiently avoid overburdening the current grid infrastructure with less electric energy flowing back to the power grid.

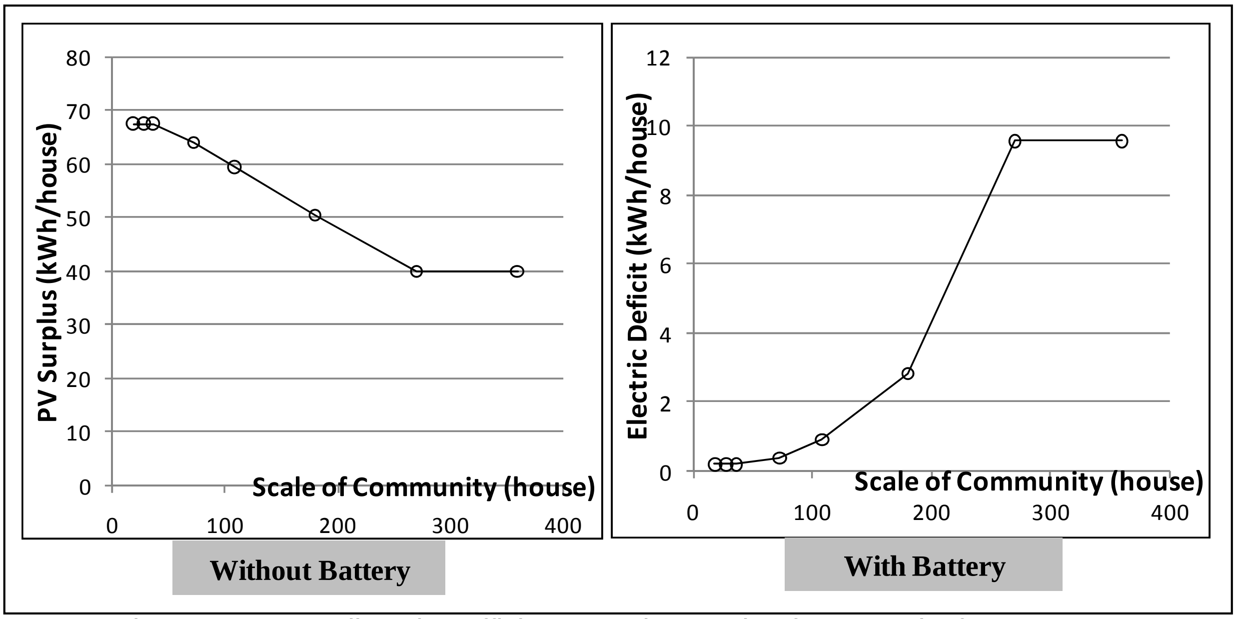

Figure 2 Energy allocation efficiency against scale of community for two cases

On the other hand, for the case with integrated battery storage, it would be ideal if the addition of battery storage could help to eliminate the necessity to use the grid power especially during the night time. However the simulation result shows that when the scale of community increases, the electric deficit (buying of grid electric) becomes increased as well. This outcome is expected because the total energy consumption of the community still remains the same as ever and the larger the community gets its total energy demand also gets larger and exceeds what the limited PV energy generation can provide. However, the required capacity of the integrated battery storage that ensures zero surplus PV energy flowing back to the power grid becomes smaller as the community gets larger (*Figure 3*) and this indicates that people can invest in a community-

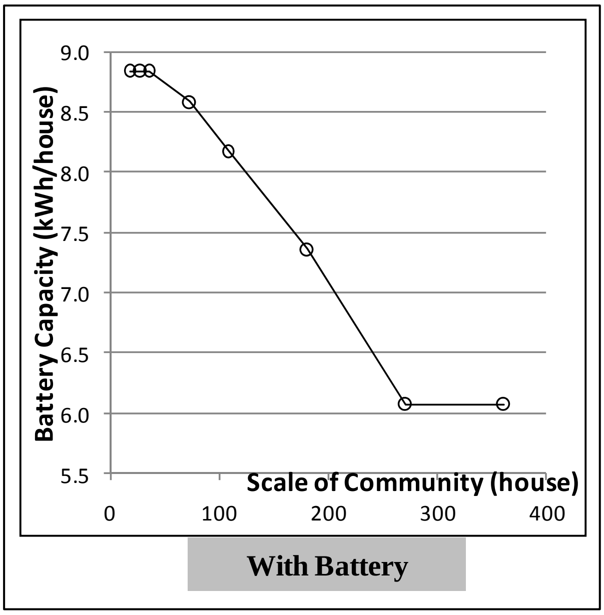

Figure 3 Required battery capacity decreases when scale of community gets larger

based battery storage to share a lower cost as the required battery capacity decreases. In *Figure 2* and *Figure 3*, the surplus PV energy, electric deficit and required battery capacity begin to stop changing in the end and this indicates the convergence of the effect of the scale of community which is believed to be constrained by the weather factor.

From the simulation results of the two cases, it is clear that community-based allocation of renewable energy is capable to yield both positive and negative outcomes depending on whether it is implemented efficiently or not. However, it is certain that under correct implementation the energy efficency of the community can be improved by minimizing the reliance on the external energy sources. Besides that, the integration of battery storage also becomes more affordable and can facilitate more creative applications to further improve the energy efficiency and even achieve greater energy saving. Of course, for more efficient implementation, not only PV energy but other forms of renewable energy and technology should be used as well to produce the best system combination and the community can involve different types of buildings and even other relevant facilitites and infrastructures to optimize the matching of energy demand.

This case study and the simulation was based on the current situation, in the future where the renewable energy technology is a lot more advanced, the integration between the building and the power grid network is a lot seamless and the cost of new technology becomes more affordable due to mass production, the community-based allocation of energy is potential not only to increase energy efficiency but also enhance energy saving which is a more practical measure to reduce the carbon footprint and strengthen energy security.

3. Conclusion

3.1 Conclusion

[1] A case study was carried out to find out how the efficiency of community-based allocation of photovoltaic energy changes under different scales of community. Two residential communities, one without battery storage and another with integrated battery storage were modelled and simulated according to certain conditions and constraints.

[2] From the simulation results, it can be concluded that in general a larger scale of community is able to improve the efficient use of renewable energy of a community-based energy system and reduce the required battery capacity that is integrated to further improve the energy efficiency. However, when the efficiency of using the renewable energy is improved, the total energy demand of the community still remains the same and thus the grid power is still needed when the limited PV energy is insufficient.

3.2 Recommendation

[1] Not only the energy efficiency but also the energy saving must be considered and improved whenever implementing any new scheme of energy usage.

[2] The simulation can be improved by considering a larger scope of parameters and other renewable energy sources and technology. While improving the realistic quality of the

simulation, the balance between simplicity to use and complexity for better result must be taken into account.

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