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Adoption of PV+EV Integration for Deep Decarbonization in Bali, Indonesia

Ratu Keni Atika[1*], Takuro Kobashi[1]

1 Graduate School of Environmental Studies, Tohoku University, Sendai, Miyagi, 980-8572 Japan
(ratu.keni.atika.r6@dc.tohoku.ac.jp)

ABSTRACT

Integration of rooftop photovoltaics and electric vehicle as battery is a promising technology to deeply decarbonize Bali, Indonesia because of Bali's high sun altitude angle. In this study, we used techno-economic analyses to evaluate the decarbonization potentials of rooftop PV system integrated with battery in EVs in year 2019 and 2030 for Bali when technology price is expected to decline. Adoption of only rooftop PV in 2019 brings cost benefits to only few regions in Bali owing to the high prices of PV system. In 2030, widescale adoption of rooftop PV in all Bali can bring 5%-38% of cost saving and 30%-43% CO2 emission reduction. Performance further increases by adopting widescale integration of EVs as battery for rooftop PV, resulting 8%-41% cost saving and 72%-96% CO2 reduction, indicating deep decarbonization is possible by enhanced uses of rooftop PVs integrated with EV as battery in Bali.

Keywords: renewable energy, climate change, decarbonization, photovoltaics, electric vehicles, techno-economy analyses

NONMENCLATURE

Abbreviations	
EV	Electric Vehicle
FIT	Feed-in-Tariff
ICE	Internal Combustion Engine
IDR	Indonesia Rupiah
NPV	Net Present Value
PV	Photovoltaic
USD	United States Dollar
Symbols	
n	Year

1. INTRODUCTION

Efforts in halting the global temperature raise to 1.5 degrees above pre-industrial levels is necessary [1]. 60% to 70% of anthropogenic greenhouse gas emissions comes from urban cities [2]; and with high confidence the cities can achieve net zero carbon emission if revolutionary change occurs [3]. Supported by the global declining trends of the prices, renewable energy (i.e., solar and wind) are increasingly becoming the first option for all the countries to satisfy their increasing demands [4].

PV application is not sufficient for decarbonization if not coupled with battery owing to its variability. Electric Vehicle (EV) battery provides a promising option as energy storage. A rapid shift from Internal Combustion Engine (ICE) vehicle to EV is expected in Indonesia providing a basis to use EVs as storage [5]. Earlier studies have shown that integrating rooftop PV with EV ("PV+EV") for urban areas (SolarEV City Concept), provide promising potentials for deep decarbonization reducing 54% to 95% of CO_2 emission from electricity and driving in Japanese cities [6]. Another study for Jakarta, Indonesia indicated that the "PV+EV" application in Jakarta can reduce CO_2 emission as well as air pollution substantially because low-latitude cities have year-long high sun altitude angle [7].

Exploring rooftop PV+EV integration in world-famous tourist destinations, "Bali" provides an opportunity to showcase decarbonization potential that can be replicated in similar low latitude urban areas. As the Provincial Government of Bali has put solar rooftop PV as one of the priorities for their decarbonization target [8], we can expect higher chance of the wide use of the rooftop PV + EV. To evaluate the PV+EV integration in different regions of Bali, we performed techno-economic analyses and identified the technology potentials for decarbonization and economic feasibility with financial and processing indicators [9].

2. MATERIAL AND METHODS

2.1 Bali, Indonesia

The Bali Province of Indonesia ("Bali") has 9 administrative area: Denpasar City as the capital province of Bali, Badung Regency, Bangli Regency, Buleleng Regency, Gianyar Regency, Jembrana Regency, Karangasem Regency, Klungkung Regency, and Tabanan

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Regency (Fig. 1) [10]. Bali has minimal seasonal variability and temperature change between 20 to 32°C [11]. There are two seasons in Bali. Rainy season occurs around November to April, and dry season occurs around May to October, which is clearly reflected in the higher PV daily generation during this period (Fig. 2)

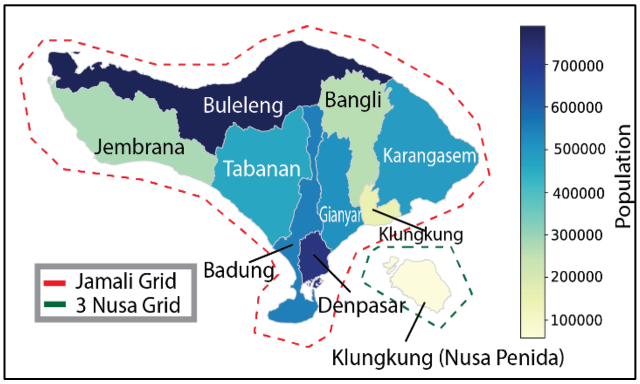

Fig. 1 Bali population (2019) and grid groups

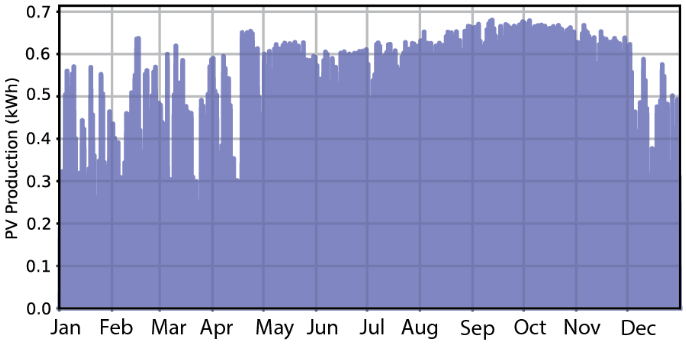

Fig. 2 PV generation (kWh/h), generated from NREL's System Advisory Model[12] *by inputting weather data for 2019 obtained from MERRA-2* [13]

Electricity in Bali is supplied from 2 different grid connections: (1) the Jamali (Jawa, Madura, Bali) grid which supplies the island of Java, Madura, and mainland island of Bali; and (2) the 3 Nusa grid, a small system grid which exclusively supply Nusa Penida Island and its surrounding small islands that is part of the Klungkung Regency [14] (Fig. 1). In 2019, the total electricity demand was 5,968 GWh, and Denpasar as the capital city of Bali Province had the highest electricity demand of 2,532 GWh (Fig.3).

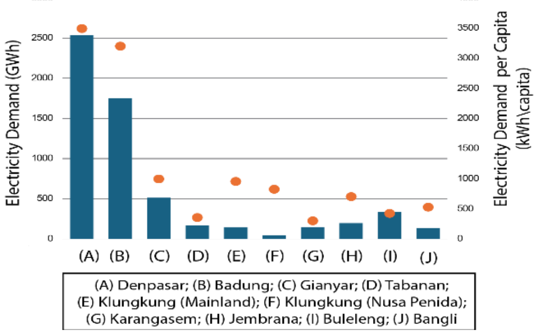

Fig. 3 Bali electricity demand in 2019, obtained from Indonesia National Power Company (PT PLN)

2.2 *Techno-economic analyses*

The techno-economic analysis is an effective method to evaluate the feasibility of renewable energy project because it investigates relevant costs and externalities, including environmental impacts, which can be a crucial decision maker [15]. The methodology to perform techno-economic analyses for rooftop PV and PV+EV follows the earlier studies of Kobashi et al [6], [16]. In this study, six scenarios (see Table 1) were evaluated for the decarbonization potentials of rooftop PV only and integration of PV+EV.

Table 1 Scenarios for techno-economy analyses

Year	Scenario	
2019	PV only with FIT	
	PV only without FIT	
2030	PV only with FIT	PV+EV with FIT
	PV only without FIT	PV+EV without FIT

The methodology considers Net Present Value (NPV) as the parameter to determine cost effectiveness of each scenario. Numerous factors of car driving profiles, number of EVs, insolation, demand profiles, prices of PV and EV battery, electricity tariffs, maintenance cost, and discount rates were considered to find the optimum PV capacity configuration with the highest NPV. The analyses were calculated with MATLAB by iterating cashflow of various PV capacity over project lifetime of 25 years at different initial investment years [16].

In this study, each administrative area was analyzed independently. For Klungkung Regency, we differentiated between the area that is in Jamali grid ("Klungkung (mainland)") and the area that is part of the 3-Nusa grid ("Klungkung (Nusa Penida)"). In addition, we also analyzed "All Bali" area that assumes the energy production from PV and/or PV+EV can be flawlessly interchangeable between the administrative areas by assuming all the areas is considered in Jamali grid.

2.3 *Parameter and assumption for calculation*

The demand profile data in 2019 was obtained from PT PLN. The data were hourly resolution in 2019 for all the area that is connected to Jamali grid (Bali mainland) and monthly data for 3-Nusa grid. We assumed the hourly demand for 3-Nusa grid follows the hourly demand for the mainland Bali in Jamali grid but the monthly totals were scaled to the obtained data for 3-Nusa grid.

To determine the PV cost in 2019 and 2030, we calculated the PV decline rate of the reported price of residential PV system in Indonesia on 2018 with IDR 18 million/kWp or USD 1,276/kWp (exchange rate in 2018: USD 1 = IDR 14,100); and reported price on 2022 with IDR 16 million/kWp or USD 1,081/kWp (exchange rate in 2022: USD 1 = IDR 14,800) [17], [18].

From Google's Open Building [19], we calculated the total rooftop area in Bali as approximately 251 km^2. Following earlier studies, we considered 70% of the total area is available for rooftop PV installations[6][7]. Assumption for the battery system in EV was adopted from Kobashi et al, which utilizes Nissan Leaf that has battery storage of 40 kWh [6], [7], [16]. Following the previous studies, we assumed EVs are connected to power systems with bi-directional charging when they are parked. Due to this, the EVs are simulated to be away from the power system for 3 hours every day between 7 am to 7 pm for driving. One hour trip is considered a 5.8 km drive that consumes 1.1 kWh; and this equates the driving distance to be 6,368 km/year. For the battery in EV, the minimum state of charge (SoC) is set at 50% and for maximum SoC is at 95%. The battery round trip efficiency is 92%. The battery is assumed to degrade 2% annually and replaced once it reaches 80% of the original capacity.

Considering economic development of the region between 2019 and 2030, we assigned different assumptions for rooftop area, electricity demand, and number of vehicles, based on the government planning. See Table 2 for the parameters and assumptions.

Table 2 Parameter and assumption used for analyses

Parameters	Unit	2019	2030
Electricity Price[1]	USD/kW	0.0912	
FIT[2]	USD/kW	0.0691	
PV maintenance cost[3]	USD/kW	31.4	
EV additional cost[3]	USD/kW	-	22
Battery replacement cost[3]	USD/kW	-	91
ICE gasoline efficiency[3]	km/L	12.6	
EV efficiency[3]	km/kWh	-	5.3
Grid Emission Factor			
Jamali Grid	KgCO$_2$/kWh	0.8	
3 Nusa Grid	KgCO$_2$/kWh	0.5	
Gasoline Emission Factor	KgCO$_2$/L	2.3	
Gasoline Price[4]	USD/L	0.72	
Discount rate[3]		3%	
Scaling up setting			
Rooftop Area[5]		1 x	1.06 x
Electricity Demand[6]		1 x	1.5 x
Number of Vehicle[7]		1 x	1.8 x

[1]Aggregated electricity price [20]; [2]FIT [21]; [3]assumption adopted from Kobashi et al [16]; [4]Non-subsidized Gasoline Price, 2019 [22]; [5]Bali Spatial Planning 2023-2043 [23]; [6]2021-2030 PT PLN Business Plan [14]; [7]Derived from population growth projection [24].

2.4 Indicators used for analyses

We considered "cost saving", "CO$_2$ emission reduction", "self-sufficiency", and "energy-sufficiency" as the indicators to evaluate the scenarios [6]. "Cost saving" is the amount of energy cost that is saved by adopting the technologies, and it is expressed as follows:

$$\text{Cost Saving} = \left\{\frac{\text{NPV}/_{\text{Project Period}}}{\sum Baseline\ Cost}\right\} \text{ x } 100\%$$

Where the baseline cost is the annual expenditure of electricity import cost and annual gasoline expense for the base scenario.

"CO$_2$ emission reduction" is the difference of carbon emissions between the base scenario and the technology adoption and can be written as follows:

$$CO_2 \text{ reduction} = \left\{1 - \frac{Grid\ emission_{scenario}}{\sum CO_2\ emission_{base}}\right\} \text{ x } 100\%$$

$\text{Grid emission}_{\text{scenario}} = E_{\text{import}}(\text{scenario}) \text{ x } EF_{\text{grid}}$

$\sum CO_2 \text{ emission}_{\text{base}} = \text{Grid emission}_{\text{base}} + \text{Gas emission}_{\text{base}}$

$\text{Grid emission}_{\text{base}} = E_{\text{import}}(\text{base}) \text{ x } EF_{\text{grid}}$

$\text{Gas emission}_{\text{base}} = n_{\text{veh}} \text{ x } d \text{ x } g_{\text{eff}} \text{ x } EF_{\text{gas}}$

Where E_{import}(scenario) is the electricity imported from the grid during technology adoption, EF_{grid} is the emission factor of grid electricity. $\sum CO_2$ emission$_{\text{base}}$ is the total CO$_2$ emission in base scenario that is calculated from CO$_2$ emission from the grid (Grid emission$_{\text{base}}$) and CO$_2$ emission from gasoline utilization of ICE (Gas emission$_{\text{base}}$). E_{import}(base) is the electricity imported in base scenario, n_{veh} is the number of cars, d is the driving distance, g_{eff} is ICE gasoline efficiency.

"Self-sufficiency" is the amount of energy supplied by the technology compared to the total demand of the area; and "energy-sufficiency" is the total amount of energy produced by the technology compared with total demand of the area. These are expressed as follows:

$$Self\ sufficiency = \left(\frac{P_{to\_load} + P_{to\_battery}}{Electricity\ Demand}\right) x100\%$$

$$Energy\ sufficiency = \left(\frac{\sum P}{Electricity\ Demand}\right) x100\%$$

$\sum P = P_{\text{to\_load}} + P_{\text{to\_battery}} + P_{\text{to\_grid}}$

Where $\sum P$ is total power produced by the technology, $P_{\text{to\_load}}$ is the power produced by the technology that is directly used by the area, $P_{\text{to\_battery}}$ is the power produced by the technology that is stored in the battery (if any), and $P_{\text{to\_grid}}$ is the power produced by the technology that is sent to the grid.

3. RESULTS

3.1 Impact on PV price decline

The implementation of “PV only” in 2019 has minimum to no economic benefit in “without FIT” because of the high price of PV cost (see Fig. 4). Cost savings of “PV only without FIT” occurred in Denpasar and Badung, and both have the highest demand per capita. The price decline in 2030 produced positive cost savings for “PV only without FIT”, with Gianyar and Klungkung (mainland), the area with 3rd and 4th largest demand per capita. This indicates “PV only without FIT 2030” is beneficial when it reaches certain economy of scale in demand per capita, because the cost per PV unit can be reduced, thereby increasing overall savings.

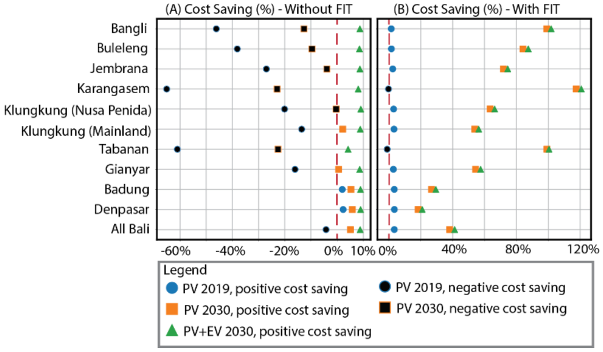

Fig. 4 Cost saving in all scenarios

In “PV only with FIT 2019”, all areas show cost benefit except for Tabanan and Karangasem which have the lowest demand per capita. Meanwhile, in “PV only with FIT 2030” shows cost saving improvement ranging from 18% to 117%. Therefore, these results indicate introduction of FIT brings significant economic benefit for “PV only 2030”.

3.2 PV+EV integration

The integration of “PV+EV” brings significant improvements to the scenarios for both “Without FIT” and “With FIT” with economic benefits. In “PV+EV without FIT”, cost saving ranges between 4% to 9% (Fig. 5). On the other hand, in “PV+EV with FIT”, the range of cost savings increases to between 20% to 120% in 2030.

As EV battery can provide electricity to the area even at night, “PV+EV” brings high self-sufficiency ranging from 58% to 76% and 81% to 98% for “without FIT” and “with FIT”, respectively (Fig. 6). In contrast, “PV only” in the year 2019 and 2030 cannot even reach 50% of self-sufficiency for both “without FIT” and “with FIT” scenarios.

The carbon emission reduction in “PV+EV” scenarios increase 1.5 to 3 times higher than those of “PV only 2030” (see Fig. 7). This is because EV batteries can supply zero emission electricity for nighttime power demand, resulting in less dependency to the carbon intensive grid electricity. “PV+EV without FIT” reduces carbon emissions by 59% to 77%, and “PV+EV with FIT” reduces carbon emissions by 82% to 99%.

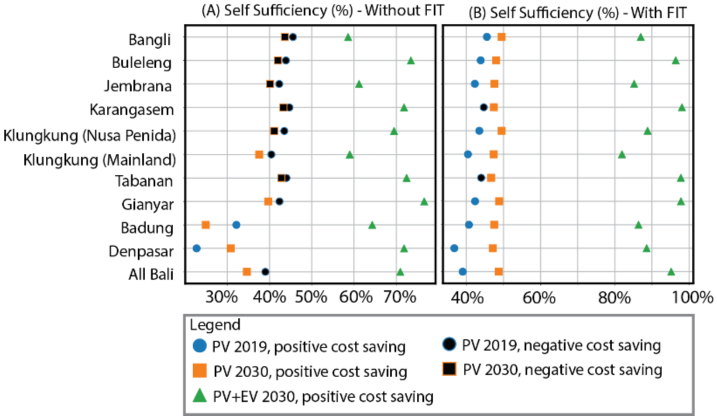

Fig. 5 Self-sufficiency of all scenarios

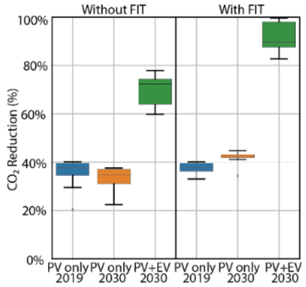

Fig. 6 CO_2 reduction in all Scenarios

3.3 Result in “All Bali”

For the “All Bali” analysis with aggregated demands, rooftop area, number of EVs, etc., the produced energy from the technology is considered to be seamlessly transferred between each area. In this context, any areas that produce excess electricity can instantly supply other areas that needs electricity. In the “PV only” scenario in 2019, “All Bali” has economic benefits only for the “With FIT” case (Fig. 5, Fig. 6). In “PV only without FIT” in 2030, “All Bali” have 5% cost saving, and the number rises to 38% for the “With FIT” case.

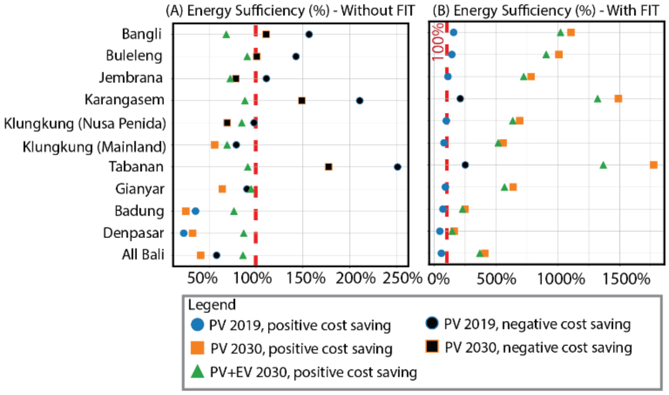

Fig. 7 Energy sufficiency for all scenarios

Next, in “PV only with FIT” and “PV+EV with FIT” in 2030, the energy sufficiency of all areas is more than 100% (see Fig. 7). In “All Bali”, the energy sufficiency is approximately 408% and 368% for “PV only 2030 with FIT” and “PV+EV with FIT 2030” respectively. This signifies Bali has large rooftop PV potentials not only to supply own demands but also to supply a large amount of clean electricity to the other islands in Indonesia.

4. DISCUSSION

4.1 Realizing Bali net zero emission

The Provincial Government of Bali has declared its target to be net zero emission by 2045, which is 15 years ahead of Indonesia’s 2060 net zero emission target [25]. This pledge shows commitment and the necessity for Bali to quickly shift from fossil fuels to renewable energy.

In this study, we found “PV only 2030” have minimum economic benefits if the technology is applied independently for different regions, but the benefits increase if the system is applied in a wide scale (Fig. 5). Further, realizing deep decarbonization of Bali is possible by adopting “PV+EV” in a wide scale with large economic benefits in 2030 (Fig. 5 & Fig. 6). It is also noted that the NPV of “All Bali” is larger than the summation of NPVs of each administrative area for the individual analyses owing to increased efficiency.

4.2 *Significance of incentives for renewable energy*

The Government of Indonesia have recently abolished the incentive policy for residential rooftop PV [26]. This policy change created less appetite for Indonesian households in installing rooftop PV [27]. “PV+EV” may bring an alternative solution to the issue because not only it can store surplus PV electricity for the nighttime demand but also it can bring economic benefits (Fig. 5). “PV+EV” system can reduce 72% of carbon emission even without FIT (Fig. 7), but with FIT further deep decarbonization can be achieved with 96% of CO_2 emission reduction (Fig. 7). In addition, high energy sufficiency in “PV+EV with FIT” indicates that Bali can be a province that is self-sufficient for their own energy and likely can contribute on other regions through surplus electricity (Fig. 8).

Currently, the Government of Indonesia heavily subsidizes fossil fuel to make electricity price to be cheap. In 2023, the subsidy increased by three times higher than that in 2021 [28]. A reform for the fossil fuel subsidy is necessary as most of these subsidies primarily benefits the middle and upper class [29]. Through the reform of subsidy allocation, renewable energy adoption can be accelerated, and clean technology will become a norm in society.

5. CONCLUSIONS

With the expected future price decline of PV, rooftop PV system can bring increased economic benefits and decarbonization in Bali. If rooftop PV is applied in a wide scale, even for the “without FIT” case, cost saving reaches 5% with 30% CO_2 emission reduction in 2030. However, by integrating rooftop PV with EV battery for all the regions of Bali in 2030, cost saving increases to 8% and CO_2 emission reduction reaches to 72% without FIT. Notably, PV+EV adoption in Bali can reduce approximately 96% of CO_2 emissions if it is induced with FIT owing to larger optimal PV capacity. This signifies that Bali’s net zero emission target can be realized with reforming the current subsidy system to prioritize renewable energy over fossil fuels.

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