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Techno-Economic Analysis of Rooftop PV Plus EV System Toward Carbon Neutrality in Shenzhen City

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ABSTRACT

Urban decarbonization is a crucial step for China to achieve the goal of carbon neutrality. It is essential to adjust the energy structure and increase the proportion of new energy in the energy structure for cities. This paper aims to construct a technical and economic model to evaluate the emission reduction potential and economic impact of the photovoltaic (PV) and photovoltaic plus electric vehicles (PV+EV) systems in Shenzhen city. It is found that both systems can reduce emissions, the PV+EV system can reduce carbon emissions by up to 45%, and the costs can be reduced by 25%. The construction of this system is cost-effective for achieving the carbon neutrality target.

Keywords: rooftop photovoltaic, PV plus EV system, carbon neutrality, techno-economic analysis

NONMENCLATURE

Abbreviations	
ICE	Internal combustion engine
EV	Electric vehicle
PV	Photovoltaic
NPV	Net present value
FIT	Feed-in-tariff

1. INTRODUCTION

The IPCC Sixth Assessment Report, the first working group report pointed out that unless rapid and large-scale greenhouse gas reduction actions are taken immediately, the global temperature control target of 1.5°C will not be achieved[1]. China pledged at the United Nations General Assembly last September that China would reach peak carbon dioxide emissions by 2030 and achieve carbon neutrality before 2060.

The IPCC report points out that global cities account for 71% to 76% of carbon emissions[2]. In this regard, a rapid decarbonization of cities especially for the energy system is critical for achieving the national carbon neutrality target.

Accelerated development of non-fossil energy sources such as photovoltaic and wind power are key to the decarbonization of urban energy systems. Among them, maximizing the use of distributed photovoltaic in a cost-effective manner is a promising area of urban energy transformation.

This article selects Shenzhen as the main research object. With the help of local car company BYD, Shenzhen has great prospects for the development of electric vehicles. As of the end of 2020, the number of new energy vehicles has ranked first in China. As a populous city, Shenzhen has entered the post-industrial stage. The potential for energy efficiency improvement has been realized by a large extent, which highlights the importance of adjusting the energy structure. Rooftop PVs systems use urban rooftops to develop distributed PVs, which effectively utilizes solar energy without sacrificing natural lands.

The PV+EV concept combines the city's rooftop photovoltaic and electric vehicles as batteries using bi-directional charging to help cities cost-effectively achieve their carbon neutral goals [13].

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This article compares and evaluates the technical potential and economics of the rooftop PV only and rooftop PV+EV coupling system in Shenzhen city, identifies the most cost-effective photovoltaic potential and emission reductions, then finally puts forward relevant policy recommendations.

2. METHOD AND DATA

2.1 Methodology

To evaluate the city's emission reduction costs and decarbonization potential, this study develops a techno-economic model [3,4], combined with the optimization process of power supply and demand matching (Fig.1).

The technical model includes two different photovoltaic utilization methods (PV only and PV+EV), combined with natural conditions such as insolation, temperature, etc., to simulate hourly photovoltaic output curves. The economic model conducts a cost-benefit analysis, calculates the cash flow, net present value, etc., and simulates optimal PVs capacity when the net present value is the largest.

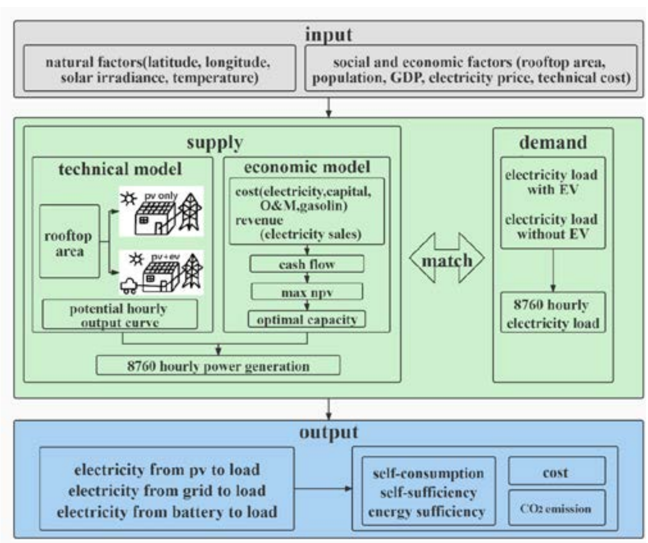

Fig. 1. Techno-economic analysis framework

2.2 Scenario design

This study uses 2020 as the base year. The base scenario assumes that no PVs were installed, all passenger cars are ICEs. Compared to the base scenario, this research designed three PVs development scenarios: 2020 PV only, 2030 PV only, and 2030 PV+EV. The PV only system shows that only the rooftop PVs are developed, while the PV+EV system combines photovoltaic and electric vehicles as the battery. The 2020 PV only scenario describes the decarbonization potential and emission reduction costs based on current rooftop area for PVs development potential. Considering the population growth and income rise, future electricity load in Shenzhen is projected to increase by 34%. At the same time, the PVs capacity increases as the capital investment cost decreases and the roof area continues to grow slowly.

To test the sensitivity of the results to electricity price, each scenario further includes the situation when there is a feed-in tariff and when there is none, so a total of six scenarios are composed. As Shenzhen is still in the urbanization stage and its economy continues to grow, some parameters will change from 2020 to 2030, some assumptions, such as population, roof area, will increase, while other parameters such as oil prices and electricity bills are assumed to be stable. In the 2030 PV+EV scenario, this research assumes that all ICEs will be replaced with EVs. Even if this assumption is difficult to achieve by 2030, this research focuses on evaluating the potential.

2.3 Parameter assumption

Table1. Parameter assumptions in 2020 and 2030

Parameters	2020	2030
Population (million)	17.56	18.5
Electricity load (million kWh)	98300	[132000,138077*]
Rooftop area (km^2)	270	330
Annual driving distance (km)	12000	10700
PVs capital cost ($/Wdc)	0.84	0.5
EVs battery cost ($/kw)	91	
city area (km^2)	1997.47	
CO_2 emission factor of gasoline (kgco2/L)	2.36	
CO_2 emission factor of electricity of grid emission coefficient (g-CO_2/kWh)	245.7	
FIT price	0.07	
Gasoline price ($/L)	1.015	
Gasoline vehicle efficiency(km/L)	12.6	
EVs efficiency (km/kWh)	5.3	
O&M cost ($/kw-year)	7.975	
Passenger vehicles population	3010000	
Electricity price ($/kWh)	0.10	

sources: The above parameters are assumed to refer to the following documents[5,6,15,7–14]

Note: *It is assumed to be 132000 million kWh for the 2030 PV only scenario, and 138,077 million kwh demand for the 2030 PV+EV scenario, with more electricity demand for more EVs. Other assumptions remain consistent with the PV+EV scenario.

3. RESULT

3.1 *2020 PV only scenario*

Based on the annual average hourly data, PVs start to generate power at 6 a.m., then reach the peak at 1 p.m. and gradually decrease until 6 p.m. At noon, the power generation by PVs exceeds the load. Under the base scenario, there will be a waste of PVs electricity (Fig. 2). In 2020 PV only and when there is a feed-in tariff, the abandonment will be exported outside the city through the grid. Residents can earn money by exporting additional photovoltaic power to the grid.

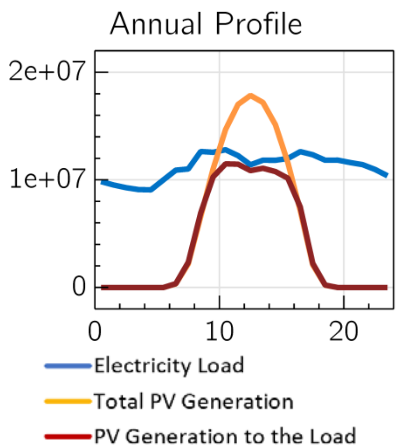

Fig. 2. 2020 annual match between PV and load

Here are some critical indicators for evaluation, which are self-consumption, self-sufficiency, and energy sufficiency (Fig. 3a). The demand is strong from May to August, but the photovoltaic production is low, generating an enlarging energy gap (Fig.3b). From the perspective of each month, there is a fluctuating relationship between photovoltaic and load. The energy efficiency will be lower from May to August due to more rainy days and less sunshine. While the biggest self-sufficiency performance happens in April, which shows the record of self-sufficiency.

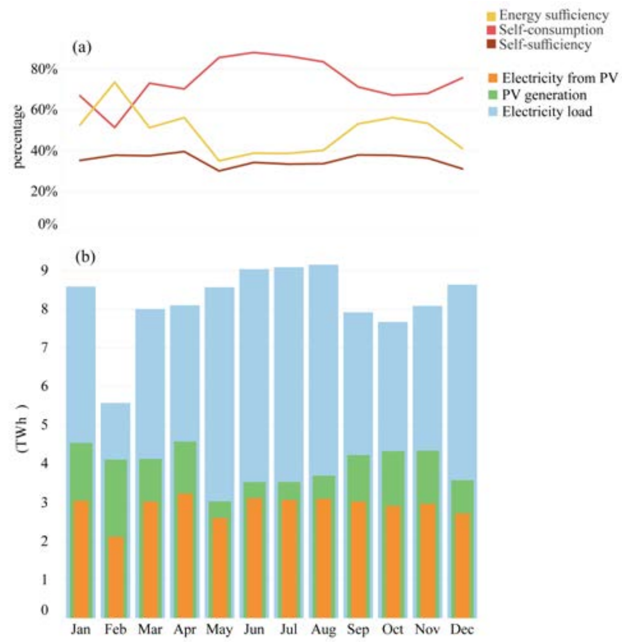

Fig. 3. 2020 monthly key indicators(a) and PV generation, load, and electricity from PV(b)

3.2 *2030 PV only and 2030 PV+EV scenarios*

Compared to 2020, it is assumed that the electricity load will increase by 34%, the roof area will increase by 22.2%. Due to the scarcity of land resources in Shenzhen city, the growth of electricity load is higher than PVs potential. From May to August in 2030, it is difficult for PVs production to reach peak power consumption (Fig. 4a). In other months, additional electricity will be generated and exported to the grid. Energy efficiency will be relatively lower (Fig. 5).

In the PV+EV scenario, the PVs generation at noon is stored in the EVs and will be released for electricity uses in the city at night (Fig.4b). Because in the PV+EV scenario, the extra photovoltaic is not transmitted to the grid but the EVs battery. This part of the electricity can be used at night so that the self-sufficiency will be higher (Fig. 5). In February, all electric vehicles will be fully stored, and there will be a small amount of extra electricity, and a small part will be exported to the grid.

With the further development of the photovoltaic industry, photovoltaic subsidies have also declined. This study explores the situation when there is no photovoltaic feed-in tariff.

When there is no FIT, residents have no incentive to export excess electricity to the grid for sale. In this case, NPV presents an inverted 'U' curve of rising first and then falling, then the optimal capacity level is determined when the maximum NPV is reached.

In the PV only scenario, the installed capacity will drop significantly, which is caused by the drop in NPV (Table. 3).

Without FIT, residents have no incentive to upload additional PVs generation to the grid, which will lose electricity revenue. With the decrease of NPV, the installed capacity and power generation will decrease. Other indicators will drop, except for self-consumption. Except for the energy sufficiency and self-sufficiency, other indicators will be higher than the PV only scenario under the 2030 PV+EV scenario. The self-sufficiency, emission reduction potential, and cost will all decrease, the self-consumption will increase significantly. In the PV+EV scenario, the cost will be reduced by 25%, and the emission reduction rate will be 45% compared to the base scenario. In the PV only scenario, the cost is only reduced by 5%-9%, and the emission reduction will be only 28% (Fig.5).

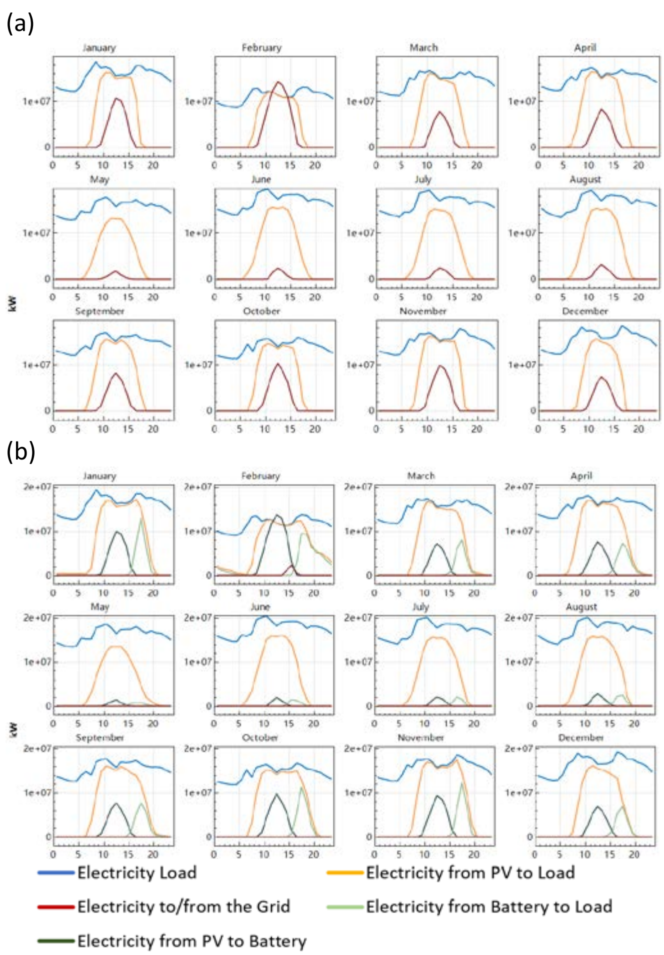

Fig. 4. Comparison of hourly PV generation and destination, EV charge and discharge and load between 2030 PV only (a) and 2030 PV+EV (b) scenarios

Table3. Economic assessment results and load in different scenarios

With FIT	2020 PV only	2030 PV only	2030 PV+EV
Discounted payback years	10.8	5.4	6.1
PV capacity (GW)	38.6	47.1	47.1
Annualized NPV (Million $)	587.4	1390.6	1282.2
Without FIT	**2020 PV only**	**2030 PV only**	**2030 PV+EV**
Discounted payback years	10.7	6.4	6.3
PV capacity (GW)	24.0	43.0	47.1
Annualized NPV (Million $)	379.5	1012.3	1278.6

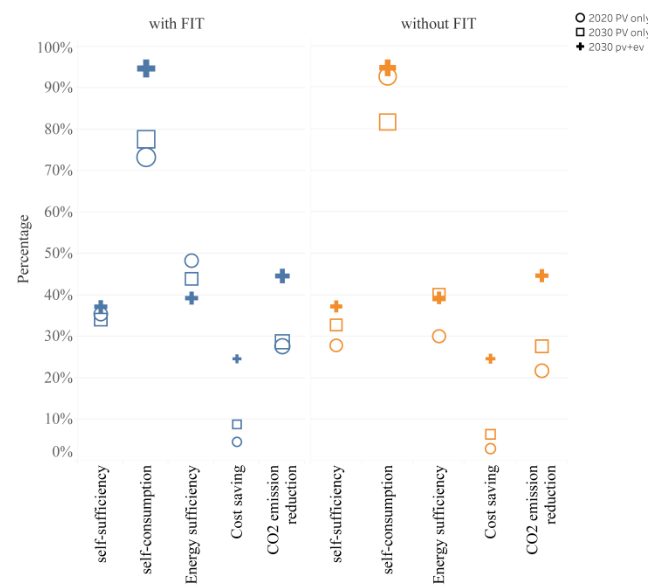

Fig. 5. Comparison of energy, economic and emission reduction impacts of PVs system between scenarios

4. CONCLUSION AND DISCUSSION

This paper aims to evaluate the rooftop PVs system and PV+EV potentials for Shenzhen City. The results show that the PV+EV system is of great significance for cities to reduce carbon emissions toward the carbon neutrality target. Moreover, with the development of the photovoltaic industry and the decrease of cost, the facade photovoltaic can also be developed in the future. At that time, the installation potential will increase significantly, and the decarbonization potential of the PV+EV system will be more significant.

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