Energy Proceedings
2022
ISSN 2004-2965

SolarEV City concept in Paris and Ile-de-France: a promising idea?

Deroubaix P[1,2], Kobashi T[3,4*], Gurriaran L[2], Benkhelifa F[5], Ciais P[2], Tanaka K[2,4*]

1 École Polytechnique, Palaiseau, France
2 Laboratoire des Sciences du Climat et de l'Environnement (LSCE), IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, Gif-sur-Yvette, France
3 Graduate School of Environmental Studies, Tohoku University, 468-1, Aoba, Aramaki, Aoba-ku, Sendai, 980-8572, Japan
4 Earth System Division, National Institute for Environmental Studies (NIES), Tsukuba, Japan
5 NEXQT, City Climate Intelligence, 9 rue des Colonnes, 75002 Paris, France
*Corresponding authors

ABSTRACT

Since the Paris Agreement adopted in 2015, global societies are increasingly aware of the needs to limit global warming to 1.5 °C and reach global carbon neutrality by 2050. However, current commitments of global societies are not sufficient, party owing to the lack of cost-effective decarbonization measures. The SolarEV City concept is proposed for cost-effective urban decarbonization combining rooftop PV with EV through bi-directional charging in a city scale. In this study, we conducted techno-economic analyses to test the concept in Paris and Ile-de-France. PV+EV systems are found to add value to rooftop PV systems raising self-consumption and self-sufficiency, when the roof coverage by PV is reached to 50-60% for Paris and 20-30% for Ile-de-France, allowing to bypass expensive stand-alone battery storage. The system allows CO_2 emissions reduction through accelerated development of EV.

Keywords: photovoltaics, electric vehicles, urban decarbonization, energy systems, V2H, V2G

NONMENCLATURE

Abbreviations	
V2H	Vehicle to Home
V2B	Vehicle to Building
V2G	Vehicle to Grid
PV	Photovoltaics
EV	Electric Vehicles
ICE	Internal Combustion Engine
FIT	Feed-in-Tariff
SAM	System Advisor Model

1. INTRODUCTION

Increasing low-carbon energy technologies and improving energy efficiency, as well as electrifying the transport system, are major pillars of decarbonization. The SolarEV City approach [1,2], a novel concept that makes use of synergies between rooftop photovoltaics (PVs) and electric vehicles (EVs), supports such pillars. When both technologies are combined (PV+EV), EVs can not only reduce the reliance on fossil fuels in the transport sector but also serve as electricity storage to address intermittency issues with PVs. Numerical modelling studies found that such approach could provide various benefits in Japanese regions and cities such as Kyoto [1,2]. In response to the interest from municipalities and industries (e.g. automobile manufactures), community-level experiments are taking place [3]. As of today, however, such a concept has been largely unexplored in Europe, despite that it may go hand in hand with region's core policy priorities to tackle climate change.

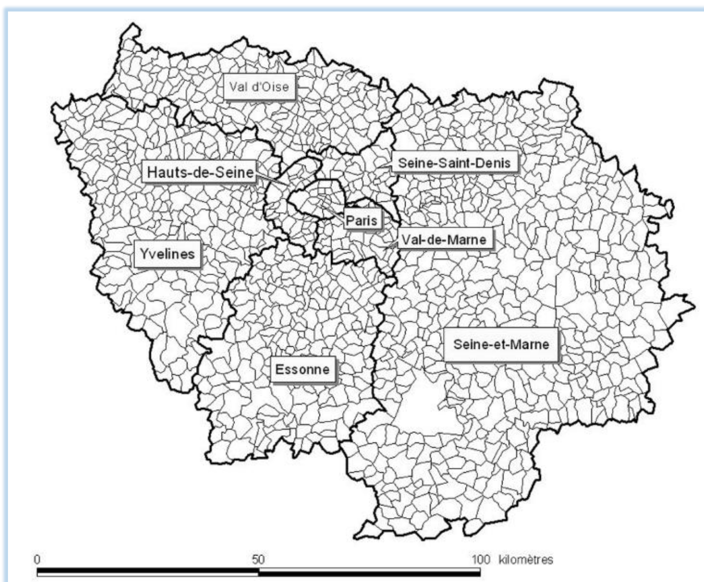

Fig. 1 Map of Paris (center) and Ile-de-France (all area)

This study aims to clarify the potential of the SolarEV City approach in Paris and Ile-de-France, the region surrounding Paris (Fig. 1, Table 1). Note that, although the administrative region Ile-de-France includes Paris in the official term, we do not consider Paris within Ile-de-France for the sake of analysis. These two areas account for 18.9% of the population of metropolitan France, the largest metropolitan area within the EU, but provide a contrast set of study sites, an urban area with a high population density and a suburban area with a relatively low population density. There are also differences in policies between the two areas. At the national level, France will ban the sale of gasoline and diesel vehicles beginning in 2040. Paris will start an equivalent ban 10 years earlier.

Table 1. Statistics of Paris and Ile-de-France

	Paris	Ile-de-France
Population	2,175,601	12,174,880
Area (km^2)	105.4	12,011
Population density (thousand people/ km^2)	20.6	1.0
Roof area (km^2)	31	402
Roof area per capita (m^2)	14	33

According to the Climate Energy Regional Agency (AREC), the region also adopted a regional energy-climate strategy in 2018 in which it set a goal of reaching 40% of renewable energy in its energy mix by 2030 (compared to less than 5% in 2019). The city of Paris has announced that it will achieve by 2050 an energy mix composed of 100% renewable energy, of which at least 20% will be produced locally. The city of Paris is thus deploying solar power plants on the roofs feeding the network.

One of the main disadvantages of PV is its intermittency. To compensate for the intermittency, PV can be combined with EV with the use of bi-directional charging as passenger vehicles are being parked most of the time. The technology is called vehicle-to-home (V2H) for residential use or vehicle-to-building (V2B) for other buildings [4]. The SolarEV City concept is to develop this idea at the level of a city, and it has shown that rooftop PV + EV systems can supply 53%–95% of electricity demand in large Japanese cities with CO_2 emission reduction of 54%–95% and energy cost saving of 26%–41% [1]. In this study we analyzed Paris and Ile-de-France to explore the potentials of SolarEV Cities in Europe.

2. Methods

We employed a methodology developed in our previous studies [1,2]. Therefore, the methodological description here is kept concise. In this study, we focused on three illustrative scenarios: "PV only", "PV + batteries" and "PV + EV". "PV only" assumes a penetration of standalone building rooftop PV. "PV + batteries" assumes a penetration of residential rooftop PV connected with batteries. Finally, the PV+EV scenario assumes rooftop PV combined with electric vehicles with bi-directional charging. In the PV + EV scenario, all vehicles are assumed to be electric and connected to V2H or V2B systems.

We studied these three scenarios for two areas: Paris "intramuros", i.e. the city without its suburbs, and Ile-de-France, which is the region around Paris (Fig. 1). We considered two periods: 2019 for PV only and 2030 for the three scenarios. Between the two periods, only the prices of technologies are different to illustrate the effects of cost decline. For each scenario, we tested a different set of hypotheses on the roof coverage, V2H system prices, electricity prices and feed-in-tariffs (FIT).

To assess the viability of the renewable energy technologies in the scenarios, we conducted techno-economic analyses. We used a publicly available energy-economic software, SAM (System Advisor Model; version 2020.11.29 Revision 2), developed by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL).

For the 2030 baseline scenario for Paris, we assumed a full penetration of EVs ("100% EV"), given the recent implementation of policies aimed at making Paris' fleet 100% electric by 2030 [5]. On the other hand, Ile-de-France has not seen an implementation of equivalent policies yet, but the policy debate is moving in this direction at the national level, with the law "LOM" (Law on Mobility Orientation). Ile-de-France has set the objective of no diesel in 2030. Therefore, we assumed that only diesel vehicles would be replaced by EVs in the baseline scenario of Ile-de-France. Under this alternative baseline scenario, cost benefits induced by saving fuel consumption were considered in the analysis. Note that with the region's stated goal of no diesel by 2030, we consider the saving only for gasoline fuel.

In addition to cost savings, we calculated other indicators: energy sufficiency, self-sufficiency, self-consumption, and CO_2 emission reduction. Energy sufficiency is defined as the total amount of electricity produced by PV in one year divided by the annual electricity demand. But the production does not always match the demand and there could be losses. Self-sufficiency is the actual electricity coming from PV consumed in a year divided by the annual demand. Self-consumption is the proportion of PV electricity that is consumed in the area to total annual PV generation. We used hourly weather data to generate PV electricity generation. We rescaled the data so that it matches the observed capacity factor. In SAM, we chose the tilt angle of the panel to be 40° and its azimuth to be 180°.

The hourly electricity demand for Ile-de-France is available for the whole year 2019 by "Réseau de Transport d'Electricité" (RTE)[6]. For 2030, we rescaled the demand by a factor of 1.08 to match the electricity demand of EV. On the other hand, data for hourly electricity demand were not available for Paris. For Paris, we thus used the hourly electricity demand of Ile-de-France multiplied by a factor of 0.18 based on the annual demand data of two regions [2].

Concerning the prices of electricity, we used the national mean prices for the year 2019, given by EDF, the main supplier for France. There are two different tariffs: the base tariff, and the "heures pleines / heures creuses" (HPHC) tariff, which means higher prices during the day and lower prices at night (from 11pm to 7am in Ile-de-France). The HPHC tariff is more beneficial for PV owners because the PV generates electricity during the day. We used base price in our main results based on the mean of 2019 prices, 0.15€/kWh. When we considered FIT, we used 0.10€/kWh for Ile-de-France, and 0.06€/kWh for Paris.

The roof area of Paris and Ile-de-France are 31 and 402 km^2, respectively. To convert the roof area into the maximum capacity of PV, we assumed an estimate of $5m^2$/kWh. In 2019, the price of a PV-system (linked to the grid) depends on the surface area of panels. For Paris, we used the price for 10-100 kW. Corresponding area covers 54% of the total roof area of Paris. For Ile-de-France, we used the 5-10 kW price. Maintenance prices were given as 22.5€/kW/yr [7] and assumed to be the same in 2030. BloombergNEF (BNEF) estimates the global price for fixed-axis utility scale PV systems in 2030 to be 69% of 2020 prices [8]. We applied the same reduction to our residential prices (Table 2).

Concerning the price of batteries, we used the global prices of energy storage given by BNEF and their projection in 2030. A currency conversion rate of 1.12US$/€ was used (2019 mean). We used Renault Zoé as a representative EV for our analysis, an EV of the largest number of sales for EVs in France since at least 2013. The vehicle is equipped with a 52kWh battery. We set the power charge to 7kW, which is the classical home charge with a Wallbox. Discharge can be expected with the same power.

It was projected that Europe will reach price parity between EV and ICE during the period 2025-2030 [9]. This led us to consider only the additional cost of the V2G system in the PV+EV scenario compared to the PV only scenario in 2030. In other words, we did not account for the cost of shifting from ICEs to EVs, since such a shift can be considered to occur irrespective of the chosen scenario. V2H systems are not commercialized yet in France. We assumed different prices from 0 to 50 €/kWh in 2030. In comparison, the price in Japan is projected at around 20.5 €/kWh in 2030 [1]. The costs of battery replacement (80% of original capacity as a threshold) are included in EV price. We limit the use of batteries only in the range from 50 to 95% of their charge to prevent battery degradations.

Table 2. Cost of PV and batteries

	Paris	Ile-de-France
PV system cost, 2019 (€/W)	1.4	1.9
PV system cost, 2030 (€/W)	0.96	1.31
Batteries, 2019 (€/kWh)	598	
Batteries, 2030 (€/kWh)	237.5	

We calculated the reduction of greenhouse gas emissions to assess the environmental benefits. Our main result first considered the emission reduction associated with electricity production. The reduction of greenhouse gas emissions were calculated in CO_2-equivalent, using the life cycle estimate of 55 gCO_2eq/kWh. For electricity, we used the mean emissions for the French electricity mix in 2019, which is 60.7g CO_2eq/kWh [10], hence abatements of 5.7gCO_2eq/kWh. We also considered life cycle emissions of EV and ICE: 247gCO_2eq/km for gasoline and 62gCO_2eq/km for electric vehicles [11]. Those values were used to compare the scenarios of PV+EV to the baseline scenario for Ile-de-France. Because the city of Paris will ban ICE in 2030, the baseline for Paris is "diesel replaced by EV" baseline.

3.Results

3.1. Paris

Paris is characterized by high electricity demand with relatively small rooftop area. The PV only scenario can bring benefits already in 2019. However, there is an economically optimum installed capacity, for 2019 and

2030. Above 50% of roof coverage, FIT becomes important to maintain cost savings. The projections with and without FIT depart at the point where the production exceeds the demand. Above this threshold, self-sufficiency diverts from the energy sufficiency. Also, from this point, self-consumption starts to decline. The optimum is higher in 2030 than in 2019.

Therefore, storage becomes relevant with a roof coverage greater than 50%. With the presence of FIT, storage brings benefits only with a roof coverage greater than 50% combined with low storage price. Thus, the PV + batteries scenario never brings benefits, because of high costs in reality. Concerning PV+EV, with no additional costs, benefits come above 50% coverage. With additional costs of 10€/kWh for V2G, a coverage of at least 70% is needed.

3.2) Ile-de-France

Ile-de-France is characterized by lower energy demand per area than Paris, having relatively large rooftop area. With or without FIT starts to make a difference with a roof coverage of above 25%. With 2019 PV prices or without FIT, the cost savings are negative. When roof coverage is larger than 25% of roof coverage, the production is greater than the demand in many hours of the year, resulting in a lower self-consumption and a larger difference between the self-sufficiency and the energy sufficiency.

In Ile-de-France, the storage becomes essential when the roof coverage exceeds 25%. However, due to their cost, batteries do not allow saving costs in our scenarios. However, there are cost savings in the PV+EV, which depend on the additional cost of V2H systems compared to normal charging installations, with or without FIT. The PV+EV scenario allows to keep a high self-sufficiency and a high self-consumption with a roof coverage greater than 25%.

4. Conclusions

Our model calculations showed that developing rooftop PV could bring economic benefits for both Paris and Ile-de-France. It was estimated to be the case already in 2019 and the benefits could increase in 2030 owing to declining costs. Up to a certain roof coverage, – that is, 50-60% of the total roof area for Paris and 20-30% for Ile-de-France, when the production does not exceed the demand, FIT or storage becomes necessary. The combination of EV with PV by V2H or V2B systems developed at the city or region level are found to be effective. They can add value to PV systems and keep a high self-consumption and self-sufficiency, particularly when the minimum roof coverage is reached owing to increasing excess electricity. The benefits depend on the prices of V2H or V2B compared to classical charging installations. It also allows bypassing the classical battery storage, which is too expensive to be profitable. Finally, the electricity production is already low carbon in France due to the reliance on nuclear power. Solar panels alone do not allow large GHG emission abatements per the investment needed. But the PV+EV scenario facilitates further GHG emission abatements directly or indirectly from the use of EV relative to that of ICE.

While the SolarEV City concept can face certain implementation barriers in Paris and Ile-de-France and may only lead to a modest reduction in GHG emissions in France, it can improve overall energy efficiencies by making use of PVs supplemented by the storage capacity of EV and may facilitate a low-carbon shift in transport as part of urban transformation. The SolarEV City concept can be one of the pillars for transformation toward sustainability and jointly addressed with other pillars. Our analysis suggested that Ile-de-France with relatively larger rooftop area would be a promising venue for deploying the SolarEV City approach.

References:

[1] Kobashi T, Jittrapirom P, Yoshida T, Hirano Y, Yamagata Y. SolarEV City concept: Building the next urban power and mobility systems. Environ Res Lett 2021;16:024042. https://doi.org/10.1088/1748-9326/abd430.

[2] Kobashi T, Yoshida T, Yamagata Y, Naito K, Pfenninger S, Say K, et al. On the potential of "Photovoltaics + Electric vehicles" for deep decarbonization of Kyoto's power systems: Techno-economic-social considerations. Appl Energy 2020;275:115419. https://doi.org/10.1016/j.apenergy.2020.115419.

[3] Takeda Y, Nakai Y, Senoo T, Tanaka K. Designing a User-Centric P2P Energy Trading Platform: A Case Study—Higashi-Fuji Demonstration. Energies 2021;14:7289.

[4] Pearre NS, Ribberink H. Review of research on V2X technologies, strategies, and operations. Renew Sustain Energy Rev 2019;105:61–70. https://doi.org/10.1016/j.rser.2019.01.047.

[5] Paris. La Zone à faibles émissions (ZFE) 2022. https://www.paris.fr/pages/la-zone-a-faibles-emissions-zfe-pour-lutter-contre-la-pollution-de-l-air-16799 (accessed May 11, 2022).

[6] Consommation quotidienne brute régionale. Open Data Réseaux Énergies. 2022.

[7] ADEME. Etat du photovoltaïque en FRANCE 2019 2021. https://www.debatpublic.fr/sites/default/files/2

021-07/HORIZEO-pvps-etat-photovoltaique-france-2019.pdf (accessed May 12, 2022).
[8] BNEF. New Energy Outlook 2019. 2019.
[9] Transport&Environment, BNEF. Hitting the EV inflection point. 2021.
[10] ADEME. Base carbone 2022. https://data.ademe.fr/datasets/base-carbone(r) (accessed May 12, 2022).
[11] The Shift Project. Étude de l’impact carbone de l’offre de véhicules. 2020.