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The feasibility of solar parking lots for electric vehicles

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A B S T R A C T

The direct coupling of solar electricity with electric vehicles is very topical due to their many co-benefits, such as reducing the electricity flow into and from the grid. This work illustrates this solution using a park-and-ride lot outside Lisbon to study its solar energy potential to charge electric vehicles. The solar resource, its exploitation and coordination with the vehicles under different charging approaches are discussed in detail, using methods extendible to other cases. A genetic-algorithm optimisation was performed to maximise the solar energy generation. To ascertain the techno-economic feasibility of the concept, several sets of assumptions are analysed, including the use of energy storage and smart charging. For current market conditions, the payback time is found to be 14 years; a modest financial public incentive would significantly improve the project economics – making the payback drop to 7 years – enabling conditions to put this inescapable and green approach at the forefront.

1. Introduction

The growing global electricity consumption – the International Energy Agency estimates a 30% increase by 2040 [1] – creates concern on the sources of electricity production for the future. In order to not compromise the objectives of the COP21 agreement, renewable energy is seen as the main solution. The large amount of solar energy reaching the earth – 101 PWh per hour [2], which is about the same as the world annual final energy demand [3] – combined with the price competitiveness of photovoltaics (PV) is enhancing the role of this technology as part of that solution.

Alongside, the transport sector is also of concern, since it contributes significantly to air pollution and greenhouse gases (GHG) emissions. The replacement of internal combustion engine (ICE) vehicles for the much more efficient battery electric vehicles (EVs) is one of the possible measures to overcome this. However, EV charging must be based on a clean, fossil-free electricity [4].

In both PV and EV cases, the grid integration is an issue: their emerging penetration may jeopardise the grid reliability, causing stabilisation and flexibility problems. The main disadvantage of PV generation is its variability and uncertainty [5]. As for the EVs, they could cause a boost in electricity demand and overload the grid, degrade power quality and destabilise the electric system [6]. One way to avoid these issues is by charging EVs directly from PV. This integration should be carefully planned, using, for example, scheduled charging plans to coordinate both technologies [7].

By doing this, on the one hand EVs could be used as storage devices and dispatchable loads, helping the grid maintaining the supply-demand balance while allowing a larger renewable penetration [8]. On the other hand, PV production could also enable a larger penetration of EVs when they charge from it. This way there is no significant net-load increase in demand. Therefore, the appropriate charging strategy can allow not only a larger amount of solar energy into the power generation system, but also a higher EV penetration, improving at the same time the grid flexibility.

Decentralised photovoltaic power plants to satisfy the EV charging demand could improve the grid operation, while decreasing GHG emissions not only by themselves but also by supporting EVs adoption through infrastructures creation. This can be done by means of electric vehicles solar parking lots (EVSPLs), i.e., solar parking lots to charge EVs. This way the grid does not have to integrate a large photovoltaic capacity nor does it need a big reinforcement to satisfy the EVs' demand. The drivers' preferences align with this, since they regard EVs and solar panels as

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complementary [9].

The interest for EVs solar charging stations has been emerging in the literature, which was thoroughly reviewed in Ref. [10]; other reviews of technological aspects are provided in Refs. [11] and [12]. Below prior recent research on the topic is summarised.

1.1. Prior recent work

One of the most important objects of the (mostly simulation) studies concerns charging strategies, which may be of two types: uncontrolled, where the EVs start charging immediately when connected to a charger; or controlled, where the charging is scheduled according to certain criteria, such as energy price or available renewable energy. The latter implies the use of an optimisation algorithm with a certain objective function. Some studies address both strategies from a price perspective, as in Ref. [13], using a multi-agent approach; it was found that controlled charging adherents were responsive to charge with renewables when that choice was given. Ref. [14] shows that, to reach the same environmental target, uncontrolled charging requires a higher storage power and energy capacity than controlled smart charging.

A controlled charging plan works according to what is defined as objective in the analytical model. The most common models use a stochastic approach to model the EV charging (see Table 1). Often the optimisation function is the minimisation of costs (for the parking operator or EV owners) or maximisation of the use of renewable electricity.

Costs can be minimised in several ways, such as taking advantage of time-of-use tariffs, as in Ref. [15]. Ref. [16] compares demand response approaches in what regards grid stability, concluding that an approach oriented to time-of-use prices leads to reduced costs to the aggregator.

As to the maximisation of renewable energy use, Refs. [17] and [18] conclude that storage greatly reduces grid dependency. In Ref. [19] the authors use an optimised PV power extraction technique to get the most advantage of the solar charging. Power sources other than photovoltaics are also considered, for example wind in Ref. [20].

The solar charging stations can be either off- or on-grid. In Ref. [21] these two types of solar systems are optimised according to CO_2 emission reduction costs; it is concluded that the cheapest alternative is the smaller off-grid solution, but the grid-connected option, bigger, reduces the overall emissions the most. A similar comparison was performed in Ref. [22], but optimising the system lifecycle cost; the results showed that a grid-connected station with storage using a supply mix of on-site PV and diesel generated electricity was the most economical option, while the renewable off-grid system was found to be the most expensive.

An on-grid EVSPL may help the grid by behaving as dispatchable loads, feeding energy into it (vehicle-to-grid, abbreviated V2G) and providing ancillary services. From this viewpoint, Ref. [23] presents a fuzzy control method to optimize the schedule of EVs charging. Ref. [24] presents an EV charging scheduling aiming to comply with the grid capacity constraints.

A microgrid framework is also used to address EV charging plans, often considering several energy sources, as in Ref. [25]. The operational optimisation of microgrids is studied cost-wise in Ref. [26], for minimising the fuel consumption on a remote island; in Ref. [27], considering the impact of using different EV charging strategies; and in Ref. [28], investigating at what extent the V2G concept can minimise its cost.

The location and sizing of charging stations have also been addressed, since they can be determinant for the projects feasibility and its grid impact. Refs. [29] and [30] address this issue from the grid stability viewpoint, using an evolutionary-based optimisation technique with positive results.

Besides the energy viewpoint, the environmental and economic angles are also addressed occasionally. The environmental perspective is taken in a limited number of EVSPL studies, such as in Refs. [21] and [22]. The economic angle has been explored under different approaches, emphasising the standpoint of the operator [13], the EV user [27] or the overall grid operation [25]. Generally, these studies show a win-win economic situation for the parties involved on V2G services. The literature shows that EVSPLs are not yet financially attractive, presenting payback times between 17 and 26.5 years, mostly due to low revenues and high investment costs [31].

Table 1 makes a summary of the literature referenced above, categorising the studies according to their distinctive characteristics.

Table 1
Summary of the literature.

Characteristics of some solar charging stations' studies				
Grid connection	Off-grid			[21,22]
	On-grid			[13–30]
Charging strategies	Uncontrolled charging			[13,14,18,21–23,26,27]
	Controlled charging	Models	Stochastic	[16,21,25,27,28]
			Fuzzy control	[23]
			Multi-agent System	[13]
		Objective function	Profits maximisation	[13,15]
			Renewable electricity use maximisation	[13–15,17–20]
			Costs minimisation	[13,15,16,24,25,27–30]
			GHG minimisation	[21]
	V2G			[14,16,19,20,25,28–30]
Ancillary services				[13,16,23,29,30]
Other power/energy sources		Diesel		[16,22,25–28]
		Wind		[16,20,24,25,27–30]
		Stationary energy storage		[14,17,18,21,22,26,27]
		Fuel cell		[25,27,28]
Environmental analysis				[21,22]
Economic analysis				[13,15,16,21,22,24–30]