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A sustainable mobility strategy based on electric vehicles and photovoltaic panels for shopping centers

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Highlights

- A novel e paradigm for mobility sectors related to the shopping centers, based on PV panels and EVs was developed.
- The proposed system can cover about 45.7 % of the investigated shopping centre electric energy demand.
- At a regional scale, in the 2050 scenario the yearly reduction of CO_2 and energy consumption are 42.0 kt and 160.0 GW h, respectively.
- The economic results show a Simple Pay Back of 2 years and a Profit Index of 5.4.

Abstract

The transition from conventional centralized energy production to a distributed one may represent one of the solutions to reduce greenhouses emissions. The present work aims at proposing a novel approach for energy and environmental issues, related to the high density of vehicular traffic for shopping centers by introducing photovoltaic panels and electric vehicles into the energy system. In order to achieve such goal a specific case study was developed for the main shopping centers located in the Campania Region, South of Italy. Two well-known simulation platforms, EnergyPLAN and TRNSYS, were purposely integrated. TRNSYS is used to develop a dynamic model of a shopping and the outputs were used as EnergyPLAN inputs to evaluate the role that this sustainable layout can play within the different sectors. Environmental, energy and economic analyses are performed for three different scenarios including the baseline one at 2019, 2030 and 2050. The proposed system can cover about 45.7 % of the shopping centre electric demand. At a regional scale, in the 2050 scenario the yearly reduction of CO_2 and energy consumption are 42.0 kt and 160.0 GW h, respectively. The economic results show a SPB (Simple Pay Back) of 2 years and a PI (Profit Index) of 5.4.

Introduction

In the next twenty years, all the State Members of the European Community will be involved in an effort to reduce greenhouse emissions, aiming at the effects of global warming-related to climate change. In this framework, the use of energy is one of the main issues related to CO_2 emissions (Wasti & Zaidi, 2020). In particular, a huge effort must be performed to reduce the consumption of fossil fuels due to the mobility sector (dominated by petroleum 92 % (IEA, 2017)) and/or to enhance the use of renewable energy sources (Engo, 2019).

The trend of emissions due to the mobility sector shows a constant increase (it will rise by 54 % by 2035 (Office of Integrated Analysis and Forecasting, U.S. Department of Energy, & Washington, 2011)). This trend is only slightly mitigated by the recent improvements in the efficiency of the combustion engine of the vehicles. This is caused by an ever growth of transport demand of heavy vehicles (trains, flights and ships) and especially vehicular cars that currently represent the main sources for transport demand. Among the possible forecasted technology solutions, the electrification of the transportation sector by the use of Electric Vehicles, EVs, seems to be one of the most promising strategies (Jones & Leibowicz, 2019). The related issues to implement this strategy are twofold: i) the infrastructure to supply the electricity, which implies: the stability of the grid, the charging points and the possible renewable sources supplying the grid and ii) the Electric Vehicles (EVs). As for EVs, the evolution of this technology during the last twenty years appears very fast. According to the World Energy Outlook of 2019 due to the decision of the many governments to ban the sale of vehicles with conventional engines (diesel and gasoline) within 2040, the projections estimate 280 millions of electric vehicles circulating by 2040 against the current 5 million (IEA, 2019). As well as the related prices are significantly decreasing of about 14 %/year (from $1000 per kWh of storage in 2007 to $300 – 400 at present) (Nykvist & Nilsson, 2015). Moreover, the performance (in terms of power and costs if the incentives are considered) of the EVs are, nowadays, comparable with the ones of a common internal combustion engine (Weldon, Morrissey, & O'Mahony, 2018). Other problems seem to be the performance (durability) and the charging (-discharging) time of the battery, even if, the OEMs are investing billions of euros in developing the next generation of battery technologies. Among these, the "ultra-fast charging" (Store-dot, 2020) and the "energy-dense" (Kreiselelectric, 2020) batteries appear to be the most promising ones, whereas, the issue related to the long-time of charging found a possible solution with the Level 3 or "fast charging" which provides a delivered power of 50–62.5 kW ensuring an 80 % of charge in about 20 min (Goli & Shireen, 2014). Currently, the real issue that remains is the number of chagrining points e the related "charging strategy" (Gong et al., 2020). In Italy in fact, they account for 3200 by 2019, which is a very small amount considering other European countries. In Europe, by 2019, the ranking is led by Germany with about 20,000 public points. At the global level, the greater spread of recharge points occurs in China and the USA followed by Japan. Moreover, in Italy, most of the recharging points are slow (levels 1 and 2) located at homes and workplaces, and only 10 % are public accessible chargers (IEA, 2019).

As regards the infrastructure to supply the electricity to the EVs, the national grid is presently the most common source. With the increase of the electricity demand forecasted to reach about 25 % of the total energy consumption by 2040 (International Energy Agency, 2015), the emissions related to this vector appear to be a not neglectable problem, since the electricity continues to be mainly fossil fuel-based (68 %) (BP, 2015). To overcome this problem, the use of solar energy (about 101 PW h/hour (Singh, 2013)) combined with the use of photovoltaic panels, which are becoming more and more efficient and cheaper (Figueiredo, Nunes, & Brito, 2017), could become part of the solution to reach the European goals. In this framework, the development of solar parking lots appears a promising paradigm to increase the percentage of renewable energy (in particular PV panels) in electricity generation. The use of this simple solution shows several advantages: i) the land used to install the PV panels does not compete with other uses (Neumann, Schär, & Baumgartner, 2012); ii) in Italy, and especially in the Campania Region, the available space to install any kind of renewable energy conversion technology is very restricted; iii) the shadings, reduce the risk of damage from the sun, of parked cars (paintwork cracked, lower internal temperature providing more comforts for the users (Robinson et al., 2014) iv) the reduction of the CO_2 emissions related to the use of energy from buildings and vehicles. In particular, the equivalent CO_2 emissions of electric cars powered from the grid varies according to the electricity mix: 126–155 g/km if it is coal-based (which resembles those from a conventional vehicle); 67–84 g/km if it is half fossil and half nuclear and/or renewable energy-based; 0–4 g/km if it is half PV and half wind-based (Müller, Zachäus, & Meyer, 2017). Moreover, a recent study suggests that the use of EV results in an increase of the energy efficiency (Bellocchi et al., 2020). Thus, the use of EVs is recommended, from both energy and environmental points of view, even when the electricity is produced by fossil fuels.

Several works dealing with solar parking lots (SPL) can be found in the literature. Most of the works analyse the grid involvement in the infrastructure and the charging strategy. However, only a few of them, are involved in economic analysis, local storage, other power sources and environmental analysis. In reference (Birnie, 2009), the authors investigate the benefits related to the installation of SPL. They conclude that SPL are crucial in order to limit the peak capacity of the grid, required to match the electricity demand for EVs charging. In reference (Karmaker et al., 2018) analyse instead, the environmental and economic feasibility of hybrid renewable energy-based electric vehicle charging station in Bangladesh based on Solar PV and biogas generator, highlighting the significative contribution in the reduction of CO_2 emission (of about 35 % with respect to a conventional system) and the relatively low value of the SPB (3–4 years). In reference (Fazelpour et al., 2014), the location and the design of a solar parking serving 1000 vehicles for a theatre in Tehran is analysed. The work shows the integration of renewable and conventional fossil fuel sources. In particular, for this specific case study, authors found optimal capacities of 19 kW for PV, 30 kW for wind turbines and 520 kW for a diesel generator. Many business models of SPL are investigated in reference (Nunes, Figueiredo, & Brito, 2016), where a comprehensive review of several business models for different stakeholders is presented: non-profit organizations, industry, single businesses, shopping centers, utilities and public and government parking lots are reported. It worth noticing that there are even a large number of papers also investigate the stability of the grid with plug-in-electric vehicles (Khalil et al., 2017) underlying the role of the controller in the communication delay. As it is possible to note in literature there are several examples of solar parking lots exploring different aspects related to the feasibility of such systems, but there are no examples of a dynamic analysis of a system involving both the PV installation, shopping malls and electric vehicles. The above-mentioned literature highlight two important gaps:

- The analysis doesn't take into account the dynamic interaction between the buildings, the PV plants and the EVs (including the traffic model);
- All the case study develop an analysis related to a specific case study not exploring the possibility to replicate to other similar solution in the territory in order to quantify the potentially installable capacity in the energy system, thus, not bridging the gap between the planning phase and the design phase;

In order to overcome the lacks in the literature, the contribution of this paper is to present a comprehensive dynamic model of a solar parking lots exploring the possible interaction between the buildings, the PV plants and the EVs taking into account the possible deployment of such a strategy on similar buildings belonging to the service sector. An analysis of such interaction on the shopping malls can offer a high contribution to the energy savings and a potential reduction of the carbon emissions (even more if this analysis is applied to a high number of shopping malls) and could have important influences on shopping tendencies and customers' lifestyle if coupled with renewable energy supplying the next generation of electric vehicles. Shopping malls are rapidly developing in southern Europe because they can provide various services such as food conservation, marketing of products and improved comfort like air-conditioned area in arid climates (which causes high energy consumption) (El-Abd et al., 2018). A SPL in a shopping mall can also provide an extra service to the customers. In fact, with the spread of electric cars, SPL can also provide the charging of customers' vehicles while they are spending time in the mall. This additional service could lead to several advantages: i) lengthen the time spent by customers within the shopping centre, thus increasing the sales of the shops inside the malls; ii) improves the image of the shopping mall; iii) the columns could be equipped with digital screens on which they can pass advertising messages (source of income for the business hosting the column).

The present work presents an analysis of a shopping mall building in the Campania region (Italy) aiming to satisfy its electric consumption with a solar plant installed in the parking area. When a surplus electricity production occurs, it is delivered to the EV grid. The novelty introduced by the authors in this paper is twofold: the PV panels field and building are dynamically simulated, thus obtaining the interaction between the building of a shopping mall and the vehicular traffic. In particular, the novelty of the work is summarised in the following points:

- the development of a new approach for reaching a sustainable solution based on the use of electric vehicles;
- the energy synergy between the private transport sector and the private building sector, represented by the several large shopping malls located in the Campania Region;
- the optimal management of the solar renewable electric energy production for covering both the load of the electric vehicle and the heating/cooling load of the shopping malls;
- an optimized synergy between the private transport sector and the private building sector, smartly managing the electricity production for both the heating, cooling and transport purposes;
- to calculate the electric vehicle demand, a detailed transport model based on data obtained by a survey extended to different shopping is considered, taking to account a lot of variables depending on the time, such as i) the average of the kilometers travelled by vehicles to the shopping mall during the day; ii) the distance-weighted kilometers and the frequency of customers during the day; iii) the variation of the frequency of customers for the different days of the week and seasons of the year;
- the design of a novel energy system reducing the CO_2 emissions of the transport sectors and building sector in order to reach the European targets by 2030 and 2050;
- guidelines for designers and shopping malls centre owners, regarding the development of a novel energy system for the supply of the next generation of electric vehicles, with the related economic, environmental and energy advantages.

In fact, this work also includes an energy planning analysis, aiming at analysing the use of the novel proposed paradigm in the energy system of Campania Region. In particular, the analysis is performed for 15 similar shopping malls in the region obtaining a possible interaction of the surplus electricity production (SEP) from the PV panels on the stability of the grid and analysing the possible critical excess electricity production (CEEP). For the first time, all the models utilized, starting from the building till the energy system of the Campania Region, are dynamically simulated, thus obtaining very affordable results. The big challenge for this kind of structure is to get a sustainable strategy which can be also cost- effective with a reasonable payback period for this business sector. Moreover, SPL must be integrated into the energy system of the territory under investigation, avoiding issues on the net transmission line.

The paper is structured as follows: after the introduction, the second section describes the method through which has been carried out the analysis, the third section of the paper introduces the case study under investigation, in the fourth section the discussion of the results is carried out and finally the main conclusions are reported.

Section snippets

Method

This section shows the models utilized to carry out the analysis. In particular, the building and the PV systems have been simulated through the use of TRNSYS 17 software, the traffic model has been developed with an excel spreadsheet, while the model of the Campania energy system has been implemented in EnergyPLAN environment. The adopted method is summarised in Fig. 1. …

Case study

Italy is the third country with the highest gross leasable area of the shopping mall in Europe (Raphael Bointner, Agne Toleikyte, & Bogdan Atanasiu, 2014). The case study under investigation has been selected among a large variety of existing shopping malls in Campania region. A “regional centre” built in 2008 has been selected. It represents a typical example of this kind of buildings in the Campania region. It is featured by a GLA of 80.000 m^2 and a parking area of 245.000 m^2. The structure …

Results and discussion

In this section, the results of the carried out analyses are described. In particular, the discussion is performed considering the results achieved by the dynamic simulation model and by the EnergyPLAN model. The dynamic simulation results are presented analysing the energy consumption and the vehicle traffic for three scenarios, 2019, 2030 and 2050, where the yearly energy demand of the mall is the same, but the energy demand of the electric vehicles increases according to Fig. 6. In addition, …

Conclusion

The transition from a traditional energy system to a distributed one can contribute to improve the energy efficiency of the system and increase the penetration of electric renewable energies sources that strongly suffer from unpredictability. This transition process passes through two main steps:

1) selecting the optimal configuration of the new distribution network in terms of technologies involved and plant capacities …

2) design the optimal operational strategies of the network …

Both the steps can be …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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> …For commercial buildings [18], analyses the environmental, energy and economic impacts of increasing EV penetration. However, only a fixed PV capacity is used in Refs. [17,18], and EV charging control is not considered. To achieve the net-zero-energy target for office buildings, an energy management method including EV charging control is proposed in Ref. [19], and the energy and economic performances are assessed.…

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…In this context, different studies have been carried out in Italy such as, the authors [35] presented the optimization of biomass in a 100% renewable energy system and exchange of electrical energy with the national system, which guarantees a balance between import and export of electricity in Bozen- Bolzano (Italy). In the Campania Region, South of Italy in Ref. [36] the authors proposed an energy and environmental study, which includes photovoltaic panels and EVs, analyzing the high density of vehicles in shopping centers. Osimo (Italy) in Ref. [37] study the possibility of reducing CO2 emissions produced by urban devices, to determine the achievable degree of self-consumption and the reduction of CO2 emissions.…

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