Design of a Smart Car Park with PV generation and BESS for Grid-on and Grid-off Operation. The SMARTEP Project

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***Abstract*—The paper presents the design state of a smart car park shelter for electric vehicle in the campus of the University of Palermo. The car park is supplied by the main grid and by a 40 kW photovoltaic system and is equipped with a Li-ion battery storage system with capacity 42 kWh. The hybrid plant is designed in order to operate both in connection with the main grid and in stand-alone mode, supplying, in this case, all car park's loads and providing one recharge to an electric vehicle. Moreover, the energy storage system and, eventually, the battery of one or more cars with V2G technologies, can be managed for providing ancillary services to the grid. In the paper, the design of the system and the choice of all components is presented. Finally, the environmental impact of the diffusion of such installations on the energy system is discussed.**

Keywords—smart parking, electric vehicle, EVH, batteries, storage.

I. INTRODUCTION

The integration of EVs in the electric power system and in the energy and ancillary services markets has been a hot topic in these last years. In [1]-[2], the authors present an interesting technical review on this topic debating on both the market and renewables integration aspects and the integration with transportation infrastructures. In [3], a charging control strategy for EVs is proposed considering both price signal and the voltage level at the point of connections of the EVs. In [4], the authors deal with the issue of complexity of charging facility decisions and the communication between multiple stakeholders, including EV drivers and the utility. In [5], a novel strategy for congestion management in a distribution system, due to the uncoordinated charging of plug-in EVs is proposed, while in [6], the impact on the power system of the aggregated load of multiple EVs with different charging algorithms is assessed and some guidelines for EV charging infrastructure planning in modern power systems are provided.

What rises from the above papers, that are only a small part of the extensive literature on this topic, is that electric mobility is a serious power system issue: its presence causes changes in the load profiles of a given distribution grid [7]-[9], can increase the voltage drop or create reverse power flow phenomena at the secondary substations, finally, it needs more power from the current generating system. On the other hand, the cited articles demonstrate how EVs, if suitably controlled, can participate in Demand Side Management (DSM) actions, supporting the integration of renewable energy sources (RES) in the grid and taking advantage from the presence of such clean energy generators.

The same RES generators can be part of a car park for EVs, allowing to supply their additional load usually from photovoltaic (PV) energy [10]-[11]. The presence of a car park for EVs can give a boost to the installation of new PV plants connected both to the LV and the MV distribution grid, eventually, equipped with battery energy storage systems (BESS) for different purposes like, f.i., maximizing the car park self-consumption, participating in the ancillary service market, or allowing the grid-off supply of the car park in case of failure of the main grid.

In this context, the SMARTEP project has the aim of developing a prototype of a smart solar car park integrating PV systems, stationary BESS for DSM actions and grid-off operation, highly efficient lighting, and Vehicle-to-Grid (V2G) technology. In this paper the design process of the solar car park and some economical assessment on its sustainability are reported. Finally, the environmental impact of such installations is discussed.

II. THE SMARTEP PROJECT

The "Roadmap for moving to a competitive low carbon economy in 2050", published on March 2011 by the European Commission, outlined a path to achieve a reduction in CO_2 emissions of 80% compared to 1990 in 2050. Another aim is to guarantee energy security and the competitiveness of the European Union economy. In this direction, the objective of European energy policy is to reduce CO_2 emissions and to carry out a transformation of the system that favors a low-carbon and extremely energy-efficient economy.

On the other hand, it should be noted that the phases upstream of the supply chain (such as those related to the improvement of the energy generation system on the networks and on the storage system, those connected to the business area linked to energy efficiency) are equally important elements. A recent survey by Confartigianato [12] highlights how the supply chains linked to renewable energy and energy efficiency recorded a relative positive change. It indicates them as driving forces for growth.

In this light, the system presented in this paper has been developed within a larger research project called *SMARTEP: Sustainable Model And Renewable Thinking Energy Parking*. The main idea is the design and subsequent realization of a smart innovative car park composed by:

- the shelter structure covering the stalls;
- a wired and wireless electric vehicle charging system oriented to Vehicle to Grid (V2G);
- a back-up electric storage system for recharging electric vehicles;

- a pavement made with mixes of innovative bituminous conglomerates, with a view to sustainability, designed to combine the traditional characteristics of durability, mechanical resistance and wear with those necessary for their energy enhancement referred to in the following point;
- a heat recovery system from the asphalted area (road thermal collector) for the construction of a field geothermal at low temperature, in order to explore the potential of thermal storage and subsequent use in heat pump or water pre-heating systems;
- an ICT system (hardware and software) for monitoring and managing the parking (control and signaling of stalls free, suggestions on the most suitable time intervals to use the service, services necessary to make payments via mobile devices, vehicle driving with route optimization) and optimal monitoring and management of energy flows (production, storage, vehicle recharging, exchange with the network).

The system object of this paper, is a structure equipped by photovoltaic panels, an integrated lighting system designed for reducing consumption and satisfying adequate requirements for the parking/passage areas, a “owl” system to monitor the level of dirt of the photovoltaic modules (dust detector), and then program the cleaning interventions and maximize the yield on an annual basis of the photovoltaic system, an electrical storage system, and sensors for the implementation of smart ICT functions. The storage system is a key element of the system because it aims to supply ancillary services together with the batteries of V2G columns and, therefore, to power the electric vehicles.

The structure is characterized by modularity so that it can be easily replicated as the number of stalls to be covered varies. During the first phase of the research project, only one module of the shelter system will be tested as prototype. Fig. 1 shows the 3D and profile of the module of prototype.

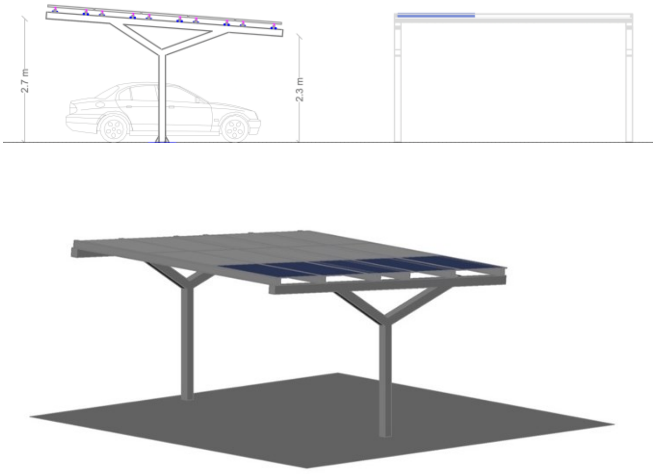

Fig. 1. 3D model and profile of the prototype module.

Each PV shelter will include:

- n. 1 RGB ledline dimmable and programmable used as a parking stall status indicator;
- n. 2 white ledline dimmable used to lit the parking surface;
- n. 5 PV modules aimed to produce energy that can be used to power devices such as the lighting system mentioned in the previous point;
- n. 1 stall occupation control system, DALI-MQTT converter and Wi-FI communication system;
- a compact and complete system of probes for measuring AC/DC voltage and current for the acquisition of experimental data and aimed at compact research.

The storage system of the whole car park and the PV panels were sized according to the procedure in Section III.

Fig. 2 shows the position of the car park in the University Campus. Fig. 3 shows the layout of the car park.

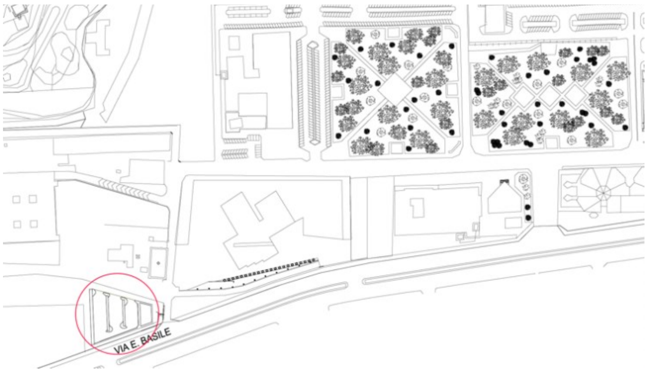

Fig. 2. Location of the parking area in the Campus.

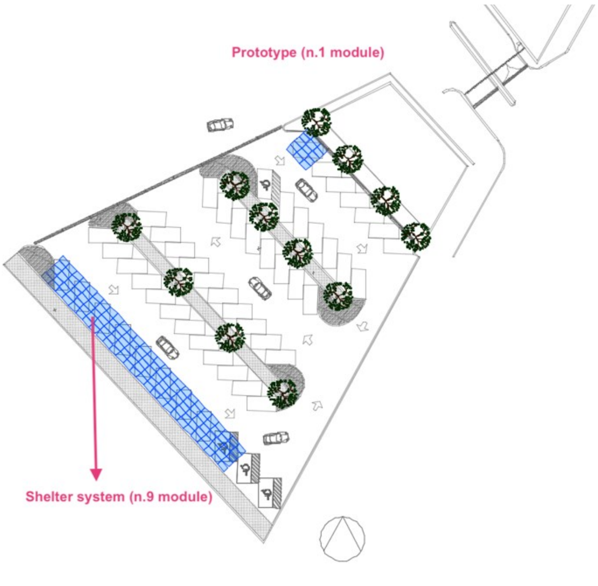

Fig. 3. Layout of the parking area with the prototype and the whole shelter system.

III. DESIGN PROCEDURE OF THE HYBRID SYSTEM

A. *Sizing of the stationary battery storage system*

For the dimensioning and design of the electrical infrastructure of the car park, daily and night-time consumptions were considered. The daytime consumption is provided by the photovoltaic systems, while the night-time consumption is provided by the BESS. Thus, the batteries are a source of energy during the evening and a load for the PV system during the day. The stationary batteries' capacity is calculated on the energy requested by the electric vehicles.

The capacity of the most common commercial electric vehicles has been, thus, evaluated and an average value of 40 kWh has been taken as a reference. It has also been assumed that each vehicle arrives at the charging station with a charge of no less than 30% of its capacity and is recharged to a charge level no greater than 80% of its capacity. Table I shows the loads of the smart car park and with the respective consumption.

TABLE I. LOADS OF THE CAR PARK.

UTILITY	**Power [kW]**	**Energy consumption [kWh]**
V2G charger station	22.00	20.00
V1G charger station	22.00	20.00
Control System	0.25	3.75
Electrical Outlets	2.00	0.20
Lighting	1.30	19.50
Other loads	1.00	15.00
Total	**48.55**	
Utilization Factor	0.80	
Total Power Required	**38.84**	
Total Consumption		**78.45**

The battery is sized taking into account only night-time consumption estimated as the sum of the consumption of the lighting system and that required for one recharge of the battery of one vehicle, that is 39.5 kWh. Therefore, according to the consumption analysis, a storage capacity of at least 40 kWh has been determined. The average daily consumption is, instead 78.45 kWh.

B. *Sizing of the photovoltaic field*

The photovoltaic field has been sized in order to obtain the balancing between energy consumption and the producibility. The following formula has been used:

$$P_{PV} = \frac{E_l}{h_{eq} K} \tag{1}$$

where: E_l: is the average daily consumption [kWh] of the smart car park, h_{eq} is the local equivalent hours of the month, and K=0.75 is the conventional efficiency of the PV system. The evaluation of the photovoltaic field power has been carried out for each month using PV-GIS database, considering south-facing modules.

TABLE II. PV PRODUCTION EVALUATION

Month	**kWh/m^2**	**h_{eq} (h)**	**P_{PV} [kWp]**
January	104.18	3.36	31.13
February	116.04	4.14	25.27
March	143.13	4.62	22.64
April	174.17	5.81	18.00
May	196.07	6.32	16.55
June	206.42	6.88	15.20
July	219.53	7.08	14.77
August	234.19	7.55	13.85
September	184.51	6.15	17.01
October	151.70	4.89	21.39
November	115.90	3.86	27.10
December	90.23	2.91	35.95

In order to ensure consumption, the rated power of the PV system must be at least 36 kWp. Therefore, a PV system size of 40 kWp has been chosen obtained from 100 panels of 400 Wp each. The photovoltaic modules have been connected to two 20kW three-phase inverters. The electrical storage associated with the inverter consists of 8 Lithium Iron Phosphate batteries modules. Each module has a nominal capacity of 5.8 kWh and integrated Battery Management System (BMS). The total capacity is 46.4 kWh, while the total useful capacity is 41.76 kWh.

In case of loss of the main grid, the presence of the stationary BESS allows to operate the car park in islanding mode. The plant will be connected to the LV network, being its rated power below 100 kW. In Fig. 4, the single-line diagram of the PV system is represented.

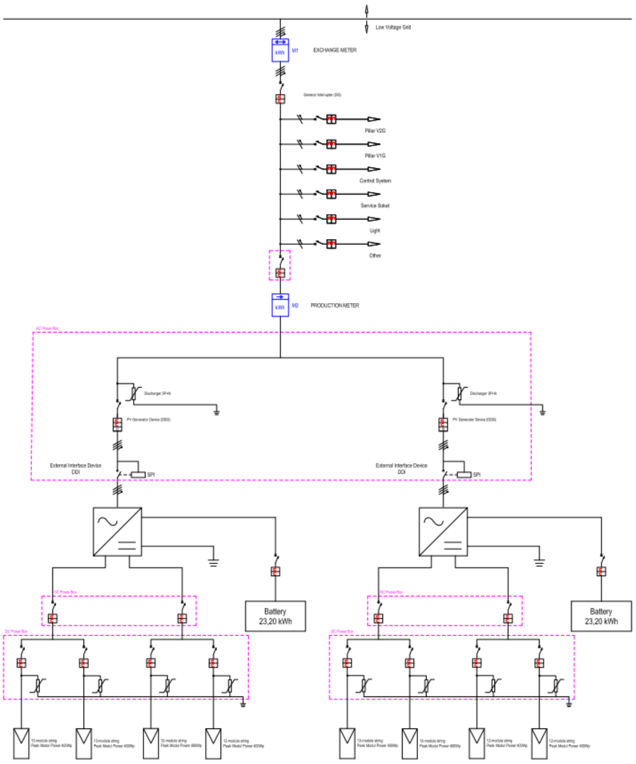

Fig. 4. PV system single-line diagram.

IV. ENERGY BALANCE AND ECONOMIC EVALUATION

The estimated average annual production is about 58 MWh; the peak of production occurs in July and the minimum in December. During the summer months, the production is double that of winter; by comparing the average energy produced daily by the PV system with the consumption of the car park loads, it is possible to identify the energy surplus during the months when production is highest. The energy surplus is injected into the grid.

The energy balance between production and consumption is calculated for day-time and night-time hours. The results of this evaluation are show in Table III for every typical day of a month.

The night-time balance provides an indication of the energy available in the batteries for charging electric vehicles during the night, after having satisfied all fixed loads' need. The day-time balance instead is the energy that can be injected in the main grid or used for charging a higher number of EVs, after having charged the BESS.

Figure 5 shows the daily load profile for each month obtained considering that the battery satisfies all loads request during night and that it is recharged during day-time at low power. Positive values indicate that the PV production is higher than the load consumption and vice versa. In case of surplus of production the energy is sold to the grid.

The possibility to supply the grid with the local energy production entails an economic benefit for the car park, that must be added to that obtained considering the savings related to the electricity self-consumption. Therefore, an economic assessment of the smart car park operation can be done considering the purchase and sale prices of electricity in Italy.

TABLE III. ENERGY BALANCE DURING DAY AND NIGHT HOURS.

Month	Night-time Consumption [kWh]	Night-time Balance [kWh]	Daily Production [kWh]	Day-time Balance [kWh]
January	23.30	18.46	100.80	35.74
February	23.30	18.46	124.20	59.14
March	20.20	21.56	138.60	76.64
April	20.20	21.56	174.30	112.34
May	18.60	21.40	189.60	129.24
June	17.10	24.66	206.40	147.54
July	17.10	24.66	212.40	153.54
August	20.20	21.56	226.50	164.54
September	20.20	21.56	184.50	122.54
October	21.70	20.06	146.70	83.24
November	23.30	18.46	115.80	50.74
December	23.30	18.46	87.30	22.24

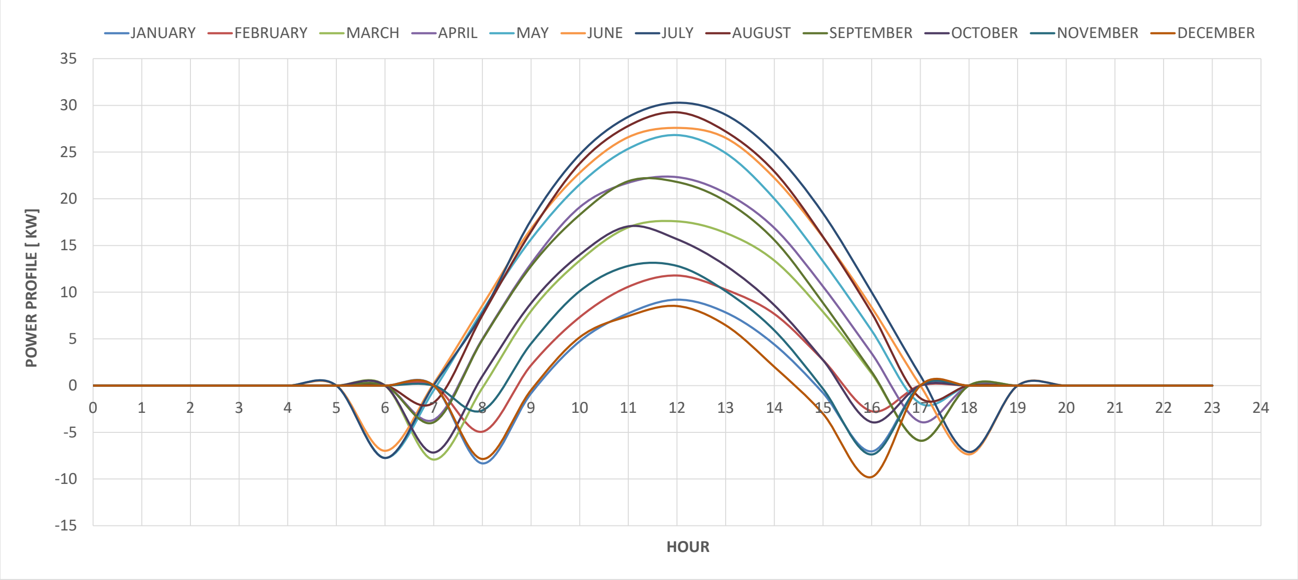

Fig. 5. Daily load profile of the smart car park for each month.

The purchase prices have been inferred from what is reported by ARERA for non-domestic users with connection power greater than 16.5 kW [13]. The costs vary according to the time bands:

- F1, 8 a.m. / 7 p.m. Monday/Friday, (peak hours);
- F2, 7 a.m. / 8 a.m. and 7 p.m. / 11 p.m. Monday/Friday, and 7a.m. / 11p.m. on Saturdays (intermediate hours);
- F3, 11 p.m. / 7 a.m. Monday/Saturday and all hours on Sundays and public holidays (off-peak hours).

The average monthly energy prices in 2020 and for the different time slots are reported in Table IV. In winter periods the cost of kWh is higher than in summer periods, which is unfavourable to the profitability of the system.

The costs related to transport and meter service and the system charges are instead reported in Table V for the same year.

Table VI reports the total consumption costs of the smart park calculated using the data in Table IV and V and taking into account the profiles in Fig. 5.

From the data in Table VI, it is found that the total yearly cost for electricity purchasing is approximately 2970 €.

In terms of the production and sale of the energy surplus, the manufacturability, and the relative gain in periods when the energy generated by the photovoltaic system is greater than the energy required has been evaluated.

TABLE IV. ENERGY COMPONENT COST IN 2020 [€/KWH].

	F1	F2	F3
January	0.07860	0.07623	0.06111
February	0.07798	0.07604	0.06235
March	0.07354	0.07447	0.05966
April	0.03896	0.04351	0.03087
May	0.03954	0.04210	0.03114
June	0.04294	0.04469	0.03438
July	0.04797	0.04921	0.03846
August	0.04088	0.04649	0.03471
September	0.04653	0.04948	0.03705
October	0.06744	0.06607	0.05234
November	0.07716	0.07120	0.05633
December	0.07934	0.07405	0.05743
average	**0.05924**	**0.05946**	**0.04632**

TABLE V. OTHER COSTS IN 2020.

	Transport free and Meter management fee	System costs	Fixed quota	TOT
Fixed fee (€/year)	24.7347	24.9096	122.9706	172.6149
Power fee (€/kW/year)	29.2501	29.4600	-	58.7101
Energy fee (€/kWh)	0.00894	0.047112	-	0.056052

TABLE VI. TOTAL CONSUMPTION COSTS 2020

Month	Energy consumption [kWh]			Daily cost [€]			Total cost [€]	
	F1	F2	F3	F1	F2	F3	Day	Month
January	17.0	0	0	2.29	0	0	3.24	100.3
February	7.7	0	0	1.03	0	0	1.46	41.0
March	6.2	7.9	0	0.80	1.03	0	2.18	67.5
April	3.9	3.7	0	0.37	0.36	0	0.95	28.5
May	1.9	8.2	0	0.18	0.81	0	1.10	34.0
June	7.4	7.0	0	0.73	0.70	0	1.84	55.3
July	7.1	7.7	0	0.74	0.82	0	1.95	60.5
August	3.2	0	0	0.31	0	0	0.48	15.0
September	9.8	0	0	1.01	0	0	1.56	46.7
October	11.1	0	0	1.37	0	0	1.99	61.8
November	10.4	0	0	1.39	0	0	1.97	59.1
December	21.1	0	0	2.87	0	0	4.05	125.7
							annual cost [€/year]	**695.5**

Considering the remuneration of the energy produced and sold to the grid through the Dedicated Buy-In (RID) by the Italian "Gestore dei Servizi Energetici" (GSE), the energy is paid at tha prices reported for 2020 in Table VII [14]. As most of the production takes place between 8 a.m. and 6 p.m., only the F1 tariffs have been considered in the calculations.

TABLE VII. 2020 DEDICATED BUY-IN PRICES FOR BAND F1.

Month	€/kWh
January	0.05668
February	0.03428
March	0.03224
April	0.02451
May	0.01891
June	0.02735
July	0.04863
August	0.05401
September	0.06666
October	0.05104
November	0.05208
December	0.06275

Using the costs value reported in Table VII, the revenue from the Dedicated Buy-In mechanism has been evaluated.

As shown in Table VIII, the highest revenues are in August (although this is not the month in which the plant has its maximum production), while the lowest values are in February. Even though December has the lowest energy production, the cost of selling the energy is double that of February, and therefore there is a higher revenue. The total annual revenue is approximately 1650 €. This is lower than the cost for the energy purchase.

In order to evaluate the benefits of the investment for the realization of the hybrid system, in addition to considering the previous revenues, one should also evaluate the economic savings due to self-consumption. Due to the storage system operation, an annual saving of about 357 € is achieved considering the power profile in Fig. 5 and the cost in Tables IV and V. Table IX reports the economic saving for each month.

Starting from this data, the pay-back period of the PV system with storage can be calculated. The cost of the PV system is about 1000 €/kWp [15]. Storage systems have still very high costs. The lithium-ion technology used in the smart car park has an average cost of 500 €/kWh [16]**Errore. L'origine riferimento non è stata trovata.**. Therefore, the total cost of the system is about 60 k€ VAT excluded.

TABLE VIII. ANNUAL REVENUE WITH DEDICATED BUY-IN (RID)

Month	€/kWh	Egen [kWh]	€/day	€/month
January	0.05668	33.95	1.9241	59.65
February	0.03428	52.53	1.8006	50.42
March	0.03224	94.79	3.0560	94.73
April	0.02451	132.74	3.2536	97.61
May	0.01891	161.50	3.0540	94.67
June	0.02735	175.55	4.8012	144.04
July	0.04863	192.78	9.3750	290.63
August	0.05401	178.71	9.6519	299.21
September	0.06666	125.37	8.3572	250.71
October	0.05104	80.77	4.1225	127.80
November	0.05208	56.27	2.9304	87.91
December	0.06275	29.62	1.8584	57.61
			annual revenue[€/year]	**1654.98**

TABLE IX. ECONOMIC SAVING.

Month	Daily Energy saving [kWh]	Daily Economic saving [€/day]	Monthly Economic saving [€/month]
January	82.5	16.42	508.91
February	77.0	15.19	425.30
March	83.4	16.11	499.40
April	81.3	11.66	349.81
May	83.3	11.97	370.98
June	85.3	12.73	382.03
July	85.3	13.35	413.79
August	81.3	11.97	370.98
September	81.3	12.58	377.43
October	81.5	14.88	461.35
November	79.5	15.50	464.88
December	82.5	16.42	508.91
		annual saving [€/year]	5133.80

Considering this data, the pay-back period is about 9 years. Nevertheless, is worth nothing that, taking into account the 2021 energy matter costs, the same would be reduced to 7 years since the energy cost for energy (VAT excluded) in 2021 was about 143% of the same cost in 2020. Therefore, the investment cost for the hybrid PV and BESS system for the smart car park is refunded in a reasonable time.

Moreover, another source of remuneration for the hybrid plant may come from the participation in ancillary service provision programmes for voltage or frequency regulation (primary through V2G or secondary and tertiary through the provision of energy in stationary storage). However, estimating such remuneration is currently not straightforward as in Italy ancillary service provision programmes by LV users are still at an experimental stage.

Finally, it must be remembered that the system has been designed to be self-sufficient by using RES with environmental benefits for the community. According to European regulations, there will be an annual saving of tonnes of oil equivalent (toe) and CO_2 emissions into the atmosphere as shown in Table X [17].

TABLE X. ENERGY PV GENERATION, ANS AVOIDED TOE AND CO_2 EMISSIONS [17]

Month	Daily Production [kWh]	toe [T]	CO_2 [kg]
January	116.2	0.022	56.13
February	131.4	0.025	63.44
March	180.6	0.034	87.23
April	220.2	0.041	106.34
May	250.4	0.047	120.93
June	264.1	0.049	127.57
July	280.8	0.053	135.65
August	270.5	0.051	130.66
September	210.5	0.039	101.69
October	165.8	0.031	80.09
November	138.1	0.026	66.71
December	107.7	0.020	52.03

The calculations in Table X are done assuming the conversion factor 0.187 toe/MWhe and the standard emission factor 0.483 tCO_2/MWhe. In the whole lifetime of the hybrid system, a reduction of 687 tonnes of CO_2 emissions is achieved and 266 toe are saved.

V. CONCLUSION

The paper has presented the design process and some economical assessments regarding the prototype of smart solar car park that the University of Palermo is building in the framework of the SmartEP project. The prototype will be able. if suitably controlled. to provide ancillary services to the grid. thanks to both the stationary BESS and the V2G charging stations. A future work will be focused on the field test on the solar car park and on the definition of a suitable automatic control strategy for optimizing its performances.

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