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Energy management of micro renewable energy source and electric vehicles at home level

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Abstract As renewable energy source (RES) tend to be integrated more and more at home and electric vehicles (EVs) take a greater share in the personal automobile market, users see a chance to charge their EVs by micro-RES. In this context, this paper presents a review about opportunities and challenges needed to be overcome by the EV users to implement a vehicle to home system in their homes, as well as the integration of micro-RES. Several practical scenarios are presented, with different demand profiles, by integrating renewable energy that could be used to charge the EV.

Keywords Plug-in electric vehicles (PEV), Vehicle to home (V2H), Micro renewable energy source (micro-RES), Challenges

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1 Introduction

Electric vehicles (EVs), either battery or hydrogen, do not emit greenhouse gases (GHGs) and reduce oil dependence [1]. Their efficiency is two to three times higher than internal combustion vehicles (ICVs). Moreover, they add value to a network when connected as a distributed storage device for ancillary services. However, a high penetration of EVs can cause overloads, voltage deviations and peak demand on distribution systems. To avoid these problems, the distribution system must be adapted. For example, the evolution of the distribution system towards smart grids brings on the implementation of management systems and charging demand from EV.

On one hand, sales of EVs are continuously growing and are expected to continue increasing in the coming years [2]. In this context, most of the drivers use their vehicles to commute from work to home and buy goods. In general, users spend every day about 75 minutes on average driving, covering an average distance of 40 km per person [3, 4]. With this data, an EV with 100 km of autonomy would be the replacement for about 85% of users, assuming daily load [5]. According to [6], most people use their vehicle from 8:00 to 9:00 a.m. and from 4:00 to 5:00 p.m. This way, most vehicles are at home from 8:00 p.m. to 7:00 a.m. and are available during 11 hours, to be used as a storage system.

Thus, the value added by an EV can be significant. It can be used as a storage device for better integration of renewable energy, as a backup system and may also contribute to reduce the energy bill and to greater efficiency in the use of energy [7]. To this end, technology is being developed to integrate the EVs at home with the least possible impact.

On the other hand, household energy consumption presents seasonal and daily variations, because of the use of appliances, lighting and heating [8]. With the data of energy consumption of households, it is possible to devise, "bottom-up" energy consumption models based on assumptions or data patterns of activity [9].

In several studies, renewable energy sources (RESs) have been integrated at home with demand management [10, 11]. For example, [12] analyses a photovoltaic (PV) production of 30 m^2 for a house of two people, such as that the energy surplus is used to charge the vehicle or feed to the grid. However, the most common problem in the proposed systems is the mismatch between RES production and electricity consumption. Hence, an energy storage system (ESS) can be justified for managing and storing the energy surplus.

In this paper, the possibility of implementing a vehicle to home system (V2H) with real generation data from PV and wind, as well as consumption data of different users is analysed. User preferences have been taken into account, such as comfort level and consumption priorities in household. The region analysed in the case study has good wind resources but not so good solar resources [13]. Hence, it is necessary to combine both systems for compensation.

The difference from the papers cited before is to demonstrate that micro RES generation could be enough energy for daily consumption of the electric vehicle, for four different scenarios in this area.

2 Vehicle to home

It is expected that the installed capacity of RES will increase in a large number of countries. This may cause adverse impacts in the electricity distribution network, due to the intermittency of some RES. In this context, the use of EV could help to solve these problems partially.

Table 1 shows the characteristics of the different interconnected systems with EV. The main feature of these systems is the possibility of a bidirectional energy transfer.

V2H concept began to have relevance when the need to implement systems to support natural disaster situations, with long time supply outages, was detected in different areas. V2H systems are designed to be implemented in smart homes, with devices that are able to manage energy. Generally, it consists of a single EV in a home and has a simple and easy configuration. There is no need for major changes in the existing home network to install this system.

The system is able to smooth the daily load profile (DLP) of households, with the exchange of active power and the supply of reactive power to the home. Besides, it can interact with vehicle to building (V2B) and vehicle to grid (V2G) systems. In addition, losses are minimized and the efficiency of RES can be improved. In short, V2H concept aims to harness all the resources and possibilities of the EV. Thus, the energy stored in the EV can be used for better integration of micro renewable resources for feeding household loads.

As shown in Fig. 1, various configurations for renewable generation systems in the home can be considered. There are systems for homes without access to the network (isolated) and with network access (grid connected, zero injection and deferred injection). The deferred injection system incorporates an ESS to store energy from RES. Commercial devices are already available [23].

Therefore, considering the possibilities described a V2H system must be composed at least of: an EV, a bidirectional charger, a set of household loads, distributed generation on a small scale (micro-RES), a smart meter and a home energy management system (HEMS), similar to that shown in Fig. 2 [24]. In addition, intelligent loads, storage systems, i.e., ESS or battery energy storage system (BESS) and even micro-generation with micro gas turbines, i.e., combined heat and power (CHP) can also be included in the system.

Thus all projects that are being carried out are intended to minimize costs to the EV owner, minimize the impact of the EV in the network, support the integration of renewable energy and identify and meet future requirements for the network [25].

The following sections describe the components of a V2H system and the energy management system.

2.1 Components of V2H

The V2H system consists essentially of an EV, a HEMS device, micro-RES generation, ESS, controllable loads and various communication systems.

2.1.1 Electric vehicle

Plug-in electric vehicles (PEVs) have been implemented in two technologies, currently on the market, that include an electric motor/generator:

1) Hybrid PEV, which produces electricity from an internal combustion that drives an electric generator.
2) Battery EV that stores electrical energy from the network in an electrochemical battery.

2.1.2 Smart devices

Today, increasing attention is being given to intelligent networks and smart homes that can monitor electricity

Table 1 Different approaches for delivering energy from EV batteries

Approach	Advantages	Drawbacks	Pilot projects
V2G	Operation at large scale	Complex operation	SMARTV2G [14]
	Supply ancillary services	Complex prediction of EV demand	eV2G Project [15]
	Reactive power support	Large number of EVs involved	CGI Project: National V2G School Bus Demonstration [16]
	Improve grid reliability	Communication infrastructure required	Grid-on-wheels [16, 17]
	Electricity market participation	User willingness required	The Nikola Project [18]
	Large scale RES integration	Lack of regulatory framework	
		More industry standards needed	
		An aggregator is needed	
		New business models	
V2B	Operation at building level	User willingness required	Nissan Leaf to Building [19]
	Ideal for small fleets	Quite complex operation	
	Improve local DER (distributed energy resources) integration	Poor market integration	
	Reduce electricity bill		
	Provide backup power		
	Easier EV demand prediction (fleets)		
	Lower investment needed		
V2H	Operation at home level	Not adequate to residential blocks, only for single family homes	Leaf to Home [20]
	Normally one EV		Toyota Smart Homes [21]
	Reduce electricity bill		Honda Smart Home [22]
	Provide backup power		
	Easy implementation		
	Provide energy in isolated houses		
	Interaction with larger systems		
	Integration of local DER		

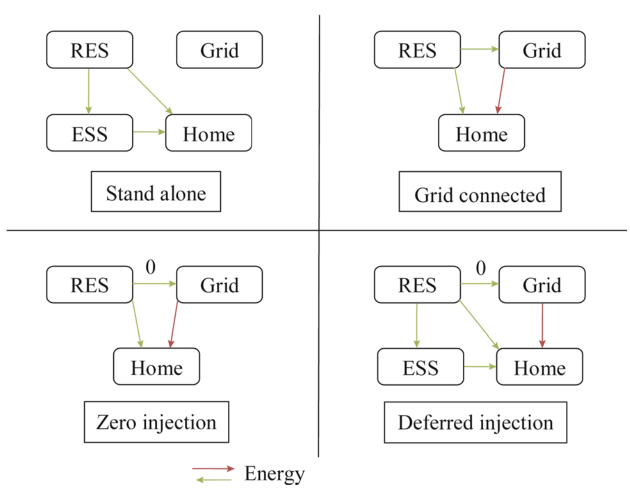

Fig. 1 Auto-consumption systems using RES

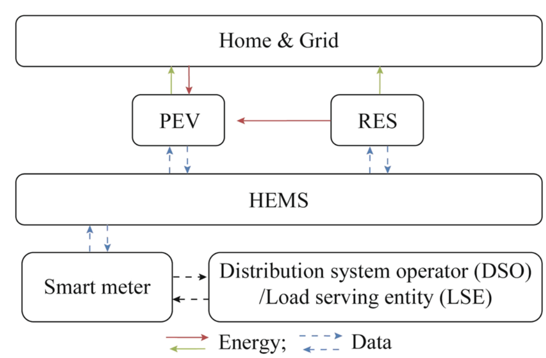

Fig. 2 Vehicle to home scheme

usage in real time and take actions to reduce costs. That is, it is focusing on managing demand response (DR), whose key strategy is to allow interaction between smart devices and users. Thus, users have to plan the use of energy (time of use, pricing, priority loads, dynamic pricing, etc.). However, while DR is a concept that is sufficiently developed for the industry, it is relatively new for residential users, which consume about 40% of electricity [10].

In this context, HEMS and smart metering infrastructure, such as smart meters (SM), play an essential role in the effective implementation of DR strategies and V2H systems for residential areas. Below, the most relevant characteristics of these two systems are presented.

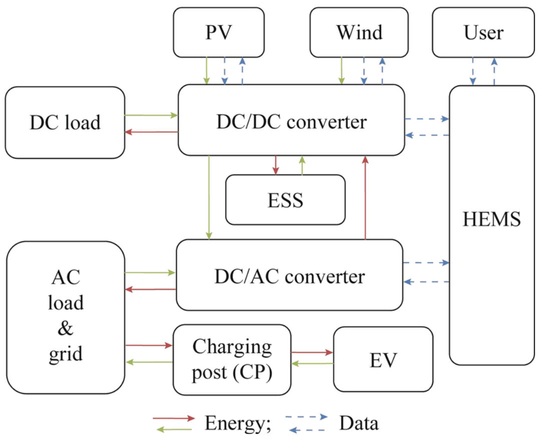

Fig. 3 V2H system scheme

1) HEMS

The HEMS allows reducing energy consumption of household loads, using intelligent monitoring and control systems. Furthermore, users are able to manage the energy they consume. Figure 3 shows the scheme of the V2H system elements controlled by HEMS, where RES generation, the PEV, storage devices and loads are integrated.

The HEMS, as shown in Fig. 3, consists on a technical platform installed inside the house, with the ability to establish two-way communication with the user, smart devices (SM) and power electronics (converters for RES and ESS). It also integrates home automation functions.

The majority of consumption appliances such as water heater, dishwasher, washing machine, etc., are connected with the HEMS. Thus, there are recorded data of uses and power demanded by the load, plus the load of the EV. At the same time, the HEMS checks the available power generation from RES.

With all these data, the HEMS manages power optimally. In addition, it receives price data from a LSE governed by a distribution company and has the function of demand and load management. The aim is to provide the most economical operation for appliances, along with consideration of user preferences, trying to move demand from peak to off-peak hours. This shift in demand depends on the configuration of the loads, which can be divided into three categories, from the perspective of HEMS: ①non-programmable loads (TV, lighting, etc.); ② controllable loads (heating, ventilation and air conditioning, refrigerator, EV, etc.); ③ programmable loads (dishwasher, washing machine, etc.).

Demand for non-programmable loads must be supplied continuously, especially to maintain the comfort level of the user. On the other hand, the energy demand of the programmable loads can be modified. In addition, it can be completely displaced from peak to off-peak hours.

Related to the charging of EVs, an example application is the electric vehicles learning static (EVLS) model [26, 27], where the integration of RES in the EV charging process is simulated. The results show the differences between uncontrolled charging, smart charging and bidirectional charging. They show that the combination of renewable generation and the integration of EVs help smooth the demand profile.

2) Smart meter

A smart meter collects electricity usage and related information from customers and delivers data to customers. This advanced metering infrastructure (AMI) differs from traditional automatic meter reading (AMR) because it allows two-way communication [28].

Measurements are diverse and real-time. Thus, it does not mean that users need to have the necessary knowledge to adequately respond to signals from the devices and the network. However, the success of demand control is based on a complete automation, using smart devices.

2.1.3 Micro-RES

Interest in energy generation from alternative sources has led to decentralized energy production through micro-grids. Besides reducing transmission losses, the micro-generation offers a way for the integration of renewable energy into the grid. Thus, micro-RES, based on photovoltaic and wind power, are becoming a key source of energy [29]. Due to the fact that residential sector is one of the largest electricity consumers, small-scale RES have a promising future in this market segment.

In this context, some studies [27, 30] show that the use of micro-RES to charge the EV may be feasible in the short term, and thus reduce electricity demand at home, also reducing the need for costly upgrades of the network. However, these studies also reveal that, in the long term, updates will be necessary in the system. That is, the energy production from renewable sources, without smart charge, will not be able to meet the increased demand due to the EV.

Considering different renewable distributed generation systems, solar panels are the most viable option when installing RES at home. Different methodologies have been considered for integrating PV and the plug-in hybrid electric vehicle (PHEV) at home [30], to determine the optimal size of a PV system for a 65 km/day range [31], to show household loads [32], to calculate solar-powered for a net zero-energy [33], to determinate economic reliability of charging PHEV with PV [34], to remark PV and PHEV impact in voltage and network losses [35], etc.

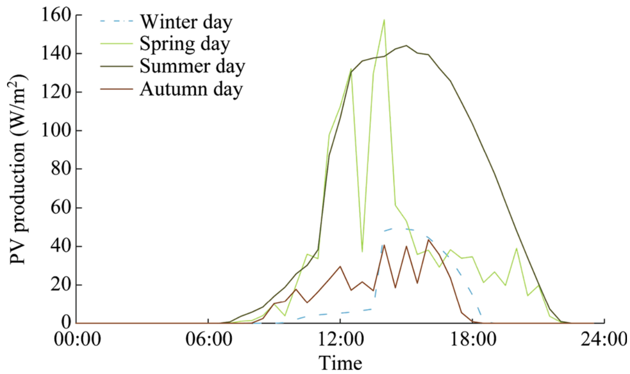

Fig. 4 Distribution of PV production

Additionally, according to [36], a V2H system with rooftop PV could provide backup energy at home between 19 and 600 hours, depending on the season of the year.

For example, Fig. 4 presents the available PV power per unit area in the case study presented in Section 4 [13]. Photovoltaic production has a predictable and progressive profile. However, the largest energy production peak does not match with the peak demand at home, between 20:00 and 23:00.

As for domestic wind generators, the optimal system is connected to a storage system, to satisfy the home demand. In addition, the knowledge of the correct sizing of the equipment and the choice of the most suited wind turbine, based on nominal wind speeds, is needed.

The profile of wind speed evidences a changing trend in the different seasons. Fig. 5 shows the data for the area considered in the case study presented in Section 4 of this paper [13]. During the winter months, the probability of generation is higher for wind than for PV, being February and March the most suitable time for this energy generation. From the data obtained, it can be concluded that in the range of 2 ~ 12 m/s, with a sustained wind speed, the power available per turbine would be under 11 kW [37].

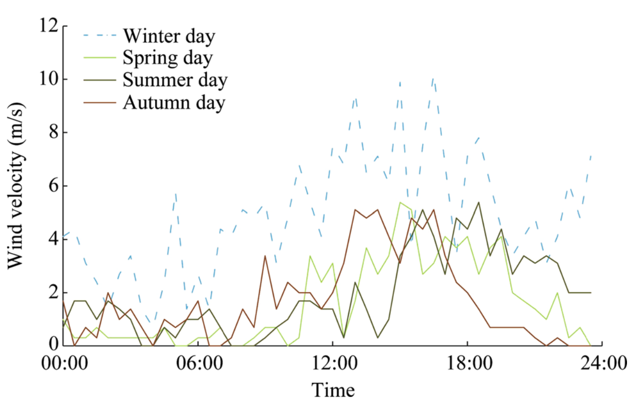

Fig. 5 Wind speed profile

2.1.4 Energy storage system

The use of the energy stored in the EV battery, to smooth the electricity demand during peak hours through V2H, can be a potential application of DR strategies. Apart from the battery that integrates the EV, there are ESSs that facilitate energy management when the EV is not connected.

Some papers analyse DR strategies for operating the ESS optimally, in smart homes [10]. Thus, [38] takes into account the expected price for the user.

Reference [39] focuses on the strategy of a HEMS for a smart home, including PV, EV and ESS. The charge is smart, based on the use of both storage systems, EV and ESS. In [40–43], one DR strategy is presented with HEMS, considering peak power limit in a smart home, including intelligent appliances and an EV. In addition, studies have been made taking into account dynamic prices, use of appliances, external conditions and comfort requirements [44–47].

These studies have contributed to the implementation of smart grid concepts at home. However, many of the options published have failed to significantly reduce the energy demand through the contribution of distributed renewable energy. That is, the V2H option is feasible to reduce peak demand periods provided that is accompanied by an ESS, along with different DR strategies in the HEMS. The most significant reduction, in terms of costs, occurs when RES and ESS systems are combined, resulting in a cost reduction up to 35% [10].

Moreover, ESS sizing depends on the installed RES power capacity. Increased capacity of both systems, RES and ESS, provides a reduction in the total daily cost of electricity. This option is due to increased flexibility for HEMS to manage the flow of energy. However, installing larger systems should be evaluated in detail, with pros and cons, considering the payback of the facility, reduced costs, etc.

For example, Tesla Motors has already presented a battery in the market, for residential use, in support of renewable generation systems. This will allow the supply of households with less dependence on the grid and the integration of solar and wind energy [48].

2.1.5 Communication systems

Communication systems are installed between HEMS management devices and appliances, as well as with the EV charger in Table 2. In addition, the power electronic based devices of RES systems and other connection devices to the network have to be communicated by cable or wirelessly, with the HEMS.

Table 2 Cable communication systems

Communication protocol	Range	Band width (Mbit/s)	Standard
DSL	> 2 km	8	ANSI T1.413
		24	
RS-485	< 1.2 km	0.1	–
	< 10 m	34	
Ethernet	< 100 m < 10 km	10	IEEE 802.3
		10e3	
CAN-bus	< 40 m	1	ISO 11898-1
	< 100 m	0.125	
PLC	> 1 km	0.5	–
	< 100 m	125	

Table 3 Wireless communication systems

Communication protocol	Range	Band width (Mbit/s)	Standard
Wi-Fi	50–250 m	54	IEEE 802.11
GPRS	< 2 km	0.056–0.114	GSM Standard
Bluetooth	< 100 m	2.1	–
RFID	< 0.1 m	0.106–0.848	IEC 14443
			IEC 15693
NFC	< 0.2 m	0.424	IEC 14443
ZigBee	< 10	0.02	EU EN300-220
	75 m	0.250	
Z-Wave	30 m	0.0096–0.04	EU EN300-220
Wavenis	< 100 m	0.0048–0.1	EU EN300-220

According to the communication distance, ZigBee could be use from home to the nearest transformer in Table 3. Data considered are the application of DR, the price of electricity, prognosis, etc. However, different wireless communication systems make available, in real time, the data necessary for optimal management by the HEMS. Thus, depending on the application and the distance between the devices, different protocols can be used.

Communication in systems such as V2G already have a standard [49]. Moreover, [50] presents a hybrid remote control between V2H/V2G, controlled and monitored via the Internet, able to respond to demand signals sent from the LSE.

2.2 Energy management

The user is the final responsible for managing the EV. To this end, the demand forecast using historical data may be useful for predicting the behaviour of the network and acting accordingly to a higher profit. Therefore, with the user preferences defined, the LSE (or user group) can take decisions about the management of HEMS at any time, according to the market and the expected RES generation. In addition, the user can modify preferences, agreed with some limit benchmarks for electric grid stability.

If the HEMS has communications, the user preference and demand data, as well as electricity prices are updated in real time. However, in facilities where no communication systems exist, it would also be possible to implement a V2H system. Demand and user preferences are two aspects that can be changed manually in the HEMS device. Table 4 shows different options of working, for a HEMS within a V2H system.

Moreover, active energy management at home can be done through an application for mobile devices, in which the users can have their own credentials. From this application, the user can view and modify the parameters that the HEMS manages (state of charge (SOC), t_{on}, t_{off}, loads at home, etc), by preferences that come instantly to the LSE. The LSE processes market data and available RES generation and returns data signals of electricity prices to HEMS, to carry out the management of energy optimally.

Table 4 Operating modes

Modes	RES ON	RES OFF
PEV charged	RES to home (R2H)	V2H
PEV discharged	RES to vehicle/home (R2V/H)	Grid to vehicle/home (G2V/H)*

Note: * Off-grid zones or "Stand Alone" it needs storages (ESS)

Figure 6 shows the flow of information between HEMS and LSE. The LSE operates on the basis of different pricing schemes, time of use (TOU), peak prices and prices in real time, etc. [51]. The main data arriving and departing to HEMS are:

1) PEV: SOC, t_{on}, t_{off} (routine use).
2) RES: generation forecast kWh.

3 Opportunities and challenges for users

Power generation systems from renewable sources, installed at home, are small scale. Adding an EV and HEMS can improve the efficiency of these systems. From this point of view, there are several opportunities and challenges for the user of the EV, with own V2H or residential generation systems. Some opportunities and challenges that still remain to be solved are pointed out.

1) Opportunities

Energy from RES generation may be sufficient during 70/80% of the year, to charge the EV, corresponding to a

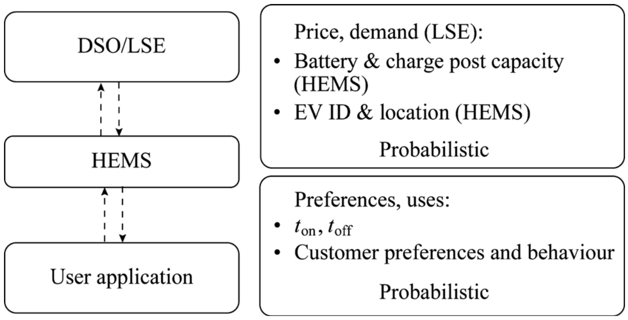

Fig. 6 Information transmitted to HEMS

daily demand for one-way journey (>2.4 kWh). It is assumed that the user's preferences and the consumer behaviour are known accurately.

The period of maximum generation (9:00-15:00) does not match with the peak demand (18:00-24:00) in the case of photovoltaic energy [52]. However, combining PV and wind systems leads to better integration of energy. In addition, an ESS can be installed.

The EV increases the maximum energy demand of the house but can be offset by an ESS. With prices in real time, the ESS also helps to reduce the cost of energy. In addition, researchers are exploring the possibility of reusing the EV used batteries for energy storage in the network and homes. So, the EV batteries could have a second life [53].

2) Challenges

Range anxiety of available kilometres is crucial for the implementation of systems as V2H. To relieve this range anxiety, user has to be informed of the power management options that are available. Through enabling applications to take control of HEMS, the user will be informed about all parameters of the V2H system in real time. Some studies show that the availability of public charge greatly decreases range anxiety and increases the use of EVs [54].

The infrastructure of the electrical distributor has to be standardized. The distributor has to ensure safely the integration of micro-generation systems. Moreover, charging of EVs involves a number of requirements, such as ground electrode at home, existence of a neutral wire in the network and load studies of the transformer close to the V2H system.

Need for knowledge by the user. The energy management through smart devices assumes that the user has the basic skills to carry it out. For example, communications should serve to better optimization of energy management. In fact, the user is who can parameterize the data concerning the EV as SOC, t_{on}, t_{off}, plus programming the appliances.

4 Case study

In the case study presented, the aim is to minimize the energy consumption from the grid by integrating RES and to analyse the final impact related to the charging and discharging of EV. Limitations considered are:

1) The EV battery must be fully charged at morning.
2) The EV battery cannot be charged from the grid during peak hours.

Four particular scenarios of demand (family home, individual home, country house and Farm house) are presented below. Table 5 shows the main features of each user and results are shown in Figs. 7, 8, 9, 10.

Wind data and solar radiation have been measured at the north of the state of Burgos (Spain), where single-family homes exist. So, it is possible to incorporate power generation with PV and Wind turbines. Data have been obtained by a weather station Alecto WS-5000.

Renewable generation considered for the four scenarios is the same: 10 m^2 of solar panels and a wind turbine of 1 kW rated power (1.5 kW peak power). The payback for a system as described is about 10 years [34]. A 1 kW wind generator has been chosen for constructive reasons, dimensioning, generation capacity and performance at speeds between 2-10 m/s. PV panels are dimensioned by the peak power recorded by the weather-station, which corresponds to 240 W/m^2. Then, for the available area, the peak power is 3 kW.

On the other hand, the use of an ESS for energy management is determined at the end of the case study, once the energy results are obtained. Energy produced by PV and micro wind does not match with periods of peak power demand at home. Thus, adding an ESS system ensures greater integration of the available RES. This way, the HEMS has to manage the energy available in the EV and the ESS.

The EV is not available at home during the working time (typically 8:00-19:00), when the ESS stores the energy generated by the micro-RES, for later consumption.

Table 5 User features

User	Number of people	Power (kW)	Principal use
Home 1	3	3.45	Continuous use
			Appliances, lighting and pumps
Home 2	1	3.45	Continuous use
			Appliances and lighting
Home 3	2	3.3	Weekend use
			Appliances, lighting and pumps
Farm	–	5.75	Weekday use
			Compressor, cereal mill, welder, lighting and electric tools

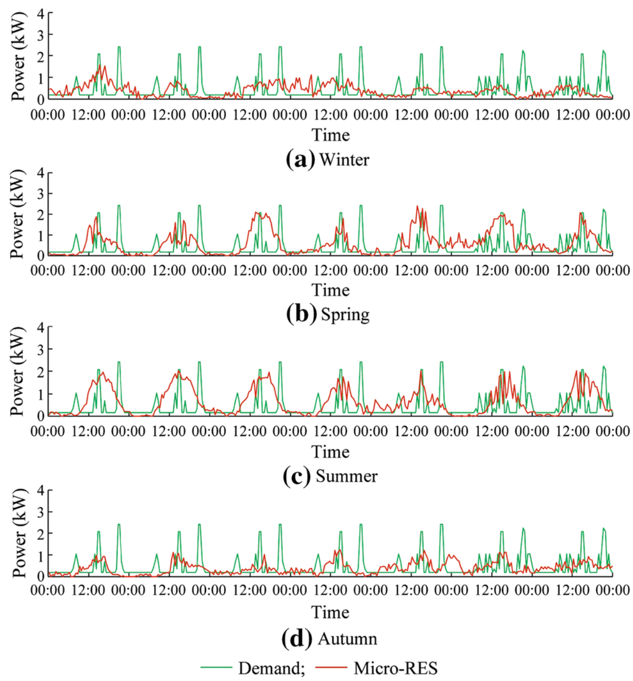

Fig. 7 Demand and RES generation for Home 1

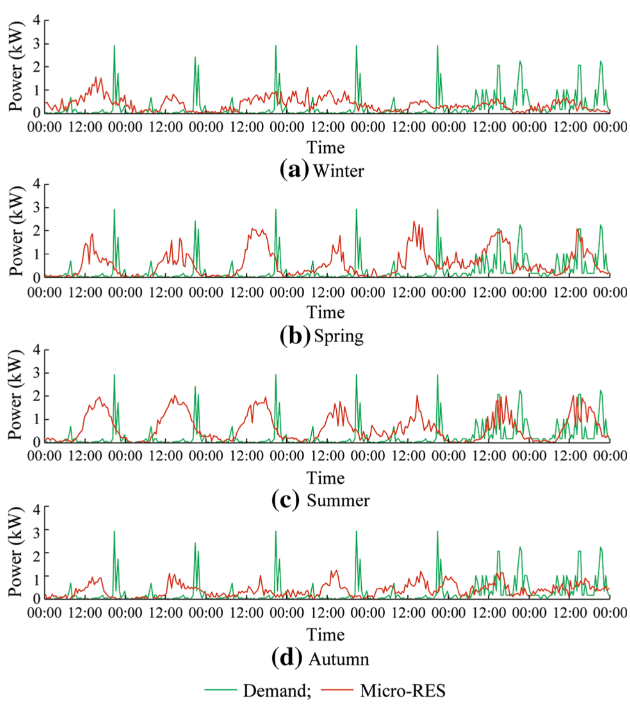

Fig. 8 Demand and RES generation for Home 2

Normally, when the workday ends, the charging of EV is done directly from the energy stored in the ESS or the micro-RES generation available at that moment.

The daily power demand is more predictable in working days than during the weekend or holidays. In addition, periods of increased energy consumption usually correspond with extreme temperatures, like very cold and heat periods.

4.1 Home 1

Figure 7 shows the wind and PV generation, along with the demand profile of scenario Home 1, in weekly periods, for the four seasons of the year. In the summer season photovoltaic dominates the generation. However, during the winter season the energy from RES comes mainly from micro-wind.

In this case, the weekly demand profile presents periods when the power demanded is greater than that generated by RES. Furthermore, in terms of energy, it can be seen that demand is greater than generation in autumn days and, to a lesser extent, in winter. In cases where demand is greater than generation, the EV can provide energy to the home by V2H concept.

4.2 Home 2

Figure 8 shows the micro-RES generation with the demand profile of scenario Home 2, in weekly periods, for the four seasons of the year. In this case, the energy demand is for a single person, so power peaks are more localized.

During the weekend the distribution is scattered and less predictive. However, the amount of micro-RES generation in all periods of the year is greater than the demand. This way, the user will have enough energy at any time. This energy surplus can be used for charging the EV.

4.3 Home 3

Figure 9 shows the energy demand and micro-RES generation, in scenario Home 3, in weekly periods, for the four seasons of the year. The energy demand during weekdays is scarce, only peak power appliances such as a refrigerator or freezer, which start occasionally or eventually. It is because this property is used exclusively for weekends. That is, the demand is concentrated in the weekend-days. Thus, during the week enough energy surplus is produced to meet the demand of the weekend. In this case, it would be able to export energy to the grid for better use and integration of micro-RES resources.

4.4 Farm house

Figure 10 shows the micro-RES generation with the energy demand profile for Farm house scenario, in weekly

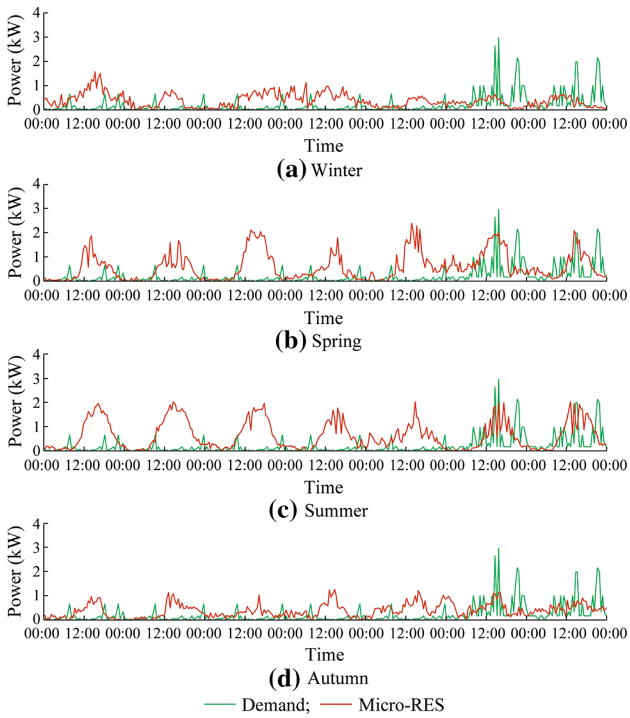

Fig. 9 Demand and RES generation for Home 3

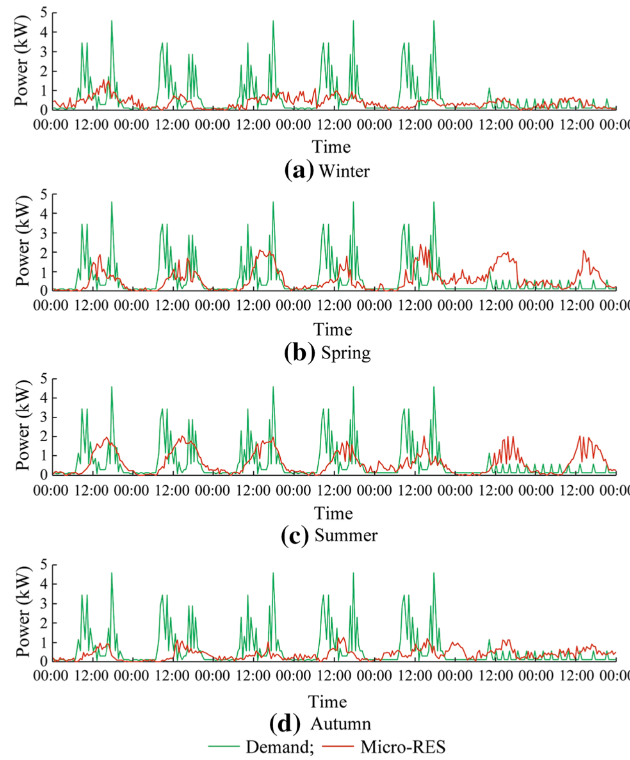

Fig. 10 Demand and RES generation for Farm house

periods, for the four seasons of the year. The profile of the farm house presents higher peaks of power, ranging from 1 to 4 kW.

The energy is mostly demanded during weekdays. As can be seen, the power demanded in no case is covered with the micro-RES generation installed. However, the energy from renewable sources is greater than the energy demanded, for approximately 70% of the year (four months a year is not enough).

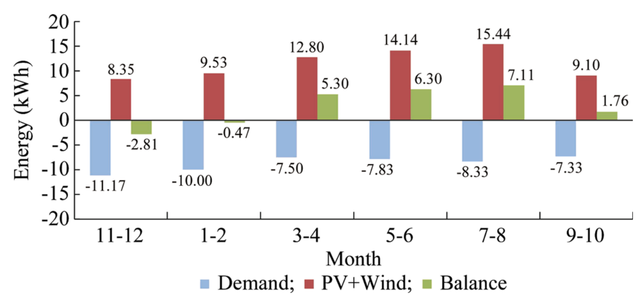

Fig. 11 Energy balance (Home 1)

4.5 Comparative analysis

For the four scenarios analysed, a model that takes into account stochastic demand values, use of the EV and use of home appliances, has been applied. RES production is given by the PV area and the wind speed.

The characteristics of energy consumption are analysed in detailed in Figs. 11, 12, 13, 14. Positive values (red) show the power generation of RES system and negative values (blue) show consumption of energy by the user. The energy balance (green colour) can be positive or negative:

1) Home 1: It is a 3 people home, with normal habits of home energy use. Given the demand profile in this case, during the autumn and winter months, the RES generation is not enough to meet the demand. The average energy demand is 8.7 kWh/day. The excess energy in the spring and summer is stored in the ESS to charge the EV or consumed in household appliances. The daily average net balance is 2.9 kWh/day in Fig. 11.
2) Home 2: One-person home. The daily average net balance is positive and corresponds to 9.5 kWh/day. It is because of the demand profile of the user and the configuration of the renewable generation. The daily average net balance demand is 2.1 kWh/day in Fig. 12.
3) Home 3: Country house with two people. The daily average demand is 4.7 kWh/day and the daily net balance is 6.9 kWh/day in Fig. 13.
4) Farm house with industrial appliances. The daily average energy demand is 438 kWh. The micro-RES

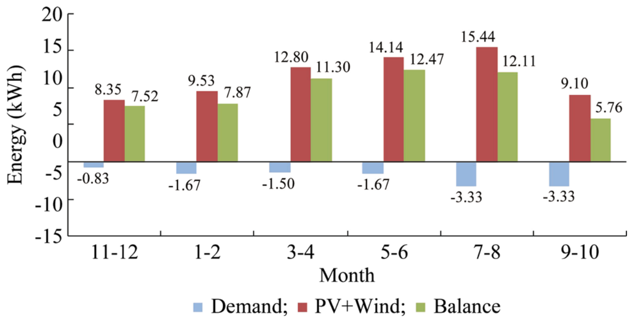

Fig. 12 Energy balance (Home 2)

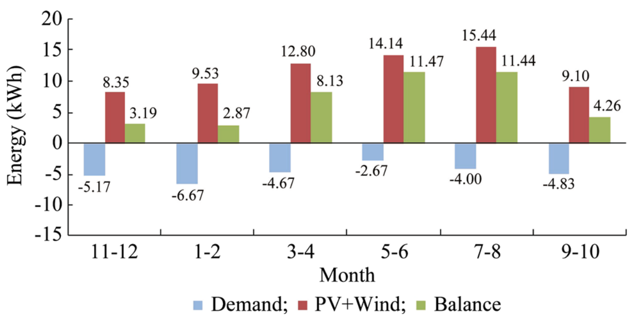

Fig. 13 Energy balance (Home 3)

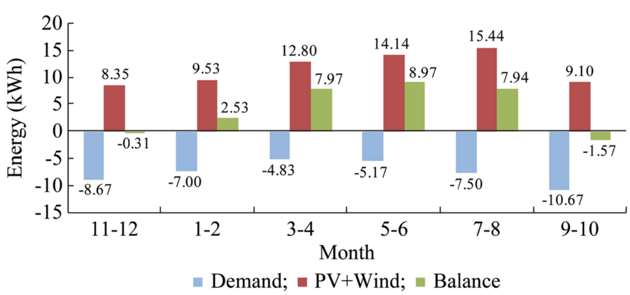

Fig. 14 Energy balance (Farm house)

generation supports the consumption and means a positive net balance of 4.3 kWh/day in Fig. 14.

As shown in Table 6, the worst case (Home 1) allows having enough energy to travel 12.3 km a day (going to work 2.4 kWh/day with energy consumption of 20 kWh/100 km). This range is useful if there is a charger available in the destination. To cover the total daily demand, about 8 kWh would be needed, corresponding to a range of 40 km in most EVs (electrical utility).

Considering the results obtained, ESS sizing has to be performed according to the surplus production of RES. According to the studied energy balances, the average power over the RES generation of all scenarios is about 5 kWh (12.1 kWh is the maximum and -2.8 kWh the minimum). Thus, the capacity of the ESS should be between 8 to 12 kWh, to ensure optimal use of the renewable resources. In the worst case, with backup of the EV battery, this energy would be enough to feed the household scenarios for at least one day. Although the range for an EV is reduced, the capacity of on-board batteries provides enough energy for household electric consumption management [11].

Table 6 Values of energy available for charging PEV

Household	Capacity (kWh/week)	EV (kWh/100km)	Distance (km/day)
Home 1	17.2	10–20 [55–58]	12.3
Home 2	57.0		40.7
Home 3	41.4		29.5
Farm	25.5		18.2

5 Conclusion

Currently, solutions given for charging electric vehicles allow offering a wide coverage at home, using low voltage systems. Additionally, there are many appliances that demand electric energy and the grid have to support them. For one hand, short term needs could be covered by residential RES. On the other hand, within a period of long time, perhaps demand cannot be met only with the current RES technology. Improvement in RES systems and network will be needed.

A suitable combination of systems based on renewable energy, storage devices, smart devices and EVs will allow to obtain significant benefits in terms of operating costs, environmental impact (by reducing oil consumption) and reliance on the power grid.

The four scenarios in this research work shows that the renewable resource available and the EV could supply enough energy to the users demand in all seasons of the year.

Additionally, smart technologies that will emerge in the future will provide more flexibility and economic possibilities. This way, the end user can participate in the energy market, provided that the regulatory framework of the electricity market keeps up with technological advances. Installation costs should also be considered in order to assess the real benefits of this type of investment.

Finally, V2H systems will support to the achievement of the overall reduction of GHGs, use of fossil fuels and meeting the objectives of sustainability, with special attention to help further integration of RES in homes and the grid.

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