Electric vehicle charging strategy to support renewable energy sources in Europe 2050 low-carbon scenario

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Abstract

The EU has undertaken a thorough reform of its energy model. Current EU 2050 climate commitment sets an 80-95% GHG reduction goal. To reach this goal, the EU must make continued progress towards a low-carbon society. Renewable energy sources and electric vehicle play an important role for a gradual transition. The power grid faces a challenging future due to intermittency and the non-dispatchable nature of wind and solar energy production, but flexibility needs can migrate from generation to load, with the expansion of demand-side resources and storage technologies. A novel grid technique is presented and evaluated in this paper for the optimal integrated operation of renewable resources and electric vehicle to increase penetration of renewable energy. It is proposed a distribute control system to manage a charge and discharge strategy to support mismatching between load and renewable generation thru V2G technology. Demand response, peak saving and ancillary services are introduced to keep a reliable power quality, stable frequency and flatten load profile.

Keywords: Europe 2050; low carbon energy;V2G; electric vehicle; renewable energy sources

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Nomenclature

BEV	Battery Electric Vehicle
CAES	Compressed Air Energy Storage
CCS	Carbon Capture and Storage
DCS	Distributed Control System
DER	Distribute Energy Resource
DG	Dispersed Generation
DR	Demand Response
DSM	Demand Side Management
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
FCV	Fuel-Cell Vehicle
G2V	Grid to Vehicle
GHG	Greenhouse Gas
HDV	Heavy-Duty Vehicle
HRE	Hybrid Renewable Energy
HVAC	Heating, Ventilating and Air Conditioning
ICE	Internal Combustion Engines
LCV	Light Commercial Vehicle
LDV	Light-Duty Vehicle
M&HCV	Medium and Heavy Commercial Vehicle
MDV	Medium-Duty Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PLC	Power-Line Communication
PV	Photovoltaic
RES	Renewable Energy Sources
SOC	State Of Charge
TOU	Time Of Use
TSO	Transmission System Operator
V2G	Vehicle to Grid

1. Introduction

Energy is a need in a modern world, but fossil fuel based energy system is polluting and depleting existing reserves. Environmental awareness is worldwide increasing. The European Council supports an EU objective to reduce GHG emissions by 80 to 95% by 2050 compared to 1990 levels. The European Council recognizes it is required a revolution in energy systems, which must start now and requests take in consideration the Europe Roadmap 2050 for moving to a competitive low carbon economy. All sectors need to contribute to the low carbon transition, although power sector has the biggest potential for cutting emissions. Electricity can almost eliminate CO_2 emissions if it would come from RES like wind, solar, water and biomass or other low emission sources. Emissions from transport could be reduced to more than 60% below 1990 levels through improving ICE efficiency and electricity could partially replace fossil fuels [1].

The power grid faces a challenging future due to the growing penetration of variable renewable energy. In order to reduce GHG, significant amounts of RES are being installed in many countries. The energy supplied by wind and solar sources is intermittent and the extensive facilities are causing critical conditions due to the presence of overproduction phenomena. At present, resource planning focuses primarily on meeting projected energy and peak load in a cost-effective manner, but with the expansion of demand-side resources, renewable generation, and other new technologies (such as storage technologies), improving planning tools has become increasingly important and urgent [2].

Electric vehicles (EVs) for road transport boost energy efficiency because of EVs do not require direct fuel combustion and rely on electricity; thereby, they contribute to a wide range of transport policy goals [3]. International Energy Agency models foresee strong changes in transport sector. The Blue Map model expects new powertrain technologies start to penetrate LDV and truck markets. Changes over time in model are based on the projected evolution of technologies and costs and assume strong policies will be enacted to encourage a shift away from conventional vehicles. The first goal of the European Commission for a competitive transport sector is developing and deploying new propulsion systems [4]. European transport Roadmap expects, from 2030 onwards, demand for non-PHEV ICEs will decline rapidly in absolute terms. The use of internal combustion engine cars will be halved in urban transport and will be achieved CO_2 - free city logistics in major urban centers. By 2050, LDV sales will be equally split between FCVs, EVs and PHEVs [5].

The present paper proposes a novel smart charging strategy that overcomes RES critical effects and support EV energy demand, improving the grid reliability and power quality. About 50 publications were reviewed for this paper and, despite being a substantial and representative sample of the state-of the-art, this number is not absolute.

Some researchers have focused on scheduling electric vehicles in response to pricing methods [6,7] or to renewable sources as wind power generation [8] or photovoltaic solar [9]. An extensive analysis of the flexibility characteristics of EV charging sessions is perform in [10-13] and [14] proposes a framework for optimized charging of EV fleet. Other research approaches focus on V2G systems and smart charging, to use EV batteries as a frequency response reserve, spinning reserve and non-spinning reserve for power regulation and keep a stable frequency, power quality and reliability [15-17]. Some papers implement smart charging to reduce energy consumption in smart homes or building [18] or have a major scale, introducing a cloud service based on distributed cooperative control strategy to provide frequency response [19]. To support these services, battery charging infrastructure should be develop at the same time. Present topologies and future trends are assessed in [20-23]. A cost-benefit analysis for the bi-directional functionality of vehicle-to-home is performed in [24]. The benefits from this use of EV batteries are peak-shaving and valley-filling on the load curve, resulting in cost reductions. This research recognize the use of this storage would allow an increased penetration of RES.

Different approaches are possible to reach grid flexibility required to manage a greener Europe. This paper contributes to knowledge with an EV charging strategy in a distributed energy resource scenario. This original idea provides support for energy transition with a strengthening of democracy and public participation to become aware of climate challenges.

Section 1 introduces the objective to reduce GHG emissions in Europa 2050 to imply a challenging energy future. RES and EV policies are considered to deal with greener energy sectors and some approaches are revised. Section 2 will detail study methods. Section 3 will provide a theoretical background about high RES and EV penetration impact. Section 4 will identify drive patterns depending on EV drive behavior and battery availability to develop EV charging strategy. Section 5 will discuss about strategy impact on grid balancing and system operator management. Finally, section 6 will present the main conclusions of the proposed model.

2. Materials and methods

In this section, we detail the methodology used to carry out the strategy to balancing grid with high RES penetration and integrate electric vehicles.

2.1.1 Modeling of 2050 electricity generation in high RES scenario

Renewable energy sources are a key ingredient in any decarbonisation strategy. In the high RES scenario, the share of renewables in electricity generation is expected to reach around 80% and may be even higher [25]. The model keep in mind the storage of electricity required to accommodate all available RES electricity, particularly at times when the demand for electricity is lower than RES generation. The high RES scenario is the most challenging scenario regarding the restructuring of the energy system including major investments in power generation with RES capacity and transmission system.

Based on the high efficiency scenario proposed by the European Commission, we extrapolate the most relevant daily average generation curves from dispatchable and non dispatchable sources. The study takes into account the main factors that determine the renewable electricity generation, such as the seasonality, latitude and climatic conditions of each region. Four characteristic curves corresponding to each season have been defined. The electric generation profile was performed with data extrapolation based on electrical statistic from Germany, France, Italy and Spain.

Table 1: EU27: High RES 2050 scenario. Source: European Commission [1]

		2050
Electricity generation	TWh	**5141**
Nuclear energy	Shares (%)	3.5
Renewables		83.1
Hydro		7.7
Wind		48.7
Solar, tidal etc.		16.4
Biomass & waste		9.6
Geothermal heat		0.6
Fossil fuels		9.6
Coal and lignite		2.1
Petroleum products		0.0
Natural gas		7.5
Coke & blast-furnace gasses		0.0
Other fuels (hydrogen, methanol)		3.9

2.1.2 Modeling of 2050 electricity demand in high RES scenario

The variations of loading demands are different in every Roadmap Europe 2050 scenario, especially between high RES and energy efficiency and business as usual scenarios. The electricity share soars further in decarbonisation scenarios reaching 36% to 39% in 2050, taking as reference the 2010 levels. The increase in electricity occurs as a result of technological changes on the demand side. On one hand, there will be more efficient buildings, appliances and industrial processes. On the other hand, transport and heating will be partially electrified in order to achieve a largely decarbonized power sector [1].

Four characteristic demand curves corresponding to each season have been defined. The electric demand profile was performed with data extrapolation based on electrical statistic from Germany, France, Italy and Spain. Electricity demand due to EV battery charging was no included at this point to allow develop an EV charging strategy.

2.1.3 Modeling of 2050 electricity demand due to EV battery charging

This paper assume transport scenario discussed by Europe Roadmap 2050 with electrification of 100% LDVs and MDVs (partially plug-in hybrids) and remain ICE to HDVs while switching largely to biofuel or hydrogen fuel cells [25].

European Union has about 250 million passenger cars and 37 million commercial vehicles [Table 2]. Load demand from EV battery charging in 2050 was extrapolated from current vehicle statistics. EV demand is expected to be quite different among countries and seasons. A characteristic EV demand curve was defined for smart grid balancing.

Table 2: Vehicles in use Europe 2015. Source: ACEA [49]

	Passenger cars	LCV	M&HCV	Buses	Total vehicles
Austria	4 748 048	375 163	68 860	9 679	5 201 750
Belgium	5 587 415	678 801	143 697	15 926	6 425 839
Croatia	1 489 338	127 395	45 757	-	1 662 490
Czech Republic	5 115 316	515 263	196 816	19 966	5 847 361
Denmark	2 404 091	395 645	41 457	8 832	2 850 025
Estonia	676 592	66 297	35 455	4 787	783 131
Finland	2 612 922	307 706	95 233	12 455	3 028 316
France	31 915 493	5 995 177	567 000	90 000	38 567 670
Germany	45 071 209	2 374 822	902 718	78 345	48 427 094
Greece	5 104 908	836 685	233 159	25 007	6 199 759
Hungary	3 192 132	389 980	86 831	17 254	3 686 197
Ireland	1 985 130	299 609	30 932	18 086	2 333 757
Italy	37 351 233	3 874 452	918 258	97 991	42 241 934
Latvia	677 561	52 612	32 908	-	763 081
Lithuania	1 244 063	46 342	50 089	7 147	1 347 641
Luxembourg	381 105	28 521	11 384	1 778	422 788
Netherlands	8 336 414	901 026	149 588	9 385	9 396 413
Poland	20 723 423	2 447 764	980 201	109 844	24 261 232
Portugal	4 538 000	1 110 000	119 000	14 700	5 781 700
Romania	5 153 182	670 119	218 728	21 123	6 063 152
Slovakia	2 037 806	235 519	94 611	-	2 367 936
Slovenia	1 130 907	71 971	32 445	-	1 235 323
Spain	22 355 549	4 520 616	526 559	60 252	27 462 976
Sweden	4 669 063	516 168	80 046	14 114	5 279 391
United Kingdom	33 542 448	4 007 331	581 645	88 186	38 219 610
EUROPEAN UNION	**252 043 348**	**30 844 984**	**6 243 377**	**724 857**	**289 856 566**

2.2 Balancing grid curves and charging strategy

After define power scenarios in Europa 2050, we extrapolate electricity curve from models assumptions. To do this, average electricity load curve is derived from Germany, France, Italy and Spain electrical statistics [26,27] to then extrapolate load and generation curves, and eventually, identify the impacts in demand and generation profile and grid balancing. With this step, the conceptual framework for high RES, efficiency and EV penetration scenario is developed.

EVs are classified according to vehicle availability to lend battery capacity to grid services. SOC and range anxiety are considerate to identify drive profiles. Then a charge and discharge strategy is suggested to support grid balancing impacts in high RES scenario.

3. Theoretical background

3.1 Energy scenarios

The scenarios in 'Energy Roadmap 2050' explore routes towards decarbonization of the energy system. All of them imply major changes in carbon prices, technology and networks. The future electricity market will be characterized by three trends: decarbonization of power system, increasing shares of (variable) renewable energy sources, and increasing needs for system flexibility [28,29]. Various deep CO_2 mitigation scenarios are developed in Europe 2050 models. The whole range of energy technologies was considered. Some scenarios focus on renewable and energy-efficient technologies and others include carbon capture and storage (CCS) and nuclear power plants. This paper assumes a green European Roadmap, with high RES and high energy efficiency scenarios as the main ones.

Table 3: Highlights high RES & energy efficiency scenarios impacts. Source: Own Elaboration.

High RES & Energy efficiency scenarios	**Impact**
Intermittency and the non-dispatchable nature of wind and solar energy production.	Matching demand and supply of electricity generation is difficult in a renewable-rich system.
Power oversupply events when large amounts of wind or sun.	Grid operator must halt renewable power plants to ensure grid stability.
High energy efficiency. Political commitment towards very high energy savings.	It leads to decrease in electricity demand on residential, commercial and industrial customers.
In order to reach the decarbonisation of energy a new strategy in heating & cooling and transport sectors is required.	Road transport and HVAC will be partially electrified with clean power.
Rise in distributed renewable energy from solar photovoltaic.	Timing imbalance between peak demand and renewable energy production. Load peak demand occurs after sunset, when solar power is no longer available, "duck curve".

3.2 Impact of high renewable penetration and energy efficiency scenario on system reliability

The share of renewable sources in power generation will grow in Europe in coming years. As a result, it is important to consider impacts from non-dispatchable energy in grid balancing. In the transition to high RES and energy efficiency system, load profile will be affected by new energy policies. Risk identification should be performed early to guarantee negative impacts do not make grid unstable. Main expected impacts are shown in Table 3.

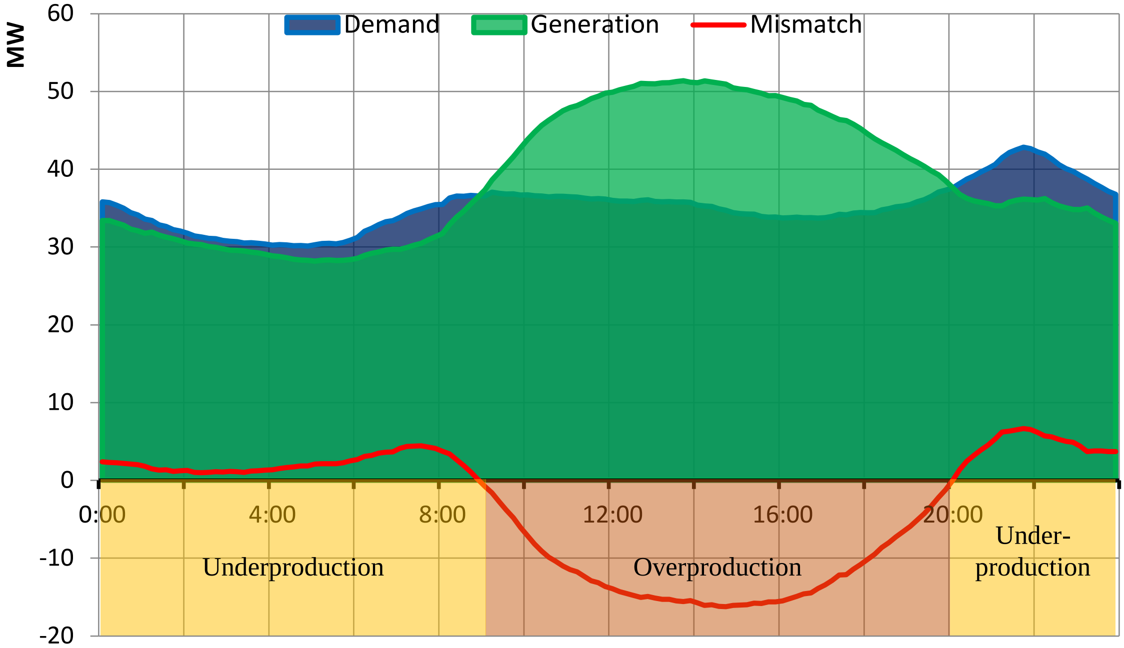


Fig. 1: Impacts in load profile in high RES Europe 2050 scenario. Source: Own Elaboration

3.2.1 Matching renewable sources and loads

Most renewable based power plants are fed by variable energy sources. Variation in solar radiation or wind speed are strongly dependent on weather conditions, with intermittent and fluctuating features, therefore, it restricts the stable operation of renewable energy facilities. A hybrid renewable energy system can be highly efficient by combining multiple renewable energy sources [30]. Battery energy storage systems have been broadly accepted as one of the potential solutions. This technology has the advantages of fast response, sustained power delivery, and geographical independence [31]. For the effective integration of photovoltaic systems into the energy mix, a two-way strategy should be employed: one strategy will require different adaptations of the generation process and the other will require adaptations of demand with a change of behavior on the demand-side [32].

3.2.2 Peak load shaving strategies

The inconvenience caused by peak load lies in it occurs for a short time every day and then grid needs additional capacity to deal with demand requirements. As consequence, some power plants are economically inefficient because they are idle for long time. Peak load shaving strategies have been suggested to improve grid efficiency. The major peak load shaving strategies are demand side management (DSM), integration of energy storage system (ESS), and integration of electric vehicle (EV) to the grid [33]. These techniques aim to improve demand profile. Different applications and processes can provide demand response (DR) potential by shifting or shedding their load. DR is proposed to implement peak reductions and power shifting based on financial incentives [34].

3.2.3 Grid flexibility

Grid flexibility is the capability of the power system to maintain balance between generation and load under uncertainty. Flexibility needs are changing as system variability migrates from load to generation. At the same time, new technologies and operational practices provide new options for flexibility. The adoption of variable generation and the evolution of demand have to respond to a need for greater flexibility [35]. The storage technologies (as pumped-hydro storage, lithium-ion batteries, adiabatic compressed air energy storage (a-CAES) and electric vehicles), demand response and European grid interconnections should be developed in order to increase these flexibility options [36].

3.2.4 Energy efficiency

Globally, energy efficiency has been improved 13% between 2000 and 2016. This improvement has reduced the need for additional primary energy. Technological innovation is creating new opportunities for progress in efficiency. Digitalization is beginning to have a significant impact on the energy sector and is creating exciting new opportunities for integrated solutions where efficiency and renewable energy work together to deliver clean energy outcomes at the lowest cost [37].

3.2.6 Power quality

A significant ongoing challenge experienced by the grid system is to maintain a balance between electricity generation and demand. If grid operator fails to match the electricity demand perfectly, several problems such as instability, voltage fluctuation, and total blackout will occur. Energy storage systems are suitable for providing ancillary grid services such as frequency regulation or spinning and non-spinning reserves.

The frequency behavior is involved in both, stochastic changes of loads and RES intermittency. Frequency deviations should be limited as much as possible in order to guarantee the quality of the power transmission. Traditional power grid frequency regulation is mainly based on generator, adjusting the power by the system operator, but Energy Storage Systems (ESSs) are one of the most promising technologies to enable RES to meet this challenge. New projects aim to develop regulation schemes/functions devoted to manage DG integrated with ESS in order to provide ancillary services to the main grid [38]. The vehicle to grid (V2G) system can provide fast response frequency regulation for grid and stable electricity network. [39,40] Demand response devices as building HVAC systems can provide secondary frequency control service to the grid. HVAC system can be controlled to modify the power consumption and provide flexibility to the grid [41].

3.2.5 Duck curve

Self-consumption of electricity generated by solar panels is increasing at homes and businesses. This consumption of PV energy takes place directly at source or in the immediate vicinity, then in midday hours on sunny days, solar generation reduce energy transmission from power plants. Grid operator shows a growing concern about the late afternoon ramping required to deal with loss of solar generation after sunset, just when peak demand begins.

According to early reports, duck curve pattern appeared in California, but now is common in countries worldwide, making the duck curve even fatter. As a consequence, grid needs more flexible generation to fill the ramp requirements to meet evening peak demand [42]. Storage facilities combined with solar photovoltaic power plants make solar energy dispatchable by supplying stored energy at later times of the day [43].

3.2.7 Cost reduction

So far, grid has no storage system or it is limited to pump water in hydroelectric power plants, thus, generated electricity should match exactly with electricity demand. In high RES penetration scenario without storage facilities, depending on weather conditions, renewable electricity generation will exceed grid demand. In that case grid operator should halt power plants to maintain power balancing.

Installed generation capacity increases with penetration of wind and solar PV facilities, due to their intermittency and lower load factors. For this reason, increase the system efficiency will save in investment and maintenance costs. The storage technologies as pumped-hydro storage, large batteries storage, adiabatic compressed air energy storage and electric vehicles are suitable to increase the system efficiency.

Nowadays, economic feasibility analyses reveal lithium-ion batteries are not cost-effective without incentives. However, that situation could change because the cost of batteries is expected to decline sharply in the coming years.

3.3 Electric vehicle

In Europe 2050 context, electric powertrain is projected to be the main technology in road transport, thus, there will be a significant extra demand on electricity. One potential opportunity to manage energy demand is provided by EVs, which act as an aggregated energy store to support intermittency in renewable sources, providing demand response, peak shaving and ancillary services. These services will provide through bidirectional charging technology, which allows bidirectional power flow between the battery of electric vehicle and the power grid.

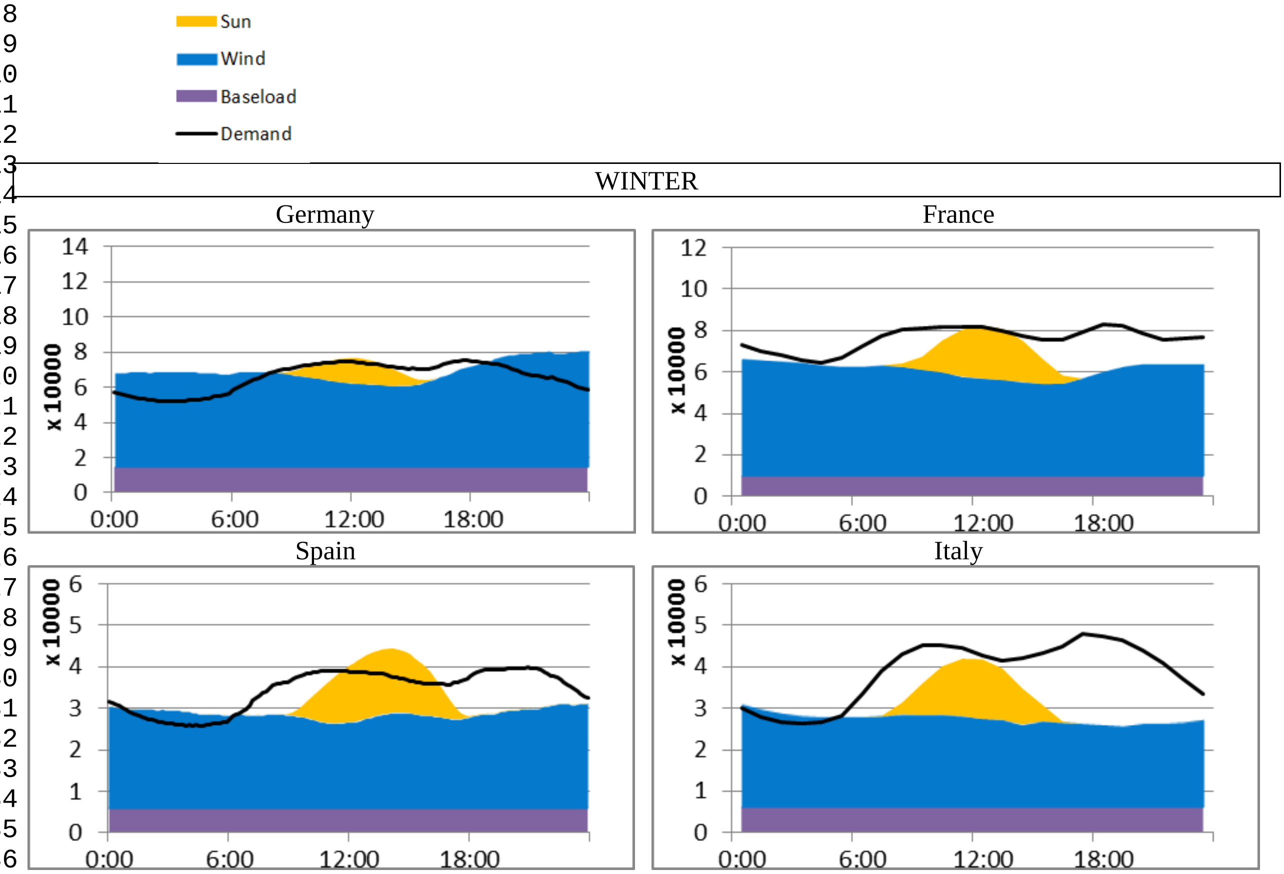
Recently, economic analyses of EV-based energy storage had reported the implementation of V2G could provide a significant source of income, and offers significant potential, for example with falling battery costs or decreased degradation [44]. Small scale projects have been developed in Europe, such as Amsterdam V2G. This project had proved the possibilities of smart energy management; pave the path for large scale adoption of renewable energies in urban environments [45]. Optimal operation under different TOU tariffs of V2G and G2V systems integrated with renewable energy was considered in [46].

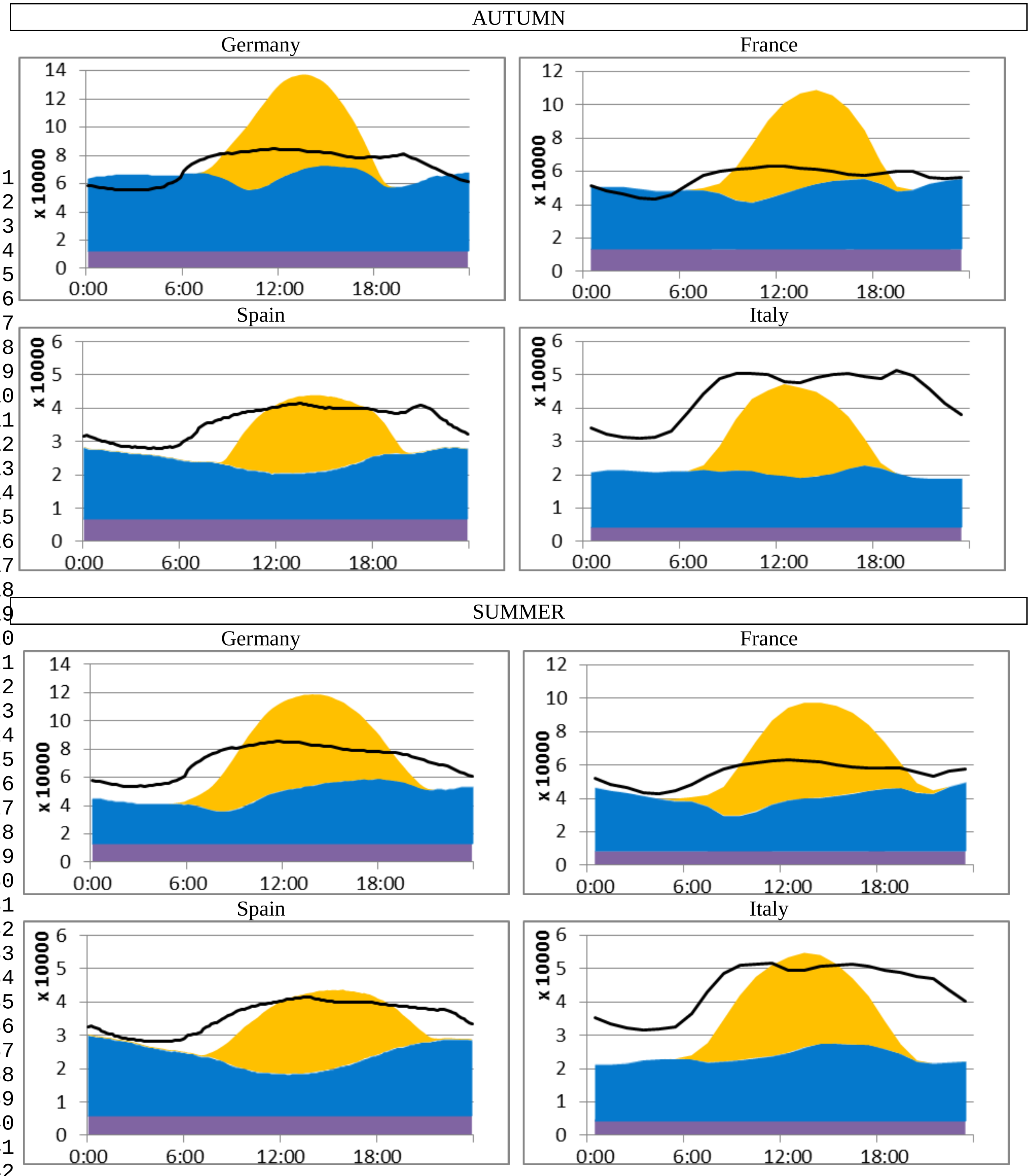
Bidirectional charger is the core device of the V2G vehicles. The EV battery charging system has to operate in both, inversion and rectification mode. A review of power electronic converter topologies for battery chargers was presented in [47]. V2G technology and smart charging aim to increase renewable energy penetration. Batteries could be used as a frequency response, spinning and non-spinning reserve. By using the V2G system as power regulation, EVs can be an important part of power utility [15].

4. Results

It was extrapolated electricity data for each season with high RES 2050 model. Diagrams show the balance among non dispatchable sources and load with no EV demand included. Non dispatchable sources group baseload, wind and photovoltaic solar. It is expected wind and solar photovoltaic sources generate almost 65% of demand in electricity. In the other hand, baseload power will generate around 15% of demand in electricity. Baseload group nuclear, coal, biomass, waste and geothermal sources. Baseload has a slow ramp to adjust its power output. That means grid supervisor has almost no control about 80% of electricity generated.

Table. 4: Non dispatchable electricity and demand in Europe 2050 high RES scenario. Source: Own Elaboration

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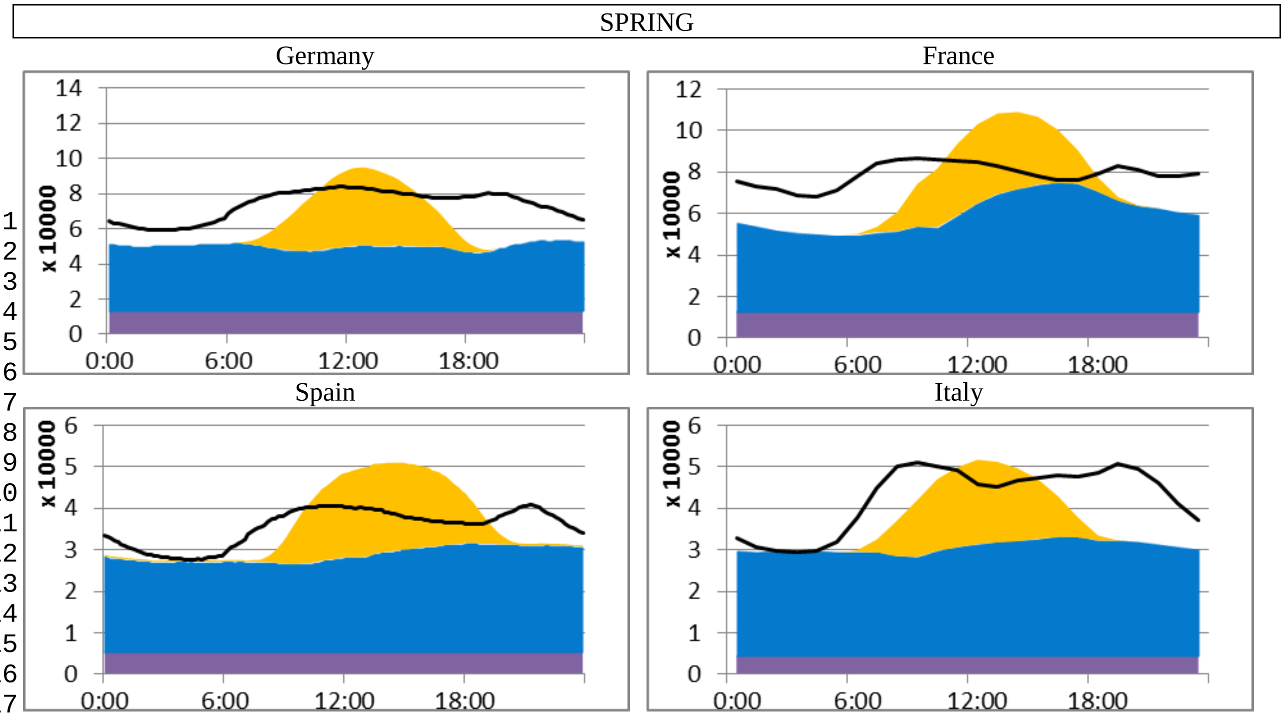

Renewable generation and demand is affected by whether conditions and seasons. Charts show gaps of energy and non dispatchable overproduction. Dispatchable power plants could fill the gaps but a huge quantity of electricity cannot match electricity demand. EV and HVAC are flexible enough to accommodate electricity consumption to balance grid and change dispatchability from generation to demand side.

At the very beginning of EV deployment in Europe, there is no certainty about which methods will be adopted to manage power supply, thus charging strategy must be developed to guarantee the minor impact on electrical grid and take advantage of storage capacity. The analysis of current usage patterns allow to identify several user types, like residents, commuters, car sharing users, taxis, visitors and entrepreneurs [48]. This paper focuses on the availability of the vehicle to offer battery capacity to grid services.

High availability vehicle - V2G

Most drivers use the vehicle in small trips and exceptionally long ones. Usually, the distance on weekday trips is between 10 and 100 km, therefore, vehicles are parked over 90% of the time. Daily power demand means a fraction of the battery capacity, so there is some capacity available as flexible resource for grid support.

Intensive usage vehicle - G2V

Business or passenger fleets and some private vehicles demand full charge battery to afford every journey. In some cases, fast charging improves availability, maintaining SOC as high as possible to deal with long distance and unexpected trips. In such cases, energy stored in batteries will be for driving purposes. When possible, these vehicles will benefit from reduced rates, as long as the availability of the vehicle will be guaranteed.

Nowadays, European Union has about 37 million commercial vehicles and 250 million passenger cars [49]. In 2050, a lot of commercial vehicles and passenger cars will be electric vehicles powered by batteries. Commercial vehicles usually fit in intensive usage pattern, but most passenger cars are suitable for V2G technology. These vehicles will be idle over 90% of the time and then a portion of their battery capacity can provide distributed energy storage.

The acceleration of the electric vehicle market will increase demand for electricity. Stochastic connections to charge EV produce overloading on peak demand, instability and ultimately blackout. As a result, a charging strategy is needed to avoid major problems to the grid. Nowadays, flatten load profile is possible shifting charging time to valley load at night, but in high renewable penetration Europe 2050 scenario, matching between generation and load will become a complex factor.

Passenger cars, with demand response technology, will be able to shift energy demand to match peak non-dispatchable energy generation. Some intensive usage vehicles can also contribute shifting demand to reduce grid impact. Demand response technology allows matching fluctuating supply with flexible demand and optimizes net congestion. On sunny or windy days in high renewable penetration scenario, excess in non-dispachable electricity generation occurs; then, demand response loads will drain energy overproduction. EV batteries with smart charger are really suitable to deal with energy fluctuation because of fast response capacity and flow power regulation.

Strategy in EV should considerate discharge capability of EV. V2G technology allows returning electricity to the grid to provide services. Sell electricity at peak demand and provide ancillary services could be a source of income for driver and improve power quality when cost of batteries decline or cycle degradation decrease. To support high grid flexibility, we suggest bidirectional chargers that provide four operating modes.

- *G2V - Constant charge:* Battery charge at constant power rate. Maximum power rate is limited by vehicle socket, SOC and battery temperature.
- *G2V - Smart charge:* Charge speed changes in order to match with a control signal or frequency regulation and vehicle parameters. In smart grid environment, smart charging provides flexibility to grid allowing demand response services
- *V2G - Power return:* Bidirectional charger allows feed power from battery to grid. Power discharge can be adjusted by control signal.
- *Ancillary services:* Power flows in both directions, grid and battery, to support frequency or correct power factor to improve power quality.

Constant charge is suitable for electric vehicles to reach enough state of charge in battery to afford planed trips. If vehicles are on the road, battery must be charged as soon as possible, and then charger provides fast charging service. When vehicles are idle at night or in a long break, scheduled charging strategy enable charge at low rates and keep the vehicle with enough energy to complete its trip plan. Slow charge mode is preferred to reduce impact in battery degradation and grid load profile.

The amount of energy used daily by most private and some commercial vehicles are smaller than battery capacity and these vehicles are usually idle and connected for long time every day. At smart grid environment, demand response EVs take advantage of sun and wind peak production. Substation Agent manages smart charge to increase or decrease charging power to accommodate to non-dispatchable renewable fluctuation. In the event of renewable surplus, it will not be enough to reach the minimum SOC, scheduled charge completes SOC to guarantee availability.

Distribute EV storage provides peak shaving to flatten load profile and minimize solar duck curve. When battery cost decrease and performance increase, peak shaving could report income to EV owner. Also provide vehicle-to-office or vehicle-to-home services to reduce peak cost. In isolated grid, EV can supply a house or neighborhood for intermittent generation or blackout.

Furthermore, idle smart EVs will be able to provide ancillary services to improve grid power quality. EV owners will be rewarded for reporting ancillary services as frequency/voltage support and reactive compensation.

Table. 5: Default EV charging parameters EV. Source: Own Elaboration

Description	Intensive	Smart
Range SOC	0-100%	0-80%
SOC minim	60-100%	30%
Smart range	0	50%
Constant recharge	YES	YES
Flexible recharge	YES*	YES
Power return	NO	YES
Ancillary services	NO	YES

*on order

Depending on scheduled trips, drivers sets EV charging plan. As consequence, vehicle adjusts battery parameters to adopt driver requirements. In 2050 is expected battery cost decrease and performance get better. Common BEV and PHEV will be able to storage energy for hundreds of kilometers or even more. Power manage framework of EV battery is proposed in Fig. 2.

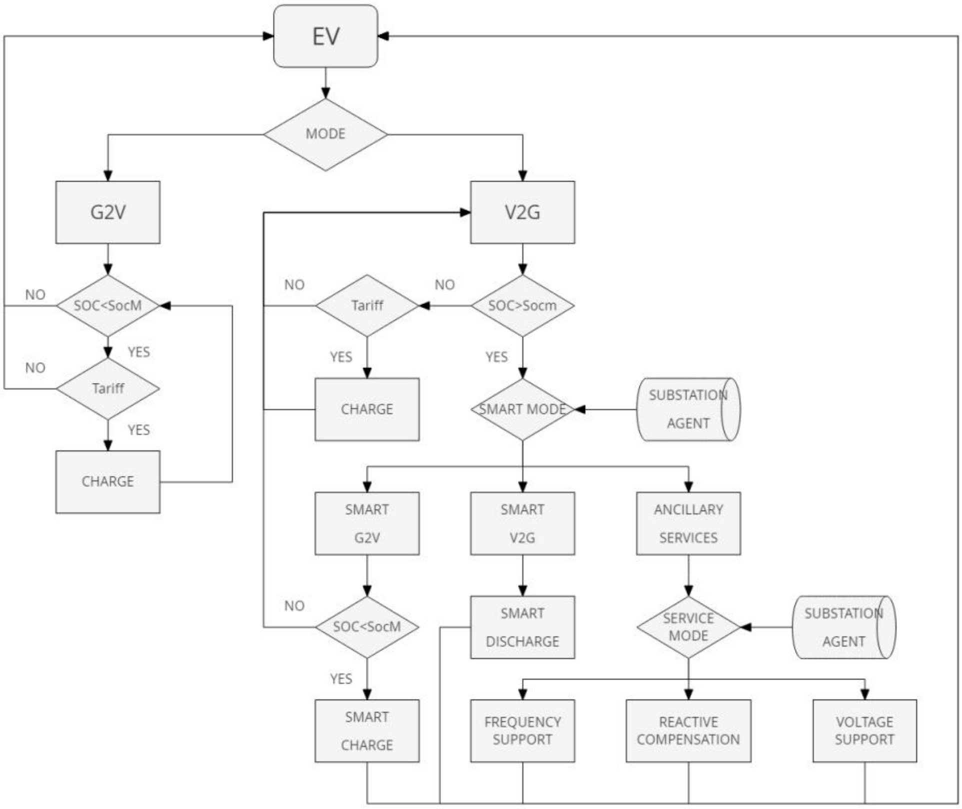

Fig. 2: Proposed iterative framework for EV charging strategy. Source: Own Elaboration

Inputs adopted to obtain outcomes achieved are:

Table. 6: Power electricity scenario. Source: Own Elaboration

Reference curve demand	REE 2018
Increase in electricity demand from 2018	42%

	2018	2050
Power demand (annual)	252.7 TWh	358.9 TWh
Share of renewable energy in electricity generation	37.7% *	81.6%
Share of non-dispatchable renewable energy	23.2% *	60.6%
Wind power capacity	22.9 GWh	64.1 GWh
Solar power capacity	4.4 GWh	24.2 GWh
Electric vehicle demand	≈ 0.1% *	16.3%

* 12-month moving average

EV model 2050

EV storage capacity

- Electric vehicles with V2G — 20 000 000
- Average grid storage capacity per vehicle — 10 kWh
- Distribute energy storage EV — 200 GWh

Electricity EV demand (day) — 158.8 GWh

- Transport — 146.3 GWh
    - Intensive Usage — 32.6 GWh
    - Smart Charging — 113.7 GWh
- Storage
    - Electricity Demand — 12.5 GWh
    - % Total EV Capacity — 6.25%

5 Discussions

High penetration on RES can report large benefits to reach CO_2 milestone to Europe Roadmap 2050. Solar and wind power is naturally intermittent and it will create technical challenges to the grid power supply especially with high amount of solar and wind power integration. Grid system must be strong enough to handle rapid changes in generation levels from non-dispatchable renewable sources. Technical analyses perform in Europe Roadmap 2050 suggest that incorporate large shares of intermittent renewables is technically feasible, but significant increase in transmission capacity are necessary as well as additional backup generation capacity [25]. On the other hand, large scale storage and distribute EV storage could become potential technologies to ensure the continuous supply of power. The size of the energy storage needed depends on the intermittency level of the solar or wind. There is a trade-off among transmission, backup and storage capacity. Backup and storage capacity can avoid the need for transmission lines used to shift power from one region to the other, but sufficient transmission capacity will allow sharing surplus generation resources between regions. The combination of these technics results in improvements in the cost, efficiency, quality and decarbonisation of the power grid.

Currently, there are 250 million passenger cars in Europe [49] and this amount will be bigger in 2050 [25]. It is expected no ICE cars will be sold in 2050, with a major contribution of BEV and PHEV in vehicle mix. Then, battery storage capacity in PHEV and BEV will be big enough to support intermittency of non-dispatchable sources. Assuming 30 to 60 kWh batteries on BEV and 10 to 20 kWh batteries on PHEV for EVs that are available and connected to the grid 50% of the time, with 10% to 25% capacity available for use by the grid operator, this could provide approximately 1 TWh of storage capacity. The 2050 power demand is similar in decarbonized pathways, at 4.800 to 4.900 TWh for the EU-27 [25]. EV storage capacity represents about 7.7% out of 13.4TWh of average daily power. Nowadays, battery storage is not cost effective to save enough money to make EV storage attractive to users. Technical barriers need to be overcome to improve cost and battery life. Those improvements could be available in the next 30 years.

On the other hand, EV demand response service has important meaning of balancing the grid and avoiding curtailment of low-carbon, low-marginal-cost resources, particularly in renewable generation. Demand response allows change in the power consumption of an EV customer to better match the demand for power with the supply. Demand response does not reduce the energy delivered in a day, but change flexibility from generation to load. System operator through DCS proposed could manage grid resources to improve matching between load and generation, overcoming RES critical effects and supporting EV demand.

As shown in Fig. 3, mismatching between generation and load is expected in high RES scenario. When sun is shining at midday, solar photovoltaic facilities do not have enough power demand to match supply energy. In the event of overproduction phenomena, demand response services and large storage facilities will fill the gap in power demand, matching renewable generation.

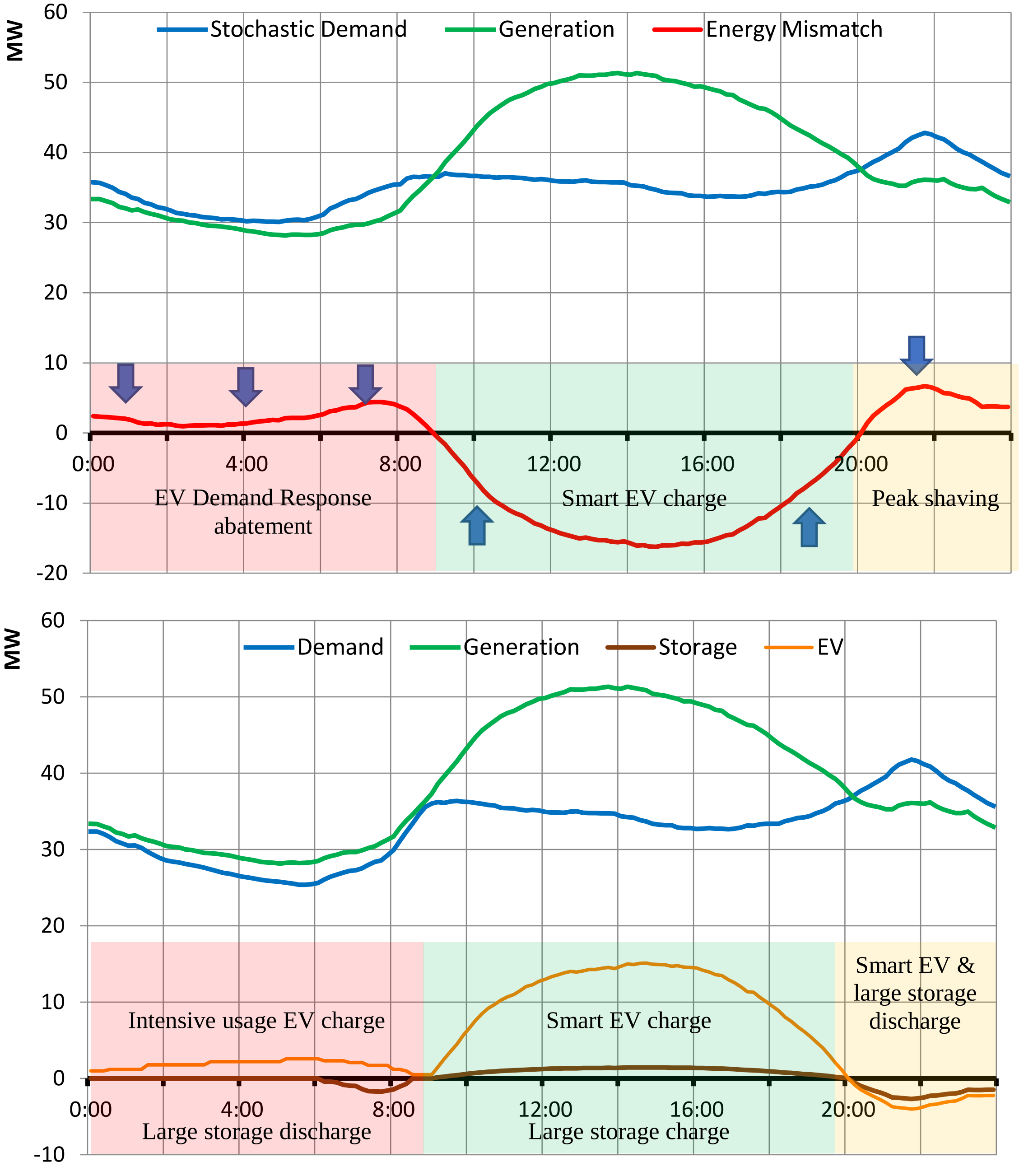

Fig. 3.a Grid mismatch in high RES Europe 2050 stochastic model and EV accommodation technologies 3.b Grid accommodation with energy storage and demand response strategies: Own Elaboration.

Fig. 4 shows a plausible scenario based on high RES penetration, large scale and EV storage and demand response technology. At night, when there is not solar photovoltaic generation, EV charge is restricted to intensive usage vehicles, as trucks, buses, vehicle fleets and public utility vehicles. The main EV charging power is shifted to midday, when solar facilities supply maximum power. Peak demand in sunset is support by V2G EV and large storage facilities. This scenario reduces inter-regional transmission as well as additional backup generation.

There is no certainty about user acceptance of V2G services for EV users in 2050 but a mobility survey on driving and parking patterns of European car drivers suggests driving profiles and charging profiles do not change significantly with electrification [50]. The study reveals the large prevalence of trips departing from home, the relatively low distance travelled on average every day by car and the long time in which the car is parked close to home. Such distances can be comfortably covered by battery electric vehicles and further R&D improvements in battery systems could ensure that the “range anxiety” factor is minimized. The survey reveals the parking time after the last trip of a day amounts to more than 16 hours per day.

It will be necessary electricity rates motivate EV users to become prosumers. Drivers could get significant cost savings buying cheap energy when renewable overproduction occurs to expend it in their trips or selling it to obtain profit when grid needs dispatchable energy or ancillary services. Batteries in EV have large capacity then a small fraction of V2G is enough to support grid requirements. Electricity demand and vehicle usage are inherently associated. Usually, drivers go to work and park vehicles early in the morning, then a huge amount of capability is available to storage photovoltaic overproduction. When drivers return home in the afternoon, demand peak occurs. Therefore, vehicles will be parked at home and EV are available to return energy for peak shaving.

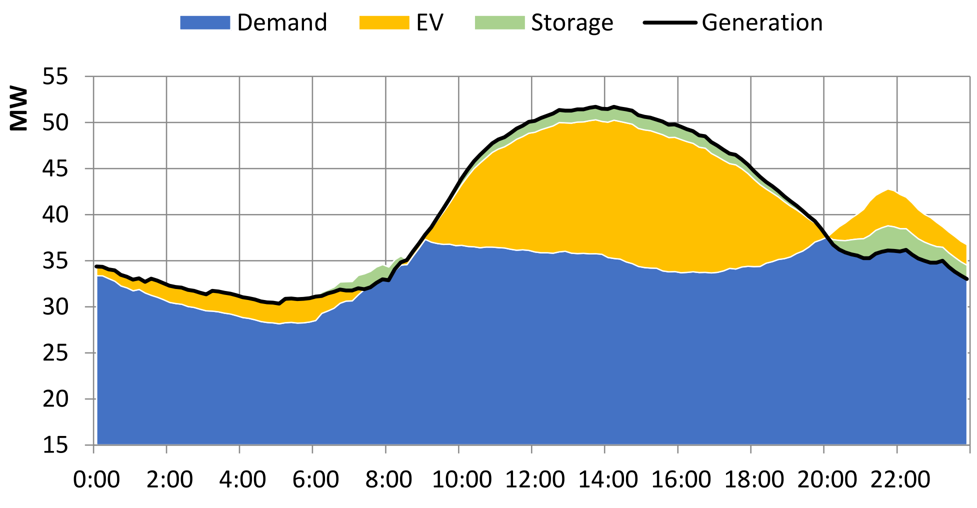

Fig. 4: 2050 EV & Large Storage power curves. Source: Own Elaboration.

An EV charging strategy allows improving matching between load and non-dispatchable generation. Fig. 3 shows EV daily power curve. The power demand of intensive usage vehicles is located at night, when valley load occurs. Passenger cars charge the battery at midday, when sun is shining and there is photovoltaic solar overproduction. Most of the required power for transport sector is obtained at this time.V2G technology uses distributed storage to return energy for peak load and also provide ancillary services to improve power quality.

As shown in Fig. 5, System Operator uses three grid control strategies. At night, when there is not solar non-dispatchable generation, wind and dispatchable power plants supply energy required. Early in the morning, dispatchable power plants and storage facilities aim to feed load. Demand response EVs shift energy demand to match with high non-dispatchable generation. At sunset, V2G and storage facilities mitigate peak demand and dispatchable resources generate remaining energy to match demand.

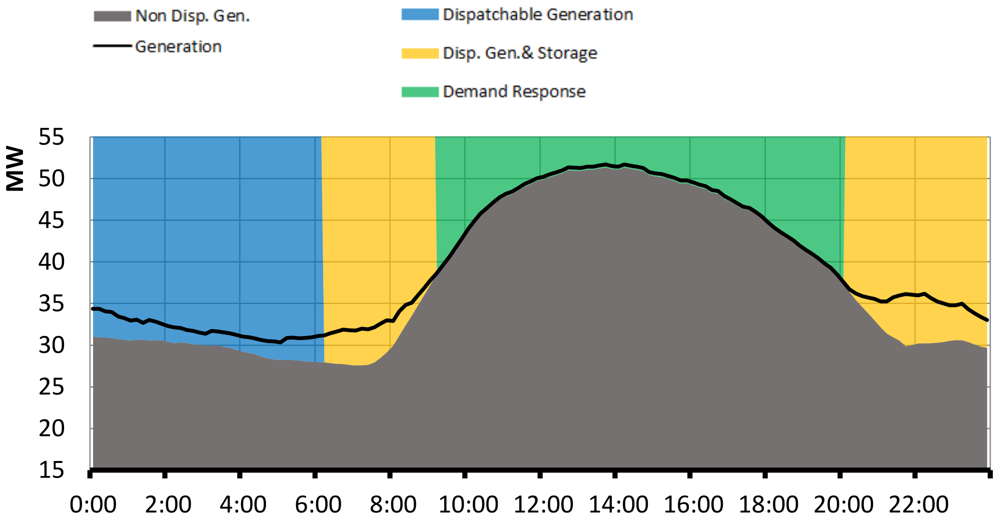

Fig. 5: Grid control. Source: Own Elaboration.

6 Conclusions

The implementation of Roadmap Europe 2050 requires a revolution in energy systems. Present grid resources are not enough in low carbon scenarios based on energy efficiency and renewable resources. A novel charging strategy is presented and evaluated in this paper. This strategy is developed to increase penetration of renewable energy by electric vehicle. A charge and discharge strategy is an essential part to greener road transport, support renewable fluctuation and do not cause major problems to the grid. A flexible G2V technique, as demand response, assists in balancing grid and support mismatching between load and renewable generation. Overproduction phenomena in wind and photovoltaic generation could be overcome. On the other hand, EV energy storage with V2G technology could support peak shaving and provide ancillary services. These services are aimed at keeping power quality, stabilizing frequency and flatting load profile. Savings in grid investment and maintenance costs could bring profits to EV owners through the electric rate.

It will be necessary to develop an infrastructure to support EV grid services. On the one hand, an effective charging infrastructure must be deployed to allow parked cars be connected to grid and a communication system must be implemented to manage the distributed resources. On the other, financial incentives in charging motivate EV users to become prosumers. Demand response flexibility will be rewarded with low electricity rates. Selling energy at peak demand and providing ancillary grid services could generate a significant source of income. Further investigation is required to implement smart grid strategies presented in this paper. The current policies and technical evolution will require adequate grid network to avoid potential distortion in electricity system. Bidirectional charging stations for EV should be developed to provide flexible G2V and V2G services. Also international standards for smart grid communication must be defined.

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Appendix

Appendix A. Distributed control system

Economy or time discriminating rates will not be enough to match renewable generation and EV demands, thus smart grid technology must be adopted. V2G EVs require a control system to coordinate demand response to shift charge, manage power return to grid and handle ancillary services. But they are not the only ones, others demand response devices like HVAC can provide services to grid.

Smart grid architectures are usually based on centralized or distributed systems. In centralized topologies, a server cluster optimizes the behaviour of smart devices to improve grid management; however, communications of each independent device can cause excessive communication flows. Because of that, this paper is based on a distributed control system (DCS). This computerized control system allows manage grid with large number of devices and loop controls. Autonomous controllers are distributed throughout the system, but there is a central system operator and substation agents to manage smart devices.

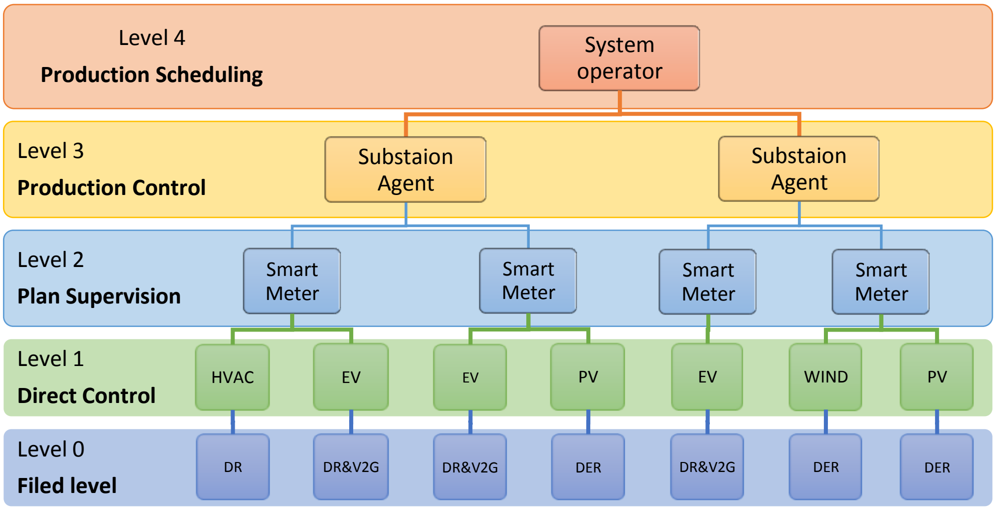

Fig. A.1: Distributed control system smart grid. Source: Own Elaboration.

In a wholesale electricity market, system operator monitories power system in real time to balance electricity supply and demand. On one hand, operator manages dispatchable generation and storage facilities to meet the demand; on the other, it handles demand response devices to shift power load.

A substation network of an electrical distribution system operates as a cloud cluster. Every cluster is under control of transmission system operator (TSO). The demand response resources in each cluster are managed attend to power generation and line capacity. In addition, the system operator reserve energy for the storage facilities or balance demand depending on tie-line congestion. In this way the safety and reliability of the power distribution network is guaranteed.

Substation Agents receive control directives from TSO and send broadcast data transmission to end devices. Message sent to a broadcast address require low bit rate, thus power-line communication (PLC) is suitable to reduce infrastructure cost. Broadcast frame codes services as: demand response, power return, frequency regulation or reactive injection.

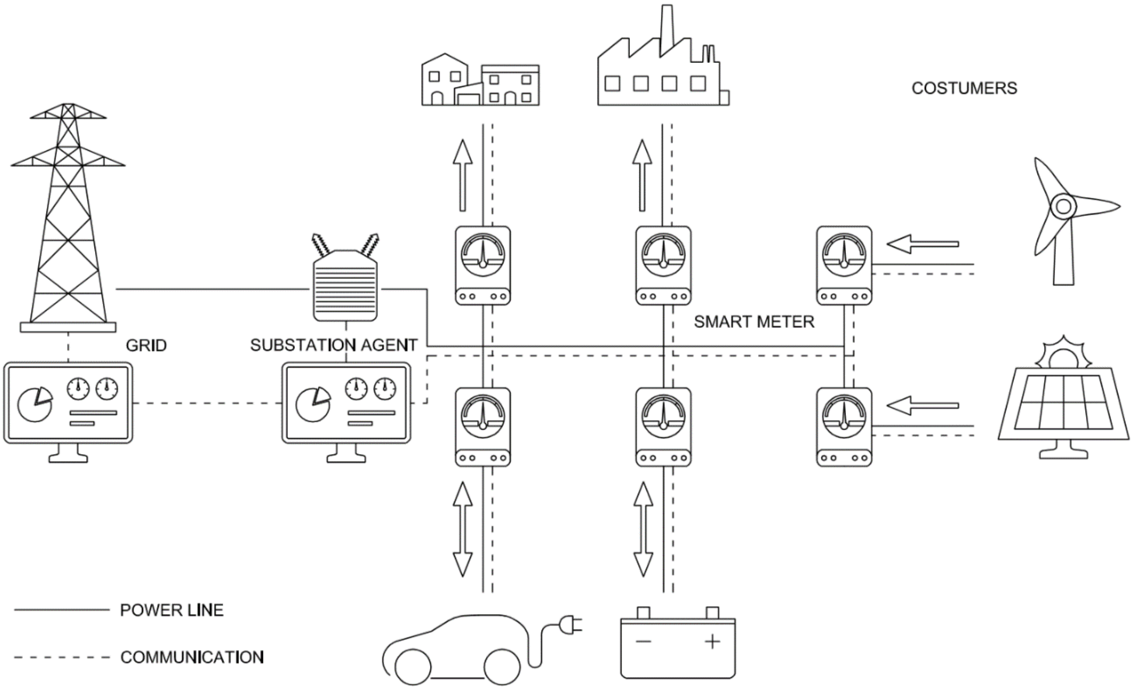

Fig. A.2: Substation cluster. Source: Own Elaboration.

The conceptual cluster framework is introduced in Fig. A.2. It contains four main parts: 1) Transmission System Operator 2) Substation Agent 3) Enhanced Smart Meter 4) End Costumers.

Substation Agents and TSO have real-time communication to coordinate flexible end devices. This approach allows trim demand response customers to deal with renewable fluctuation. Three main control modes are defined:

Generation control: when load demand is bigger than non-dispatchable renewable generation, spinning reserves and dispatchable generation, renewable or not, supply energy to balance grid. That happens in Fig. 5 at night, when solar photovoltaic non-dispatchable generation does not produce energy. In the event of night wind overproduction, control grid change to demand response control.

Storage support: when load demand is bigger than non-dispatchable renewable generation, storage facilities help spinning reserves and dispatchable generation to support grid balancing. High speed response from battery storage helps to handle fast load change, improving electricity quality.

Demand response control: in the event of non-dispatchable renewable generation exceeds load demand, demand response devices will turn on to drain overproduction. Electric vehicles with V2G technology will be able to change charge speed in order to match with renewable power fluctuation.

System operator manages every cluster according to grid parameters as proximity to generation facilities, line and substation congestion and fair treatment of costumers. Cluster Substation Agent sends regularly broadcast frames to smart meter and smart customers. Depends on system operator instruction and power flow in substation, cluster Substation Agent manages smart customers. To match supply and demand and ensure integrity of the power distribution network, Substation Agent makes requests to smart costumers to reduce or increase the amount of power dispatched.

Smart grid costumers will play an important role in grid balancing. In 2050, some costumers become prosumers, therefore, they will consume and produce electricity, selling and buying energy. This electricity will come from solar or wind sources and some of them will have energy storage capacity and will provide demand response and ancillary services. These services are focused on strengthen grid power quality and support high renewable generation.

Electric vehicles with smart charging will provide grid services. When smart EV receives a Substation Agent request, it considers trip planning and SOC to attend the service requested. EV charger keeps grid voltage and frequency under observation to determinate control behavior. Demand response, frequency support, power return and reactive compensation will be usual services in V2G vehicles.

Enhanced smart meter provides real-time power monitoring and record power and timing to match price and energy flow. The recorded data is transmitted to the Substation Agent for billing purposes. Demand response electricity consumers will be rewarded with low rates prices to give advantage of renewable overproduction. Enhanced smart meter watches smart costumers and electrical capacity hired. Over ranged customers will be disconnected by smart meter to guarantee grid integrity.