How can the use of electric vehicles affect the curtailment of renewable generation?

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Abstract

Facing climate change has made governments galvanize and implement actions to stem it. Difficult tasks have to be managed: among them is the integration of renewable energies into electric energy systems. This lets emerge problems for the system operation most notably during off-peak hours (nights and weekends) when high levels of generation from renewable energies encounter low consumption levels.

Curtailing a part of this generation may be necessary to maintain system stability. Additional flexible consumers are needed to bear these circumstances without curtailing valuable energy. The intended massive introduction of electric vehicles could kill two birds with one stone. Electric vehicles can act as additional consumers during off-peak hours and absorb a part of the high wind or solar production rates. Electric vehicles are also quite flexible as they may be connected to the grid during an important part of the day, especially during off-peak hours, when curtailments are more probable, and thus give enough flexibility to the system to decide when to charge them. Furthermore, they help reducing emissions if the electricity mix includes even higher renewable energy shares.

A model is used that is able to optimise the short-term operation of the electric system with electric vehicles. We analyse different renewable penetration scenarios for Spain for 2020 and study the profile of curtailed wind energy. Then, these scenarios are analysed introducing electric vehicles. Charging electric vehicles can happen either taking into account the overall system conditions in each day or in a predefined schedule. Results on reduction of curtailed wind generation and profiles as well as charging hours of electric vehicles and cost savings are presented.

Keywords: Wind Energy, Electric Vehicles, Unit commitment

1 Introduction

In January 2011 installed wind capacity added up to approximately 20 GW in Spain. This is the second highest value within the European Union although Spain is located in the fifth rank comparing the energy demands of the EU. Forecasts for 2020 determine this installed capacity almost to double (38 GW, see [1]). In the same time horizon electricity demand is supposed to increase 43%. As wind energy is injected with priority due to the current regulation, the maximum hourly share of wind production in demand coverage of 54% until 2010 is very likely to be outreached. In the year 2010 0.6% of the produced wind energy had to be curtailed during low demand hours to keep the electric system operating with normality [2]. Indeed, scaling up historic demand and wind energy series with the mentioned forecasts for 2020 leads to 19 hours with negative net demand. That is the demand minus wind and other distributed energies. Another 219 hours are below 7 GW, which is the maximum production output of the Spanish nuclear park normally running in base-load at full capacity. Without changes on the demand or generation side or potent energy storage facilities, the only way to cope with so much wind energy is to curtail a part of it. This is not desirable as Renewable Energies are backed by the politicians to approach a more sustainable energy system.

Fortunately, Electric Vehicles (EV) have recently appeared again on the horizon and one expectation of their additional electricity consumption is the absorption of high wind productions during low demand times. As consumption pattern of Electric Vehicles seem to be opposed to the rest of electricity demand: people driving in cars don't consume electricity at home or at their work place and cars use to be parked and may be connected to the grid during low demand hours at night. So, to the idea of additional electricity consumption in low demand periods comes the capability of the EVs batteries as an energy storage which may be able to generate during peak hours. Different national and international projects analyse the effect of Electric Vehicles may have in the Spanish electric system [3, 4].

In works such as [5, 6] Electric Vehicles are analysed as additional consumers as well as generators. The study of [7] focuses on distribution grid integration and absorption of distributed renewable energy production.

2 Modelling Approach

We use a short-term operation model to determine the unit commitment and dispatch of one day. The results of the last hour of that day are the starting point for the next day. In that way a whole year is calculated. The model is based on a cost minimisation objective and takes into account technical constraints such as energy balance, reserve constraints and minimum and maximum power limits, ramps, minimum on and off time and the logical order of start-up, shutdown and unit commitment decisions for thermal plants. Production and consumption targets are given for pumping storage hydro units to orientate water usage regarding the weekly or yearly work cycles of the reservoirs.

Electric vehicles are considered in two senses in this model: as an additional consumption since they may be connected to the grid to charge their battery and under certain limitations as well as electricity storage to supply a part of the demand in system peaks. Including these considerations into the problem statement means adding two extra terms in the demand balance regarding the consumption and production of an electric car in an hour. As the electricity is stored in the battery an extra balance for the electric car has to be added. This balance must take into account the battery charge level, electricity consumption on the road, electricity consumption to recharge the battery and electricity generation injecting into the grid. Furthermore maximum charge and discharge rates have to be defined similar to the ramping rates in conventional thermal plants and the daily consumption of electric energy during the use of the car. Electric Vehicles can have three possible states: they can be connected to the grid, parked but disconnected from the grid or driving. Connected vehicles can be charged and discharged taking into account the respective efficiencies. We supposed that disconnected vehicles which are not driven do not to have any energy loss. Driving vehicles follow certain usage patterns which indicate distances and hours travelled. More information on selected data is given in section 3.1.

For the case study in section 3 we adapted the model in a first stage so that Electric Vehicles are not able to generate electricity. This seems to be the simplest and most straightforward way in which EV could be operating in the system. The number of Electric Vehicles present in the system are modified in different scenarios. In a second stage three options are analysed: Dumb charge in which Electric Vehicles charge either under a predefined schedule or smart chartge where it is the model who decides when to charge. A third option lets the model decide about the time of consumption and as well generation of Electric Vehicles in the smart charge and generation option. The model is obliged to charge the battery in such a way that, considering the vehicles usage pattern with hours and distances, the battery contains enough energy to last until the vehicle is connected again to the grid (following a connection pattern to be explained as well in section 3.1).

The model is structured as a mixed-integer problem and written in GAMS 23.6. It gives results on generation output, wind curtailment and Electric Vehicles Charge and discharge profiles.

3 Case Study Spain

Spain is the country with the second highest installed wind capacity in the European Union. The year 2020 is a common time horizon for future analysis within the European Union due to the 20-20-20 objectives for 2020. Therefore, this year and this country have been chosen to be studied in detail in continuation.

3.1 Data for 2020

Data for Spain was taken principally from public sources. If no data was available approximations based on expert knowledge have been made. The forecast of total electricity demand for 2020 has been taken from [1] and adjusted to mainland Spain (373TWh). The same source contains forecasts of installed capacities and productions by renewable energies, which are the basis for the data used in this case study. Historic time series of mainland Spain, taken from [8], have been scaled with the mentioned forecasts. Namely, this applies to data input for electricity production by wind, biomass, biogas, small hydro, solar thermal and photovoltaic, cogeneration and waste as well as for demand. Installed capacities of thermal plants including nuclear, coal, combined cycles and gas turbines have been taken from [9].

We require enough upwards reserve to be available to cover the failure of the largest generation unit and 95% of all demand and wind forecast errors. Downward reserve should cover a 95% of demand forecast errors. These values correspond approximately to a 2σ criterion common in the sector to cover forecast errors within the range of twice the standard-deviation, assuming normal distribution of errors.

Concerning the data for electric cars, we supposed an average travel distance of 35 km/day considering different time patterns for weekday and weekend. We supposed the same distance for weekdays and weekends following the report of [4, Fig.81]. For weekdays the behaviour of a typical commuter is supposed geared to the work of [10]. The distance is travelled between 7 and 10 a.m. as well as between 5 and 8 p.m. without a connection to the grid between these two time-intervals. This means we are assuming that EVs will not be plugged in the work's parking space. Note that this is a restrictive assumption, since EVs will not be able to help reduce demand peaks during that time. For weekends the use of the vehicles is spread over the whole day (10 a.m. to 8 p.m.). These driving patterns lead to the percentage of plugged-in vehicles in each hour (see fig. 1).

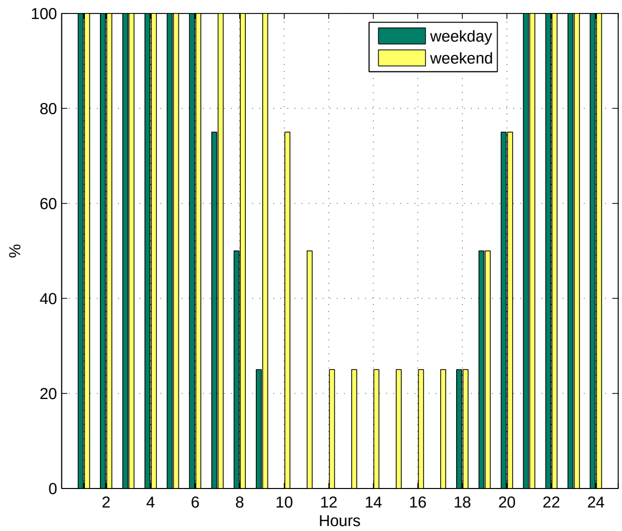


Figure 1: Percent of Plugged-in Electric Vehicles

We assume an average specific consumption of 0.13 kWh/km and about

22 kWh of mean battery capacity.

Table 1: Characteristics of different Electric Vehicles penetration scenarios

Scenario name	0EV	100kEV	250kEV	500kEV	1000kEV
Number of EV	0	100,000	250,000	500,000	1,000,000
Charging behaviour	Smart Charge in all scenarios				

Two analysis are realised: one considering several EV penetration scenarios from zero to one million vehicles (see table 1) using smart charge behaviour, and the other one analysing the charge behaviour changing the intelligence of EV charging and discharging behaviour from dumb charge to smart charge to smart charge plus generation (see table 2).

Table 2: Characteristics of different Electric Vehicles charge behaviour scenarios

Scenario name	DumbCharge	SmartCharge	SmartCharge +Generation
Number of EV	1,000,000	1,000,000	1,000,000
Charge of EV	predefined schedule	result of optimisation	result of optimisation
Generation of EV	-	-	result of optimisation

In the dumb charge scenario Electric Vehicles are charged as soon as they connect to the grid. Smart charge lets the system decide when to recharge and in the smart charge plus generation scenario the system decides when to consume and when to generate electricity.

3.2 Results

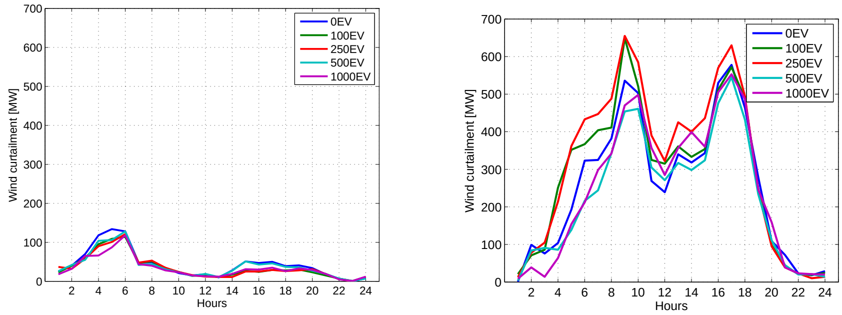
3.2.1 Results of EV penetration scenarios

In the first analysis the number of Electric Vehicles present in the electric system is increased from zero to one million. We find that the curtailment of wind energy (see table 3) increases around 5% and another 5.7% when integrating first 100,000 and then 250.000 electric vehicles. Only in the 500kEV and 1000kEV scenario wind curtailments decrease to 79% and 73% compared to 0EV values, respectively. This wind spillage reduction during average work days and days on weekend can be observed in the profile shown in figure 2. Especially in the high penetration scenario 1000EV significant wind curtailment reductions can be identified. The wind curtailment of the 1000EV scenario happens during off-peak times as well as during the evening well below the 0EV scenario.

Operational costs increase when integrating electric vehicles (see table 3). We observe a 0.3% increase in operational cost with 100.000 EV and another increase of 0.1% in the 250kEV and again 0.1% in the 500kEV scenario. Doubling the number of EVs from 500 thousand to one million

Table 3: Annual cost and wind curtailment for different EV penetration scenarios

Scenario name	0EV	100kEV	250kEV	500kEV	1000kEV
Wind curtailment [GWh]	990	1,040	1,096	780	722
Annual Cost [Mio. Euro]	13,703	13,747	13,759	13,766	13,835



(a) Weekday

(b) Weekend

Figure 2: Wind curtailment profile for different EV penetration scenarios (a) and (b)

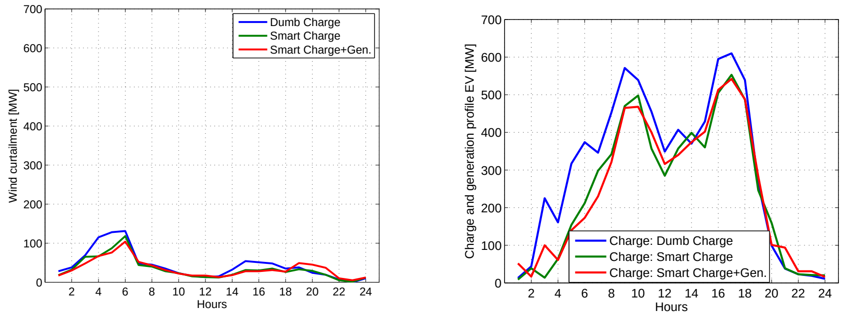
leads to another 0.5% cost increase with respect to a zero EV scenario. The increase in the consumption is not only absorbed by a disminution in the curtailed power but also by conventional energy. Combined cycle production is increasing the higher the number of EVs is. In comparison to the 0EV scenario electricity production by coal is around 2% higher mainly due to the fact that electric vehicles charge during off-peak hours. The changes in the generation technologies are small compared to their total annual productions. For example, combined cycles produce during the whole year 130,562 GWh in the 0EV and 131,978 GWh in the 1000kEV scenario, which makes a difference of around 1%. Even in the 1000kEV scenario the annual electricity consumption by electric cars amounts only to 0.5% of the annual demand.

3.2.2 Results of EV charging behaviour scenarios

If we now compare different charging behaviours as explained in table 2, we find a slight decrease in cost, one million Euro or 0.01%, in the intelligent charge scenario and a stronger decrease in the smart charge and generation scenario, 118 million Euros or 0.86%. Wind curtailment is decreasing 20% when electric vehicles are charged in a smart way. However, when EVs are able to generate as well this curtailment reduction amounts only to 2%.

The smart charging scenarios, smart charge and smart charge plus generation, apply different production technologies compared to the dumb charge scenario to cope with the same number of EV (1 million in this case). In the dumb charge scenario more electricity is produced with coal units (0.4% and 8.7%) and less with combined cycles (-0.9% and -1.6%) than in the smart charge and smart charge plus generation scenario, respectively.

Observing the wind curtailment profile on weekdays and as well on weekends in figure 3 the smart charge scenarios are clearly below the curtailments of a dumb charge especially during off-peak hours (1 to 6 a.m. and 1 to 5 p.m on weekdays and almost during the whole day on weekends). Wind curtailment is only higher than in the dumb charge scenario when EVs are able to produce electricity during peak hours on weekdays.



(a) Weekday (b) Weekend

Figure 3: Wind curtailment profile for different charging behaviour scenarios (a) and (b)

The charging profile in figure 4 is very illustrative for these opposite charging behaviours. In the dumb charge scenario it is supposed that Electric Vehicles are charged as soon as they connect to the grid, which happens in this case study between 6 and 8 p.m. So, charging on weekdays occurs between 6 and 10 p.m during the general evening demand peak and from 7 to 10 p.m. on weekends. On the contrary, applying smart charging EVs are charged mainly during night and early morning hours 1 to 8 a.m. with a consumption maximum at four and five o'clock on weekdays. The charging process is more distributed over the day on weekends. The consumption of electricity in the smart charging and generation scenario is much higher due to the additional generation produced during peak hours in the evening.

Electric vehicles produce electricity during peak hours, at the same time when under the dumb charge regime vehicles are charged.

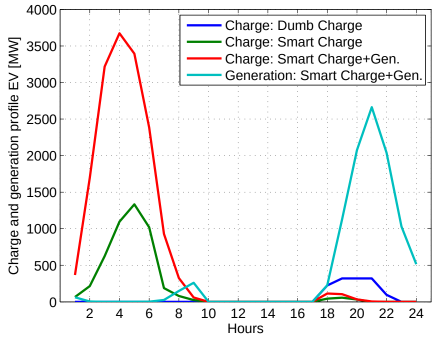


Figure 4: Charge and generation profile EV on weekday

It could be seen that using smart grid technologies to charge Electric Vehicles at times when the system has enough resources to do so, leads to significant reductions in wind curtailments. Nonetheless the additional electricity consumption is not only absorbed by high wind productions during night times but also by conventional energies leading to an increase in operation cost with an increasing number of Electric Vehicles. Using the ability of Electric Vehicles to operate as energy storage helps consuming much more energy during off-peak hours and thus absorbs a higher quantity of curtailed wind energy. On the other hand the demand peak in the evening hours is reduced slightly.

4 Conclusions and Future Work

Electric Vehicles will enter the electric system first and foremost as additional consumers. Due to their consumption pattern, opposite to the usual demand pattern, the possibility of absorbing high wind energy productions during night is given. This is only possible when the charging process is supervised by smart technologies. Electric Vehicles may also be able to reduce demand peaks using their battery as an energy storage and generate during peak hours.

This paper has shown how high Electric Vehicle numbers decrease wind curtailment in Spain. Nonetheless, not all EV electricity consumption is absorbed by wind and thus conventional generation, most of it combined cycles, are producing more. Charging as soon as EVs connect to the grid leads to an increase in overall system peaks during the evening. On the contrary, under smart charge and discharge behaviour a decrease in the evening peak as well as an increase in consumption during off-peak hours and thus less wind curtailments and costs can be achieved.

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