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Power to Gas technology under Spanish future energy scenario

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Abstract

Power to Gas (PtG) has been pointed out in the last years as a promising energy storage technology to smartly manage the renewable intermittent power generation that limits the operational flexibility of the network. In this work, we present a prospective study for the Spanish case, in which the implementation potential of PtG technology is evaluated in terms of the estimated renewable surpluses. We found that the annual surplus for the year 2050 would vary between 1.4 TWh and 5.2 TWh, and the PtG capacity required would be in the range 7.0 – 13.0 GW, depending on the renewable production pattern considered.

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Keywords: Power-to-Gas; methanation; SNG; Spain; prospective

1. Introduction

The increase of the renewable share in the energy production mix brings along fluctuating surplus power that limits the operational predictability and flexibility of the electricity market. To smartly manage this renewable intermittent power, energy storage technologies will play an important role in the future energy infrastructure. Power to Gas is one of most promising methods for energy storage, since it overcomes the limited storage potential of other

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technologies by presenting better discharge times and storage densities [1]. PtG stores electricity by converting H_2 and CO_2 into synthetic natural gas (SNG), which can be distributed in an easy way through the natural gas network.

Some European countries have evaluated the potential implementation of PtG in their electricity systems. In Germany, Jentsch et al. [2] found the economic optimum for PtG installation between 6 GW and 12 GW for a 85% renewable scenario. Moreover, Schneider L. and Kötter E. [3] studied the geographical limitations of installing PtG and determined that the maximum capacity that can be implemented in Germany is 15.4 GW. In Great Britain, Qadrdan M. et al. [4] evaluated the possible benefits of Power to Gas given the large capacity of wind power expected to be installed in the northern parts of England and Wales. They found that wind curtailment could be decreased between 27% and 62% depending on demand, and the network operation cost would be reduced an 11%. In this case, the PtG capacity to be installed would be in the range 5 – 12 GW.

This study presents the implementation potential of Power to Gas technology in a future Spanish energy scenario. We estimate the evolution of the Spanish electricity system for 2050, in terms of power capacity, energy production, and demand. Then, we use this scenario for analyzing the amounts of renewable surplus that can be expected under different renewable generation patterns, and calculate the power capacity of Power to Gas that could be installed in Spain.

2. Framework and prospective of the Spanish electricity system

Currently, hydropower presents 20.3 GW of installed capacity and an estimated potential of 33 GW. Large projects are not expected to occur in mid-term since proper locations are unknown (last evaluation was in 1980) and public acceptance is quite limited. Future development may be based on already existing infrastructures by restoring plants, renovating equipment, or implementing turbines in irrigation dams [5].

Wind power has become the renewable source with the largest installed capacity in Spain. Total capacity is expected to rise up to 24 GW for 2020, whilst repowering could contribute by adding 5 GW in the mid-term. Besides, growth potential concerning off-shore wind power is estimated between 5 GW and 8.5 GW [6].

In 2010, the Spanish solar thermal power accounted for the 60% of worldwide capacity. Prospective establishes 4.8 GW – 10 GW to be installed for 2020, and 20 GW as a target capacity for 2050 [7].

In 2008, photovoltaics experienced the greatest annual growth of the Spanish energy mix, with an increment that amounted to the 60% of the current installed capacity. The generous bonuses destined to PV caused an accelerated implementation. Nowadays, due to reduction of bonuses, the expansion has been broken, and the expectative of 7.25 GW for 2020 will probably take more time [8].

The maximum potential for biomass power, with a controlled exploitation of resources, would lie between 3 GW and 5 GW. In 2030, the expected share of biomass is around 5 % of total production [9].

CHP is industry-dependent so its development has come to a halt because of Great Recession. To overcome this situation, the Spanish CHP association intends to invest 1500 M€ for increasing the efficiency of more than the behalf of the installed capacity [10].

Combined cycles appeared in Spain in 2002, and in 2007 they had already become the most spread technology with the largest installed capacity in the country. This uncontrolled expansion has led yearly operations below 1000 h, and up to 16 plants –of a total of 49– without covering costs. So, progressive shutdowns are expected to occur whenever the government allows it [11].

Coal capacity has barely changed from 2007 onwards, but its participation has diminished since then. Combined cycles, which are less polluting, are fulfilling the demand thus setting coal aside. For the incoming years, the prospective regarding NO_X policies lead to 10.3 GW of installed capacity in 2020 [11]. Carbon capture technologies could soften the progressive reduction of coal share, but they are not expected to be reliable until 2030.

Nuclear power has not planned projects for increasing installed capacity. Since the period 1983–1988, 7 plants (about 1 GW each) participate in the energy market with average operations above 7700 hours. According to their licenses, all of them should shut down between 2020 and 2024, although the Spanish electricity system cannot face the loss of such thermal gap. Therefore, their lifetime should be periodically extended beyond 60 years as in other countries [12].

This information related to the different energy sources which are part of the energy mix in Spain has been used to build the plausible future energy scenarios which will be considered to assess the potential penetration of PtG in the country for 2050.

3. Methodology

The developed model of the future Spanish electricity system consists of two independent blocks: the projected energy demand and production. We estimated both separately, and cross results to check whether the restrictions imposed to arrange a coherent scenario are met (Fig. 1). Whenever restrictions are not fulfilled, the expected installed power capacity (Section 2) is modified accordingly.

The energy demand is based on The Global Calculator tool [13], which models the world's energy, land and food systems to explore the future thermal requirements, electric demands, and greenhouse gas emissions. Different scenarios can be outlined based on multiple variables like social habits, industrial investments, or policies. Based on standards of living and evolution trends in the country, we lay out a scenario in which demand increases a 1.36% per year, and the increment of the global mean temperature by 2100 is restricted to 2ºC. To obtain this moderate growth in electricity demand, investments must be focused on improving the efficiencies of fossil power plants, paper industries and cement industries, instead of on electrifying the transport. Besides, the treatment of wastes and residues has to be highly promoted.

The energy production is calculated as the product of installed power capacity by the equivalent hours. The installed power capacity should preserve the expected development presented in Section 2, whilst the hours of operation for renewable and nuclear sources are estimated by taking into account the historical trend, current policies and technology maturity (operation of fossil sources is set once the scenario is established since they act as backup power). Hydropower and small hydro remain stable with periodic fluctuations according to natural, wet and dry cycles. Average nuclear operation slightly diminishes since all plants date from before 1988 and unplanned shutdowns get more frequent. Wind power stood just above 2000 annual equivalent hours, mostly due to weather but also because government's policies limited reimbursed retribution only for the first 2350 hours. Similarly, photovoltaics swiftly grew up to its bonus limit. Nowadays, subsidies to renewable sources are individualized and progressively lessened, so operation is expected to rise. Solar thermal power and CHP were not affected by this limitation, so their equivalent hours increase according to the development of the technology.

Finally, the imposed restrictions that help to arrange a coherent scenario might produce changes in the initial prospective. The main restriction establishes a minimum backup power (biomass, coal and natural gas) able to complete the demand when only the 45% of renewable power and the 95% of base power (nuclear and CHP) are available, thus taking into account the variability associated to the renewable sources. Besides, the backup capacity must have enough operating hours to ensure its economic viability. Furthermore, biomass will have preference against fossil fuels, and the equivalent hours of natural gas and coal should be balanced.

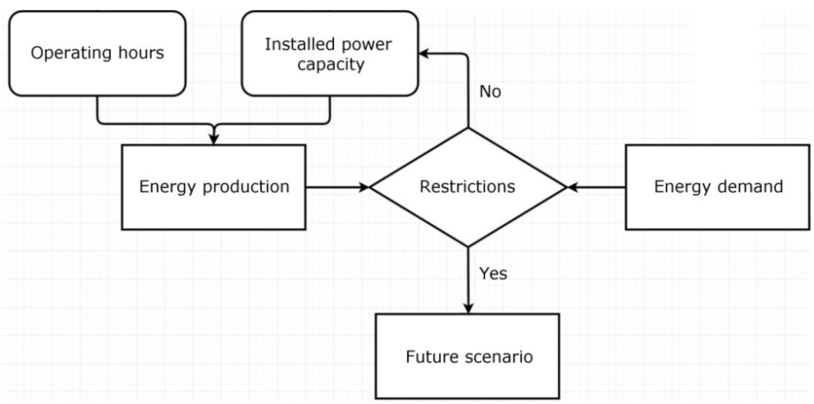

Fig. 1. Model flow chart.

3.1. Time discretization

Once the future scenario is defined, the potential energy storage is obtained as the difference throughout time between the demand and the expected energy production. We discretize the year in daily periods since an hourly interval would be unnecessarily precise (errors for long-term prospective might be important), and monthly periods would not allow detecting energy surplus situations.

Energy demand pattern mainly depends on aspects concerning everyday life, festivities and seasons, which barely vary in long-term. So, we classify the year in a list of day-types together with their typical demand (average from 2010 to 2013). Then, future daily demand is calculated as the product between the total annual demand and the corresponding daily consumption (in annual percentage).

The energy production patterns from renewable and base load power are not conditioned by the behavior of the energy consumption. CHP and nuclear permanently produces stable power, whilst renewable sources have seasonal productions. Among them, wind power is the only one presenting remarkable daily fluctuations. Therefore, we discretize energy production in monthly periods except for wind power, for which we use five historical wind patterns (2009 – 2013). Thus, we obtain an interval of possible productions reflecting the wind variability. Then, biomass, coal and natural gas patterns fulfill demand.

4. Results

The moderate annual increment (1.36%) fits properly the analysis of implementation trends. Thus, for the year 2050 the energy production from CHP is doubled, small hydro participation increases up to 4.0% – 4.5%, and biomass installed capacity reach 5GW (Table 1). Besides, renewable sources provide more than the 63% of the power production, and fossil fuels fall below to 11%.

The nuclear power must be maintained in operation. Such base load cannot be replaced by renewable energy from an economic point of view, since the required minimum backup power set for reaching a coherent scenario would be excessive and underused (biomass, coal and combined cycles). Even nuclear operations of 7300 hours lead to participations of coal power and combined cycled between 1270 and 2000 equivalent hours.

Data of wind power and natural gas are given as a range since surplus power varies according to historical wind patterns. Greater energy storage potential implies worse agreements between demand and wind production, what increase the requirement of natural gas power support. Surplus power may span between 1.4 TWh and 5.2 TWh depending on the wind pattern.

Table 1. Estimated equivalent hours, power capacity and power production for the year 2050 in Spain.

	Equivalent hours (h)	Power capacity (GW)	Power Production (TWh)
Hydropower	1660	19.2	31.9
Small hydro	2760	6.4	17.7
Wind power	2700	35.8	95.2 – 91.4
Photovoltaics	2650	9.1	24.1
Solar thermal	3500	20.3	71.2
Biomass	6750	5.3	35.9
CHP	5600	11.6	65.2
Nuclear power	7300	6.1	44.7
Coal power	2005	8.6	17.2
Combined cycle	1277 – 1466	20.4	26.0 – 29.8
Total	–	142.8	429.1
Surplus power	–	–	1.4 – 5.2

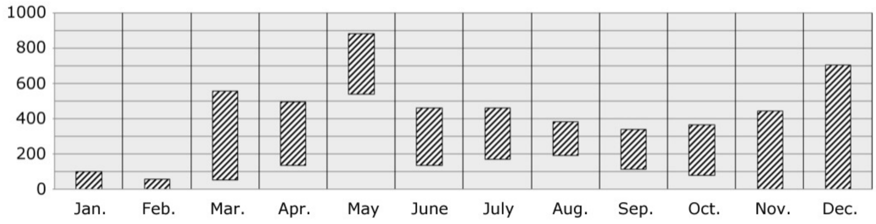

Fig. 2. Intervals of possible monthly surplus power [GWh] for the year 2050 in Spain.

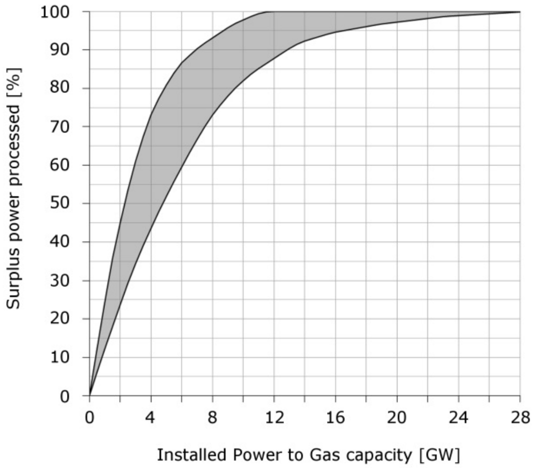

Fig. 3. Surplus power processed [%] as a function of installed PtG capacity [GW] for the year 2050 in Spain.

Through the difference between the demand (which has been assumed to annually rise a 1.36%) and the expected energy production, we calculate the energy excess. Potential storage situations are detected after distributing these production and demand through time, thus observing that they are gathered around May (Fig. 2). In addition, surplus power is guaranteed between March and October regardless of the wind pattern. Moreover, December presents strong variability because the different agreements that can take place between the renewable production and the scarce demand of the last week of the year. In contrast, January and February might lack of energy excess in 2050 even existing high shares of renewable power in the energy mix.

The sizing of the required Power to Gas capacity for processing the energy surplus must be adapted to the maximum hourly excess. In systems characterized by base loads around 20 GW and high presence of wind power, like the Spanish one, surplus behaves smoothly with hourly peaks that rise up to the 8% of the daily excess at most [14]. Therefore, maximum capacity to be installed should be able to process in an hour the 8% of the energy excess produced during the day of the highest daily surplus power. However, a capacity to process the 100% of energy surplus would be underused, because we could process even the 90% of annual excess with less than the half of that capacity (Fig. 3). Thus, a suitable option for the Spanish electricity system is to install 13 GW of PtG, what would guarantee to store more than the 90% of excess power regardless of the wind pattern. Besides, if the agreement between demand and wind production is favorably adjusted, the power capacity needed to process the 90% of excess could be reduced down to 7.0 GW.

5. Conclusions

The expected renewable surplus power and future PtG potential have been assessed in Spain for the year 2050, on the basis of historical data, current policies, technology maturity, and future prospective. A scenario of moderate increment in electricity demand was considered (1.36% annually), which has allowed respecting the prospective of Spanish institutions. However, the nuclear power should be maintained in operation beyond 2050. Such base load cannot be replaced by renewable energy since the minimum required backup power would be highly underused. Still, fossil sources present equivalent hours in the range 1270 – 2000, what makes clear that coal needs to improve its economic and environmental performance under flexible operations, as the H2020 program highly promotes [15].

In 2050, renewable sources would provide more than the 63% of the power production, whilst fossil fuels fall below to 11%. Thus, the annual amounts of renewable surplus would amount to 1.4 – 5.2 TWh depending on how the wind production pattern fits the energy demand. Potential storage situations gather mainly around May, with assured surplus power between March and October. The required PtG capacity for processing the 90% of total excess regardless of wind pattern is 13.0 GW, although it could be as low as 7 GW if the wind production favorably matches the energy demand. These values are similar to those previously presented from the studies of Germany and Great Britain.

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