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Power-to-Gas: Analysis of potential decarbonization of Spanish electrical system in long-term prospective

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ABSTRACT

Climate targets set by international organizations require the implementation of innovative technologies that ensure the decarbonization of energy sector. It may be partially achieved through a large penetration of Renewable Energy Sources. Massive energy storage is essential to handle excess electricity associated to RES and Power-to-Gas represents a promising option to chemically convert electricity surplus into energy carriers that may attend demands substituting fossil fuels. Aiming to avoid the influence of policies and market implications, this study approaches the decarbonization of Spanish system through the analysis of technical potential of RES. Several scenarios with different shares of RES are defined to cover a number of levels of energy demand. First, required wind and photovoltaic power has been estimated together with the required sizes of PtG to completely decarbonize electrical generation and industrial CHP. These scenarios may be reached by installing RES capacities below the technical potential coupled with PtG capacities between 80 and 90 GW. The stored energy amounts to 17% of total primary energy consumption. Secondly, scenarios are modified to consider denuclearization of electrical system. Required installed RES power still does not surpass the technical potential but become extremely high and the economic feasibility should be further analysed.

1. Introduction

The current European energy policy was established in 2009 through the European Renewable Energy Directive (RED 2009/28/EC) [1], which sets a minimum of 20% of renewable share in the European final energy consumption by 2020 and a 10% of renewable penetration in transport sector. The Commission updated these figures on November 2016 with a new proposal to ensure 27% renewables in the final energy consumption in the EU by 2030 [2].

Each country should fulfill individual targets adapted to their different resources and the features of its own energy market. In the case of Spain, Spanish National Renewable Energy Action Plan (NREAP) gathered the 2011–2020 road map to meet the requirements of the Renewable Energy Directive. Spanish Royal Decree 661/2007 regulates electrical energy production under special regimes and provided for the drafting of a Renewable Energy Plan for implementation during the period 2011–2020 (REP 2011–2020) [3].

All Member States but the Netherlands showed an average 2013/2014 RES share equal or higher than their corresponding indicative trajectory of the European Directive. In 2015, European RES share was estimated to be around 16.4% of gross final energy consumption, while the Directive had projected only 13.8%. Thus, Spain fulfilled its indicative European RED trajectory with a RES share of 16.2% in 2014 and 15.6% in 2015 [4]. However, larger penetration of renewables will be required in the next decades to achieve the global figure (20% in 2020 or 27% in 2030) and further work must be done to increase the current 0.5% of biofuels penetration in transport up to the Directive target [5].

The high shares of renewable sources in the electricity production system will lead to fluctuating periods of surplus power that could limit the operational predictability and flexibility of the electricity network [6] which will be only partially mitigated through Power to Heat and electrical vehicle deployment [7,8].

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Thus, energy storage technologies are imperative in future electricity systems to manage renewable intermittent power. Current storage techniques (pumped hydroelectric storage, compressed air energy storage, flywheels, electrochemical storage, thermal energy storage) present limited storage potentials for large scale applications due special location requirements, short storage periods, slow discharge times or low energy storage densities [6]. Hydrogen energy storage (HES) overcomes these issues but it lacks a proper distribution infrastructure and transformation technology. Besides, HES implies additional handling safety measures. To avoid the mentioned limitations, Power-to-Gas energy storage has been pointed out in the last years as a very promising solution, which converts mixtures of renewable H_2 and CO_2 into synthetic natural gas (SNG) [9]. This final energy carrier can be easily stored and distributed through the existing gas grid and transformed into electricity or heat in conventional equipment with high efficiency, durability and limited investment costs (Fig. 1) [10].

The potential increase of installed capacity of non-dispatchable energy sources in Spain is extremely high. Installed wind power in 2016 was 22.8 GW, while prospective studies established a feasible installed capacity of 52.5 GW in 2030 [11] and a maximum potential in the country between 332 and 393 GW [12–14]. Similarly, photovoltaic installed capacity in 2016 was around 4.4 GW, although several reports show there is room to install up to 66.5 GW [15]. Moreover, several nuclear plants are near to finish their lifetime in Spain, so the nuclear debate is currently open. Both situations clearly foster the idea of a Spanish electrical system mostly based on renewable sources, thus promoting the decarbonization and the energetic independence. Emission factors of Spanish electricity producers ranges from 0 to 360 gCO_2/kWh in 2016 [16] with an average value of the electrical mix of 306 gCO_2/kWh in 2016 [17] which is still quite far from the targets of specific emissions established for 2020 (207–218 gCO_2/kWh) [18]. Regarding the energy dependence of the country, external dependency in 2016 represented 72.3% of gross primary energy versus the average value in Europe set in 50% [19].

Therefore, the development of improved energy storage technologies is especially relevant to exploit the greatest amount of the renewable potential in the country without introducing instabilities in the future renewable electric system.

The objective of this study is to quantify the renewable power and Power-to-Gas capacities required to decarbonize and denuclearize the energy mix of the Spanish electricity system under different energy scenarios. The technology used for electric power production varies in each scenario to increase the decarbonization and denuclearization of the system.

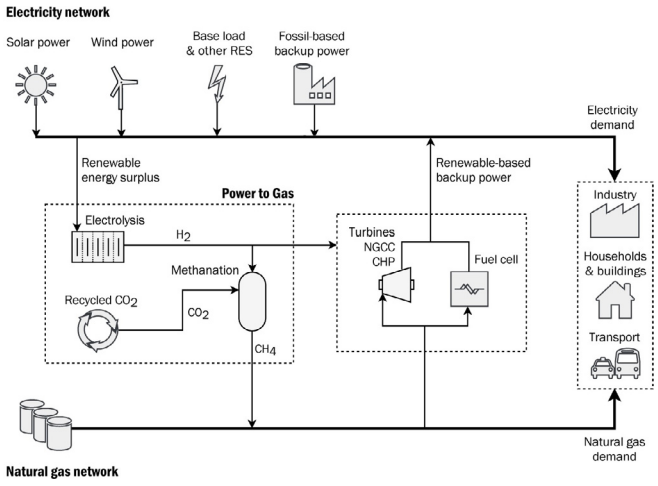

Fig. 1. Scheme of the energy system with PtG.

2. Energy scenarios: scope and limitations of the study

In literature, several studies quantify Power to Gas potential under future scenarios of national energy systems in which RES installed capacity is high enough to frequently lead to electricity surplus situations [20,22,23,32]. However, when these scenarios are tried to be foreseen, the strong uncertainty coming from economics, regulatory policies and technology evolution leads to disputable results. Thus, the attempt of defining an accurate estimation of future installed capacities such as those annually predicted by international organizations [24] mainly based on economic, political and technologic situation is discarded in this study, and a similar approach to that followed by Guandalini et al. [25] and Colbertaldo et al. [26] is applied instead.

Guandalini et al. looked for the upper technical limit of installed power for each non-dispatchable technology since long-term energy systems will ideally make the most from their resources, and therefore will tend to reach the maximum installation potential. Considering geographical and climate constraints together with the development of the state of the art in technology, the maximum reasonable power capacity for a given region may be estimated (Table 1) [12,13,15]. Wind and photovoltaic are those non-dispatchable technologies with larger growing potential and, therefore, those considered to define the scenarios under study. The possibility of decarbonizing and denuclearizing the Spanish electrical mix under different technological scenarios through the penetration of massive wind and photovoltaic energy sources is assessed. Then, results of wind and PV installed capacities are compared with the technical maximum as a measure of its feasibility.

Electric demand is assumed to keep constant and similar to the current situation. Although the electrical demand has slightly grown in the last years in Spain (annual growth of 0.7% in 2016 and 1.2% in 2017 [27]), the trend in European countries is the conservation or slight decrease of demand as a consequence of energy efficiency improvements and limited economic growth. As an example, total net electricity generation in the EU-28 in 2015 was 4.5% lower than its relative peak of 2008 [28]. Therefore, it must be kept in mind that the results obtained from this study will be valid in case this assumption is fulfilled.

Thus, this study is conducted using the electric demand data and hourly distribution corresponding to 2016 (last reported data by Spanish transmission system operator) which is considered the reference year [17]. This demand is covered through a combination of base power (CHP and nuclear power), non-dispatchable power (small hydroelectric, geothermal, concentrated solar, wind and photovoltaic) and back-up technologies.

2.1. Current Spanish scenario and selected technical potential for wind and PV power

Firstly, current situation of the Spanish electrical mix must be analysed to better understand the motivation and justification of

Table 1
Technical potential in Spain.from different studies.

Technology	Technical potential [GW]	References
Wind	392.95	[12]
	340.00	[13]
	151.00–332.00	[14]
Photovoltaic	66.51	[15]