Abstract

For the present project, six simplified models of an electricity zone with 100% renewables are developed. The approach is applied to three different hypothetical scenarios: (i) a combination of wind energy and methanol storage, (ii) a combination of PV solar energy and methanol storage, (iii) a combination of wind energy with PV solar energy and methanol storage. Those are developed for two European countries with a very different distribution of renewables energies and electrical network: Belgium and Spain.

These three scenarios are not entirely realistic as in reality, wind and solar will be complemented by other sources such as hydro or biomass. However, the idea is to study the impact of having large shares of variable renewable sources with different variability profiles on the electricity grid.

The purpose of this study is to minimize the energy cost (euros/kWh) by determining the optimal combination of energy generators (windmills, solar panels or both) and long-term storage based on methanol production (power-to-fuel). This combination must respect two constraints, a period of LOLH (lost of load hours) lower than 0.25h during the period (5.8 years for Belgium and 4 years for Spain), and preserve the same storage level (amount of methanol stored) at the beginning and the end of the period. This condition ensures the match between installed capacities and system requirements.

Then, this model determines the viability of power-to-fuel storage technology. One significant advantage of power-to-fuel methanol is the fact that the storage is very very cheap (storing a liquid at ambient T and P) so that the marginal cost of storage itself is neglected.

Another assumption is that curtailed energy occurs when wind and/or solar generation surpasses both the demand and the storage capacity without incurring on detrimental consequences to the grid stability. Furthermore, all the models consider a system optimum rather than an agent-based approach. So, it is assumed that the energy that is stored is free as a result of a zero cost for the storage units. Also, market competitiveness, other applications for methanol or oxygen (electrolysis by-product), and grid limitations and control costs are not contemplated.

The grid of both of the countries considered in this job is different. In Belgium, natural gas and nuclear energies are much more exploited. However, in Spain, the coal is the second energy source more used, but the demand supplied by renewables energies is 15% higher in this region. Consequently, the actual emissions of CO_2 per kWh are much higher in Spain than in Belgium, being 243.23 gCO_2/kWh and 175.91 gCO_2/kWh, respectively. The average capacity factor for wind is similar in both countries (0.277 Belgium, 0.240 Spain) but, for solar it is almost double in Spain (0.111 Belgium, 0.217 Spain). Finally, the average load during the sample period in Belgium is 8.89 GW and in Spain 28.70 GW.

The first system proposed is the 100% wind energy system. In Belgium, the optimum is found for 9119 windmills with 45.6 GW installed and 58250 storage units with 14.56 GW installed. Wind directly energy served is 72.7% of the total energy served between windmills and power-to-fuel units. In Spain, the resulting grid has 28965 windmills with 145 GW installed and 182295 storage units with 45.57 GW installed. In this country, the energy served by windmills is higher than in Belgium, 81.80%. The final electricity price is 88.3 euros/MWh for Belgium and 85.9 euros/MWh for Spain. The CO_2 emissions savings compared to the actual grid are more significant for Spain, with 94.24%; 92.04% in Belgium.

For the 100% PV solar energy system scenario, the installed capacity needed is enormous due to the low capacity factor. Therefore, these are not realistic systems. In Belgium the resulting grid has 2520 millions of PV panels with 760 GW installed, 405159 power-to-fuel units with 101.29 GW and a 48% of the total energy served by PV cells. In Spain, the optimum cost is obtained for 70430 millions of PV cells with 2112 GW installed, 479565 storage units with 120 GW installed, and 81.42% of energy demand supplied by PV cells (almost double than in Belgium). The energy cost is 951.6 euros/MWh in Belgium and 753.9 euros/MWh in Spain. As said before, neither the system or the energy cost is realistic. The CO_2 emissions are reduced by 74.42% in Belgium and 81.50% in Spain.

Finally, the lowest price is found for a 100% wind and PV solar energy system. In this scenario, the Belgian grid is composed by 8007 windmills with 40 GW installed, 29.92 millions of PV panels with 9 GW installed, and 51256 storage units with 12.81 GW installed. With 76.14% of the total energy served by wind and PV solar. On the other hand, the Spanish grid is formed by 15413 windmills with 70.07 GW installed, 237.56 millions of PV panels with 71.23 GW installed, and 139891 power-to-fuel units with 35 GW installed. In this case, the energy served by windmills and PV panels is 82.62% of the total. The final energy cost is 86.2 euros/MWh in Belgium and 71.10 euros/MWh in Spain. This last one experiences a more considerable decrease on the final price with the combination of both energy sources. That and the larger cost of storage units electricity in Spain for a 100% wind energy system shows that the harmony between the peak load periods and energy generation by renewable sources periods reduces the cost of power-to-fuel energy and, consequently, the final electricity cost. However, for this scenario, the percentage of CO_2 emissions savings is slightly larger in Belgium (88.80%) than in Spain (88.11%).

So, for all the scenarios considered, the final energy cost is larger in Belgium than in Spain, and the overcapacity is necessary for the full energy demand supply. Nevertheless, for both cases, due to the lower installed capacity required, energy cost, and energy curtailed, the most efficient system is the 100% wind and PV solar energy system. With this energy grid, the energy cost in Belgium is less than twice the actual one and, in Spain, around 65% larger. Still, the CO_2 emissions savings are larger for the scenario 100% wind energy system.

In conclusion, to achieve the European Commission objectives assuring the energy supply, and a reasonable energy cost, a 100% RES system combined with power-to-fuel storage is a realistic alternative to the actual grid system.