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Solar electricity in a changing environment: The case of Spain

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ABSTRACT

In Spain, solar electricity (photovoltaic and thermoelectric) has reached a stable annual capacity factor above 20% since 2009; while wind achieved 23% since more than 10 years ago. This is the demonstration of an ongoing transition towards a more sustainable energy mix, further corroborated by the reduction of the capacity factor of gas-fired technology, which has seen a decline to values lower than 10% after an initial promising rise; this is a very low value for a fossil-fuel technology. Additionally, hydro installed capacity, which has been stable for the past 20 years, have demonstrated that can be used as a back-up power source in combination with solar and wind electricity, and it is capable of producing energy peaks that may increase from a stable base of 2000 GWh/month up to 6000 GWh/month and therefore meet demand at some particular times when solar and wind are generating less electricity without the need of installing new additional capacity at national level.

1. Introduction

The electricity mix of European countries is steadily reducing the amount of green-house-gas emissions per unit of generated energy [1–3]. The case of Spain deserves particular attention, since a changing environment of different regulations and economic crisis have moved this country from a promising scenario for the deployment of renewable electricity technologies to a dire perspective of financial crash for already existing facilities and stagnation of any new project for renewable additional capacity [4,5]. Here we show that the analysis of purely technical data demonstrates that a combination of solar electricity, both photovoltaic and thermoelectric, and wind technology, backed up by already installed hydro capacity can cope with the variable part of the power demand at national scale and even bite deep in its constant baseline. In particular, generation peaks from photovoltaic correlates well with the times of maximum demanded power and therefore will cover the demanded energy at those peak times in a natural way without the need of installing additional non-renewable capacity. Furthermore, wind and solar electricity generation shows a clear anti-correlation trend and therefore both technologies are an ideal complement when considered within a large enough geographical scale and can be regarded as the technologies of choice in order to meet future growths of installed capacity. The capacity factor of the technologies under consideration has been calculated and it enables a comparison between renewables and non-renewable technologies providing further evidence of an excess of non-renewable installed capacity, in particular gas-fired technology. This result should have an impact in the public debate about the need of installing new capacity based on gas-fired facilities and will be a starting point for a detailed calculation of the avoided emissions associated to each technology throughout its entire life cycle [6–8].

Sustainability is becoming a key concept when decisions are made about how to meet an always increasing energy demand [9]; the multiple dimensions of sustainability are difficult to quantify in a single parameter, but regarding electricity generation, the green-house-gas (GHG) emissions per kWh of generated energy is considered as a good parameter which defines the sustainability of the electricity system at different scales (a small isolated installation, a local micro-grid or a grid considered at national level). Nevertheless, GHG emissions is a dynamical parameter and before a final figure can be provided a full life cycle analysis of every electricity generating technology has to be accomplished for the particular location of each of the facilities under consideration. The first step for this task is to provide a time-dependent energy mix, i.e. the share of each technology contributing to the energy generated instantaneously, and to correlate this value with the installed capacity and how efficiently this capacity is being used. This information is provided by the capacity factor which enables a fair comparison of different renewable and non-renewable technologies.

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The article includes a brief section about methodology followed by a larger section with results and discussions about actual power and energy generation and the comparison of solar electricity with other sources; the evolution of installed capacity in Spain and an analysis of the capacity factor of photovoltaic, thermoelectric, wind and gas technologies. Finally, a conclusion is presented.

2. Methodology

The results presented in this article have been obtained by a detailed analysis of official data provided by the Spanish National Grid (Red Eléctrica Española, REE), a public state-owned company which measures national power generation every 10 min [10]; the data refer to peninsular Spain, i.e. the instant power and electricity production of the Balearic and Canary Islands are not included because they constitute a different grid (also owned by REE). In the case of Balearic Islands, the energy exchange (via submarine cable) is included and receives the same treatment as international exchanges. Installed capacity refers also to peninsular facilities (and therefore all calculated parameters refer to peninsular Spain, although for the sake of simplicity we will just use the term "Spain" in the following sections).

Processing of data for the past 23 years allowed us to obtain the instant power, the energy generated and the capacity factor of the main technologies which contribute to the Spanish electricity mix and its evolution in time. Capacity factors have been calculated on a monthly basis, using the data of installed capacity for the given year and the energy produced per month; this produces a slight deviation for the initial and final months of each year on top of the usual seasonal energy variation (for renewable sources); nevertheless, this slight deviations are compensated when the average of monthly capacity factors are calculated in order to provide an annual capacity factor, which is the parameter usually cited in the literature. The error bars shown for the annual capacity factors account for the standard deviation of the data series.

3. Results and discussion

This section is organized in three subsections, the first one is devoted to the analysis of more recent data of electricity generation and illustrates the actual structure of the energy mix in Spain, the second one analyses the evolution of the installed capacity which has shown an important change in that mix, and in particular has seen a strong penetration of solar electricity technologies (both photovoltaic and thermoelectric) and wind technology, the final subsection presents historical data of the generated energy from different renewable and non-renewable sources and the focuses on the calculation and discussion of the capacity factor.

3.1. The installed power capacity and present generation of energy

As an example of results, we present in Fig. 1 the instantaneous power for the week running from the 3rd to the 9th of August 2013; the time resolution of the graphs is 10 min. The power presents a typical profile with two daily peaks and a baseline; the main peak reached a value of 32.88 GW on 8th of August 2013 with a contribution of the different technologies that can be seen in Fig. 1A, where solar electricity generated by photovoltaic and thermoelectrical facilities is shown in bright yellow and contributed a 15% of total power at national level, a remarkable result taking into considerations that solar electricity is only 6% of the total installed capacity in 2013 (of which 4.43 GW are photovoltaic and 2.05 GW are thermoelectric). When the time-dependent power function of each technology is integrated throughout the whole day, month or year, then the generated energy per day, month or year is correspondingly obtained.

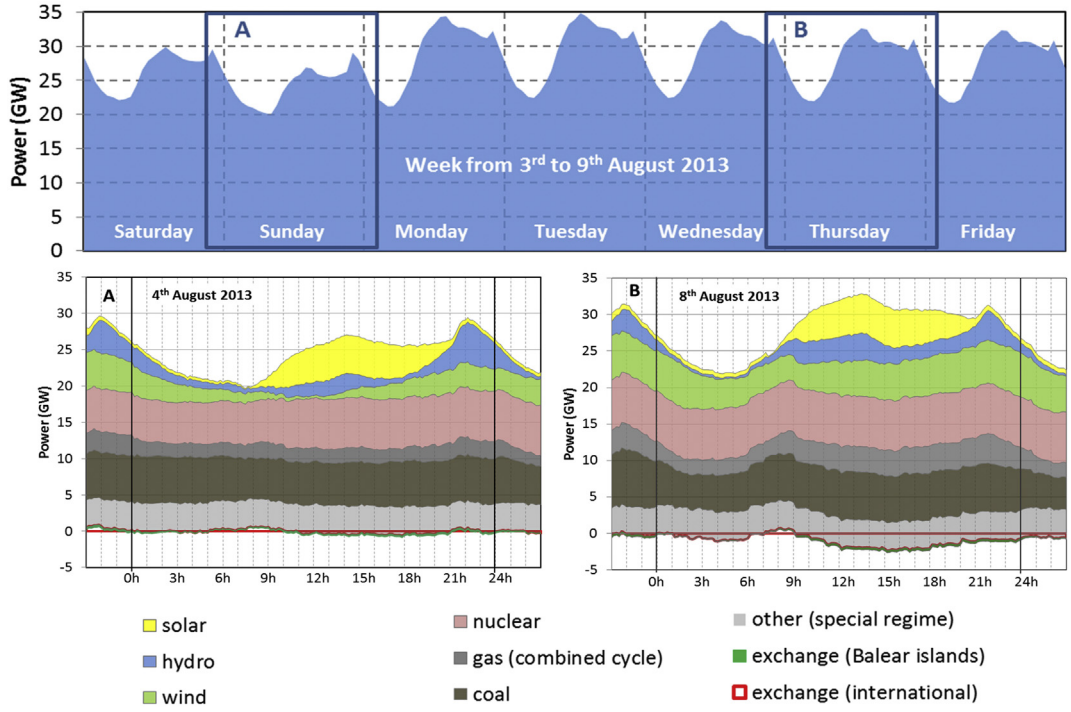

Fig. 1. Power generation at national level in Spain. The upper graph shows a typical power profile for a week in August 2013 (from 3rd to 9th), details of the share of different technologies are shown in plots A and B for a Sunday and a Thursday where two main peaks rise above a baseline. Contribution of solar electricity (in yellow) reached 15% of instant power at 13:30 on 8th August. More details of percentage for other technologies are shown in Fig. 2 (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)