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Is coal extension a sensible option for energy planning? A combined energy systems modelling and life cycle assessment approach

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ABSTRACT

As in many countries, coal-fired power plants in Spain account for a significant contribution to the electricity mix. Nevertheless, renewable energy options and natural gas are paving the way for coal retirement. Alternatively, it is possible to reduce the emissions (especially SO_2 and NO_x) associated with coal combustion through technology retrofits focused on desulphurisation and denitrification in line with the EU Industrial Emissions Directive. Within a context of low coal and CO_2 prices, lifetime extension of coal-fired plants emerges as an option for power plant owners. This article prospectively evaluates the announced retrofit for 3560 MW of the Spanish coal power capacity under three alternative energy scenarios. In addition to prospective electricity production mixes, the evolution of key life-cycle sustainability indicators (climate change, human health, energy security) is assessed with time horizon 2050 using an enhanced energy systems optimisation model of power generation. When compared to the reference scenario, the results show that coal extension could favour the penetration of renewables in the long term. Notwithstanding, this would come at the expense of undesirable increases in climate change and human health impacts. Consequently, the implementation of the sustainability dimension in energy plans could avoid a "coal conundrum" situation in Spain.

1. Introduction

The Spanish electricity production mix shows a wide-ranging portfolio of technologies. This makes the prospective evaluation of the potential retrofitting of conventional coal thermal plants especially interesting, focusing on their techno-economic and environmental performance. The idea of implementing retrofits in coal plants, although exploratory, is founded on recent news. At the end of 2016, the former Spanish Ministry of Industry received the interest of some power generation companies to invest in retrofitting solutions for their facilities in order to meet the European Industrial Emissions Directive (IED) (2010/75/EU) requirements (European Parliament and European Council, 2010). Plant owners asked for extra time, thus opening a period to either retrofit or close down by 30th June 2020. Additionally, there is a national plan resulting from another EU regulation (Council Decision 2010/787/EU) forcing the closure of uncompetitive coal mines (Council of the European Union, 2010). Hence, power generation with Spanish coal will vanish. Nevertheless, Spanish coal-fired power plants could continue operating by using imported coal and adapting to the new NO_x, SO_2 and particulate matter (PM) limits. This article evaluates this uncertain situation by means of an energy systems modelling (ESM) approach based on cost optimisation of the Spanish electricity production mix from 2016 to 2050. The value-added is the consideration of a life-cycle sustainability perspective through the prospective assessment of climate change, human health and energy security.

1.1. Retrofitting coal power plants in Spain

Coal burning is one of the main stationary sources of CO_2 and local air pollution. In this sense, the European IED aims at operating changes in large combustion plants to enhance their environmental profile, with reductions in NO_x, SO_2 and PM emissions according to certain threshold values included in each Transitional National Plan (TNP). Even though retrofitting existing coal-fired power plants is not a solution in terms of climate change abatement –unless retrofits also include CO_2 capture systems–, it is highly successful regarding NO_x and SO_2 emissions, with the implementation of deNO_x and deSO_x systems, leading to reductions around 50–70% in NO_x and 90% in SO_2 (Fernández Montes, 2016).

In the specific case of Spanish coal thermal plants, retrofits are limited to auxiliary units reducing NO_x, SO_2 and PM emissions. The Spanish coal capacity is ca. 10.1 GW (REE, 2017). Practically the whole

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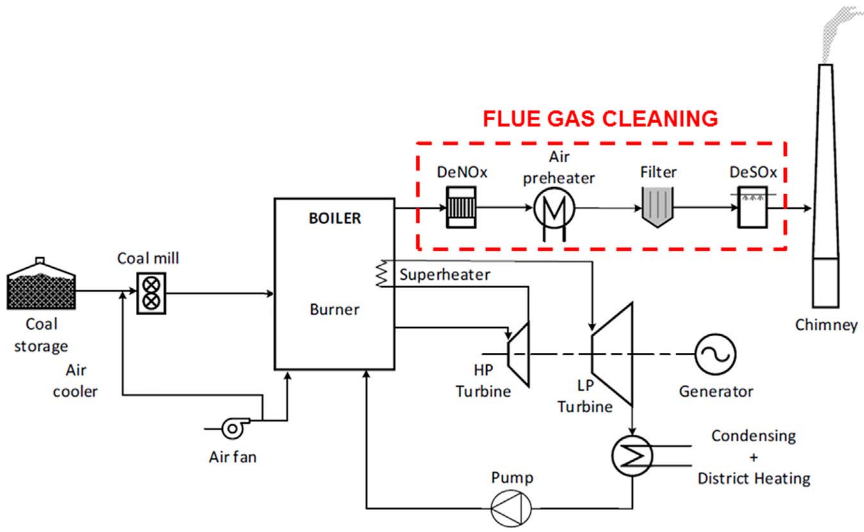

Fig. 1. Scheme of a large coal-fired power plant with flue gas cleaning (modified from Danish Energy Agency (2016)).

sector, except for a 365 MW plant closing by 2023, accepted to be included within the TNP (European Commission, 2016a; MAPAMA, 2015). The Spanish TNP was approved on 25th November 2016 in order to transpose the European IED, assuming the period 2016–2020 as interim to push facilities for investments in less polluting technologies. In particular, the Spanish TNP includes details about the planned measures for each of the power units in every coal-fired plant. Accordingly, there are 5650 MW committed to install deNO$_x$ systems as well as 4070 MW committed to install both deNO$_x$ and deSO$_2$ systems, in case the corresponding facilities want to continue operating beyond 2020.

Fig. 1 shows the scheme of a coal-fired power plant including flue gas cleaning, i.e. a retrofitted coal power plant. Denitrification systems refer mainly to selective catalytic reduction (SCR) technologies in which NO$_x$ react with ammonia at flue gas temperature (Gutberlet and Schallert, 1993). SCR also decreases secondary fine PM emissions by reducing nitrate aerosol (Li et al., 2015). On the other hand, deSO$_x$ systems comprise a set of flue gas desulphurisation (FGD) methods, being wet or semi-wet scrubbing the most usual one. Since SO_2 is an acid gas, it is necessary to use an alkaline material (e.g., lime) as sorbent. The resulting products are calcium sulphite and water, which can be processed to marketable gypsum (Galos et al., 2003). There are alternative FGD systems using e.g. magnesium hydroxide as sorbent (Córdoba, 2015).

According to the Danish Energy Agency (2016), retrofitting coal-fired power plants could extend the lifetime of these plants up to 15–20 years. Among the list of required works, retrofitting involves replacement of instrumentation and control systems as well as revision of electrical systems. Furthermore, the implementation of flue gas cleaning technologies requires electricity, thereby reducing the net efficiency of the power plant. A shift from 39% to 38% net efficiency is assumed herein (Carlsson et al., 2014; Danish Energy Agency, 2016; OECD/IEA, 2010). Finally, the costs of retrofitting coal power plants can be found in (Conesa López et al., 2017).

1.2. The energy transition paradox

After the 70's oil crises, many countries began to face the problems associated with the use of fossil fuels. In particular, oil dependence arose as the driving force regarding countries' decisions on energy planning. In this sense, it is generally accepted that a new energy transition from fossil fuels to renewable sources began to happen at that time (Scott, 1994). The first energy transition took place from biomass to coal in the XIX century, later from coal to oil, and we are currently experiencing oil retirement (Allen, 2012).

Energy transitions are lengthy processes usually taking decades or even centuries. According to Sovacool (2016), the transition to coal lasted 96–160 years while the transition to oil was shorter, 47–69 years. Besides, energy transitions are non-linear progressions (Sovacool and Geels, 2016), as observed in the well-known German *Energiewende*, where CO_2 emissions have been growing since plan approval in 2011 (Smil, 2016). In this regard, these CO_2 increases, mostly due to emissions from coal-fired power plants, should be understood as a temporary situation in the transition to a highly renewable long-term electricity mix. This paradoxical effect is usually known as "the coal conundrum".

At some point in the future, renewable energy technologies will be predominant in most of the countries. However, nowadays renewable electricity accounts for only 18.3% of the final energy consumption worldwide (IRENA, 2017). Using recent data from IEA (OECD/IEA, 2016), the coal share in global electricity production meant 40.8% in 2014, natural gas 21.6%, oil 4.3%, nuclear 10.6%, hydro 16.4%, and renewables 6.3%. The comparison with 1973 statistics is relevant. Then, coal meant 38.3%, oil 24.8%, natural gas 12.1%, nuclear 3.3%, hydro 20.9%, and renewables 0.6%. In other words, fossil fuels reduced their contribution from 75% to 67%, with a decreasing relevance of oil but a growing participation of natural gas and coal. Within this context, and considering that the coal production peak could happen in the period 2042–2062 (Maggio and Cacciola, 2012), it is necessary to discuss in depth the role played by coal within the fossil-renewable energy transition.

The role of coal is different depending on the country. For instance, most of the European nations have experienced the retirement of coal from their electricity production mix mainly due to the increasing environmental awareness regarding climate change. However, there are exceptions such as Poland, a great coal producer and consumer, whose economy is largely based on this commodity. The case of Spain is pertinent for analysis because it is a country that still uses coal and is on the edge of a "coal conundrum" situation similar to the German energy transition paradox. By 2021, a nuclear phase-out will begin in Spain and the use of coal could play a significant role for a long-term transition to an almost 100% renewable electricity production mix. Consequently, it is necessary to develop and apply a methodological framework able to evaluate prospectively the key sustainability aspects associated with the techno-economic evolution of the national power generation mix under alternative energy scenarios based on the lifetime extension of retrofitted coal-fired power plants.