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The effects of scale-up and coal-biomass blending on supercritical coal oxy-combustion power plants

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ABSTRACT

Carbon Capture and Storage (CCS) with biomass is called to be one of the most important technologies to reduce the climate change all over the world. In addition, supercritical pulverized coal plants have been pointed out as interesting power installations because its high efficiency. In this work, the effects of plants scaling and biomass-coal co-firing level on net present value (NPV), cost of energy (COE) and cost of CO_2 avoided (CCA) have been studied on a supercritical pulverized combusting coal/biomass blends. Aspen Plus© was used to implement technical simulations. Finally, the main factors affecting plants viability were identified by a sensitivity analysis. The results obtained revealed that the use of biomass reduces the NPV in (−0.23,−1.75) M€/MWe, and increases the COE by (0.007,0.263) M€/MWe. However, plant scaling was found to be a more important factor, by reaching an impact of 4.32 M€/MWe on NPV variation in best case. The reduction of oxy-plants viability by biomass using as raw material could be compensated by an increasing of the designed scale-up. Finally, 300 MWe power plants with 40–50% biomass co-firing level were identified as a compromise solution between economy and risk, improving in this way the interest for potential investment.

1. Introduction

In the new global economy, climate change has become a central issue for the international community. It is becoming increasingly difficult to ignore the important role of the connection between the science community, party and non-party stakeholders to benefit the intergovernmental process and Paris Agreement implementation. In order to improve this work, the last Earth Information Day was organised by the UNFCCC and celebrated in Casablanca on last November. In that conference, 2015 was presented as the warmest year, over 1 °C higher than pre-industrial period [1] by the WMO. According with this finding, the concentration of long-lived greenhouse gases continues to increase, reaching in 2015 the world mean value of 400 ppm (CO_2), 1845 ppb (CH_4) and 328 ppb (N_2O). A considerable amount of literature has been published on the consequences of this situation, such as a record warming at ocean surface and subsurface, the rising on sea levels or more irregular precipitations (very dry in some places and wet in others) [1,2]. In addition, high impact extremes have been attributed to the climate change: 7800 deaths in the Philippines attributed to Typhoon Haiyan, 2013; 250000 excess deaths attributed to drought and famine in 2011–2012 in the Horn of Africa or 4100 deaths attributed to heatwaves in Pakistan and India in 2015 [2]. The causes of this situation must be identified in order to avoid higher disasters.

Many authors have identified the principal cause with the increasing of energy demand due to the economic development and the population growth. The IEA expects a continuous rising on energy demand of OECD countries from 5500 Mtoe in last 2014 for the next 25 years. In addition, developing countries and regions, such as China, India, South and Central America and the Middle East are expecting to be the main sources of the energy demand increasing in that time. In addition, some geopolitical uncertainties in Middle East countries have stablished increasing concerns about the future oil supply. In Europe, the recent United Kingdom decision about leaving the European Union has no precedents in Europe uncertainties.

In this international context, the European Commission stablished the Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy

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Abbreviations (in order of appearance on text)

UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization
UNEP	United Nations Environment Programme
IEA	International Energy Agency
OECD	Organization for Economic Co-operation and Development
CCS	Carbon Capture and Storage
NPV	Net Present Value
COE	Cost Of Electricity
CCA	Cost of CO_2 Avoided
RYIELD	Aspen tool used to simulate reactions with stablished yields
RGIBBS	Aspen tool used to simulate reactions when free Gibbs energy is minimised
ASU	Air Separation Unit
DESOX	Desulfurization Unit
TEC	Total Equipment Costs
NETL	National Energy Technology Laboratory (U.S. Department of Energy)
CEPCI	Chemical Engineering Plant Cost Index
FCI	Fixed Capital Investment
TCI	Total Capital Investment
EBTF	European Benchmarking Task Force
NREL	National Renewable Energy Laboratory (U.S. Department of Energy)

from renewable sources [3]. All the while, it was published the Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 with the objective of reduce the EU States greenhouse gas releases in a time frame of 10 years, up to 2020. Therefore, a 2011–2020 Renewable Energies Plan was designed by the Spanish Energy Department [4] to increase the energy pool production by green energies by a minimum of 20% in 2020. Recently, the European Union approved the programme Horizon 2020 as the European Investigation and Innovation Framework Programme in the same field.

A considerable amount of literature has been published about different technologies to reduce greenhouse gases emissions [2,5,6]. Between them, carbon-based combustion with CO_2 capture has revealed to be one of the most interesting one for reducing the anthropogenic CO_2 emissions [7]. CCS has been considered a promising solution because: (1) anthropogenic global climate change is a serious problem and (2) there is a need for large reductions in carbon dioxide (CO_2) emissions [8]. Between the different CCS technologies, oxy-combustion can be stablished as a valid solution due to it can be used as a CO_2 sink, reducing the greenhouse gases environment effects. Oxy-combustion processes are characterised by burning fuel in an atmosphere composed by a mixture of CO_2 and O_2 [9]. After combustion, flue gases are partially returned to the combustor stream feed in order to control the flame temperature [10]. The Spanish Renewable Energies Plan stablished the objective of designing CCS plants with, at least, 40% efficiency from 2017 to make CCS plants cost competitive since 2020.

Supercritical power plants are expected to be one of the possible solutions to increase the CCS efficiency that Spanish Renewable Energies Project considers [11].

Many raw materials have been used as oxy-combustion feedstock. Between them, biomass is a suitable bioresidue for being used in waste combustors to generate high enthalpy steam, good for producing electricity. Biomass is also called to modify the carbon balance of different energy processes from positive (fossil fuels) to neutral or negative (Bio-energy with CCS, also called Bio-CCS) [5].

In previous works, several biomasses oxy-combustion were analysed and biomasses were selected based on their oxy-combusting behaviour [12]. After selection, the oxy-combustion experimental conditions were optimized and the transport phenomena occurring in the particles during oxy-combustion was studied by the application of the conservation equations [10].

The present study was designed to determine the effect of the power size escalation and the biomass with coal co-firing level on the economic viability of a supercritical oxy-combustion power plant. This study was performed by assessing the NPV, COE and CCA variation for five proposed biomass co-firing levels: 0%, 15%, 25%, 50% and 100%. In addition, these levels were combined with different gross electric energy production: 140 MWe, 300 MWe and 460 MWe. These gross power productions were in accordance with Stanger et al. [13] works when they stated: “oxy power plants with CO_2 capture to be built should have capacities in the range of 100–500 MWe (gross)”. The conclusions obtained by the evaluation of the fifteen proposed scenarios added to a growing body of literature on oxy-combustion technology and were considered useful to improve several alternative processes to traditional electric production by only coal combustion.

2. Materials and methods

2.1. Materials

Two raw materials were used in this study: a bituminous coal obtained from the northern located mines of León (Spain) and a lignocellulosic biomass blend used in previous works [14]. The biomass was delivered from the north of Spain. The biomass blend proportion was stablished in 70% rape vs. 30% corn according to best oxy-combustion results (pending publication). It was taken as a field bioresidue. The procedures used in biomass characterisation were described in previous works [10]. However, the same properties values in the bituminous coal case were obtained from the data project of a power plant with the same coal as main feedstock [15].

Table 1 summarised the physical and chemical properties of raw materials used in simulations.

Table 1
Physical and chemical properties of raw materials used in simulations.

Material	Coal	Biomass
Proximate analysis		
Moisture (%)	12.0	10.1
Volatile matter[a] (%)	32.0	52.4
Ash[a] (%)	25.5	14.4
Fixed carbon[a,c] (%)	30.5	23.1
Ultimate analysis		
C[b] (%)	65.1	57.3
H[b] (%)	2.9	4.6
N[b] (%)	1.4	0.8
S[b] (%)	1.9	1.0
O[b,c] (%)	28.7	36.3
Calorific value		
HHV (MJ/kg)	25.08	19.18
Properties		
Grindability index	50	27
Dielectric constant	5.0	2.5

HHV = high heating value.
[a] Dry basis.
[b] Dry ash free basis.
[c] Calculated by difference.