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Technico-economic assessment of coal and sawdust co-firing power generation with CO_2 capture

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ABSTRACT

Biomass, in contrast with different type of fossil fuels, is considered a renewable energy source (RES), having a neutral carbon impact in burning processes. As a result, biomass co-firing offers a good potential solution for reducing greenhouse gas emissions in conventional coal fired power plants. This paper evaluates the technical and economic aspects of biomass co-firing electricity production with and without CO_2 capture (CC) using different mixtures of coal and sawdust. The impact of biomass co-firing on power plant performances were evaluated in terms of energy efficiency, auxiliary power consumption, capital costs, operational & maintenance (O&M) costs, specific CO_2 emissions, electricity cost and CO_2 avoidance costs. Depending on the feedstock composition, the biomass co-firing power plant generates 750–800 MW electricity in the case of carbon capture and 980–1027 MW electricity without capture. The results indicate a continuous decrease in both technical and economical performances with the increase of biomass content in the feedstock.

1. Introduction

The current trend of industrialization, technological development and global population increase, especially in emerging economies like China, India and Brazil, led to continues growth of electricity demand (Evans et al., 2010; Hoffmann et al., 2012; Liang et al., 2013). The use of fossil fuels to satisfy this rapidly increasing energy consumption can accelerate the depletion of natural reserves and enhance climate change and global warming by the increased greenhouse gas emissions (Muresan et al., 2013). For this reason, it has become a global concern to increase the share of RES in electricity production. In the recent years, many governments offered financial, institutional and educational support to promote the use of RES in the power sector (Mizsey and Racz, 2010). This led to a rapid growth of renewable energy markets and industries which supplied an estimate of 19% of global final energy consumption in 2011 (REN21, 2013; White et al., 2013). Among the potential RES, biomass-based heat and power generation is the most accessible, even in the poorest countries, and unlike other alternatives (e.g. solar, wind) it is available whenever it is needed (Basu et al., 2011; Xydis, 2013). Moreover, according to the literature, biomass is the most profitable RES after hydropower, regarding the total energy and carbon reduction costs but it is also affected by location and availability like any another RES (Evans et al., 2010; Hatje and Ruhl, 2000). However, even in the case of bioenergy production there can be identified negative aspects like conversion of natural ecosystems into energy-crop plantations, deforestation of tropical rainforests, soil erosion problems and rising food prices (Abbasi and Abbasi, 2010; Naik et al., 2010). Still, due to its “neutral carbon impact”, biomass became the world's fourth largest source of energy after oil, coal and natural gas, accounting for more than 10% of global primary energy supply (Chum et al., 2011; REN21, 2013).

Current bioenergy systems rely mainly on solid biomass like agriculture and forestry residues, various streams of organic waste, and dedicated crops or perennial systems (Carneiro and Ferreira, 2012; Purohit, 2009). It is notable that more than 80% of the solid biomass used in the power sector derived from fuelwood while the remaining 20% from energy crops, residues and by-products generated in the agriculture sector (Bringezu et al., 2009; Chum et al., 2011). This can be accounted to the fact that fuelwood (80–415 GJ/ha) ensures a higher energy yield per unit area than other type of solid (2–155 GJ/ha) or liquid (16–200 GJ/ha) biomass feedstocks (Chum et al., 2011).

Thanks to the high energy density and its neutral carbon impact, fuelwood has gained significant attention as a substitute for fossil

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fuels (Evans et al., 2010; Kamimura et al., 2012). The use of fuelwood is also justified by the fact that it can be implemented in coal-fired power plants in a relatively short period of time and without major technical and economical difficulties (Basu et al., 2011). Considering that the global capacity of coal fired power plants is about 800 GW, it means that each percentage of coal substituted with biomass would produce 8 GW electricity and a reduction of CO_2 emission by approx. 60 Mtons (Al-Mansour and Zuwala, 2010). With this outlook, Hoffmann et al. presents a technico-economic assessment for co-firing woody biomass from energy forests with low rank Brazilian coal (Hoffmann et al., 2012). The use of biomass for power generation is also targeted by the government of Malaysia which plans to increase its palm biomass power generation capacity to 500 MW by 2020 (Ng et al., 2012). Similar attempt can be noticed in the case of Thailand which disposes of a high amount of eucalyptus and rubber wood sawdust with energy potentials of 3.2 and 1.4 EJ/year (Chakritthakul and Kuprianov, 2011; Ghani et al., 2013).

The use of fuelwood as an alternative for coal substitution in coal-fired power plants is also targeted by the European Union (EU) (Nikolopoulos et al., 2013; Zuwała, 2012). Literature data shows that biomass co-firing in the EU is feasible from both technical and economical point of views (Lüschen and Madlener, 2013; Nikolopoulos et al., 2013). This is also sustained by the fact that there are more than a hundred biomass co-fired power plants in the EU (Al-Mansour and Zuwala, 2010), which consumed over 4.54 EJ of biomass in 2011 (Hansson et al., 2009). These provided more than 66% of all renewable energy or 5.4% of the total gross inland energy consumption (Esteban and Carrasco, 2011; EUROSTAT, 2011). For this reason, wood pellet consumption increased significantly in the EU, reaching 11.4 million tons in 2010, equal to almost 85% of the global wood pellet demand (Chum et al., 2011). This induced a gap of 2.14 million tons between production and consumption which was covered by about 670 pellet plants around EU and by massive import flows from USA, Canada and Russia. It is also important to note that almost a half of the consumed wood pellets are traded among EU member states (Chum et al., 2011). In order to reduce the dependency of energetic imports and to ensure the necessary supply for the future, the EU has developed strategic plans for the increase of wood production (de Wit and Faaij, 2010; González-García et al., 2014). Supply assessments indicate a potential of 900000 km^2 land for bioenergy crop production by 2030 with an estimated overall bioenergy supply of 27.7 EJ/y of which the share of cumulative total forest supply potential can reach 20% (de Wit and Faaij, 2010).

Among EU countries, Romania has an area of about 6.4 million ha covered by forests of which 66% are in the mountain areas, 24% are in hilly areas and 10% in the plains. The total standing wood volume was estimated to about 1350 million m^3, of which 39% is coniferous, 37% beech, 13% oak and 11% other species. The bioenergy related potential of available woody biomass was estimated at 73.7 PJ/y while the theoretical one, according to the total biomass increment in Romanian forests, is around 332 PJ/y (Scarlat et al., 2011). Nevertheless wood is used mainly for process heat generation, with a total installed thermal power of about 1200 MW_{th}, but it could be also used to ensure Romania's 24% renewable energy share of the gross energy consumption by 2020 (Dusmanescu et al., 2014; Scarlat et al., 2011). It is important to note that more than 50% of the proposed renewable energy mix for 2020 is covered by solid biomass (Dusmanescu et al., 2014).

Considering the potential bioenergy supply of Romanian forests and the fact that small plants for processing wood waste into lighters and pellets began to develop (Dusmanescu et al., 2014) the current study evaluates the possibility of using woody biomass in the form of sawdust for direct co-firing in coal fired power plants. In order to emphasize the differences between power plant performances for different coal and sawdust mixtures, important technico-economical parameters were evaluated such as energy efficiency, auxiliary power consumption, capital costs, O&M costs, specific CO_2 emissions, electricity and CO_2 avoidance costs, at constant gross electric output. In comparison to other studies (Khorshidi et al., 2013, 2014) this paper also includes cash flow analysis for both power plant configurations with and without CO_2 capture using well defined mixtures of coal and sawdust.

2. Process description

2.1. Plant configuration

Biomass is the only renewable fuel which can be used for combustion-based power generation and can be regenerated relatively quickly through photosynthesis (Esteban and Carrasco, 2011). This is very important because the world's power generation is based mainly on the conversion of thermal energy obtained from the burning of fossil fuels. To reduce CO_2 emissions and avoid large investment costs it is necessary to find technological alternatives for the combustion-based conversion of biomass into electricity in the existing power plants. Considering the technical superiority of solid fossil fuels, it would be adequate to co-fire biomass and coal in the existing power plants. It has been proven that biomass co-firing offers the least cost among the several technologies available for greenhouse gas reduction and can be easily implemented in coal-fired power plants (Basu et al., 2011). This is also sustained by the technico-economical data provided by more than 150 installations worldwide which co-fire different types of solid biomass and fossil fuels (Basu et al., 2011).

The co-firing technologies employed in these units may be broadly classified under three main categories: direct, indirect and gasification co-processing (Basu et al., 2011). Most of these installations employ direct co-firing due to the fact that it is the simplest, cheapest alternative and does not require large modifications to the running power plants (Basu et al., 2011). For the above reasons in the current work it has been chosen to assess sawdust and coal direct co-firing for electricity generation with and without carbon capture. The biomass co-firing power plant assessed in this paper, Fig. 1, has the following main components: biomass drying unit, flue gas desulphurization (FGD), acid gas removal unit (AGR), CO_2 Drying and Compression (Muresan et al., 2013). For instance, Fig. 1 also shows the mass balance data obtained in the ChemCAD simulation for the case study with 50% coal/sawdust.

2.2. Feedstock characteristics

For the present work, one of the most common types of biomass (sawdust) was investigated in mixture with coal, as feedstock for combustion based power generation. The choice is motivated by the fact that sawdust is one of the most important wood exploitation residue which gained significant attention as raw material for wood pellet production (Muresan et al., 2013). Using coal and sawdust co-firing for combustion based power generation with CO_2 capture and storage would reduce the negative impact on the environment and also would contribute to the preservation of natural coal reserves (Muresan et al., 2013).

Coal and sawdust characteristics were determined by ultimate and proximate analyses. The composition analysis indicates a much higher ash content for coal that in the case of sawdust. As a result the increase of sawdust concentration in the feedstock can reduce the amount of solid waste materials (ash) generated in the process. However the high moisture content (about 40% wt.) of sawdust can