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Technical properties of biomass and solid recovered fuel (SRF) co-fired with coal: Impact of on multi-dimensional resource recovery value

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ABSTRACT

The power plant sector is adopting the co-firing of biomass and solid recovered fuel (SRF) with coal in an effort to reduce its environmental impact and costs. Whereas this intervention contributes to reducing carbon emissions and those of other pollutants related with the burning of fossil fuel, it may also result in hidden impacts that are often overlooked. When co-firing, the physical and chemical properties of the mixed fuels and the subsequent technical implications on the process performance and by-products are significant. Interconnections between multiple values nested within four domains of value, i.e. environmental, economic, technical and social, mean that changes in the one domain (in the co-firing case, the technical one) can have considerable implications in the other domains as well. In this study, using a systematic and flexible approach to conceptualising multi-dimensional aspects associated with the co-firing of biomass and SRF with coal, we unveil examples of such interconnections and implications on overall value delivered through the use and recovery of waste resources. Such an analysis could underpin the selection of useful metrics (quantitative or semi-quantitative descriptors) for enabling a systemic multi-dimensional value assessment, and value's distribution amongst interconnected parts of resource recovery systems; key in enabling sound analysis and decision-making.

1. Introduction

Combustion of coal for electricity production is one of the most significant sources of air pollution worldwide. This is owing to emissions of particulate matter (PM10 and PM2.5), carbon dioxide (CO_2), oxides of sulphur (SO_x) and nitrogen (NO_x) and acid gases (e.g. HCl, HF) (Sami et al., 2001), which lead to negative impacts on human health and ecosystems. The need to control and reduce carbon emissions and air pollutants has driven various interventions, most of them focusing on lowering fossil fuels dependence through the use of alternative sources of energy (Buchanan et al., 2014; Sami et al., 2001).

Biomass, which can be sourced from forestry and agricultural residues, or from dedicated energy crops (IEA-ETSAP and IRENA Technology, 2013), has long been used in power plants as a renewable fuel contributing to global energy production. Solid recovered fuel (SRF), a highly heterogeneous mixture of high calorific fractions of non-hazardous waste materials produced based on EU specifications (European Committee for Standardization, 2011), has been recognised as a viable alternative to fossil fuels, already used as a co-firing fuel in various industrial sectors, including power plants (Agraniotis et al., 2009; Cocchi et al., 2015; Dunnu et al., 2009a; Gehrmann et al., 2012; Hilber et al., 2007b; Velis and Cooper, 2013; Wu et al., 2009).

Co-firing coal with biomass and/or SRF has increasingly been considered as a way to decrease reliance on coal and its associated impacts (Cocchi et al., 2015; Nussbaumer, 2003b; Velis et al., 2012; Wu et al., 2009). Co-firing can be achieved via three main options: direct co-firing; parallel co-firing; and indirect co-firing (Al-Mansour and Zuwala, 2010; Basu et al., 2011; Dai et al., 2008; Maciejewska et al., 2006; Tillman, 2000). The technologies used for indirect and parallel co-firing are not mainstream owing to their high investment costs. Conversely, direct co-firing offers savings in installation time, fewer modifications, shorter shutdown periods, and lower investment costs (Grammelis et al., 2010; Nussbaumer, 2003a), making it the co-firing method considered in this study.

The potential environmental benefits of using SRF and/or biomass as a fuel in power plants are improved carbon emissions (related to the carbon neutral attribution to their biogenic carbon fraction) (Séverin et al., 2010)), and reduction in other types of air pollutants owing to their low nitrogen and sulphur contents (Cocchi et al., 2015; Sami et al., 2001; Velis et al., 2010; Wu

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et al., 2009). The costs of sourcing and processing (transportation, grinding, etc.) biomass and SRF may be lower compared to the costs associated with coal, making these fuels more affordable in some cases (Sami et al., 2001; Wu et al., 2009). They may also attract subsidies for production of renewable and/or carbon neutral energy, which depends on the exact policy mixture applicable in each country.

However, the decision to partially replace coal with either biomass or SRF also has technical implications. These implications result from the biomass and SRF characteristics and their synergistic effects with coal, of which real impact on wider systems is not yet fully clear, altering the balance between the environmental, economic, and social benefits (positive changes in value) and impacts (negative changes in value). For example, the relatively high sodium (Na), potassium (K), and chlorine (CI) contents of biomass and SRF compared to coal, may lead to increased ash deposition on the boilers (Cocchi et al., 2015; Jappe Frandsen, 2005); the economic impact of which may depend on the technology used, as well as on the types and proportion of biomass and SRF co-fired with coal (level of substitution of coal). Another drawback of co-firing SRF and biomass with coal is that their relatively higher Cl content (e.g. for SRF it can be around 1% wt. (Velis et al., 2010)) may compromise the quality of the pulverised fly ash (PFA), thereby affecting its end uses (Wu et al., 2009). PFA is widely used as a technical addition partially replacing cement in concrete, improving its structural properties and reducing its carbon emissions (Imbabi et al., 2012; Purnell and Black, 2012). Changes in the quality of PFA can render it unsuitable for use in concrete production, thus limiting its recovery as a valuable resource (Baxter, 2005) and impacting an economically, socially and environmentally significant system dependent on the power generation sector.

Therefore, this study aims to describe how the physical and functional properties of biomass and SRF may affect the direct co-firing process and to assist in understanding of how these technical implications can result in environmental, economic and social benefits and impacts. This analysis is based on a systematic and flexible approach to conceptualising multi-dimensional aspects associated with the co-firing of biomass/SRF with coal; useful in providing insights into how to best capture the highest value of input and output materials from the co-firing system, thereby supporting the recovery of resources from waste. As such, in Section 2 the physical and technical characteristics of SRF and biomass are outlined as the basis of the exploration of the potential implications that these physico-chemical characteristics can bear on the co-firing system. Then in Section 3, the varying technical quality of biomass and SRF are explored in terms of their potential to directly affect the creation and or dissipation of technical. The systemic environmental, economic, and social valuation of co-firing SRF and/or biomass with coal is then discussed in Section 4, unravelling the potential opportunities and constraints associated with co-firing.

2. Physical and technical characteristics of biomass and SRF

2.1. Biomass properties and uses

Biomass is a material with a composition of approximately 80% volatile matter and 20% fixed carbon (as a measure of comparison, bituminous coal has 70–80% fixed carbon and 20–30% volatile matter) (Tumuluru et al., 2011). This composition renders biomass suitable as a fuel (Maciejewska et al., 2006). It can be imported or supplied locally, and may include residues or waste streams from forestry and timber processing (e.g. saw dust, wood chips, etc.), agriculture (e.g. corn husks, wheat chaff, etc.), pulp and paper, and sugar industries, as well as husk/shell wastes (e.g. almond, olive, walnut, palm pit, cacao). In addition dedicated energy crops, including short-rotation woody crops like hard wood trees and herbaceous crops like switchgrass, are agricultural crops that can be grown solely for use as biomass fuels (Demirbas, 2004; Maciejewska et al., 2006; Sami et al., 2001). Oil, sugar and starch crops are currently widely used for the production of liquid transport fuels, and their utilisation in power plants is currently economically unjustified (Demirbas, 2004; Maciejewska et al., 2006).

Biomass is generally high in moisture content (MC) and has a low net calorific value (NCV) (Nunes et al., 2014). Its NCV is generally slightly over half that of coal, its particle densities are about half that of coal, and its bulk densities are about one fifth that of coal. This results in an overall fuel energy density roughly one tenth that of coal, meaning that more biomass has to be burnt to compensate for the energy equivalent of the coal that it replaced (Al-Mansour and Zuwala, 2010; Backreedy et al., 2005; Baxter, 2005; Demirbas, 2004; Nunes et al., 2014; Tumuluru et al., 2011). Biomass can also be processed into liquid, solid and gaseous fuels in order to transform often bulky, difficult to handle, and relatively low energy content material into one with the physico–chemical characteristics of traditional fuels, which permit economic storage and transferability through pumping systems (Demirbas, 2004; Maciejewska et al., 2006).

Chemical properties such as the Cl, nitrogen (N), Na, K, calcium (Ca) and sulphur (S) content vary widely amongst different types of biomass fuels (Demirbas, 2004; Maciejewska et al., 2006; Sami et al., 2001). Generally, wood and woody materials tend to be low in Cl, N, and ash content, while agricultural materials such as straw tend to contain high amounts of alkali metals (mainly K) and Cl (Kassman et al., 2013; Teixeira et al., 2012). Biomass fuels may also have a varying ash content (i.e. the inorganic and incombustible mineral fraction of biomass fuels that is left after complete combustion) with agricultural materials presenting a higher ash content than woody materials (Demirbas, 2004; Nunes et al., 2014). However, biomass fuels have generally less ash, and very low or almost negligible N and S content compared to most coals (Sami et al., 2001; Tumuluru et al., 2011), reducing as such the fuel-related SO_2 and NO_x emissions responsible for acidification and ozone pollution, respectively (Easterly and Burnham, 1996). Due to the large property variations presented by the different types of biomass, it is difficult to establish a representative biomass classification. However, some typical biomass fuel properties are presented in Table 1, and are compared to those of bituminous coal (i.e. coal with 70–80% fixed carbon and 20–30% volatile matter).

Stand-alone biomass plants purport to convey environmental and economic benefits via e.g. the utilisation of a renewable fuel, the diversion of biodegradable material from landfill, and subsequent eligibility for tax credits and subsidies, but they involve a high capital cost and significant investment risk associated with the security of the feedstock supply, regulatory volatility (especially regarding the stability of subsidies) and thus the long-term viability of the plant (Maciejewska et al., 2006). Seasonality aspects may affect the availability of biomass fuel, while the dispersed nature of most biomass fuels produced in different regions and their lack of proximity to existing infrastructure can add further project risks (Maciejewska et al., 2006).

Combining biomass with other fuels (e.g. coal and SRF) for energy production in existing power plants can mitigate and address some of these technical, economic and environmental uncertainties. This is especially the case when biomass is sourced locally, making co-firing more economically attractive (Basu et al., 2011). If local sources are not sufficient, high energy–density, pre-treated biomass (e.g. wood pellets) can be used, in which case long-distance transportation logistics (e.g. availability of suitable infrastructure such as ports, rail, roads etc.) play an important role in both the economic viability and the overall environmental