Applied Energy 187 (2017) 873–885

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Renew, reduce or become more efficient? The climate contribution of biomass co-combustion in a coal-fired power plant

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HIGHLIGHTS

- Coal mining is more energy and CO_2 efficient than biomass production.
- Co-combustion of 60% biomass with coal doubles mass transport compared to 100% coal.
- Low co-combustion levels reduce GHG emissions, but the margins are small.
- Total supply chain efficiency is the highest for the coal reference at 41.2%.

ARTICLE INFO

Article history:
Received 4 July 2016
Received in revised form 25 October 2016
Accepted 8 November 2016
Available online 16 November 2016

Keywords:
Biomass
Bio-energy
Co-combustion
Supply chain analysis
Pulverised coal power plant

ABSTRACT

Within this paper, biomass supply chains, with different shares of biomass co-combustion in coal fired power plants, are analysed on energy efficiency, energy consumption, renewable energy production, and greenhouse gas (GHG) emissions and compared with the performance of a 100% coal supply chain scenario, for a Dutch situation. The 60% biomass co-combustion supply chain scenarios show possibilities to reduce emissions up to 48%. The low co-combustion levels are effective to reduce GHG emissions, but the margins are small. Currently co-combustion of pellets is the norm. Co-combustion of combined torrefaction and pelleting (TOP) shows the best results, but is also the most speculative.

The indicators from the renewable energy directive cannot be aligned. When biomass is regarded as scarce, co-combustion of small shares or no co-combustion is the best option from an energy perspective. When biomass is regarded as abundant, co-combustion of large shares is the best option from a GHG reduction perspective.

1. Introduction

During the last hundred years, pulverised coal combustion has been widely applied for electricity generation [1]. More recent, deregulation of the European power sector [1], low coal prices and a plethora of inexpensive emission certificates have increased the lock-in effects of pulverised coal firing in the EU. Currently, technological innovation is applied as a means to decrease the environmental impact of coal combustion, by increasing the boiler efficiency, co-combustion with biomass or carbon capture and storage [1].

The renewable energy directive (RED), [2] as constituted by the European Commission (EC), emerged from increasing awareness about climate change. Hence, the focus is on the reduction of greenhouse gas (GHG) emissions, by using indicators as: increased use of renewable energy sources, energy saving and more efficient use of energy. Biomass has the largest contribution to renewable energy production in the European Union (EU); almost two-thirds of the primary production of renewable energy originates from biomass [3]. Despite criticism on the actual sustainability of biomass for energetic purposes [4,5] biomass is often co-combusted in coal-fired power plants in the Netherlands. Fig. 1 shows the quantity of biomass co-combusted in the Netherlands from 1995 until 2012. The annual co-combusted biomass quantities after 2005, were directly related to the Dutch subsidy structures [6]. During the last decade a tenfold increase in coal exports from the United States (US) to the Netherlands has taken place, up to 230 PJ in 2015. In the same period, the domestic consumption of coal in the Netherlands for electricity generating purposes increased with approximately 60% up to 400 PJ in 2015. Pellet exports from the US to the EU28 increased with a factor nine since 2009 up to 81 PJ in 2015. The amount of imported pellets was

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http://dx.doi.org/10.1016/j.apenergy.2016.11.033
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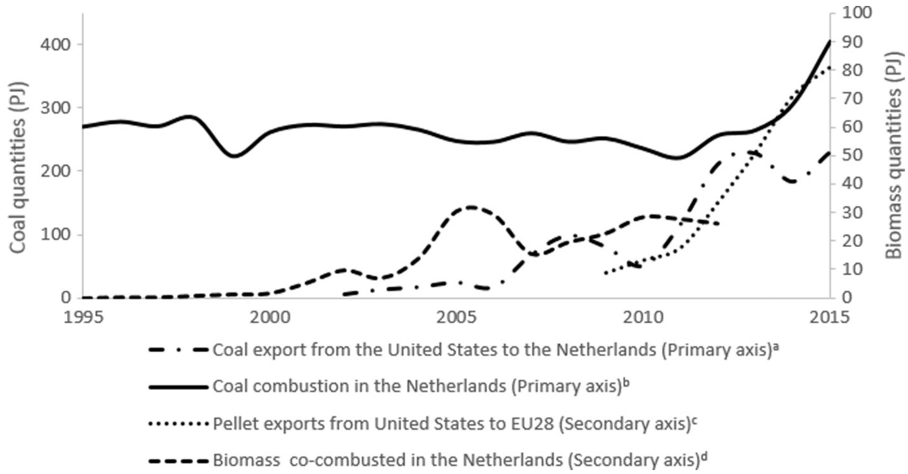

Fig. 1. Coal exports from the United States to the Netherlands (PJ), coal quantities combusted for electricity production (PJ), pellet exports from the United States to the EU28 (PJ) and co-combusted biomass in the Netherlands (PJ). (a) [14] (b) [15] (c) [16,17] (d) [18].

equal to the domestic consumption in 2011 in the Netherlands. Assuming that the imports are evenly distributed over the domestic consumption, then about 40% of the consumed pellets in the Netherlands originated from the US. This corresponds to roughly 7 PJ, which is 25% of the co-combusted pellets in the Netherlands. The Dutch Energy Agreement for sustainable growth [7] has put a maximum on biomass co-combustion of 25 PJ in 2020. This maximum underlines that the debate regarding the environmental sustainability and optimal application of biomass is still ongoing.

Biomass is a rather dispersed resource [8] and generally available in regions with low energy and material demand. This low regional demand results in the need for transport to more material and energy intensive regions. The larger part of the co-combusted biomass in the Netherlands originates from North America [9]. Giuntoli et al. showed that low energy densities of biomass result in lower transport efficiencies compared to e.g. coal [10]. The logistic disadvantages of biomass can be reduced by applying pretreatment to increase the energy density (MJ kg^{-1}).

When biomass is applied for co-combustion, a supply system complementary to that of coal has to be designed. However, the impact of the biomass supply chain on the total system performance is often neglected. This is in line with Iakovou et al. whom state that little research focuses on supply chain issues, whilst taking the whole supply chain into account [11]. Lin et al. showed that long distance transportation of wood pellets is economically feasible [12], just as Uslu et al. showed that biomass transportation could be economically and energetically feasible under certain conditions [13]. However, the actual net quantities of renewable electricity from biomass co-combustion and the related greenhouse gas (GHG) emissions of long distance supply chains are still unsure, since conversion is not taken into account by Uslu et al. [13] and Lin et al. [12] only focus on the economic aspects of biomass supply, which at least in the Netherlands has a strong relation with subsidy structures [6].

Therefore, within this article a chain analysis with a variety of biomass supply chain scenarios, including different pretreatment technologies and different co-combustion levels, was performed. The aim of this analysis is to determine the effectivity of different pretreatment technologies, different levels of biomass co-combustion and conversion on the RED indicators, GHG emissions, the energy efficiency, energy consumption and renewable energy production, when the whole supply system is taken into account. Currently, co-combustion of pellets is the norm in the Netherlands. This research studies the effect of co-combustion of different shares of poplar wood chips, torrefied wood chips, pellets and combined torrefaction and pelleting (TOP). The analysis indicates whether renewable energy from biomass co-combustion results in energy saving, increased energy efficiency and finally a reduction in GHG emissions compared to the combustion of coal.

This paper continues with a methodology section describing the qualitative and quantitative aspects of the supply chains. Subsequently, the supply chain scenarios are discussed after which the results are presented. Furthermore, a discussion section, finalised with a sensitivity analysis, and a general conclusion are presented.

2. Methodology // system components

There are two separate upstream supply systems, which merge at the midstream conversion stage (Fig. 2). Coal is first mined, transported to a harbour and subsequently transported overseas to the port of Rotterdam in the Netherlands. Poplar is produced, harvested, chipped and dried (up to 20% moisture on a wet basis) on the production site, before the wood chips are transported to a harbour. At the harbour, no further pretreatment, or torrefaction, or pelleting or TOP is applied. Subsequently, the biomass is transported overseas with a Supramax bulk carrier (in line with [10]) and grinded together with coal at the coal-fired power plant. The coal and biomass are co-combusted on the Maasvlakte where the GDF Maasvlakte pulverised coal-fired power plant is located. This power plant is theoretically able to co-combust up to 60% biomass [19]. Fig. 2 gives an overview of the system boundaries of this research and the design of the supply chain scenarios, which are further elaborated upon in Fig. 3. The midstream part of the biomass supply chain is equal to the coal supply chain, where both feedstocks are grinded and combusted for electric power production. In the following, the individual steps in the supply chains are discussed. This section further elaborates on the calculation of the energy use in transport, the conversion efficiency, the calculation of the share of renewable electricity produced, the 12 supply chain scenarios, and the coal supply chain reference scenario.

For ease of comparison 1 $MJ_{electric}$ output was taken as the functional unit for all supply chain scenarios. This results in demand driven supply chains scenarios. Hence, the calculated conversion efficiency and the energy content of the pre-treated biomass determine the required quantities of biomass.

2.1. Coal mining

The first step in coal supply is mining of the resource. Ditsele and Awuah-Offei provide a life cycle analysis of the impact of mod-