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Life cycle assessment of direct co-firing of torrefied and/or pelletised woody biomass with coal in The Netherlands

Georgios-Archimidis Tsalidis [a, *], Yash Joshi [a], Gijsbert Korevaar [b], Wiebren de Jong [a]

[a] Process and Energy Laboratory, Technical University of Delft, Leeghwaterstraat 44, 2628 CA Delft, The Netherlands
[b] Engineering Systems and Services Department, Technical University of Delft, Jaffalaan 5, 2628 BX Delft, The Netherlands

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A B S T R A C T

In this paper the Life Cycle Assessment (LCA) is used to evaluate the environmental benefits on global warming, acidification and photochemical oxidation potentials, of biomass direct co-firing with coal on a 20% energy input basis, when compared with coal-fired power generation in The Netherlands. The solid biofuel is produced from Dutch or Canadian forestry biomass via pelletisation, torrefaction or torrefaction and pelletisation. The results show that torrefied biomass co-firing chain can be considered the best option when Dutch biomass is utilised. The reduction is approximately 12% for global warming, 7% for acidification and 5% concerning photochemical oxidation potentials. Even when biomass is imported from Canada, this also results in substantial reduction regarding global warming potential, when compared to the reference case. Alternatively, co-firing of domestic biomass results in a better performance than Canadian biomass for all three impact categories. Therefore, concerning global warming all the suggested resources for co-firing result in environmental benefits compared to coal-fired power generation.

1. Introduction

Diminishing the usage of fossil fuels is one of the main tasks faced in the prevention of global warming and, to a further extent, climate change. In this regard the coal is a fuel with the highest environmental impact, as it is the largest CO_2-emitting fossil fuel in terms of weight per unit of energy produced. Therefore, on a European and on a national level there have been attempts with policies and drivers to reduce the use of coal, especially in electricity generation as approximately 43% of the emitted CO_2 is derived from electricity and heat production industry (IEA, 2012). One of the options to reduce coal utilisation in power generation is its partial or total replacement with biomass.

In this paper information regarding the Dutch political field corresponds to the year 2012. Dutch policy is strongly related to EU policy. The Dutch subsidy for biomass co-firing in coal-fired power plants ended (Sawin et al., 2012). However, the Dutch government made clear that its intention is mandating biomass co-firing in all power plants. The government discussed and agreed on a minimum of 10% of biomass input on weight basis (Gibson, 2011). On the other hand, power companies produce emissions that contribute to significant environmental impacts, such as global warming. Therefore, in planning new production capacities, the Dutch power companies will have to seek a more sustainable energy balance.

Life Cycle Assessment (LCA) is continuously getting more attention as it can help evaluate products and services and identify possible improvements. During the past decade there was a rapid increase in LCA studies (Guinée et al., 2011). Therefore, LCA is now considered a powerful tool with respect to sustainability. Additionally, concerning power generation, there have been LCA analyses of national electricity generation systems, combustion of coal, biomass co-firing with coal and single fuel biomass combustion. More specifically, Hartmann and Kaltschmitt (1999), Mann and Spath (2001), Tabata et al. (2011), Huang et al. (2013), Royo et al. (2012) and Fan et al. (2011) have all conducted LCA studies with respect to biomass co-firing with coal. Whereas, Damen and Faaij have performed a Life Cycle Inventory (LCI) on biomass import chains in The Netherlands (Damen and Faaij, 2003). All authors mentioned above either focused on global warming impact or on Greenhouse Gas (i.e. GHG) emission production. However, none of them has yet focused on a relative novel, high prospect technology such as torrefaction or torrefaction combined with pelletisation (TOP), of woody biomass. Finally, no LCA studies on direct co-firing of biomass with coal in the Dutch context have been conducted.

* Corresponding author. Tel.: +31 626729229.
E-mail address: g.a.tsalidis@tudelft.nl (G.-A. Tsalidis).

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Torrefaction is a promising technology, with potential to have a major impact to the commodification of biomass. Its considered added value is the production of a more coal-alike solid biofuel with higher energy density and better physical and combustion properties, which consumes substantially less energy to be pelletized than fresh biomass. Additionally, this solid fuel has significant lower moisture content than fresh biomass, it is hydrophobic and more homogeneous. Torrefaction adds value in the logistics chain as well; torrefied and pelletised biomass is considered safer for transportation than conventional pellets, whereas cost savings are also expected (Bridgeman et al., 2008; Bagramov, 2010; Carter, 2012; Phanphanich and Mani, 2011; Patel et al., 2011; Shah et al., 2012).

Woody biomass in The Netherlands is mainly derived from four sources, such as forests, roadside, orchards and wood processing industry. In this paper woody biomass originates from forests and roadside. The Netherlands has 360,000 ha of forest, of which almost 25% has a protected area status. Furthermore, 55% of the available forest is harvested annually which corresponds to 1.2 Mtons of fresh wood (Probos, 2011). 70% of the available wood is used as round wood for industrial use, whereas the rest is used as residential firewood, energy pellets and small to medium scale bioenergy applications (Kuiper and Oldenburger, 2006). Wood pellets were the main form of biomass used in the Dutch power plants until 2010 and almost the only one imported for co-firing purposes (Goh et al., 2012).

Canada was selected to be the country to produce and deliver the alternative biomass source in this paper. Canada is the largest wood pellets exporter to The Netherlands and it is very rich in biomass resources, approximately 645 Mtons are harvested annually. As more than 60% of wood pellets are produced in British Columbia (Magelli et al., 2009), this region was selected for this analysis.

In this paper 55% of the available total annual increment of forestry biomass is harvested for co-firing purposes, as mentioned above regarding current Dutch practices, while the rest is left on site to avoid carbon stock depletion. However, this proportion can be further increased up to 80%, similar to sustainably managed forests in Europe.

There are several Dutch electricity companies which co-fire biomass with coal already. That said, wood pellets still are the dominant form of biomass used for co-firing purposes (Dutch Ministry of Economic Affairs, Agriculture and Innovation, 2010). Most of the co-firing power plants in The Netherlands are located in South-Holland or close to this province, and the port of Rotterdam is one of the largest globally and it already has a clear interest of becoming a bioenergy-hub. Therefore, the Rotterdam's area was selected as the most suitable area for location of the power plant in this paper. As a result it was decided that the pretreatment plants and the cement factory would be located close to the port, and approximately not more than 130 km away. Finally, the source of biomass was selected to be no further away than 200 km from the pretreatment plants. Both are average distances, which can be realistic as The Netherlands is a small country.

The aim of this paper is to evaluate the environmental benefits on global warming, acidification and photochemical oxidation potentials, of biomass direct co-firing with coal on a 20% energy input basis, when compared with coal-fired power generation in The Netherlands. LCA is used for this evaluation. The solid biofuel is produced from Dutch or Canadian forestry biomass via pelletisation, torrefaction or TOP. The results show that torrefied biomass co-firing chain can be considered the best option when Dutch biomass is utilised. The reduction is approximately 12% for global warming, 7% for acidification and 5% concerning photochemical oxidation potentials. Therefore, it is important to notice that the selected environmental impacts are associated with not only the co-firing stage, but also with the entire biomass supply chain.

2. Materials and methods

The CMLCA software, developed by Heijungs and Leiden University (Heijungs, 2009) and the CML and Traci models are used in this paper to acquire assessment results on the environmental impacts.

2.1. LCA methodology

2.1.1. Goal definition

The aim of this cradle-to-gate LCA study is the comparison and evaluation of benefits regarding selected impacts of pretreated biomass co-firing chains in The Netherlands, with respect to coal combustion for power generation. Additionally, identification of the most influential life cycle stages in the entire chain is pursued in order to suggest possible improvements or bottlenecks. Therefore, focus has been given on the whole biomass chain; from harvesting to transportation of the produced ashes to the cement production factory. Moreover, the use of waste resources was considered in this paper. As a result, waste woody biomass, derived from Dutch forest maintenance, has been selected as the biomass source, and the produced mixed ash from the power plant was used as feedstock in a cement production factory.

The choice of this comparison is made because the Dutch government considers making co-firing mandatory for Dutch power plants. Furthermore and as explained above, torrefaction is a very promising technology regarding bioenergy systems; and Rotterdam port is one of the largest globally, with an interest of becoming a bioenergy-hub. Finally, if the environmental benefits are not strongly influenced by transportation stage, this analysis can also be applied to other European countries, bigger than The Netherlands.

2.1.1.1. System boundaries. The cradle-to-gate system boundaries of a woody biomass supply chain for power generation are shown in Fig. 1. The biomass co-firing chains consist of several stages including: harvesting and chipping of the woody biomass on production-site, storage, transportation, pretreatment in order to produce a solid fuel, co-firing and, finally, transportation of the produced mixed ash to a cement production factory. Furthermore, the life cycle steps of the production chain of coal, such as mining, processing and transportation, were also taken into account in the boundaries. On the other hand, regarding the reference case the stages included are mining and processing of hard coal, transportation, combustion and, finally, transportation of the produced ash.

Consumption of materials and energy regarding the construction and demolition of relevant infrastructure are excluded from the system boundaries, as several studies have shown that their contribution is insignificant and negligible when compared with the fuel production or operational stages (Damen and Faaij, 2003; Hartmann and Kaltschmitt, 1999; Mann and Spath, 2001).

2.1.1.2. Functional unit. The selected function unit is 1 kWh of electricity produced by the power plant. The functional unit is used to compare the environmental impacts of the different pretreated biomass co-firing systems and reference system.

2.1.1.3. Allocation. Economic allocation is used in this paper in multifunctional processes to allocate material and/or energy consumption, and produced environmental emissions. A multifunctional process is a process which has more than one functional flow, i.e. flows that constitute the process goals. Economic allocation is