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Norwegian Waste-to-Energy: Climate change, circular economy and carbon capture and storage

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ABSTRACT

Recently, the European Commission has adopted a Circular Economy package. In addition, climate change is regarded as a major global challenge, and the de-carbonization of the energy sector requires a massive transformation that involves an increase of renewable shares in the energy mix and the incorporation of carbon capture and storage (CCS) processes.

Given all this strong new momentum, what will the Norwegian waste-to-energy (WtE) look like in a decade? What threats and opportunities are foreseen? In an attempt to answer these questions, this study combines process-based life-cycle assessment with analysis of the overall energy and material balances, mathematical optimization and cost assessment in four scenarios: (1) the current situation of the Norwegian WtE sector, (2) the implications of the circular economy, (3) the addition of CCS on the current WtE system and (4) a landfill scenario.

Except for climate change, the CCS scenario performs worse than the WtE scenario. The energy recovering scenarios perform better than the recycling scenario for (1) freshwater eutrophication and human toxicity potentials due to secondary waste streams and (2) ozone depletion potential due to the additional fossil fuel used in the recycling processes. The inclusion of the near-term climate forcers decreases the climate change impacts by 1% to 13% due to a net cooling mainly induced by NO_x.

Circular economy may actually give the WtE system the opportunity to strengthen and expand its role towards new or little developed value chains such as secondary raw materials production and valorization of new waste streams occurring in material recycling.

1. Introduction

The European Union's approach to waste management is based on the waste hierarchy, which sets the following priority order: prevention, reuse, recycling, energy recovery and, as the least preferred option, disposal (European Union Council 1999). The waste hierarchy's practical consequence is to divert waste from landfills to material and energy recovery. As a result, the number of Waste-to-Energy (WtE) plants has increased during the last decade in Europe (IEA Bioenergy, 2013). Recently, the European Commission has revised legislative proposals on waste and adopted a Circular Economy package – an economic system that leaves no waste to be landfilled and that keeps all material flows in the economy loop through reuse, redesign, material recovery or energy recovery. The European Circular Economy Package encompasses two main elements related to municipal solid waste (MSW): (1) Landfill ban/cap on specific waste fractions and (2) Recycling targets (European Commission, 2015). As an EEA/EFTA country member, Norway implements all European directives and thus has a similar waste and WtE regulatory framework, e.g. Waste Hierarchy, landfill ban on biodegradable waste, Landfill Directive, Waste Framework Directive and the upcoming 2030 Energy Strategy and WtE and circular economy-related legislation and strategies.

In Norway, the latest trends in the waste management sector can be summarized as (Becidan et al., 2015): (1) strong increase in the total WtE capacity (from about 1.25 Mt/y in 2010 compared to 1.70 today) – with an average throughput of about 90% of their nominal capacity; (2) landfill ban for organic waste (2009) followed by a reduction in the number of landfills; (3) significant MSW export to Sweden (several hundred thousand t/y); (4) a significant fraction of the energy (heat) produced is not delivered to any customer, especially during the

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summer; (5) the capital city Oslo has newly implemented source sorting of food waste (in addition to paper, plastic, glass and metal) and is working on the implementation of carbon capture and storage (CCS).

Almost all of the MSW (and waste in general) exported from Norway goes to Sweden and almost exclusively to WtE plants (mainly delivering district heat). Detailed statistics are difficult to obtain but it is estimated that 1.6 million tonne of MSW per year were exported over the last five years. The topic is complex, and lower gate fees in Sweden (which has a WtE overcapacity) are pointed to as being the main reason for the MSW exports. On the other hand, Norway has imported around 400′000 t waste per year in the last years. For the WtE plants in particular, mainly refuse-derived fuel (RDF) from the UK has been used as fuel (Norwegian Environment Agency, 2017).

Not all the materials can be recycled, and resource consumption, emissions, losses and contamination − as well as additional new waste streams − occur while material recycling (Bartl 2014). To estimate the overall environmental performance of a system and to avoid potential problem shifting when changing models − in this case from a linear to a circular economy − life-cycle assessment (LCA) is a frequently applied methodology. LCA results give an overview of how various types of environmental impacts accumulate over the different life-cycle phases, providing a basis for identifying environmental bottlenecks of specific technologies and for comparing a set of alternative scenarios with respect to environmental impacts (Finnveden 1999; Hellweg and Canals 2014).

LCA has been used extensively within the last decade to evaluate the environmental performance of waste treatment systems (Arena et al., 2003a; Bergsdal et al., 2005; Cherubini et al., 2008; Cherubini et al., 2009; Rigamonti et al., 2009; Consonni et al., 2011; Giugliano et al., 2011; Ning et al., 2013; Passarini et al., 2014; Lausselet et al., 2016). For WtE systems that combine incineration with energy recovery, or WtE value chains, the life-cycle burdens are sensitive to the energy recovery rate (Riber et al., 2008; Gentil et al., 2010; Fruergaard and Astrup 2011), the conventional fuel displaced for heat or electricity generation (Riber et al., 2008; Passarini et al., 2014; Burnley et al., 2015), the reuse of the bottom ash (Birgisdóttir et al., 2006; Birgisdóttir et al., 2007; Allegrini et al., 2014; Allegrini et al., 2015b), the leaching of key chemical elements from bottom and fly ashes (Doka and Hischier 2005; Astrup et al., 2006; Hauschild et al., 2008; Allegrini et al., 2015a; Yang et al., 2015) and the recovery of the metal or aggregate from the bottom ash (Morf et al., 2013; Burnley et al., 2015). WtE plants have been found to be a robust technology and a competitive alternative to fossil fuel based energy systems (Turconi et al., 2011; Brunner and Rechberger 2015).

LCAs available in the literature provide a variety of insights on WtE systems that combine anaerobic digestion with energy recovery, or biogas value chains. In general, biogas energy systems have lower greenhouse gas (GHG) emissions than fossil energy systems, especially when biogas is used as fuel in transportation (Liu et al., 2013; Niu et al., 2013; Lozanovski et al., 2014; Lyng et al., 2015). The results are sensitive to the management of the digestate; open storage leads to uncontrolled emissions of GHG like CH_4 and nitrous oxide (N_2O) (Blengini et al., 2011; De Meester et al., 2012; Boulamanti et al., 2013) and the use of digestate in agriculture increases the risk for human toxicity, acidification and eutrophication potentials due to the heavy metals (Patterson et al., 2011) and the high nutrient level it contains (Lozanovski et al., 2014). A recent study of Iordan et al. (2016) highlights the sensitivity of biogas systems to the choice of climate metrics and the influence of the near-term climate forcers (NO_x, SO_x, particulate matters, black carbon and organic carbon).

The different plastic recovery routes, as well as their challenges and opportunities, are explored broadly (Arena et al., 2003b; Perugini et al., 2005; Shonfield 2008; Al-Salem et al., 2009; Astrup et al., 2009a; Eriksson and Finnveden, 2009; Hopewell et al., 2009; Kunwar et al., 2016; Lupo et al., 2016). A review on plastic waste management conducted by Lazarevic et al. (2010) shows: (1) the majority of the LCA study to exhibit a preference for recycling rather than for WtE, (2) the conclusions sensitive to the level of contamination and to the replacement of virgin plastic ratio, (3) landfills as the least preferred option, except for climate change. The selection of the appropriate avoided primary production of materials is also a crucial parameter in LCA studies on material recycling systems (Brogaard et al., 2014; Rigamonti et al., 2014; Turner et al., 2015). Recycling material often, but not always, reduces climate change impact (Björklund and Finnveden 2005). As an example, for paper recycling, Merrild et al. (2008) show through an LCA that recycling is clearly better than landfilling, but equal or better than WtE only if the recycling technology is at a high environmental performance level. Merrild et al. (2012) find environmental benefits when recycling the material fractions paper, glass, steel and aluminum instead of incinerating them. On the other hand, they find incineration to be a potentially better option than recycling for cardboard and plastic in some situations.

Waste treatment systems are by definition complex (Laurent et al., 2014a, 2014b); they are embedded with uncertainty (Scipioni et al., 2009; Clavreul et al., 2012), and waste composition varies over time and region, influencing the results (Slagstad and Brattebø 2013; Astrup et al., 2015). In addition to treating waste and producing energy, WtE plants are becoming increasingly recognized as a means to recover materials of high importance for the economy (Morf et al., 2013; Boesch et al., 2014; Brunner and Kral 2014). Also, WtE technologies enable energy production with the advantage of not competing for land occupation as woody biomass does. Thus, in contrast to long rotation woody biomass (Cherubini et al., 2012; Guest et al., 2013a, 2013b), waste can be considered a carbon-neutral fuel.

Climate change is regarded as a major global challenge (IPCC, 2007) that has motivated the international community to implement mitigation strategies aiming at limiting the average increase of global temperature (Riahi et al., 2007; Luderer et al., 2013). A reduction in global emissions of CO_2 can slow down the rate of warming, but a stabilization of global temperature can only occur if CO_2 emissions approach zero (Myhre et al., 2013). Energy industries have contributed to approximately 32% of global CO_2 emissions over the last 20 years (Janssens-Maenhout et al., 2012), and the de-carbonization of the energy sector requires a massive transformation that involves an increase of renewable shares in the energy mix, improvements in power plant efficiency and the incorporation of CCS processes in fossil and biomass-fuelled energy plants (Azar et al., 2013; Myhre et al., 2013; IEA 2015).

Several works analyzing the incorporation of absorptive CO_2 capture technologies in bio-refineries for liquid fuel production via gasification of woody biomass can be found in the literature (Haro et al., 2013, Heyne and Harvey 2014). Other papers study the design of pre- and post-combustion CO_2 capture technologies and the associated environmental impacts for large-scale woody biomass power plants (Corti and Lombardi 2004; Carpentieri et al., 2005; NETL 2012b, 2012a; Schakel et al., 2014). Fewer works present techno-economic and environmental assessment of medium (1–100 MWth) fossil-fuelled CHP plants with a wide range of CO_2 capture processes (IEA 2007; Soukup et al., 2009; Singh et al., 2011). A recent series of articles analyzes the techno-environmental performance of absorptive and adsorptive pre- and post-combustion technologies in small scale woody biomass CHP (Oreggioni et al., 2015; Luberti et al., 2016; Oreggioni et al., 2016)

A wide range of LCA studies have been conducted on energy systems, including WtE, biogas and CCS. Yet, to our knowledge, few studies have focused on scaling up WtE technologies to a national level (e.g Gentil et al. (2009b)). A gap also exists in the knowledge base for process design and LCA studies for WtE plants with CO_2 capture technologies. In this study, we conduct an LCA and a cost assessment on the current situation of the Norwegian WtE sector, the implications of the circular economy and the introduction of CCS. The specific objectives are to assess: (1) the current situation of WtE in Norway, (2) the influence of implementing the circular economy package on the Norwegian WtE sector, (3) the addition of CCS on the current WtE plants, (4)

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