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The economic value of imports of combustible waste in systems with high shares of district heating and variable renewable energy

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ABSTRACT

This study analyses the socio-economic value of trade of combustible waste, taking Denmark as an example for importing countries with large district heating networks and already high shares of variable renewable energy. An integrated systems analysis framework allowed to assess under which circumstances import of wastes leads to less expensive waste management and energy, accounting for increasing ambitions for a circular economy and renewable energy. The dynamics of both systems are captured through two optimization models, which are solved simultaneously. OptiFlow optimizes Danish waste management and transport, and Balmorel, the Northern European energy system.

Results show that waste import to cover the existing Danish incineration overcapacity during wintertime has definite economic value. Conversely, summertime import can have negative value unless a gate fee is received, with the exception of imports of waste with high calorific content (>16.2 GJ/t). In some cases, mothballing of up to 14% of the existing incineration plants is a cost-efficient alternative to decrease the level of over-capacity. In the longer term, results show a socio-economic value of importing waste, being mainly sensitive to assumptions regarding biomass prices and wind power cost, as the technologies would compete with incineration plants.

The present methodology can be applied to other countries where waste-to-energy participates in district heating, and where variable renewable electricity and constraints on biomass resources are becoming important. A pan-regional approach regarding waste management planning to maximize the value from combustible waste might be desired, along with a coherent taxation to avoid competition based on tax differences.

1. Introduction

The European Union (EU) addresses solid waste management from the perspective of being a key area to achieving resource efficiency and ultimately a circular economy (CE) (European Commission 2011, 2017a; 2018). As a result of consistent legislative pressure manifested especially through specific targets, municipal solid waste (MSW) landfilling has seen an average annual decline of 4.2% in the period 1995–2016 (falling from 145 Mt to 59 Mt) and now represents 24% of total MSW management, while recycling and biological treatment have grown to 46% and incineration waste-to-energy (WtE) to 27%. Nevertheless, differences between EU member states (MS) are significant, with five having already recycling rates above 50%, while half of all MS still have landfill rates above 50% (Eurostat, 2018).

The role of WtE in the context of the CE has recently been subject to scrutiny and significant debate. Several authors assert that WtE can be an integral part of sustainable waste management without violating waste hierarchy principles or compromising reuse and recycling (Ng et al., 2014; Brunner and Rechberger, 2015; Cucchiella et al., 2017). Technical and in some cases economical barriers make the recycling of some waste fractions difficult or even impossible, and thus currently can either be landfilled or incinerated (Arena, 2015). Aside from recovery of energy, WtE can ensure that some hazardous materials and chemicals are removed from cycling into the economy (Brunner and Rechberger, 2015). The potential presence of hazardous contaminants, found even in commonly recycled materials (Pivnenko

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et al., 2016, 2017), is of concern and considered at EU level (European Commission, 2017b). Metal recovery from the bottom ash and land conservation are two other arguments for WtE. Japan's Sound Material-Cycle Society Plan, which focuses on the 3R concept (reduce, reuse and recycle), considers power and heat generation from waste as part of the reuse strategies, because of the need to divert from landfilling due to increasing land constrains (Silva et al., 2017). Although it can be contested that energy recovery can be regarded as a form of reuse, the other points above are valid. The European Commission finally concluded on this debate by taking a quite restrictive position stating that "waste-to-energy processes can play a role in the transition to a circular economy provided that the EU waste hierarchy is used as a guiding principle and that choices made do not prevent higher levels of prevention, reuse and recycling" (European Commission, 2017b).

Through WtE, solid waste management can be seen to have a role also in a future more renewable energy system. For example, the EU has a target of 27% renewable energy in 2030, according to the European Renewable Energy Directive (European Parliament, 2009; European Commission, 2016); nevertheless, Denmark has already fulfilled this objective and the government aims for 30% renewable energy by 2020 and at least 50% in 2030, through measures such as expansion of wind and solar power and district heating (DH) (Danish Ministry of Energy, Utilities and Climate, 2018). Waste incineration, currently supplying around 20% of DH and 5% of electricity (Danish Energy Agency, 2016), could act as a backup for intermittent electricity production and source for heating (Madsen et al., 2013).

A decreasing or stable domestic waste generation in combination with increasing recycling on the one side, and requirements to warrant contracts of DH supply and to pay off investments on the other side, have resulted in a number of EU countries to experience incineration overcapacity and to import increasing quantities of combustible waste from other MS. Germany, the Netherlands, Sweden and Denmark are main importers while, so far, the UK and Ireland have been the main exporters (Wilts et al., 2017; CEWEP, 2016; Danish EPA, 2016). Nonetheless, in total less than one percent of generated MSW was traded for incineration in the EU in 2013 (Wilts et al., 2017). At first glance, trade of combustible waste appears to be a simple match of waste diverted from landfill in some countries and spare incineration capacity in others. But actual quantities exported depend on alternative costs levels, including waste-related taxes, thus reflecting local political priorities (Sahlin, 2013; Olofsson et al., 2005; Dubois, 2013). Accordingly, a correlation between export and landfill-tax levels has been observed in England, where export of combustible waste has become cheaper than domestic landfilling when the landfill tax surpassed 50 £/t, and WtE facilities were setting their gate fee at a level to undercut the landfill route after considering processing and shipping costs, ranging from 33 £/t in Netherlands to 61 £/t in Germany (UK Environment Agency, 2015; Brown, 2016). But without high alternative costs and political push at the national level, e.g. through landfill taxes, willingness and ability to export may be low.

The view on longer-term consequences of trading waste for incineration differs. Some bring forward the risk that a transition to a more resource-efficient economy is hindered by lock-in to large and long-term investments as incineration. For example, institutional, technical, cultural and material lock-in to incineration, negatively impacting the development of recycling and biogas production (Corvellec et al., 2013), and the risk of competition between incineration and recycling of plastics in Northern Europe has been reported (European Commission, 2013). Others claim such lock-ins and competition as myths, and stress the need for incinerating non-recyclable waste and the fact that plants can be converted to other fuels if needed (Swedish Waste Management Association, 2016).

The above emphasize the need for assessments of the role of waste-to-energy plants in future European systems. Assessments need to capture both waste management with increasing ambitions for material recycling and a growing international market, and an energy sector with larger integration of variable renewable energy. This calls for decision-support tools that can help in calculating efficient solutions without incurring suboptimal alternatives. Among such tools are optimization models, which can analyse allocation problems as well as arrange and provide meaningful insights from a large amount of data and constraints (Hoogmartens et al., 2016). However, waste-to-energy has mainly been modelled in the context of either waste management or energy systems (Juul et al., 2013). Few models have integrated both sectors (Münster, 2009), and the most common method is to focus on one system and to consider the other as part of the background, performing scenario analysis to assess uncertainty in that surrounding system (Ljunggren Söderman, 2003). Assumptions on the surrounding system might influence results considerably (Eriksson and Bisaillon, 2011). Impacts of waste-to-energy technologies in energy systems might not be marginal, as shown by Münster and Meibom (2010) and Aracil et al. (2018), who assessed the techno-economic impacts of implementing different thermal conversion strategies in regions with low heat demand (Southern Europe), and found the electricity price to have the largest impact on the internal rate of return of the investments, especially for waste incineration plants. One study linking a DH model and a waste management model found that the approach allowed very valuable insights of the consequences of different simultaneous changes in the two systems (Eriksson and Bisaillon, 2011). Therefore, an approach that considers the waste, electricity and district heating systems in an integrated way can be argued as necessary when evaluating the role of waste incineration.

This paper aims to support the discussion around trade of waste for incineration, and thus also the future role of incineration in general. The economic value of importing waste for incineration from a European country to Denmark is evaluated, as an example of a country with extensive district heating and an already large share of variable renewable energy in its power mix, e.g. wind energy generated the equivalent of 43.4% of the national consumption in 2017 (Dansk Energi, 2018). A literature review on incineration found few contributions "genuinely economic in the approach and methodology" (Massarutto, 2015). Therefore, this study also endeavours to provide new insights regarding economic valuation of waste incineration of domestic and imported waste. For this purpose, two programming models are applied in a fully integrated way: OptiFlow for waste management (Pizarro et al., 2014, 2015; Münster et al., 2015) and Balmorel for energy (Ravn, 2001). Investments and operations of Danish waste management are optimized within the framework of current and future energy systems with high geographical and temporal resolutions that capture spatial constraints and temporal variations associated to resource transportation, district heating and variable renewable energy. Dynamics of both waste management and energy sectors can thus be represented (Münster and Meibom, 2010). The impact of several qualities and quantities of imported waste is analysed in a historic perspective, represented by 2014, and a prospective one until 2035.

The paper is organized as follows: after this introduction, Section 2 explains the methodology, i.e. the waste and energy systems optimization models, and Section 3 describes the main data sets. Additional information from Sections 2 and 3 can be found as Supplementary Material. Sections 4 and 5 present and discuss model-based results, respectively, and conclusions are shown in Section 6.