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Estimation of marginal costs at existing waste treatment facilities

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ABSTRACT

This investigation aims at providing an improved basis for assessing economic consequences of alternative Solid Waste Management (SWM) strategies for existing waste facilities. A bottom-up methodology was developed to determine marginal costs in existing facilities due to changes in the SWM system, based on the determination of average costs in such waste facilities as function of key facility and waste compositional parameters. The applicability of the method was demonstrated through a case study including two existing Waste-to-Energy (WtE) facilities, one with co-generation of heat and power (CHP) and another with only power generation (Power), affected by diversion strategies of five waste fractions (fibres, plastic, metals, organics and glass), named "target fractions". The study assumed three possible responses to waste diversion in the WtE facilities: (i) biomass was added to maintain a constant thermal load, (ii) Refused-Derived-Fuel (RDF) was included to maintain a constant thermal load, or (iii) no reaction occurred resulting in a reduced waste throughput without full utilization of the facility capacity. Results demonstrated that marginal costs of diversion from WtE were up to eleven times larger than average costs and dependent on the response in the WtE plant. Marginal cost of diversion were between 39 and 287 € Mg^{-1} target fraction when biomass was added in a CHP (from 34 to 303 € Mg^{-1} target fraction in the only Power case), between −2 and 300 € Mg^{-1} target fraction when RDF was added in a CHP (from −2 to 294 € Mg^{-1} target fraction in the only Power case) and between 40 and 303 € Mg^{-1} target fraction when no reaction happened in a CHP (from 35 to 296 € Mg^{-1} target fraction in the only Power case). Although average costs at WtE facilities were highly influenced by energy selling prices, marginal costs were not (provided a response was initiated at the WtE to keep constant the utilized thermal capacity). Failing to systematically address and include costs in existing waste facilities in decision-making may unintendedly lead to higher overall costs at societal level. To avoid misleading conclusions, economic assessment of alternative SWM solutions should not only consider potential costs associated with alternative treatment but also include marginal costs associated with existing facilities.

1. Introduction

Solid waste management (SWM) facilities are often characterised by large investments requiring relatively long pay-back periods, e.g. 10–15 years for an incineration facility (World Bank, 1999), and by rather long technical lifetimes such as 30–40 years. Although the design of a waste facility is based on the local conditions and costs estimates at the time of design, natural

Abbreviations: %PC, Power Consumption as percentage of LHV; AC, Average Cost; ACAPEX, Amortization of Capital Expenses; AD Cost, Ash Disposal Cost; AFC, Annual fixed costs; AIC, Annual Insurance Cost; ALC, Annual Labour Cost; AMC, Annual Maintenance Cost; AR, Allocation Ratio; AWP, ammonia water price; BA, Bottom Ash; BADC, Bottom Ash Disposal Cost; CAE, Combustion Air Energy; CAPEX, Capital Expenses; CHP, Combined Heat and Power; DK, Denmark; DR Cost, Cost related to the dioxin removal; ERS Cost, Energy Recovery System Cost; ES, Spain; F Cost, Fixed Cost; FA, Fly Ash; FADC, Fly Ash Disposal Cost; FGC Cost, Flue Gas Cleaning Cost; FGC, Flue Gas Cleaning; FGLbe, Flue Gas Losses at the boiler exit; FI, Finland; HR, Heat Revenue; LHV, Lower Heating Value; LSP, Limestone price; m, mass; MC, Marginal Cost; NLHV, Nominal Lower Heating Value; NWA, Nominal Waste Amount; OAT, Once at a time; OL, Other losses; OLbe, Other Losses at the boiler exit; PC Cost, Power Consumption Cost; PP, Power Price; PR, Power Revenue; RDF, Refused-Derived-Fuel; RF Cost, Cost related to the reaction fraction; RF, Reaction fraction; RFP, Reaction Fraction Price; SNCR Cost, Cost related to the SNCR; SNCR, Selective Non-Catalytic reduction; SR, Sensitivity Ratio; STE, Steam Energy; SWM, Solid Waste Management; TEf, Turbine Efficiency; TF, Target fraction; TI, Total Input in weight; UCR, Utilized Capacity Ratio; WC Cost, Water Consumption Cost; WCE, Water Condensation Energy; WCL, Water Condensation Losses; WI, Waste Input in weight; WSS, Wet Scrubbing system; WtE, Waste-to-Energy; WW Cost, Cost related to WW treatment/disposal; WW, Wastewater.

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developments occur during the lifetime of a waste facility (e.g., changes in: regulations, emission limit values, waste management strategies and waste composition and generation). Some of these developments (e.g. trends in waste amounts routed to incineration) may be anticipated in the design-phase and accommodated in the design capacity (and business plan), whereas other changes may be difficult to anticipate (e.g. changes in political priorities regarding waste management, taxes and establishment of new facilities within an area). The latter changes in framework conditions may potentially have considerable effects on the operation of existing facilities.

Despite the fact that major societal decisions about alternative SWM strategies are often supported by economic assessments, the consequences for the existing waste facilities are frequently neglected, e.g. Martinez-Sanchez et al. (2015) and Sonesson et al. (2000) did not include effects on existing incineration facilities when diverting organic waste towards (an)aerobic digestion facilities. Here, it is important to distinguish between costs defined in the design-phase ("design costs", e.g. related to long-term capital investments associated with the design itself) and new costs induced during the operational phase of a facility ("post-design costs", e.g. related to operational adjustments in response to changes in framework conditions).

From a waste management planning perspective, both cost types play an important role. Design costs are needed to: identify economies of scale and scope (Bohm et al., 2010; Callan, 2001; Criner, 1995; Dijkgraaf and Gradus, 2007; ENEA, 2007; Kinnaman, 2006; Tsilemou, 2006), assess the economic viability of new facilities (Coelho and De Brito, 2013; Franchetti, 2009; Kang and Schoenung, 2006), and compare average costs of different SWM systems (Bel and Fageda, 2010; Bel and Mur, 2009; Bel and Warner, 2008; Carlsson Reich, 2005; Consonni et al., 2005; Damgaard et al., 2011; De Feo and Malvano, 2012; De Jaeger et al., 2011; Dijkgraaf and Vollebergh, 2004; Gomes et al., 2008; Jamasb and Nepal, 2010; Kim et al., 2011; Zhang, 2013). On the other hand, post-design costs are required to assess specific consequences of a change in the SWM system when existing facilities are affected. Waste management systems are typically "closed systems" and a change within such system can have consequences in multiple waste facilities. Assuming "free" adaption of existing capacities may underestimate the consequences being assessed. For example, increasing the share of anaerobic digestion of waste previously incinerated may cause considerable changes in operation not only for the anaerobic digestion facility (new "receiving facility") but also for the incineration facility ("diverting facility"). Hence, post-design costs at both the "receiving facility" and the "diverting facility" should be evaluated in complete assessments of alternative SWM systems. Until now, these post-design costs have not been addressed in economic assessments of SWM systems.

For estimation of post-design costs, it is important to distinguish between marginal and average costs (Rasmussen, 2013). Marginal costs represent the additional cost associated with an additional quantity of something (Massarutto, 2015), e.g. changes in the total costs of a facility to treat and extra tonne of waste, while average costs (also called unit cost) result from dividing total costs by the total quantity of input or output, e.g. waste treated at the facility. While marginal costs could be estimated based on statistical regression of empirical data (Bel and Fageda, 2010; Bel and Mur, 2009; Bel and Warner, 2008; De Jaeger et al., 2011; Lombrano, 2009), very few full-scale data are available limiting the applicability of such regression. So far, literature studies have included only changes in waste amount and not waste composition, although changes in waste composition may have dramatic effects on operation of existing waste facilities. A possible solution to overcome this may be a bottom-up approach first correlating average costs to key operational and waste compositional parameters and second estimating marginal costs as the difference between the average costs of two situations (alternative and reference). Such a modelling approach has not previously been attempted for estimation of marginal costs of waste management technologies.

The main aim of this investigation is to develop a methodological approach to assess economic consequences of alternative SWM system for existing waste facilities (i.e. to estimate post-design costs). Failing to systematically address and include these post-design costs in decision-making may unintendedly lead to higher overall costs at societal level. The applicability of the methodological approach is demonstrated with a Waste-to-Energy (WtE) facility as example of "diverting facility" affected by several diversion strategies. The specific objectives are to: (i) define a detailed bottom-up cost model representing post-design costs at WtE facilities, (ii) identify marginal costs related to diversion of five selected waste fractions, (iii) identify sensitive parameters in the cost model and evaluate differences between average and marginal costs, and finally (iv) provide recommendations for applying marginal costs in economic assessment of waste solutions. For simplicity, post-design average and marginal costs are hereafter referred as average and marginal costs, as design costs are beyond the scope of this investigation. While focus is placed on costs at WtE facilities, the assessment principles can be applied to any waste facility/technology.

2. Methodology

2.1. Modelling approach

Fig. 1 illustrates the modelling approach developed and used in this investigation to estimate marginal costs at existing waste facilities caused by a change in the SWM system. The method consisted on the following steps:

(i) Definition of the cost model describing average costs of WtE as a function of key facility and waste parameters. In this step, the individual cost items and functions are defined, using key parameters able to capture the change in the system, based on the available data and process understanding.
(ii) Estimation of average costs related to the reference situation (i.e. situation without the change being assessed) applying the cost model defined in step "(i)" and the waste data representing the reference situation.
(iii) Evaluation of average costs related to the reference situation, the results of the cost model for the reference situation are evaluated by comparing the results with literature data (empirical and full-scale data to the available extent).
(iv) Definition of the marginal change being assessed (e.g. diversion of 1 Mg of plastic from a WtE facility). In this step, the type of response initiated at the facility affected by the change is critical. For example, if plastic waste is diverted away from a WtE facility, the WtE operators may react by finding alternative fuels, e.g. imported RDF (Refused Derived Fuel) or biomass, to compensate for loss of thermal input. Another reaction may be to simply continue operation at a lower thermal load, i.e. lower utilization of the facility.
(v) Estimation of average costs associated with the alternative situation (i.e. situation with the change being assessed) applying the cost model defined in step "(i)" and the waste data representing the alternative situation, i.e. including the variations caused by the change being assessed.
(vi) Estimation of the marginal costs associated with the change being assessed as the difference between the average costs in the reference situation and in the alternative situation (from steps "(ii)" and "(v)").