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Review

Comparison of alternative methods for managing the residual of material recovery facilities using life cycle assessment

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ABSTRACT

Excessive waste generation caused by exponential growth in resource use for the production of consumer goods, electronics and packaging has placed a growing burden on waste management globally. In Australia, waste is currently generated at a rate of 43 million tonne per annum and has a projected growth rate of 4.5% per annum. Diminishing landfill capacity adds to the pressure faced by governments to consider alternative waste technologies put forward by industry. In Australia, residual waste from material recovery facilities is under consideration by energy and waste companies for alternative management by waste-to-energy. This waste is not feasible to be efficiently separated for further processing. In this study, the environmental performance of the material recovery facilities' residual waste based in Sydney, Australia, is assessed using a life cycle assessment that estimates the potential impacts of acidification, climate change, eutrophication and photochemical oxidation. A sensitivity analysis tests different waste fractions of MRF residual waste composition. The study found that landfill had the lowest greenhouse gas emissions regardless of whether credits offset electricity, and of the carbon accounting methods used to measure biogenic carbon dioxide. The results also found landfill to have the lowest acidifying emissions but found the waste-to-energy technologies performed better in minimizing euthrophying and photochemical oxidation emissions. Aggregated by normalization and weightings, landfilling was found to have the lowest single score. The study reported electricity generation potentials through thermal turbine, synthetic gas engine and landfill gas combustion, and found incineration to have highest electricity generation potential, followed by gasification-pyrolysis.

1. Introduction

Globally, average material use has increased from 5.0 t to 10.3 t per capita per annum between 1950 and 2010 due to population growth, industrialisation and an increase in socio-economic power (Schaffartzik et al., 2014). Following this global trend, Australia now generates a total of 2.5 t of waste per capita per annum from municipal, commercial and construction waste based on a six year growth projection at 4.5% from a baseline of 1.9 t in 2011 (Commonwealth of Australia, 2010; Australia Bureau Statistics, 2011). Landfill is the primary method used to manage waste in Australia; however, some Australian state and local governments have shown interest in introducing waste-to-energy technologies predicated on improved efficiency and environmental performance (Coote, 2017; Lazzaro, 2017). In 2017, the Victorian state government announced a $2-million Waste-to-Energy Infrastructure Fund to support the development of waste-to-energy technology (Victorian Goverment, 2017). A proposed waste-to-energy plant in regional Victoria, claiming to avoid 500,000 t of carbon dioxide (CO_2) emissions per year from avoided natural gas, is also being assessed (Lazzaro, 2017). In Western Australia (WA), there are three waste-to-energy plants under construction to manage residual waste from material recovery facilities (MRF) (Douglas, 2014; New Energy, 2014, 2016). One plant argues its reason to not pre-treat MRF residual waste prior to incineration is because the treatment process would be too energy intensive and expensive (Douglas, 2014). The other plants planned to manage waste in low-temperature gasification have not specified any treatment of MRF residual waste in their process descriptions (New Energy, 2014,2016). In New South Wales (NSW), there

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is particular interest concerning the environmental feasibility of the refuse derived fuel (RDF), a residual waste to be managed by waste-to-energy instead of landfill (Energy Australia, 2017). The RDF is material that is not feasible for further material reprocessing that does not have a consistent composition or source (Luger, 2017). It is estimated to be one third biomass, with remaining materials including plastic and other non-recyclables (Luger, 2017). The Mount Piper Power Station, a black-coal fired power plant outside Sydney, is under consideration for separate combustion of RDF waste-to-energy (Luger, 2017). Potentially, a grate or fluidised-bed incinerator would generate an estimated 1.1 MW h of electricity per tonne of RDF (Luger, 2017). Energy Australia claims that the RDF feedstock can be considered as a renewable energy source (Coote, 2017). Indeed, the Renewable Energy (Electricity) Act 2000 does allow biomass-based components of MSW to be considered renewable (Commonwealth of Australia, 2016b). Energy Australia (2017) states that the proposed waste-to-energy facility managing 100,000 t RDF from residual waste per year can avoid 60,000 t of net greenhouse gas (GHG) emissions whilst supporting the NSW Government's best practice waste-to-energy policy (Energy Australia, 2017). The RDF would be sourced from residual waste from material recovery facilities (MRF) in Sydney (Energy Australia, 2017) but literature has not specified if that waste would be subject to pre-treatment or pre-sorting. The three WA waste-to-energy plants have not proposed to treat MRF residual waste feedstock. A final decision on the Mount Piper waste-to-energy plant is expected in 2018 (Energy Australia, 2017).

A general material recovery facility (MRF) is a multi-input, multi-output system used to recover post-consumer waste for reprocessing into new materials. MRFs receive co-mingled municipal solid waste (MSW), then sorts valuable materials including glass, paper, plastics and aluminium into single streams (War on Waste - Episode, 2017, KS Environmental Group, 2015). A typical MRF rejects, on average, 7.8% of material input (e.g., residual waste) (Carre et al., 2013). The MRF's residual waste contains non-recyclable materials and recyclable materials not in a physical form to be extracted through the mechanical separation process (War on Waste - Episode, 2017). Other high value options for MRF residual waste are unlikely, due to the variety of materials and the absence of quality controls to meet end market specifications, therefore the material is not considered feasible for furthering processing.

This paper aims to assess the alternative waste management of the MRF residual waste in Sydney, Australia, using life cycle assessment (LCA). Landfill is assessed as the status quo waste management technology. Incineration and gasification-pyrolysis are assessed as the alternative thermal treatment technologies.

The degradation of biomass waste in landfill produces direct emissions to air of CO_2 and methane (CH_4) (IPCC, 2006), commonly known as landfill gas (LFG). Electricity produced through the combustion of captured LFG can be exported to the electricity grid. Waste material also degrades to leachate, processed in a wastewater treatment plant, through which additional emissions to water and air are formed. The carbon that is lost to leachate generally represents less than 1% of total stock (IPCC, 2006). In LCA, this carbon is inventoried as total organic carbon (TOC), dissolved organic carbon (DOC), biological oxygen demand (BOD) and chemical oxygen demand (COD) (Doka, 2009). Other emissions from leachate include sulfate, hydrogen sulfide, ammonium, nitrate and phosphate (Doka, 2009). Incineration is the combustion of waste materials using a fuel, such as natural gas in a furnace to maintain temperatures of 800–1600 °C (Doka, 2003). The heat recovered from the furnace can drive a steam turbine to produce electricity. Incineration emissions include CO_2, carbon monoxide, water, sulfur oxides, nitrogen oxides, ammonia, hydrocarbons and organic acids (Gavrilescu, 2008). In addition, incineration produces slag, flue gas and wastewater (Doka, 2003). Ancillary materials products that contribute to indirect emissions include sodium hydroxide, calcium carbonate or lime, hydrochloric acid, iron chloride and ammonia (Doka, 2003). Gasification-pyrolysis has been reported to produce fewer air emissions than incineration (Khoo, 2009). The process uses two main thermal chambers; the first chamber is a reductive zone that compresses waste at 600 °C; and the second chamber is a high temperature gasifier, using oxygen and natural gas to reach temperatures of approximately 2000 °C (Hellweg, 2000). The melted inorganic residue from the gasifier forms a solid waste stream equivalent to slag in the incineration process. The synthetic gas (syngas) released from the gasifier chamber has a typical composition of hydrogen (25–42%), carbon monoxide (CO) (25 – 4%), CO_2 (10–25%) and water (Hesseling, 2002). It can be combusted in the gas engine to generate electricity. Ancillary materials products including sodium hydroxide, cement, iron chloride and general inorganic and organic chemicals contribute to process emissions on a system level, and include CO_2, CO, formaldehyde, non-methane volatile organic compounds and polychlorinated dibenzodioxins (Hellweg, 2000). Emissions to water include adsorbable organic halides (AOX) and COD compounds (Hellweg, 2000).

There are several waste management LCA studies, however, there is little analytical attention paid to the MRF residual waste. In fact, many LCAs of waste management including those in Victoria, Australia (Grant et al. (2001),(2003); and Carre et al. (2013)) focus on assessing the potential benefits of recycling over other waste management alternatives. An LCA study of recycling and landfill in NSW, Australia, assessed sensitivities of GHG emissions in landfill (Department of Environment Climate Change and Water NSW, 2010a). The study found the GHG impact of individual biomass materials resulted in a net decrease of 55% for paper, 41% for timber and 45% for garden waste if carbon sequestration was included. Finnveden et al. (2005) and Moberg et al. (2005) published a two-part LCA study which assessed the performance of waste packaging material (newsprint and PET) in landfill, incineration and recycling in Sweden. The carbon accounting methodology in these studies is similar to ours where carbon sequestration in landfill is not included and biogenic carbon emissions impacts are included. The study that has the most likeness in scope and concept with our study is by Assamoi and Lawryshyn (2012), who undertook an LCA of the residual waste of diverted MSW, in Toronto, Canada. The Assamoi and Lawryshyn (2012) study based the quantity of the MRF residual waste on projections from 2011 to 2040 to form the functional unit. The two scenarios developed were landfilling the entire functional unit, and incinerating 1000 t of waste per day whilst landfilling the remainder. The study's impact assessment uses characterisation factors for potential impacts of acidification, global warming and nutrient enrichment (Assamoi and Lawryshyn, 2012). The findings of Assamoi and Lawryshyn (2012) study showed that incineration outperformed landfill in each environmental impact category if credits for electricity produced from fossil fuels (coal, oil and natural gas) were included in the system boundary. Importantly, if these credits were excluded, then landfill outperformed incineration in each environmental impact category (Assamoi and Lawryshyn, 2012).

For the case of gasification-pyrolysis, there is also limited available LCA research. Zaman (2010) researched the treatment of MSW in Sweden through landfill, incineration and gasification-pyrolysis, similar to the scope of our study. However, the MSW is not broken down by material, nor are the emissions reported by sub-processes in the system, making origins of burdens untraceable. The study also included the energy inputs to operate the technologies and the energy generated on a system level, however, the energy in relation to MSW-heating values are not reported. The major findings were that for acidification and eutrophication, landfill had the lowest impact, while for global warming potential (equivalent to CCP in this study) gasification pyrolysis had lowest impact, and incineration has lowest photochemical oxidation impacts (Zaman, 2010). Another study by Zaman in 2013 of the treatment of MSW in incineration and gasification-pyrolysis found gasification-pyrolysis performed better in relation to acidification by approximately 58%, GWP by approximately 2%, eutrophication by approximately 35% and photochemical oxidation by approximately