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Refuse recovered biomass fuel from municipal solid waste. A life cycle assessment

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HIGHLIGHTS

- An innovative waste treatment process is proposed and evaluated by means of LCA.
- The MARSS process produces a biomass fuel with a marketable quality for CHP plants.
- The recovery of energy and metals generates significant environmental benefits.
- Valuable resources can be recovered from waste and be feedback to the urban systems.

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ABSTRACT

Waste disposal is a controversial issue in many European countries: concerns about potential health effects and land value loss as well as the fulfillment of the European Landfill Directive and Waste Framework Directive have significantly changed the way waste should be managed. An appropriate management of municipal solid waste (MSW) may allow a significant enhancement of efficiency in resources use, by recovering both energy and materials from waste, otherwise landfilled, thus replacing fossil fuels and virgin materials with renewable sources. Separation and recovery of the biodegradable fraction of municipal solid waste is encouraged as a mean to produce bioenergy. Therefore, if not source segregated, innovative waste refining technologies may provide potential solutions for separation of organic fraction and improved energy and materials recovery.

This paper presents a comprehensive system study of a recently developed technology aimed to improve the MSW management in order to decrease the demand for new landfill space and, at the same time, contribute to the urban energy needs. As part of a wider Life Plus Project entitled MARSS (Material Advanced Recovery Sustainable Systems), funded by European Community in 2012, the environmental assessment of an innovative and enhanced mechanical and biological treatment (MBT) demo plant installed in Mertesdorf (Germany) was performed by means of the SimaPro 8.0.5 LCA software, utilizing ReCiPe (H) Midpoint method for the impact assessment. The plant under study is designed to concentrate the biodegradable part of MSW in the <40 mm fraction, through a series of refining and recovery steps, to remove contaminants and obtain a suitable biomass fuel with a final marketable quality fulfilling the requirements for biomass power plants to generate urban decentralized production of heat and power (CHP). This study aims at understanding if and to what extent the MBT-MARSS plant is environmentally sound, by investigating environmental costs and benefits of replacing MSW landfilling and waste-to-energy disposal by means of boosted separation of biomass for energy generation in CHPs and other recoverable fractions (metals, plastic). Steps and/or components that can be further improved are also assessed. Sensitivity of impacts to assumptions regarding the source of replaced electricity was also tested. Results not only emphasize the novelty of a promising new technology, but also the extent of benefits that can be achieved depending on the actual power generation technique that is replaced by means of the energy recovered in the process. The quantitative evaluation of the MARSS technology shows that appropriate design and management of the MBT plant lead to substantial reduction of environmental impacts as well as material and energy resource savings, thus putting forward a technical solution suitable for those cities/countries where other solutions are still lacking or inappropriate or unfeasible.

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1. Introduction

Sustainable management of waste is a topic of increasing importance worldwide. The EU Waste Framework Directive (WFD) demands the reduction and treatment of municipal solid waste (MSW) prior to landfill disposal (Art 4.1/4.2, WFD) [1]. In particular, the organic fraction of municipal solid waste (OFMSW) may be a source of trouble in management. Due to its putrescible nature, it contaminates recyclable material in combined waste collection systems and releases methane to the atmosphere when deposited in landfill sites [2]. Different strategies have been pursued over time for reducing the environmental impact of this fraction. The main one has been the decomposition of the organic material before its reuse or final disposal.

Hence, the EU Landfill Directive (LFD) states that the amount of biodegradable substances directed to landfill needs to be reduced by 65% compared to the amount of biomass landfilled in 1995 (Art 5.2c, LFD) [3].

In order to comply with political targets, many EU countries have introduced landfill levies and some countries, including Germany, have placed an outright ban on dumping untreated OFMSW.

Organic waste source-segregation at the household may contribute to the goal of the LFD [4]; yet, recent studies have highlighted that such a strategy may end up being inefficient (mass- and energy-wise) as a consequence of the losses occurring at the household and during pre-treatment processes [5]. Consequently, the effort of European member States to comply with the EU waste legislation and to properly pretreat OFMSW has translated in the proliferation of mechanical and biological treatment (MBT) plants all over Europe in the last decades [6–10]. The currently installed capacity of 33 million ton/yr, which is provided by about 330 MBT plants in Europe, is expected to increase up to 46 million ton/yr and 440 plants within the next decade [11]. MBT, which is characterized by the implementation of material specific treatment, can be combined with energy recovery and/or material recycling and represents a valid and often preferential alternative to conventional thermal waste-to-energy (WtE) plants, as WtE plants face opposition by local populations in many EU member states [12–14].

The original purpose of MBT plants – as they were under operation in the 1990s – was to divert from landfill disposal biodegradable substances, to which the main polluting emissions (landfill gas, leachate) are associated. As a consequence, the long term pollution potential of landfills can be decreased, in the overall purpose of protecting environment and human health [15,16]. MBT plants have in common some basic principles: they generally integrate mechanical processing with a bioconversion step [17]. The waste is mechanically pre-treated in order to prepare it for subsequent biological processing. Besides homogenization and shredding, this may include separation of metal concentrates (ferrous and non-ferrous) for material recycling or a high calorific fraction for energy recovery, given there is a related demand. The biological treatment consists of either (1) aerobic degradation (composting) to reduce the share of biodegradable substances and produce a stabilized material for environmentally sound landfilling or (2) biological drying aiming to produce a refuse derived fuel (RDF) for energy recovery and provide an option for advanced material recovery (metals and plastics) from the dried waste output by mechanical post-treatment, or finally (3) a combination of anaerobic digestion (fermentation) for biogas production and aerobic stabilization prior to the final disposal of the residual fraction [18].

Many studies have been carried out to assess the environmental performance of MBT technologies, especially *versus* WtE, and to demonstrate their environmental, resource and socio-economic relevance [6–10,19–22]. In spite of the recovery of additional resources and the range of possible energy recovery applications [20], MBT technologies increase system's complexity by adding inherent system losses, requiring additional energy consumption and representing a potential source of direct emissions. In particular, Di Maria et al. [23] highlight that the changing composition of waste and the increased amount of OFMS causes two main negative effects in MBT plants based on aerobic process: (i) increase in energy consumption as a consequence of the increased need for process air; (ii) lower stabilization level of the organic material. For these reasons, an upgrading of the existing MBT plants is still called for and a further reduction and stabilization of the organic content of the OFMS along with a lower energy demand need to be pursued [23]. Upgrading the MBT technology to enhance the production of a solid refined fuel can be an effective solution [24,25].

The overall goal of this paper is twofold: (1) presenting the technical features of the MARSS module, designed within the framework of the EU Life Plus project MARSS (Material Advanced Recovery Sustainable Systems) (www.marss.rwth-aaachen.de) and currently operating in Mertesdorf (Germany) at demonstration plant scale alongside an already existing MBT plant, and (2) providing decision-makers with recommendations for sustainable waste management policies, based on accurate evaluation of costs and benefits of the different options. The MARSS technology, thoroughly described in the next section, allows to concentrate the biogenic part in the <40 mm fraction of the dried MSW, to remove contaminants and produce an environmental-friendly biomass fuel (refuse recovered biomass fuel – RRBF) which shows a final marketable quality suitable for biomass power plants for the urban decentralized combined production of heat and power (CHP) applying a fluidized bed furnace. The rationale behind the MARSS innovation is therefore dual: firstly, experience shows the practical impossibility to collect both pure organic material, not contaminated by the presence of inorganic waste fractions, and valuable other fractions (metals, plastics, glass), not contaminated by organic materials, in spite of large effort to provide information and support to population. This makes treatment very difficult and expensive, if not impossible. Secondly, pure organic fractions have a non-negligible content of energy that can be recovered in biomass based plants. Additional recovery of residual ferrous and non-ferrous metals also provides an indirect energy saving and environmental advantage, that is generally lost in conventional treatment plants. Moreover, the upstream waste collection can be hugely simplified, no longer requiring full separation of plastics, inorganic and organic fractions, thus offering an operational advantage to a large number of urban systems where separate waste collection is not easy due to architectural and aesthetic barriers, population ageing, technological inadequacy of the collection system, sometimes unaffordable economic costs as well as possible misinterpretations of citizens in complex separation systems. This is the case of a large number of European and worldwide cities and translates into environmental, health and normative conflicts as well as non-negligible economic loads due to resource losses and recurring emergency situations. The innovative MARSS module allows a technological treatment in support of the deficiencies of inaccurate human intervention, which is most often an obstacle to full recovery of energy and materials. Moreover, the MARSS module is proposed as an integration and upgrade to the large number of existing MBT plants, that are presently unable to boost the separation and the refining of the output products in a way that makes their recovery feasible, so that the final destination of a large fraction of the treated waste remains the landfill. Upgrading the MBT plants would translate into a huge improvement of the total waste management capacity in urban systems as well as of bioenergy production, as the biogenic origin of a fraction of carbon

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