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Sustainability assessment of industrial waste treatment processes: The case of automotive shredder residue

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ABSTRACT

To date numerous environmental, economic and societal indicators have been applied to evaluate and compare the sustainability of products and processes. This study presents a set of ad hoc sustainability indicators suitable for assessing and comparing processes for the treatment of industrial waste streams and for allowing to address efficiently all aspects of sustainability. This set consists of the following indicators: energy intensity, material intensity, water consumption, land use, global warming, human toxicity and treatment cost. The application of these indicators to industrial waste treatment processes is discussed in depth. A distinction is made between direct contributions to sustainability, occurring at the process level itself, and indirect contributions related to the production of auxiliaries and the recovery of end products. The proposed sustainability assessment method is applied to treatment processes for automotive shredder residue (ASR), a complex and heterogeneous waste stream with hazardous characteristics. Although different strategies for recycling and valorization of ASR were developed, with some of them already commercialized, large quantities of ASR are still commonly landfilled. This study concludes that for ASR the most sustainable alternative to the present landfill practice, both in short and long term perspective, consists of recycling combined with energetic valorization of the residual fraction.

1. Introduction

Analysis of industrial waste treatment processes should enable to address all sustainability aspects that are of importance to the respective stakeholders (European Commission Environment, 2011). Often, several treatment options and/or strategies are technically feasible for one specific waste stream. In that case, besides technical considerations, an in depth analysis should be conducted to achieve the optimal selection (Stehlik, 2009). Numerous sets of indicators have been suggested from a life cycle assessment (LCA) perspective and are commonly applied to evaluate and compare products and industrial processes (Azapagic and Perdan, 2000). Studies concerning the impact of (industrial) waste treatment processes are usually limited to an environmental impact assessment (Astrup et al., 2009; Boughton and Horvath, 2006; Ciacci et al., 2010; Mendes et al., 2004; Tarantini et al., 2007; Vos et al., 2007) and do not address sustainability as a whole. Conceptual variations in the definition of sustainability often hamper the proper implementation of this concept (Sikdar, 2012). While it is impossible to define sustainability in an absolute sense, relative gain or loss of sustainability (over time or between alternatives) can be determined through the practical use of sustainability indicators (Azapagic and Perdan, 2000; Martins et al., 2007; Schwarz et al., 2002; Sikdar, 2003). The development and/or selection of a sufficient and relevant set of sustainability indicators can enhance the implementation of this concept in the assessment of industrial waste treatment processes.

Within the context of sustainability evaluation, most commonly encountered methods are those that address eco-efficiency issues, as for instance proposed by the World Bussiness Council for Sustainable Development (Verfaillie and Bidwell, 2000), the Canadian National Round Table on the Environment and the Economy (NTREE, 2001) and BASF (Salling et al., 2002). A number of papers (Azapagic and Perdan, 2000; Martins et al., 2007; Schwarz et al., 2002; Sikdar, 2003, 2009, 2012) propose the use of three-dimensional (3D) sustainability indicators, if necessary complemented with two- or one-dimensional (2D or 1D) sustainability indicators. The method for sustainability evaluation,

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Table 1
Reuse and recycling/recovery targets, set by EU Directive 2000/53/EC, expressed in % of an ELV's mass.

Target	Current (%)	By 2015 (5)
Reuse and recycling	80	85
Reuse and recovery	85	95

proposed by Sikdar (2003, 2009,2012), aims at using a limited set of 3D, all or not complemented with 2D, sustainability indicators that are easily quantifiable and can be deduced from readily available data. This evaluation method allows to obtain information on 3 dimensions of sustainability without necessitating specialized, 1D, indicators on each dimensions for which data are often not available. Applying this methodology, the present paper proposes a set of sustainability indicators, to assess, evaluate and compare the sustainability of industrial waste treatment processes. This set consists of the following indicators: energy intensity, material intensity, water consumption, land use, global warming, human toxicity and treatment cost. These indicators are specifically selected to cover the most important problems that can be encountered during industrial waste treatment (e.g. loss of resources and energy, consumption of water, land use, etc.) and to quantify these problems in terms of sustainability. This way, it is possible to determine which of the proposed or applied treatment strategies can be considered as 'most sustainable' for a certain industrial waste stream.

Moreover, the application of these indicators to industrial waste treatment processes is discussed in depth, making a clear distinction between direct and indirect contributions to sustainability. Direct contributions occur at the process level itself, i.e. energetic and non-energetic resource consumption, land use, water consumption and emissions to air and water. Indirect contributions occur upstream or downstream of the process and are mainly related to the production of auxiliaries, and the recovery of end products. Auxiliaries have caused a certain impact on each of the indicators during their production; recovery of end products can avoid a certain impact as they replace newly processed products. The inventories of these indirect processes and their corresponding sustainability impacts, have been summarized in so-called *impact factors*. These impact factors are defined as the impact of an indirect contribution (e.g. NH_3, NaOH, cement, electricity, plastics, metals, etc.) on a certain sustainability indicator, expressed per unit of energy, per unit of mass or per unit of mass times unit of distance. For any given indirect contribution, an impact factor for each sustainability indicator can be calculated. Making a distinction between direct and indirect contributions, limits the input and output inventory to the level of the process itself, thus facilitating the comprehension of the results and the identification of bottlenecks/strengths of the process.

The proposed sustainability assessment method is applied to the most commonly proposed and commercially applied treatment processes for automotive shredder residue (ASR). ASR can be defined as the 15–25% of an end-of-life vehicle (ELV) mass, remaining after de-pollution, dismantling, shredding of the ELV, and subsequent removal of ferrous and non-ferrous metals (Simic and Dimitrijevic, 2012; Vermeulen et al., 2011). As it is a complex and heterogeneous waste stream, large quantities of ASR are still commonly landfilled in Europe and throughout the world. This fraction is believed to further increase in the future as the amounts of plastics used in vehicles are increasing at the expense of metals and efficient separation of plastics from ASR is thus for not common practice (Passarini et al., 2012). To limit this otherwise growing waste stream, Europe has imposed very stringent targets regarding reuse, recovery and recycling of ELVs in the EU Directive 2000/53/EC (Council of the European Union, 2000). Present and future targets in terms of ELV mass have been given in Table 1.

Using the most recent Eurostat data (Eurostat, 2012), it can be concluded that substantial efforts still need to be done in the EU-15 to reach the ELV reuse and recycling/recovery-rate (Council of the European Union, 2000). In 2009, the average ELV reuse and recycling-rate in the EU-15 amounted to 81.9% and the average ELV reuse and recovery-rate to 84.8%. A further increase of these rates by 2015 can be accomplished by focusing on two routes: increased recycling and/or increased recovery of ASR. Assuming that about 10% of an ELV is removed in view of reuse during de-pollution and dismantling, and on average 70% of the present metals (ferrous and non-ferrous) can be separated from the shredded fraction in view of recycling, the residual ASR fraction will represent 20% of the original ELV mass. This way the ELV targets of 2015 can be re-calculated in terms of ASR fractions:

- Recycling of ASR ≥ 25% (5% of an ELV mass).
- Recovery of ASR ≤ 75% (15% of an ELV mass).
- Landfill of ASR ≤ 25% (5% of an ELV mass).

Alternative treatment options to landfill of ASR, include: recovery of different materials by use of post shredder technologies (PSTs) in view of recycling and incineration of ASR with energy recovery (waste-to-energy) and thermo-chemical treatment of ASR (pyrolysis, gasification) (Boughton and Horvath, 2006; Ciacci et al., 2010; Srogi, 2008). A combination of different methods will be inevitable for a complete treatment of ASR that meets the European targets.

To date, only very few papers have addressed the evaluation of ASR treatment processes (Boughton and Horvath, 2006; Ciacci et al., 2010; Duval and Maclean, 2007; Passarini et al., 2012) and depending on specific assumptions, e.g. the applied indicators, system boundaries, etc., their conclusions differ (Vermeulen et al., 2011). Agreement exists on the fact that landfill should be seen as the least preferred option. Moreover, these studies are limited to an environmental impact assessment (Boughton and Horvath, 2006; Ciacci et al., 2010; Passarini et al., 2012) or an economical assessment (Duval and Maclean, 2007), but none of them address sustainability as a whole, which is the goal of the present study.

2. Sustainability indicators

After intensive literature screening (Azapagic and Perdan, 2000; Martins et al., 2007; Goedkoop et al., 2009; Guinée et al., 2002; Schwarz et al., 2002; Sikdar, 2003, 2009, 2012) and elaborate discussion with actors in the field, the following set of sustainability indicators is proposed:

- *Energy intensity*: the net amount of energy consumed or recovered due to the processing of the functional unit of 1 metric tonne (t) of industrial waste. It is expressed in GJ/t of industrial waste and is a measure for the energy demand of a process.
- *Material intensity*: the net amount of non-energetic or mineral resources consumed or recovered due to the processing of the functional unit of 1 t of industrial waste. It is expressed in kg Fe-eq./t of industrial waste and is a measure for the mineral resource demand of a process.
- *Water consumption*: the net amount of water consumed or recovered due to the processing of the functional unit of 1 t of industrial waste. It is expressed in m^3/t of industrial waste and is a measure for the water demand of a process.
- *Land use*: the land area occupied due to the processing of the functional unit of 1 t of industrial waste. It is expressed in m^2 y/t industrial waste and reflects the damage to ecosystems due to the effects of occupying land.