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End-of-Life in the railway sector: Analysis of recyclability and recoverability for different vehicle case studies

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ABSTRACT

The railway system represents one of the most resource-efficient answer to our ever-growing demand for transport service and the development trends for the following years forecast a substantial increase in this sector. Considering the European Union, rolling stock realizes a significant share of both goods and passengers carriage while it is responsible for a derisory quota of environmental impact and energy consumption involved by transportation. Contrary to the low environmental impact, the amount of End-of-Life (EoL) waste generated by rolling stocks in relation to the number of vehicles is notable, much greater than in the case of road vehicles. As railway vehicles are constituted by many heterogeneous components, the EoL rolling stock is a precious source of materials, whose recycling brings measurable economic benefits and needs to be appropriately debated. The paper presents calculation of recoverability/recyclability rate for different typologies of vehicles representative of railway transport; calculation is performed on the basis of primary data and according to the recyclability and recoverability calculation method issued by UNIFE in the context of Product Category Rules (PCR). The typologies of railway vehicles taken into account are electric metro, diesel commuter train and high-speed electric train. The analysis envisages also to replicate the calculation in case innovative materials and manufacturing technologies are adopted in the construction of car-body structure. Results show that recyclability/recoverability rates are abundantly over the quota of 90% for each one of the three trains, these latter being made in major part of metals that benefit from very efficient recovery processes. The adoption of innovative materials and manufacturing technologies for car-body structure involves a scarce reduction of recyclability and recoverability rates (about 2% and 0.2% respectively) due to the introduction of components and materials characterized by critical dismantlability and low efficiency recovery processes; recoverability results less affected by lightweighting because post-shredding thermal recovery treatments are roughly independent with respect to dismantlability. A sensitivity analysis based on different dismantling scenarios reveals that the effectiveness of dismantling has a moderate influence on recyclability/recoverability rate (the variation does not exceed 3%). The low variability of recyclability/recoverability rate can be explained by the following reasons: predominance of metals in trains material composition, efficiency of metals separation processes close to 100%, post-shredding recycling processes of metals characterized by recovery factors equal to the ones of post-dismantling recycling processes.

1. Introduction

Our global society is strongly dependent on transportation with development trends indicating a substantial growth in this sector over the coming decades (Hawkins et al., 2012). Currently the transportation industry is the second largest contributor to anthropogenic GreenHouse Gas (GHG) emissions within the European Union and around 20% of these emissions are generated by road transportation (Witik et al., 2011; Solomon et al., 2007). More specifically light-duty vehicles ownership could increase from roughly 700 million to 2 billion over the period 2000–2050 (World Business Council for Sustainable Development, 2004), forecasting a dramatic increase in fuel demand with inevitable implications on energy security, climate change and urban air quality (Hawkins et al., 2012).

To date, sustainability analyses and eco-design solutions have been applied in depth to all Life-Cycle (LC) stages of automotive vehicles and components (Bein et al., 2016; Berzi et al., 2013, 2016a,b; Cappelli et al., 2007; Dattilo et al., 2016; Delogu et al., 2015, 2016a,b; Mayyas et al., 2012; Zanchi et al., 2016a,b). In this context, many Life Cycle Assessments (LCAs) (Chanaron, 2007;

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Finnveden et al., 2009; ISO 14040, 2006; ISO 14044, 2006) of both conventional (Finkbeiner et al., 2006; Schmidt et al., 2004; Spielmann and Althaus, 2006) and innovative (Alves et al., 2010; Du et al., 2010; Duflou et al., 2009; Luz et al., 2010; Mayyas et al., 2011; Vinodh and Jayakrishna, 2011; Zah et al., 2006; Zanchi et al., 2016) alternatives for personal transportation have been performed. On the other hand, less interest has been paid to transportation by railway. Considering the European Union (EU-28), rail transport contributes for 11% to goods carriage and 8% to passengers one (European Commission, 2015); in absolute terms the total number of passenger vehicles is slightly lower than 100.000 while it exceeds 400.000 for goods wagons. Despite the notable significance of railway in the global pictures of transportation, rolling stock (both passengers and freight) is responsible for merely 0.6% of Green-House Gas emissions (GHG) and 2% of energy consumption in transport (Merkisz-Guranowska et al., 2014; Stodolsky et al., 1998; Rozycki et al., 2003; Chester et al., 2009; Chester and Horvath, 2010). Contrary to the low environmental impact of railway transport with respect to other transport modes, the amount of End-of-Life (EoL) waste generated by rolling stocks in relation to the number of vehicles is notable; to give an example of this, it is much greater than in the case of road vehicles. This is confirmed by Merkisz-Guranowska et al. (2014) which states that the disposal of a passenger railcar in terms of weight of the obtained waste corresponds to the same of 36–42 passenger vehicles. As railway vehicles are built from many components which include ferrous and non-ferrous metals, elastomers, polymers, glass, fluids, modified organic natural materials, compounds, electronics and electrics, the EoL rolling stock is a precious source of materials. The possibility to recover the highest amount of these materials presents two beneficial effects with respect to the environmental aspects: on one hand it involves the reduction of the demand for primary raw materials, on the other hand it reduces the environmental perils of improper management such as contamination of ground and water with hazardous substances used for their production. Materials recover leads also notable economic benefits: reduction of costs involved by raw materials extraction, production, decrease of capital consumption/energy production and avoidance of expensive waste landfilling.

Considering the increasing attention on environmental issues of railway vehicles manufacturers (whose European association – UNIFE – proposed an assessment framework to be used on voluntary basis), transport operators and potential customers, the present study deals with the topic of EoL treatment of a panel of railway vehicles. The paper is organized as follows. Section 2 reports an overview related to EoL of railway vehicles in terms of contextualization of the problem (i.e. numbers of circulating vehicles and estimation of EoL numbers), treatment practices and guidelines, literature in LCA and EPD perspective. Section 3 deals with the assessment of recoverability and recyclability rate of three vehicles representative of railway transport according to the calculation method developed by European Rail Industry (UNIFE) in the context of Product category Rules (PCR). In Section 4 outcomes and results are reported and discussed; recyclability/recoverability rates are analyzed, the influence of lightweighting on recyclability/recoverability is treated and a sensitivity analysis for different dismantling scenarios is performed. Finally Section 5 reports conclusions.

2. Overview on railway vehicles End-of-Life

2.1. Estimation of circulating vehicles and expected EoL numbers

The estimation of the amount of waste materials and scraps related to railway sector is affected by a number of uncertainties due to variability of typology, lack of precise statistics about vehicles going out-of-service and their mass. However, a rough estimation on the basis of available data and on a 30-year lifespan hypothesis is exposed in Table 1. Such estimation demonstrates that the total mass of railway vehicles to be scrapped is about 60,0000 t/year. As comparison, such value is about 10% the mass of ELVs such as passenger cars treated in Europe according to Eurostat data (Eurostat, 2016), which is considered a critical waste flow.

Considering literature, rare correspondences can be found for such estimation; most frequently, railway vehicles production and recycling activities are studied in relation to metal consumption (this class of material is by far the most used in rolling stock) and data regarding material flows (especially metals) are divided by macro-sectors (Bonnin et al., 2013; Ciacci et al., 2013; Hatayama et al., 2009; Wang et al., 2015). Literature provides several studies which treat with use, consumption and recycling of metals. Hatayama et al., 2010 analyzes the steel stock and flow for 42 countries using dynamic analysis. The work shows that steel world stock in 2005 mainly consists of construction (60%) and vehicles (10%). The forecast reveals that in the next three decades Asia will dominate with 65% of world stock while total consumption will increase due to a notable growth in vehicles demand. Wang et al., 2015 is an additional work on ferrous metal flow and consumption and it deals with the Asian context. Hatayama et al., 2012 discusses the potential of aluminum recycling between now and 2050, focusing on introduction of next-generation vehicles and scrap sorting; recycling potential, aluminum demand and discard in Europe, the United States, Japan, and China are evaluated by Material Flow Analysis (MFA). The MFA indicates an increase in aluminum stock and demand in the next future due to developing China, while aluminum usage in developed countries seems mature for traditional products. With regard to potential of recycling, the authors estimate that, if applied to end-of-life vehicles, scrap sorting can lead to a 15–25% reduction in primary aluminum consumption and a lowering in generation of unrecyclable scrap. At the same time the paper stresses the importance of material collection from all end-of-life products in order to enhance the effectiveness of scrap sorting. Other studies treating with aluminum are Hatayama et al., 2007 and Melo, 1999. Hatayama et al., 2007 performs a dynamic substance flow analysis of aluminum and its alloying elements in Japan; results show that the amount of aluminum recovered in Japan would be about 1800 kt in 2050, which is 2.12 times that recovered in 1990. Melo, 1999, is one of the few examples of disaggregated data available in literature; it describes train as responsible for 4% aluminum consumption in Germany, road vehicles being 75%. Railway vehicles, however, have been also recognized as a non-negligible source for Copper materials (Ruhrberg, 2006). In this regard, Bonnin et al., 2013 performs a quantitative description of copper life cycle in France in the years 2000–2009 through an approach based on substance flow analysis and waste stream characterization. Results show that currently most copper scrap comes from WEEE while the quantity of copper in end-of-life vehicles is expected to increase exponentially, as there is twice as much copper in electric cars than in classical cars. The authors arrive to the conclusion that the improvement of copper management can be performed mainly by improving waste management.

In the light of context previously described, the municipalized companies all around the world increasingly require that rolling stock manufacturers develop policies and methods for vehicles EoL management; the selection of materials and their recoverability are two key factors in order to implement such a typology of policies. Therefore, the low environmental footprint represents a necessary requirement in order to be competitive in the market and green policies are becoming a proper element of market strategy. In this regard, manufacturers are taking environmental

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