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SOLID WASTE RECYCLING FOR REMANUFACTURING AND BIOREMEDIATION

BY

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Abstract. Economic growth and increased urban agglomerations lead to rapid increase in volume and types of waste. Ideal situation according to the cradle-to-cradle principle is a world without waste, but this it is not yet achievable. The manners in which the growing amount of solid waste are managed influence the human health and the environment and could contribute significantly to resources conservations. In recent years the attention was focused on the fact that solid waste should be managed according to the hierarchy of waste which comprises the most and less favorable options for waste management. Methods like recycling, reuse, remanufacturing, bioremediation were applied to diminish the amount of waste, pollution of the environment, as well as to reduce the amounts of virgin raw materials used for different product manufacturing so as to obtain economic and social benefits. Recycling materials can offer valuable products for industry in the process of remanufacturing. Also, some of these materials possess a high potential to be applied in environmental bioremediation, in particular as sorbents. This paper discusses the situation of solid waste in Europe and the real chances to reduce the waste quantities by remanufacturing and/or valorize them as sustainable tools in bioremediation.

Key words: bioremediation, recycling, remanufacturing, waste management.

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1. Introduction

Waste management and energy are becoming key issues, once the world economy grows, while resources are increasingly depleted (EC, 2007; Ghinea *et al*., 2012). Recycling is one of the processes which play an essential role in the movement towards sustainable production and consumption by reducing waste going to disposal, improving energy efficiency and reducing consumption of natural resources (Chen, 2005; EC, 2007; Ghinea *et al*., 2012; Kuo, 2006; Smith *et al*., 2001; Spilka *et al*., 2008).

Recycling can reduce the environmental impacts caused by products and production, with the disadvantages that the recycled materials could be affected by reprocessing and reuse and ultimately should be removed from the circuit (Kuo, 2006). Recycling is often preferred to incineration. On the other hand, the disposal of non-renewable materials can be sustainable only whether it is efficient in terms of costs (Bjorklund & Finnveden, 2005; Otegbeye *et al*., 2009).

The key to successful development of waste recycling option is the design of waste management systems adapted to local needs and traditions, rather than the selection and transfer of a single process or technology from one country or region to another (ISWA, 2009). Consequently a substantial decrease in final volumes of waste could be accomplished, while the recovered material and resources could be used to generate revenues, which can fund the waste management further actions (Consonni *et al*., 2005; Tchobanoglous, 2009; UNEP, 2009).

Materials from municipal solid wastes are the most problematic to recycle, while metals, paper, glass, plastic are easily to recycle (Bontoux *et al*., 1996). About 50% of the waste paper and plastics materials come from packaging, the major part of glass waste is packaging (bottles, jars and small containers) packaging accounts for a minor part of metal scrap (steel cans, aluminium cans) (Bontoux *et al*., 1996). Today, many leading companies are focusing on product recovery and reverse logistics (Mahadevan & Pyke, 2003).

In the United States and Europe remanufacturing is very well established (USITC, 2012). US is the largest remanufacturer in the world with remanufactured goods as IT products, aerospace, wholesalers, motor vehicle parts, medical devices, machinery, consumer products and others (USITC, 2012). Recycling and remanufacturing are the two ways in which recovery of products are usually performed (Gungor & Gupta, 1999).

Bioremediation represents a low cost method to conventional technologies for treating wastes and contaminated media. The solid waste management in EU and remanufacturing and bioremediation methods are discussed in this paper.

2. Solid Waste Management

2.1. Waste Generation and Composition

The analysis on waste characterization and quantification with projections for future performed by various authorities, stakeholders and scientists have shown that most of the municipal solid waste could be diverted for material and resource recovery, leading to a significant reduction in the final volume of waste and resources recovery (EC, 2011; Gavrilescu, 2011; Ghinea & Gavrilescu, 2010).

In 2011, in EU almost 40% of treated municipal waste was recycled or composted, up from 27% in 2001 according to Eurostat (2013), 503 kg of municipal waste was generated per person, while 486 kg of municipal waste was treated per person. The treatment methods differ among the EU members: incineration is the common method in Denmark, recycling in Germany and composting in Austria.

More than 99% of municipal waste treated was landfilled in Romania, while the highest allocation of incinerated municipal waste were observed in Denmark, 54% of waste treated, followed by Sweden 51% and Belgium 42% while recycling was the most common method in Germany (45%) and composting in Austria 34% (Fig. 1).

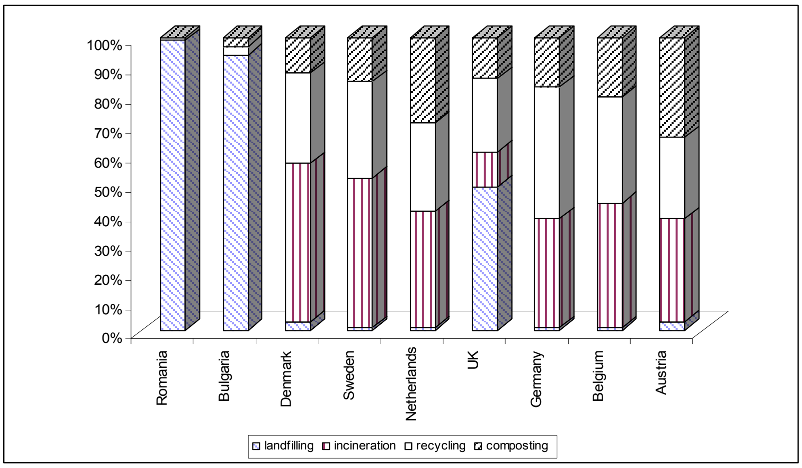

Fig. 1 − Municipal waste treated (%) in some countries from EU, in 2011 (Eurostat, 2013).

Between 2001 and 2010 12 countries increased their recycling performance by more than ten percentage points, while 10 recorded an increase of between five and ten percentage points. The introduction of EU requirements to improve municipal waste management has taken effect in many but not all countries (EEA, 2013). According to EEA (2013) the majority of countries will need to make an extraordinary effort in order to achieve the target of 50% recycling by 2020. Five countries (Austria, Belgium, Germany, the Netherlands and Switzerland) succeeded in the accomplishment of 50% recycling objective, while six countries (Ireland, Italy, Luxembourg, Slovenia, Sweden and United Kingdom) will achieve the 50% by 2020 if they can maintain the annual rate of increase in recycling that they recorded in 2001–2010, while the remaining countries all need to accelerate the shift to recycling.

2.2. The Potential for Material Recovery and Processing Secondary Materials

The recovery of products aims to minimize the amount of waste sent to landfills by means of recycling and remanufacturing (including reuse of parts and products) (Gungor & Gupta, 1999). The municipal solid waste management systems are different between industrialized and developing countries: waste reduction and material recovery are the main differences. According to Hall (2010) the secondary materials are recovered waste materials which are to be sold and reused in manufacturing. Extra revenues are generated from sales and use of secondary materials. Recycling of secondary materials involves more stages of work which implies change in types of employment and more employment. In JRC (2009) the secondary materials are grouped in five main categories: industrial waste, municipal solid waste, construction and demolition waste, end-of-life vehicles, waste from electric and electronic equipment. According to Hall (2010) the materials which can be recovered from municipal solid waste include: paper (basis for new paper production); glass (basis for new glass production or direct re-use of bottles), plastic (basis for new plastic production); electronic scrap and metals (recovering of gold, molybdenum, copper etc.); energy (from residual waste: incineration with CHP (combined heat and power)). Recycling of paper uses less energy than virgin paper production and generally paper has a low hazard potential. The collected waste paper in Europe consists in 42% deinked paper, 37% corrugated paper, and 21% mixed other paper (JRC, 2009). In 2010, in the EU-27, the amount of paper and cardboard generated was 62 kg per capita including a wide range starting from Germany with 88 kg per capita to Romania with 12 kg per capita (Eurostat, 2013). It is considered that to every tonne of paper waste recycled 17 trees are saved (JRC, 2009). Recycling of glass uses less energy than manufacturing glass from sand, lime and soda and in recent years the demand for waste glass has increased. In glass production in EU around 65% from the raw materials used is recycled glass. From the world glass market the European glass market represents 27% (a market with a long tradition) and is followed by the US 20% and Japan 18% (JRC, 2009). In 2010, in the EU-27 the glass packaging waste generated was 32 kg per capita. Amount generated at the top consumer was 65 kg per capita in Luxembourg and 44 kg per capita in France and UK (Eurostat, 2013). The plastic main sources are: municipal solid waste, distribution and industry waste, electronic waste, waste from automotive industry, waste from construction and demolition and agricultural waste. Recycled polymers can not completely substitute for virgin materials because of the property loss during their lifetime. The EU 27 is a net exporter of waste, parings and scrap of plastics (JRC, 2009). The amount of plastic packaging waste recycled was above 38 kg per capita in 2010, in Luxembourg, Ireland, UK and Estonia.

3. Remanufacturing

Remanufacturing, the ultimate form of recycling, is the industrial process of bringing a used product/assembly to a "like-new" condition through inspection, disassembling, cleaning, reprocessing, reassembling and testing (Gungor & Gupta, 1999; Hatcher *et al.*, 2013; Ostlin 2009; Rathore *et al.*, 2011).

It is considered an effective way through both environmental impacts and costs of the manufacturing processes are reduced (Pigosso *et al.*, 2010). The remanufacturing process differs from traditional recycling because does not require raw material processing or component manufacturing (Hatcher *et al.*, 2013). When is compared to other end-of-life processes remanufacturing can be considered more energy-saving and cost-effective (Hatcher *et al.*, 2013). Not all products are suitable for remanufacture. The product must be able to withstand multiple lifecycles and to contain high-value parts in order to be remanufactured, and also must be ease of disassembly, easy to clean, easy to control, easy to replace parts, easy handling, wear resistant and easy to reassemble (Hatcher *et al.*, 2013; Pigosso *et al.*, 2010). Also the most important aspect is that there must be a market demand for the remanufactured products (Hatcher *et al.*, 2013). From economical point of view remanufacture is an interesting strategy because it preserves the product's value added during the design and manufacturing processes (Pigosso *et al.*, 2010).

Gungor & Gupta (1999) pointed factors which induce complexity in a remanufacturing system:

− *probabilistic recovery rates of parts from the inducted,*
− *unknown conditions of the recovered parts until inspected,*
− *the part matching problem,*
− *the added complexity of a remanufacturing shop structure,*
− *the problem of imperfect correlation between supply of cores and demand for remanufactured units,*
− *uncertainties in the quantity and timing of returned products.*

A product life cycle is illustrated in Fig. 2. The main flow include raw material extraction, primary industry, manufacturing, usage and product discarding at its end-of-life. The secondary flows are: reuse, remanufacturing and recycling.

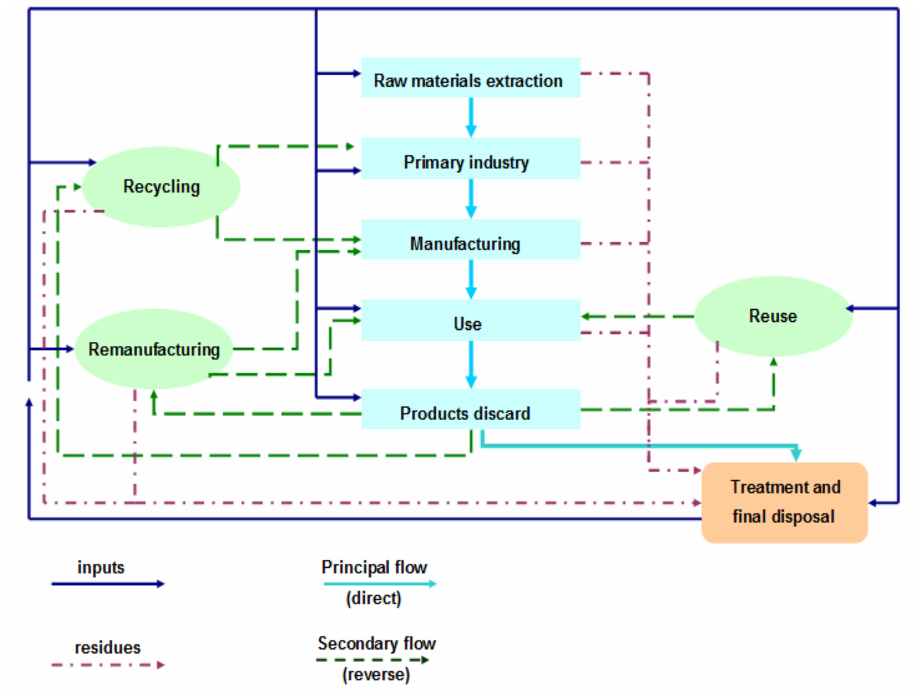

Fig. 2 − Product life cycle (adapted upon Pigosso *et al*., 2010).

Remanufacturing process can be performed for product (used products are remanufactured to ‘‘as-new’’ or upgraded status), component (used components are remanufactured to ‘‘as-new’’ or upgraded status), component cannibalization (used products are cannibalized for components, and the components are then remanufactured to an ‘‘as-new’’ or upgraded status) (Ostlin, 2009).

In recent years several studies were performed based on analysis of remanufacturing processes thus: Hasanov *et al*., (2012) propose some production, remanufacturing and waste disposal models, while Ostlin (2009) focused on how to provide remanufactured products in an effective way during the product’s life-cycle. Hatcher *et al*., (2013) analysis the design for remanufacture and e-waste in China as a remanufacturing industry. Fukushige *et al*., (2012) proposes a method for supporting the design of product lifecycles and evaluated three scenarios:

− recycling first – obtaining 100% profit and 100% CO_2 emissions reduction,

− reuse first - 101% profit and 99% CO_2 emissions reduction

− and remanufacturing first - 102% profit and 79% CO_2 emissions reduction.

Cooper *et al*., (2008) analyzed modeling recycling and remanufacturing processes within metropolitan regional economies at the micro and macro levels. A strategic decision making method for designing environmentally and economically efficient was proposed by Kondoh & Salmi (2011). Mahadevan & Pyke (2003) investigate the performance of the remanufacturing system as a function of return rates, backorder costs and manufacturing and remanufacturing lead times. Matsumoto & Umeda (2011) investigate the companies' motives and incentives for remanufacturing in Japan. Four product areas were evaluated and three requirements for remanufacturing were identified: collection of used products, efficient remanufacturing processes and demand for remanufactured products.

Pigosso *et al*. (2010) presents some ecodesign methods focused on the integration of different 'end-of-life' strategies, mainly remanufacturing. Piñeyro & Viera (2012) found the optimal remanufacturing amount for the particular case of only one period fixed as positive-remanufacturing period. Rubio & Corominas (2008) consider the possibility of implementing remanufacturing policies in a lean production environment.

According to Xiong *et al*. (2013) environmental groups and governments are increasingly encouraging manufacturers to engage in remanufacturing. It is considered that by introducing remanufactured products at a low price to the market increases the overall demand (Xiong *et al*., 2013). Remanufacturing cannot always deliver a positive effect to the environment even if the life-cycle environmental impact of remanufactured products is assumed to be zero (Xiong *et al*., 2013). Bulmuş *et al*. (2013) consider that firms can save between 40% and 60% of the cost of manufacturing a new product by adopting remanufacturing. Rubio & Corominas (2008) established the main reasons why a company may consider application of remanufacturing:

− **economic**: considering consumption of raw materials, reduction of disposal costs, recovery of the added value of used products and environmentally friendly image and compliance with current and future legislation;

− **legal**: in many countries current legislation holds companies responsible for recovering or properly disposing of the products they put on the market;

− **social**: society is aware of environmental issues and demands that companies behave more respectfully towards the natural environment.

The remanufacturing process begins with the collection of the core (used product) (Saavedra *et al*., 2013). The steps of remanufacturing are disassembly of the product, parts cleaning, inspection and storage parts, reconditioning and replacement of parts reassembly of the product. The execution order of these steps is different and it can vary according to the product to be remanufactured.

Remanufacturing of recycling materials in waste steams. Remanufacturing is an operation included in the solid waste management and uses fewer materials and reduces waste (Dumas, 2006). The share of municipal waste recycled has progressively grown from 10% in 1995 to 22% in 2008 in the EU 27. 40% of the waste collected by EU-27 municipalities ends up in landfill sites, 40% was recycled or composted and 20% incinerated in 2008 (Eurostat, 2010).

There are big differences regarding waste collection and processing between the countries from European Union (EU) (Ghinea & Gavrilescu, 2010). An increasing number of local authorities which collect waste from households are introducing source separation systems for recyclables and hazardous waste. The most common methods for collection of waste include kerbside collection of unsorted and sorted waste streams and the “bring” system for specific waste to local recycling stations (Eurostat, 2010).

The collected materials are capable of being recycled in different proportion. Remanufacturing of recycled materials has gained more and more attention and is applied for glass, metals, plastic, paper waste etc. An important aspect for manufacturing companies is efficiency. For example for a company manufacturing fabricated metal products the main resource efficiency measures are “ecodesign, changing procurement practices, reusing materials in a closed loop system such as remanufacturing and waste prevention (using production processes that do not create waste)” (EC, 2013; Georgiadis, 2013). The top two measures from total maximum potential benefit for the fabricated metal products sector are ecodesign (40%) and material reuse (22%), followed by waste prevention using new technology (12%). From average estimated annual resource efficiency benefits for a fabricated metal manufacturing company the material reuse including remanufacturing which represents about 50 000 € with payback more than 3 years (EC, 2013). It was proved that by recovery of materials and remanufacturing of them can be obtained environmental, economic and social benefits.

4. Bioremediation

Bioremediation includes processes and actions performed in order to biotransform an environment, already altered by contaminants, to its original status (Boopathy, 2000; Sharma, 2012; Thassitou & Arvanitoyannis, 2001). Microorganisms either immobilize or transform environmental contaminants to innocuous end products through bioremediation process. It is and accepted option for the clean up of contaminated soils and aquifers. According to Thassitou & Arvanitoyannis (2001) and Boopathy (2000) the bioremediation methods are:

− *land farming:* solid- phase treatment system for contaminated soils; may be done in-situ or in a constructed soil treatment cell;

− *composting:* an anaerobic microbial driven process that converts solid organic wastes into stable, sanitary, humus-like material;

− *intrinsic bioremediation:* relies on the natural assimilative capacity of the ground to provide site remediation and control contaminant migration;

− *slurry bioreactor:* soil and water agitated together in reactor;

− *bioventing:* method to treat contaminated soils by drawing oxygen through the soil to stimulate microbial activity;

− *biofilters:* use of microbial stripping columns to treat air emissions;

bioaugmentation: adding of bacterial cultures to a contaminated medium; frequently used in both in situ and ex situ systems;

− *biostimulation:* stimulation of indigenous microbial populations in soils or ground water by providing necessary nutrients;

− *pump and treat:* pumping ground water to the surface, treating, and reinjecting.

Compared to other techniques such as landfilling or incineration several advantages are offered by bioremediation: can be done on site, is often less expensive, it eliminates waste permanently, has greater public acceptance, can be coupled with other physical or chemical treatment methods (Boopathy, 2000). Among the limitations of the method may be mentioned: some chemicals are not amenable to biodegradation, microbial metabolism of contaminants may produce toxic metabolites in some cases (Boopathy, 2000). The major factors affecting bioremediation are (Boopathy, 2000):

− **microbial factors**: growth pending critical biomass; mutation and horizontal gene transfer; enzyme induction; enrichment of the capable microbial populations; production of toxic metabolites;

− **environmental factors**: depletion of preferential substrates; lack of nutrients; inhibitory environmental conditions;

− **substrate**: too low concentration of contaminants; chemical structure of contaminants; toxicity of contaminants; solubility of contaminants;

− **biological aerobic *vs.* anaerobic process**: oxidation/reduction potential; availability of electron acceptors; microbial population present in the site;

− **growth substrate *vs.* co-metabolism**: type of contaminants; concentration; alternate carbon source present; microbial interaction (competition, succession, and predation);

− **physico-chemical bioavailability of pollutants**: equilibrium sorption; irreversible sorption;

− **mass transfer limitations**: diffusion and solubility of oxygen and diffusion; solubility/miscibility in/with water.

McMahon *et al*. (2008, 2009) evaluated the potential of using composting and bioremediation processes for wood waste materials. Tyrrel *et al.* (2008) used waste-derived filter media in order to perform bioremediation of leachate from a green waste composting facility.

Adekunle (2011) revealed that composted wastes have the potential for bioremediation of soils polluted with petroleum products (crude oil, spent engine oil, and diesel fuel). The compost bioremediation is a soil cleanup technique and can be used for removal of heavy metal and organic contaminants (USEPA, 1997). According to Bonoli & Dall'Ara (2012) has been an increasing use of paper sludge in environmental restoration. The organic wastes can be recovered and transformed into soil conditioners and fertilisers through aerobic and anaerobic biological treatment technologies (ISWA, 2009). Reeh & Moller (2001) compared aerobic composting and anaerobic digestion of organic waste considering a number of environmental effects and energy balance, nutrient recycling, global warming potential, emission of xenobiotic compounds, and economy. Kirkeby *et al*. (2006) identifying environmental benefits and disadvantages of anaerobic digestion for source separated household waste.

5. Conclusions

Solid waste management is of great interest as a topical issue discussed and reviewed internationally. Interdisciplinary studies have been conducted worldwide to assess sustainable solid waste management. The main objectives of a sustainable waste management should be: preservation of natural resources and energy, minimizing pollution and environmental impacts, establishing a high quality performance of the environment. The Europe is working to become a recycling society that looks for waste avoiding and using as resource by adopting waste policies such as the "*Thematic Strategy on the prevention and recycling of waste*". It entails the use of economic instruments to implement the waste hierarchy so that, key actions have to be set out to modernize the existing legal framework and to encourage waste prevention, reuse and recycling, with waste disposal only as a last option. Application of methods like recycling protects the environment by recovering materials or components of used products, resulting in new products.

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REFERENCES

Adekunle I.M, *Bioremediation of Soils Contaminated with Nigerian Petroleum Products Using Composted Municipal Wastes*. Bioremediation Journal, **15**, 230−241 (2011).

Björklund A., Finnveden G., *Recycling Revisited-Life Cycle Comparisons of Global Warming Impact and Total Energy Use of Waste Management Strategies*. Resources, Conservation and Recycling, **44**, 309−317 (2005).

Boopathy R., *Factors Limiting Bioremediation Technologies*. Bioresource Technology, **74**, 63–67 (2000).

Bonoli A., Dall'Ara A., *A Bioremediation Case of an Ex-Quarry Area Restored by Paper Sludge*. Journal of Biotechnology, **157**, 499–504 (2012).

Bontoux L., Leone F., Nicolai M., Papameletiou D., *The Recycling Industry in the European Union: Impediments and Prospects.* A Report Prepared by IPTSfor the Committee for Environment, Public Health and Consumer Protection of the European Parliament, 1-59 (1996).

Bulmuş S.C., Zhu S.X., Teunter R., *Capacity and Production Decisions Under a Remanufacturing Strategy*. International Journal Production Economics, http://dx.doi.org/10.1016/j.ijpe.2013.04.052i (2013).

Chen C.C., *An Evaluation of Optimal Application of Government Subsidies on Recycling of Recyclable Waste*. Polish Journal of Environmental Studies, **14**, 137−144 (2005).

Consonni S., Giugliano M., Grosso M., *Alternative Strategies for Energy Recovery from Municipal Solid Waste Part B: Emission and Cost Estimates*. Waste Management, **25**, 137−148 (2005).

Cooper J., Jackson R., Leigh H.G., *Modeling Regional Recycling and Remanufacturing Processes: from Micro to Macro*. on line at: http://rri.wvu.edu/wp-content/uploads/2012/11/jacksonwp2008-6.pdf. (2008).

Dumas R.D., *Energy Usage and Emissions Associated with Remanufacturing as Part of a Solid Waste Management Life Cycle Inventory Model*. Department of Civil Engineering North Carolina State University, 1−24 (2006).

EC, *Annex I to the Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions*. Commission of the European Communities, Brussels (2007).

EC, *The Opportunities to Business of Improving Resource Efficiency*. Final Report, European Commission, AMEC Environment & Infrastructure and Bio Intelligence Service, 31305 13071i1 (2013).

EC, *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Thematic Strategy on the Prevention and Recycling Waste*, COM (2011), 13 final, Brussels.

Fukushige S., Yamamoto K., Umeda Y., *Lifecycle Scenario Design for Product End-of-Life Strategy*. Journal of Remanufacturing, **2**, 1−15 (2012).

EEA, *Managing Municipal Solid Waste - a Review of Achievements in 32 European Countries*. European Environment Agency, 1−40 (2013).

Eurostat, *Environmental Statistics and Accounts in Europe*. Eurostat, European Union, (2010).

Eurostat, *Packaging Waste Statistics* (2013), on line at: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Packaging_waste_statistics.

Gavrilescu M., *Sustainable Industrial Production*. Ecozone Press, Iaşi, România (2011).

Georgiadis P., *An Integrated System Dynamics Model for Strategic Capacity Planning in Closed-Loop Recycling Networks: A Dynamic Analysis for the Paper Industry*. Simulation Modelling Practice and Theory, **32**, 116–137 (2013).

Ghinea C., Gavrilescu M., *Models for Sustainable Waste Management*. The Bul. Inst. Polit. Iaşi, s. Chemistry and Chemical Engineering, **LVI (LX)**, *2*, 21−36 (2010).

Ghinea C., Petraru M., Bressers H., Gavrilescu M., *Environmental Evaluation of Waste Management Scenarios – Significance of the Boundaries*. Journal of Environmental Engineering and Landscape Management, **20**, 76−85 (2012).

Gungor A., Gupta S.M., *Issues in Environmentally Conscious Manufacturing and Product Recovery: a Survey*. Computers & Industrial Engineering, **36**, 811–853 (1999).

Hall D., *Waste Management in Europe: Framework, Trends and Issues*. PSIRU, Business School, University of Greenwich, Park Row, London SE10 9LS, U.K. (2010).

Hasanov P., Jaber M.Y., Zolfaghari S., *Production, Remanufacturing and Waste Disposal Models for the Cases of Pure and Partial Backordering*. Applied Mathematical Modelling, **36**, 5249–5261 (2012).

Hatcher G.D., Ijomah W.L., Windmill J.F.C, *Design for Remanufacturing in China: a Case Study of Electrical and Electronic Equipment*. Journal of Remanufacturing, 3:3, 1−11 (2013).

ISWA, *Waste and Climate Change* ISWA WHITE PAPER AKA, International Solid Waste Association, AKA Print, Aarhus, Denmark (2009).

JRC, *Study on the Selection of Waste Steams for end of Waste Assessment*. Final Report, Joint Research Centre, Institute for perspective Technological Studies, 1-373 (2009).

Kirkeby J.T., Birgisdottir H., Hansen T.L., Christensen T.H., Bhander G.S, Hauschild M., *Evaluation of Environmental Impacts from Municipal Solid Waste Management in the Municipality of Aarhus, Denmark (EASEWASTE).* Waste Management and Research, **24**, 16−26 (2006).

Kondoh S., Salmi T., *Strategic Decision Making Method for Sharing Resources Among Multiple Manufacturing/Remanufacturing Systems*. Journal of Remanufacturing, 1:5, 1−8 (2011).

Kuo T.C., *Enhancing Disassembly and Recycling Planning Using Life-Cycle Analysis.* Robotics and Computer-Integrated Manufacturing, **22**, 420−428 (2006).

Mahadevan B., Pyke D.F., *Fleischmann M., Periodic Review, Push Inventory Policies for Remanufacturing*. European Journal of Operational Research, **151**, 536–551 (2003).

Matsumoto M., Umeda Y., *An Analysis of Remanufacturing Practices in Japan*. Journal of Remanufacturing, 1:2, 1−11 (2011).

McMahon V., Garg A., Aldred D., Hobbs G., Smith R., Tothill I.E., *Evaluation of the Potential of Applying Composting/Bioremediation Techniques to Wastes Generated within the Construction Industry*. Waste Management, **29**, 186–196 (2009).

McMahon V., Garg A., Aldred D., Hobbs G., Smith R., Tothill I.E., *Composting and Bioremediation Process Evaluation of Wood Waste Materials Generated from the Construction and Demolition Industry*. Chemosphere, **71**, 1617–1628 (2008).

Ostlin J., Sundin E., Bjorkman M., *Product Life-Cycle Implications for Remanufacturing Strategies*. Journal of Cleaner Production, **17**, 999–1009 (2009).

Otegbeye M., Abdel-Malek L., Hsieh H.N., Meegoda J.N., *On Achieving the State's Household Recycling Target: A Case Study of Northern New Jersey. USA*. Waste Management, **29**, 647−654 (2009).

Pigosso D.C.A., Zanette E.T., Filho A.G., Ometto A.R., Rozenfeld H., *Ecodesign Methods Focused on Remanufacturing*. Journal of Cleaner Production, **18**, 21–31 (2010).

Piñeyro P., Viera O., *Analysis of the Quantities of the Remanufacturing Plan of Perfect Cost*. Journal of Remanufacturing, 2:3, 1−8 (2012).

Rathore P., Kota S., Chakrabarti A., *Sustainability Through Remanufacturing in India: a Case Study on Mobile Handsets*. Journal of Cleaner Production, **19**, 1709−1722 (2011).

Reeh U., Moller J., *Evaluation of Different Biological Waste Treatment Strategies* (2001) on line at: http://orgprints.org/198/1/Evaluation_UR.pdf.

Rubio S., Corominas A., *Optimal Manufacturing–Remanufacturing Policies in a Lean Production Environment*. Computers & Industrial Engineering, **55**, 234–242 (2008).

Sharma S., *Bioremediation: Features, Strategies and Applications*. Asian Journal of Pharmacy and Life Science, **2**, 202−213 (2012).

Saavedra Y.M.B., Barquet A.P.B., Rozenfeld H., Forcellini F.A., Ometto A.R., *Remanufacturing in Brazil: Case Studies on the Automotive Sector*. Journal of Cleaner Production, 53, 267−276 (2013).

Smith A., Brown K., Ogilvie S., Rushton K., Bates J., *Waste Management Options and Climate Change*. Final report to the European Commission, DG Environment (2001).

Spilka M., Kania A., Nowosielski R., *Integrated Recycling Technology*. Journal of Achievements in Materials and Manufacturing Engineering of Achievements in Materials and Manufacturing Engineering, **31**, 97−102 (2008).

Tchobanoglous G., *Solid Waste Management*. In: Environmental Engineering, Vol. **3**, Nemerow N.L., Agardy F.J., Sullivan P., Salvato J.A., (Eds.), Wiley and Sons, New York, 177−304 (2009).

Thassitou P.K., Arvanitoyannis I.S., *Bioremediation: a Novel Approach to Food Waste Management.* Trends in Food Science & Technology, **12**, 185–196 (2001).

Tyrrel S.F., Seymour I., Harris J.A., *Bioremediation of Leachate from a Green Waste Composting Facility Using Waste-Derived Filter Media*. Bioresource Technology, **99**, 7657–7664 (2008).

UNEP, *Developing Integrated Solid Waste Management Plan*. Vol. **3**, Targets and Issues of Concern for ISWM, United Nations Environmental Programme, Division of Technology, Industry and Economics, International Environmental Technology Centre, Osaka/Shiga, Japan (2009).

USEPA, *Innovative Uses of Compost Bioremediation and Pollution Prevention*. United States Environmental Protection Agency, EPA530-F-97-042 (1997).

USITC, *Remanufactured Goods: An Overview of the U.S. and Global Industries, Markets, and Trade*. United States International Trade Commission, Investigation No. 332-525, USITC Publication 4356 (2012).

Xiong Y., Zhou Y., Li G., Chan H.C, Xiong Z., *Don't Forget your Supplier when Remanufacturing*. European Journal of Operational Research, European Journal of Operational Research, **230**, 15–25 (2013).

RECICLAREA DEŞEURILOR SOLIDE PENTRU REMANUFACTURARE
ŞI BIOREMEDIERE

(Rezumat)

Dezvoltarea economică şi evoluția aglomerărilor urbane au condus la creşterea rapidă a volumului şi tipurilor de deşeuri. Situația ideală conform principiului *cradle-to-cradle* ar însemna o lume fără deşeuri, dar acest lucru nu este încă posibil.

Modalitățile prin care o cantitate tot mai mare de deşeuri solide este gestionată influențează, pe de o parte sănătatea umană şi calitatea mediului, dar ar putea contribui semnificativ la conservarea resurselor. În ultimii ani, atenția specialiştilor a fost concentrată asupra managementului deşeurilor în conformitate cu ierarhia deşeurilor, care cuprinde atât opțiunile favorabile cât şi cele mai puțin favorabile pentru sistemele de gestiune a deşeurilor. Metode, cum ar fi reciclarea, reutilizarea, remanufacturarea, bioremedierea au fost aplicate pentru a reduce cantitatea de deşeuri, poluarea mediului şi pentru a diminua cantitatea de materii prime din resurse naturale utilizate pentru fabricarea de produse cu beneficii economice şi sociale.

Materialele reciclabile pot constitui produse valoroase pentru industrie prin remanufacturare, iar bioremedierea poate utiliza deşeuri ca suport pentru reținerea unor contaminanți, urmată de o prelucrare ulterioară.

În această lucrare se analizează atât situația deşeurilor solide reciclabile în Europa cât şi cele două metode de valorificare a deşeurilor prin reciclare (remanufacturare şi bioremediere) şi aplicațiile lor în domeniul managementului deşeurilor.