Lechner P. (Hrsg.): Waste matters. Integrating views. 2nd BOKU Waste Conference 2007, 16. - 19. April 2007, Wien. Proceedings; Facultas Verlags- und Buchhandels AG, ISBN 978-3-7089-0060-5

Material Recovery of Plastics and Textile Waste – Reducing Greenhouse Gas Emissions?

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Abstract
Waste recycling is a growing field of activity. Recycling can reduce the use of virgin raw materials, energy and thus greenhouse gas emissions. In this study, new concepts for material recovery of wastes were assessed for their potential to decrease greenhouse gas emissions. We collected information and data on new Finnish material recovery concepts for wastes in the following material categories: wood fibres, plastics, glass, metal and textiles. A number of concepts were identified as relatively fresh and promising, but data for calculating their greenhouse gas emissions were not available for most of the concepts. However, rough estimates of the potential for producing savings in greenhouse gas emissions for one concept in each material category were calculated. Whilst missing process-specific data, we used data for similar processes, or from public databases.

Two concepts, which on the basis of these rough calculations showed potential for reducing greenhouse gas emissions, were chosen for a more detailed assessment. The two concepts chosen were 1) recovering textile waste for the production of oil absorption mats, and 2) recovering plastic waste for plastic profiles. The greenhouse gas emissions from these two concepts were compared with emissions from the processes using primary raw materials for the same products (i.e., reference products). This comparison was performed using the principles of life cycle inventory (LCI) analysis. The results show that the analyzed concepts have potential for the minimization of greenhouse gas emissions only if certain conditions are met. However, choices concerning the reference product and the substitute energy source for waste combustion are decisive for the results.

1 Introduction
People have always recycled and utilized certain waste fractions as raw materials for new products. Recently, however, utilization and recycling of waste has become even more important due to the scarcity of virgin materials and the concern over the non-sustainable use of natural resources. Also, the increasing price of waste management, limited landfill space and perhaps most importantly, the climate change impacts produced by waste decomposing in landfills has increased

interest in recovering waste as either material or energy. Wastage of resources can be avoided by recycling and energy can be saved by using waste as the raw material for new products.

The aim of our study (Hiltunen and Dahlbo 2007) was to find existing material recycling concepts in which the recovered material is reprocessed into new products and then assess the possible greenhouse gas emission savings from these material recovery concepts. This study is part of a larger project ("New waste management concepts for reducing greenhouse gas emissions and the development of the concepts towards business in the medium term" (UJKON)) (Mroueh et al. 2007), where in addition to material recovery technologies, also energy recovery technologies, biological treatment methods and landfill gas collection and control methods are assessed for their potential to minimise greenhouse gas emissions. In this study the focus was on the main greenhouse gases (CO_2, CH_4, N_2O) hence other emissions and environmental impacts were not assessed.

In a survey conducted on the existing material recycling concepts a variety of concepts for different material groups (i.e. wood fibre, glass, textile, plastic and metal), where recycled material is used as the main raw material of the new product, were discovered. The products made from recovered material can either serve the same purpose (e.g. bottle to bottle) or fall into different category of application (e.g. from glass to fibre). To demonstrate the potential of material recycling in reducing greenhouse gas emissions we chose, on the basis of our survey and rough calculations, two material recycling concepts for more in depth analysis i.e., for case studies. One concept was chosen from the plastics material group and one from textiles, because the greenhouse gas emission reduction potential of recycling these materials has not been widely studied. In the plastic concept the recovered waste plastics are reprocessed into *plastic profiles* and in the textile concept the discarded textile from the textile industry is reprocessed into *oil sorbents (mats)*. The potential of these two concepts in the reduction of greenhouse gas emissions are discussed in this paper.

2 Potential of waste management to reduce greenhouse gas emissions

Waste management generates greenhouse gas emissions both directly and indirectly. Direct emissions are generated during waste collection and transportation, during waste pretreatment (sorting, crushing etc.), in waste utilization processes, in landfill during decomposing, in waste combustion and in biological treatment. Indirect emissions are connected to waste management from other functions such as energy consumption in the production, transportation and use of materials, emissions from production processes (not related to energy consumption) and emissions from production and transportation of the raw materials of the products.

The most efficient way to reduce greenhouse gas emissions in waste management is to reduce consumption and thereby reduce waste generation. Also material recycling can decrease both the direct and indirect greenhouse gas emissions.

Direct emissions are decreased when waste is not disposed of at landfills nor treated in any other way (e.g. combustion). Indirect emissions can be reduced by decreasing the energy consumption both in acquiring and producing raw materials and also in manufacturing the product itself. Furthermore, at the production stage greenhouse gas emissions can be decreased by avoiding emissions originating from sources other than energy consumption. It is possible to substitute virgin material with recovered material in which case the emissions from manufacturing a product from virgin material can be avoided. In most cases the replacement of virgin materials by recycled materials decreases the use of net energy and thus the greenhouse gas emissions originating from energy production decrease. Greenhouse gas emissions can also be reduced by avoiding the use of materials, which produce emissions directly in the production phase (Turkulainen and Johansson 2001). On the other hand, recycling can produce greenhouse gas emissions if transportation operations increase or waste processing generates emissions.

3 Calculating the greenhouse gas emission reduction potential of plastic and textile waste recycling

The greenhouse gas emission reduction potential of the two chosen concepts was assessed by comparing the emissions of a product manufactured from recovered material with a reference product, serving the same purpose of use but manufactured from virgin raw material. The reference product does not necessarily have to be of the same material as the recycled product, as long as the function is the same. In this study the reference product for the plastic profile was chosen to be impregnated wood, because in most applications the plastic profile replaces impregnated wood and less frequently other materials. Polypropylene fibre was chosen for the reference product for the textile concept due to the fact that nowadays oil sorbents are increasingly made from recycled textile fibres but many are still made from virgin polypropylene.

The Life Cycle Inventory (LCI) method was used in assessing the emissions produced by the recycled and the reference product. LCI is a phase of Life Cycle Assessment (LCA), a standardized environmental management tool for assessing the environmental impacts of the lifecycle of a product, process or activity – from raw material extraction, processing, transportation, manufacturing, distribution, use, re-use, recycling to waste disposal (Guinée et al., 2002). The scope of an LCA can be limited for example to specific life cycle stages e.g., end of life, or specific environmental issues such as energy consumption or global warming. In this work the scope was restricted to greenhouse gas emission savings of different waste recovery concepts. Therefore full LCA does not have to be conducted, the study could be restricted to the Life Cycle Inventory (LCI) phase. LCI involves data collection and calculation procedures to identify and quantify relevant inputs and outputs of the product system under examination. (ISO 14041, 1998).

For the inventories, site specific emission data was used when possible, oth-

erwise the data was gathered from best available sources such as PlasticsEurope (2005), Finnish Pulp and Paper Research Institute (KCL Datamaster), Lipasto (the calculation system for traffic exhaust emissions, VTT 2002) and Ecoinvent database (2005).

Functional units, i.e., the reference units against which all the input and output data are calculated thereby making it possible to compare different products and services, were defined for the product systems. For the plastics concept case study the functional unit (FU) was defined as 100 meters squared (m^2) of board. The area based FU was chosen instead of mass based because the weight of the plastic profile differs from that of the impregnated wood and thus different amounts of materials are needed to fulfill the same purpose of use. For the textile concept case study the FU was defined as one ton of oil sorbent mat, since there is no significant difference in the adsorbent capacity between the reference product and recycled product.

The system boundaries set for the product systems for this study are presented in Figure 1.

The product systems studied covered all the processes in the life cycles of the

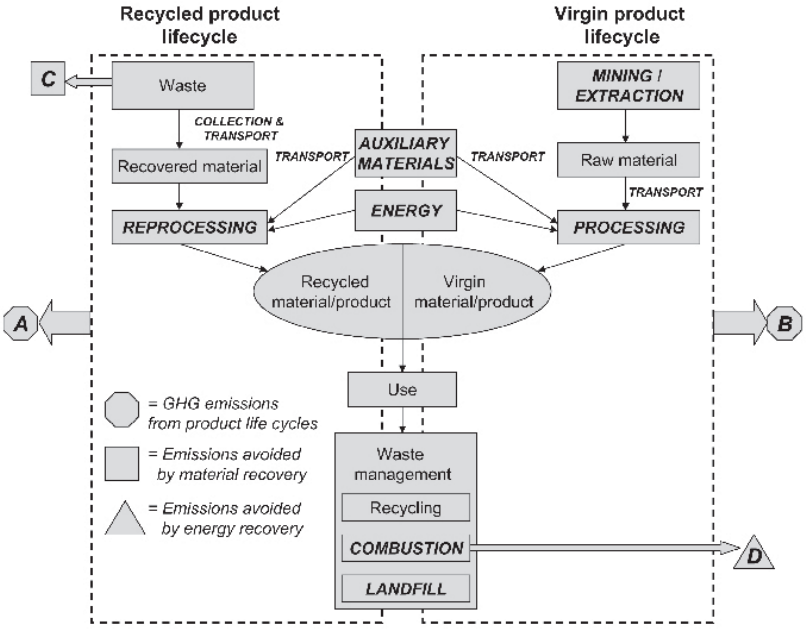


Fig. 1: System boundaries of the recycled and virgin product. Capital letters indicate the life cycle stages from which the emission data were gathered. (Modified from McDougall et al. 2001)

products from raw materials to the disposal of the products (Fig. 1). The product systems were divided into life cycle stages to enable evaluation and comparison of the relative contributions of the interventions between stages within the product system and between the stages between different product systems. The emission data was gathered from life cycle stages marked with capital letters in Figure 1.

In addition to the emissions produced by the life cycles of the recycled and reference product, the emissions avoided by material or energy recovery within the systems were taken into account in the overall greenhouse gas emission saving calculations. The calculation principles were as follows. (The letters A-D refer to Figure 1).

- Greenhouse gas emissions from the recycled product life cycle (A) were quantified where possible. The manufacturing of auxiliary materials, the energy production, the transporting of auxiliary materials and the collection and transportation of the recovered material to the reprocessing site and waste management were taken into account.
- (A) was then deducted from the emissions generated during the whole life cycle of an equivalent amount (functional unit) of the virgin product (B).
- The greenhouse gas emissions avoided by material recovery (C) were then added. These emissions could be avoided when the waste (raw material of the recycled product) entering the product system was recovered, not disposed of at landfill or combusted to produce energy.
- Finally, the emissions avoided by energy recovered (D) from waste combustion were added. The energy recovered from waste combustion replaces energy generated with other energy sources; in the basic calculations the average Finnish electricity and heat generation.

The overall greenhouse gas savings resulted from B - A + C + D. There will be greenhouse gas savings as long as the result is positive (B - A + C + D > 0). If the result is negative no emission reduction can be obtained from the system.

4 Results

The results of the greenhouse gas emissions from the five product systems studied are shown in Figure 2. For the plastic profile two product systems are presented; in the first one, the cast-off profile is combusted (PLPI) and in the second one it is disposed of at landfill sites (PLPL). For impregnated wood and cast-off oil absorbent mat (both classified as hazardous waste) combustion was the only waste treatment alternative considered. The plastic profile results can only be compared with the results of the impregnated wood (IW) product system and similarly the results from recycled textile mat (RT) can only be compared with the results from polypropylene mat (PP) product system.

The results show that if the cast-off plastic profile was combusted (PLPI), the greenhouse gas emissions, expressed as CO_2 equivalents, from the plastic profile

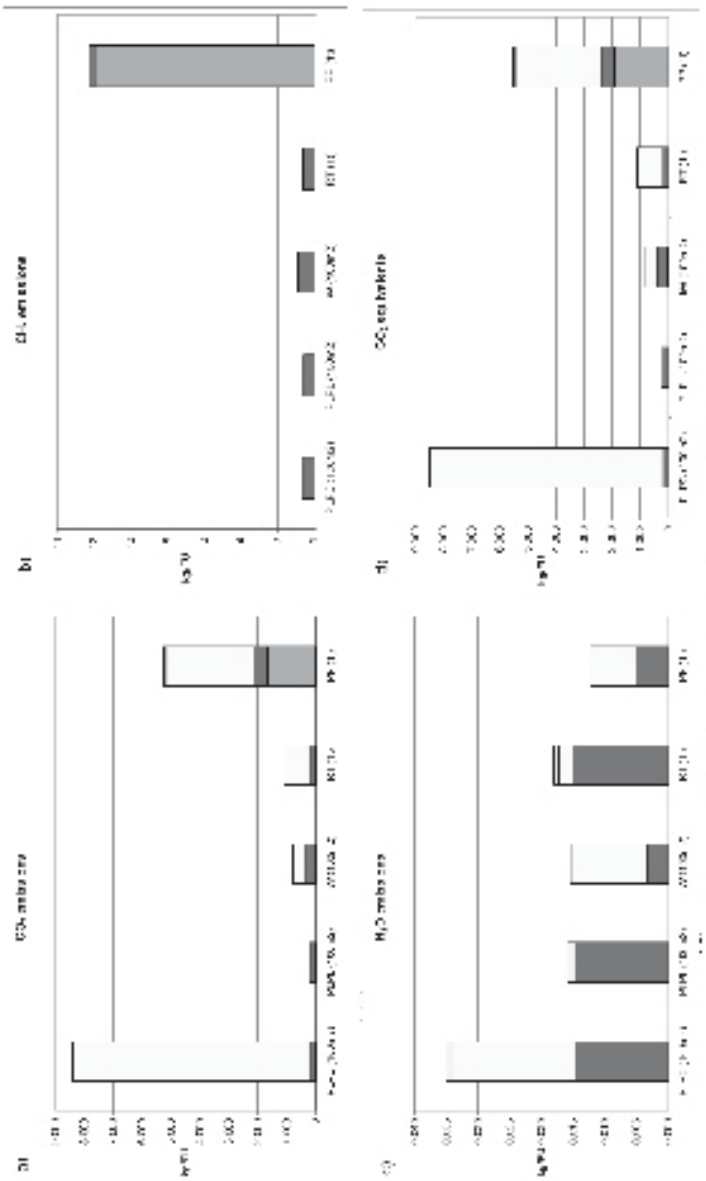


Fig. 2: a) CO_2 emissions, b) CH_4 emissions, c) N_2O emissions and d) CO_2-equivalents from the product systems studied. Abbreviations: PLPC = Plastic profile combustion, PLPL = plastic profile landfill, IW = impregnated wood, RT = recycled textile mat, PP = polypropylene mat, FU = functional unit (100 m^2 or 1t).

life cycle would be multifold compared with the emissions from the life cycle of impregnated wood (IW). But if the profile was disposed of at landfill sites (PLPL), the emissions would be less than from impregnated wood. The results of the textile concept show, that there is a great advantage from recycling textiles. Namely, the emissions from the oil absorbent mat made of virgin polypropylene would be five times higher than from the mat made of recycled textile.
Most of the CO_2 emissions are caused by the waste management stage in all other product systems except for the plastic profile (landfill) (PLPL). On the contrary, most methane emissions originate from product manufacturing with the exception of the polypropylene mat (PP) product system, where raw material acquisition (includes crude oil acquisition and the production of the polypropylene fibre) is the most methane emitting life cycle stage. Most of the N_2O emissions originate from the waste management and product manufacturing stages and only a small share comes from transportation.

In calculating the overall greenhouse gas emission saving potential of the product systems, the avoided emissions from material and energy recovery were taken into account (Table 1). In both case concepts, sub-cases were formulated in order to include the different waste disposal options available 1) for the waste if it was not recovered as material: landfilling or energy recovery (combustion), and 2) for the end-of-life products, both of recycled and virgin material origin: landfilling or energy recovery (combustion). In the plastic case the sub-cases are marked with 1a, 1b, 1c and 1d and in the textile case with 2a and 2b.

Tab. 1: Greenhouse gas emission saving potential (environmental benefits) from waste plastic and waste textile recycling. A plus sign indicates emission savings and respectively a minus sign indicates a situation where no emission savings occur. The more signs, the stronger the effect.

		Emission saving potential
Case: Plastic Plastic profile made from recycled plastic vs. virgin impregnated wood		
Subcase		
1a	Waste plastic is not combusted; plastic profile is combusted.	-
1b	Waste plastic is not landfilled; plastic profile is combusted.	- - -
1c	Waste plastic is not landfilled; plastic profile is landfilled.	-
1d	Waste plastic is not combusted; plastic profile landfilled.	+

Case: Textile Oil absorbent made from recycled textile vs. oil absorbent made from virgin polypropylene		
Subcase		
2a	Waste textile is not combusted; recycled textile oil absorbent is combusted.	+
2b	Waste textile is not landfilled; recycled textile oil absorbent is combusted.	+ +

In the plastic concept the results show that the only situation when emission savings would be obtained by replacing impregnated wood with plastic profile is if the waste plastic was recycled instead of being combusted and the cast off profile was disposed of at landfill (sub-case 1d). The emission savings derive from the following: First, the energy that would have been obtained from the combustion of plastic waste is assumed to be produced by using the average Finnish electricity and heat model, which produces lower emissions. And secondly, when the plastic profile is disposed of at landfill sites, no emissions are assumed to be generated.

In all other sub-cases within the plastic concept the results turn out to be negative, i.e., no emission saving potential occurred with the boundaries set in this study. The worst alternative would be recycling the waste plastics instead of sending it to landfill it and combusting the profile at the end of its lifecycle (sub-case 1b). The waste plastics does not in practice degrade in the landfill, hence no emissions would be saved when the waste is recovered. Combusting the cast off plastic profile at the end of the lifecycle produces more emissions than the substituted energy source, hence emissions increase and the emission savings decrease.

In the textile concept, the oil absorbent mat made from recycled textiles replaced the oil absorbent mat made from virgin polypropylene fibre. There are only two sub-cases in the textile case study because combustion was the only disposal method considered for used oil absorbent mats. The results show that, if recycled textile waste was used to replace virgin polypropylene fibre in oil absorbent mats, greenhouse gas emissions would decrease. Most emission savings would be obtained in sub-case 2b, when the waste textile is recycled instead of being sent to landfill. High emission savings are due to the avoided emissions from textile decomposition in the landfill, calculated following the calculation principles of IPCC (2000). Respectively in sub-case 2a, the textile waste is recycled instead of being combusted and the amount of energy, which would have been obtained by textile combustion, now has to be generated with other energy sources. When the average fuel mixture of Finnish electricity and heat generation replaces the energy produced with textile waste, more emissions are emitted and thus the emission savings are smaller than in sub-case 2b.

5 Sensitivity analysis

Sensitivity analysis was performed on some of the issues that were expected to have a major influence on the outcome of the calculations. First, the effect of the type of energy substituted by the energy generated within the product system, was analysed by using 1) coal and 2) renewable fuels instead of the Finnish average fuel mixture. Second, the effect of the length of the life-time of the plastic profile was analysed by assuming a three-fold life-time for the profile. Third, the effect of the assumed origin of the recycled material (bio or fossil based) in the textile concept was analysed by using different percentages for the composition of the material.

The sensitivity analyses showed that the aspects studied had no major impacts on the overall results except for in one case. The use of renewable fuels instead of the Finnish average fuel mixture made producing plastic profiles from plastic waste favorable over impregnated wood.

The key issue in the assessment thus is the reference product and its origin.

6 Conclusions

In our study the reprocessing of plastic waste into plastic profile and the reprocessing of textile waste into oil sorbents were chosen as examples to demonstrate the potential of material recycling in greenhouse gas emission abatement. The definition of the reference product turned out to be the key issue for the outcome of the results. The reference products for our concepts were chosen on the basis of the markets and were impregnated wood for the plastics profile and polypropylene based oil sorbent for the recycled textile oil sorbent. Focusing only on these two reference products is definitely a limitation, i.e. the choice of other products would have lead to different findings. Therefore the results must be handled with caution.

The results showed that it is possible to reduce greenhouse gas emissions by material recycling if certain conditions are met. By processing waste plastics into plastic profile, emissions can be reduced in situations where the waste is recycled instead of being combusted and the discarded plastic profile is disposed of at landfill sites. In greenhouse gas emission calculations, the biogenic reference product gains more advantage from e.g. compensating fossil fuels in energy production than the fossil-material-based recycled product. The results would thus be more favorable for plastic waste recycling if the reference product was of fossil origin instead of biogenic origin or if renewable energy sources were used as the substitute energy instead of the average Finnish electricity and heat production. The results of the textile recycling case study revealed that when textile waste is used to replace virgin plastic product the greenhouse gas emissions can be reduced substantially. The results only represent the situation in these case studies hence they can not be generalized to cover the whole field of material recycling.

In this study the focus was on greenhouse gas emission reduction potential of material recycling. To get an extensive picture of the overall positive effects of

material recycling on the environment other environmental impacts should also be taken into account. For example if the impacts of material recycling on biodiversity had been assessed the use of recycled plastics would have turned out to be more favourable than the use of impregnated wood.

Recycling is one of the elements of sustainable development. However, there are challenges in increasing material recycling. Currently, waste plastic is too often not clean or homogenous enough to be used in reprocessing processes and hence ends up in landfills. This presents a challenge in term of the development of sorting and cleaning technologies for different waste fractions. The left over textiles from textile industry can easily be recovered because they are homogenous and easy to collect but discarded textiles from households are more difficult to utilize. This is partly due to the heterogeneity of household textiles and the auxiliary materials such as buttons and zips they include. New applications of textiles recycling should also be invented to increase the utilization of waste textiles. Today, a large share of waste textiles from households still ends up in the landfills within the municipal waste. However, plastics and textile recycling is likely to increase in the future, when more experience from this field is obtained.

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