Reducing Greenhouse Gas Emissions by Recycling Plastics or Textile Waste?

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EXECUTIVE SUMMARY

Waste recycling is a growing field of activity. Recycling can reduce the use of virgin raw materials and energy, and thus also greenhouse gas emissions. In this paper, concepts for material recovery of wastes are assessed for their potential to decrease greenhouse gas emissions. The paper is based on two Finnish research projects. In the first one 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 available for almost none of the concepts. Rough estimates of the potential for producing savings in greenhouse gas emissions for one concept in each material category were, however, 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 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.

In the second research project data on a concept for recycling plastic waste into drainpipes has been collected. For the purpose of this paper this concept was assessed for it's greenhouse gas reducing potential using the same calculation principles as mentioned above. These data and calculations are, however, preliminary and may change in the duration of the project.

The results from this comparison show that the analyzed concepts have potential for the minimization of greenhouse gas emissions. When plastic waste compensates for virgin plastic, greenhouse gas savings are obvious. Emission savings can also be gained when textile waste compensates for virgin plastic. But when plastic waste compensates for wood, savings can only be generated if certain conditions are met. Choices concerning the reference product and the substitute energy source for waste combustion are decisive for the results.

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. The wastage of resources can be avoided by recycling and energy can be saved by using waste as the raw material for a new product.

The aim of this paper is to demonstrate the potential of certain recycling concepts for reducing greenhouse gas (GHG) emissions. The concepts have been studied in two Finnish research projects.

The first study concentrated on recycling concepts in which the recovered material is reprocessed into new products. The recycling study included two cases: The first case was a plastic waste recycling concept where plastic profiles are produced from waste plastics, and the second case was a textile waste recycling concept in which 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. This study was 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 were assessed for their potential to minimize greenhouse gas emissions. The focus was on the main greenhouse gases (CO_2, CH_4, N_2O) hence other emissions and environmental impacts were not assessed.

The second project is a currently ongoing study on the combustible wastes and the alternatives for their recovery in different regions in Finland (Environmental and economic impacts from recycling of combustible wastes, POLKU-project, www.environment.fi/syke/polku). In this project, data on a plastic waste recycling concept has been collected for regional waste management system modelling (Myllymaa et al. 2007). In this concept plastic waste is processed into drainpipe. For the purpose of this paper a calculation of the potential of this concept to reduce greenhouse gas emissions is produced and a comparison to the above mentioned plastic profile concept is provided. These data and calculations are, however, preliminary and may change as the project is being finalized.

WASTE MANAGEMENT AND GREENHOUSE GASES

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.

Material recycling can decrease both the direct and indirect greenhouse gas emissions. It is possible to substitute virgin material with recovered material and consequently avoid the emissions from virgin product extraction and manufacturing. Moreover, 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. Lastly, material recycling reduces the amount of waste disposed of at landfill sites and thereby the amount of greenhouse gas emissions released from landfills. However, the most efficient way to reduce greenhouse gas emissions in waste management is to reduce consumption and thereby reduce waste generation.

METHODOLOGY USED IN ASSESSING THE GHG REDUCTION POTENTIAL OF WASTE RECYCLING

The greenhouse gas emission reduction potential of the recycling 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 reference product for drainpipe made from recycled plastics is drainpipe made from virgin high-density polyethylene (HDPE).

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, otherwise the data was gathered from best available sources such as Boustead (2005a, 2005b), Finnish Pulp and Paper Research Institute (KCL Datamaster), Lipasto (the calculation system for traffic exhaust emissions, VTT 2002) and Ecoinvent database (2005). (Hiltunen & Dahlbo 2007).

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 profile 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 fulfil the same purpose of use. For the textile 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.

For the plastic drainpipe concept one ton of the product was used as the FU. It was assumed that one ton of recycled plastic granulate compensates for one ton of virgin plastic. This requires, however, that the plastic waste is clean and homogenous. Lower plastics quality might force the end product to be thicker than the one made of virgin plastics. Then one ton of recycled plastic would no more compensate for one ton of virgin plastic in drainpipe production (Myllymaa et al. 2007).

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

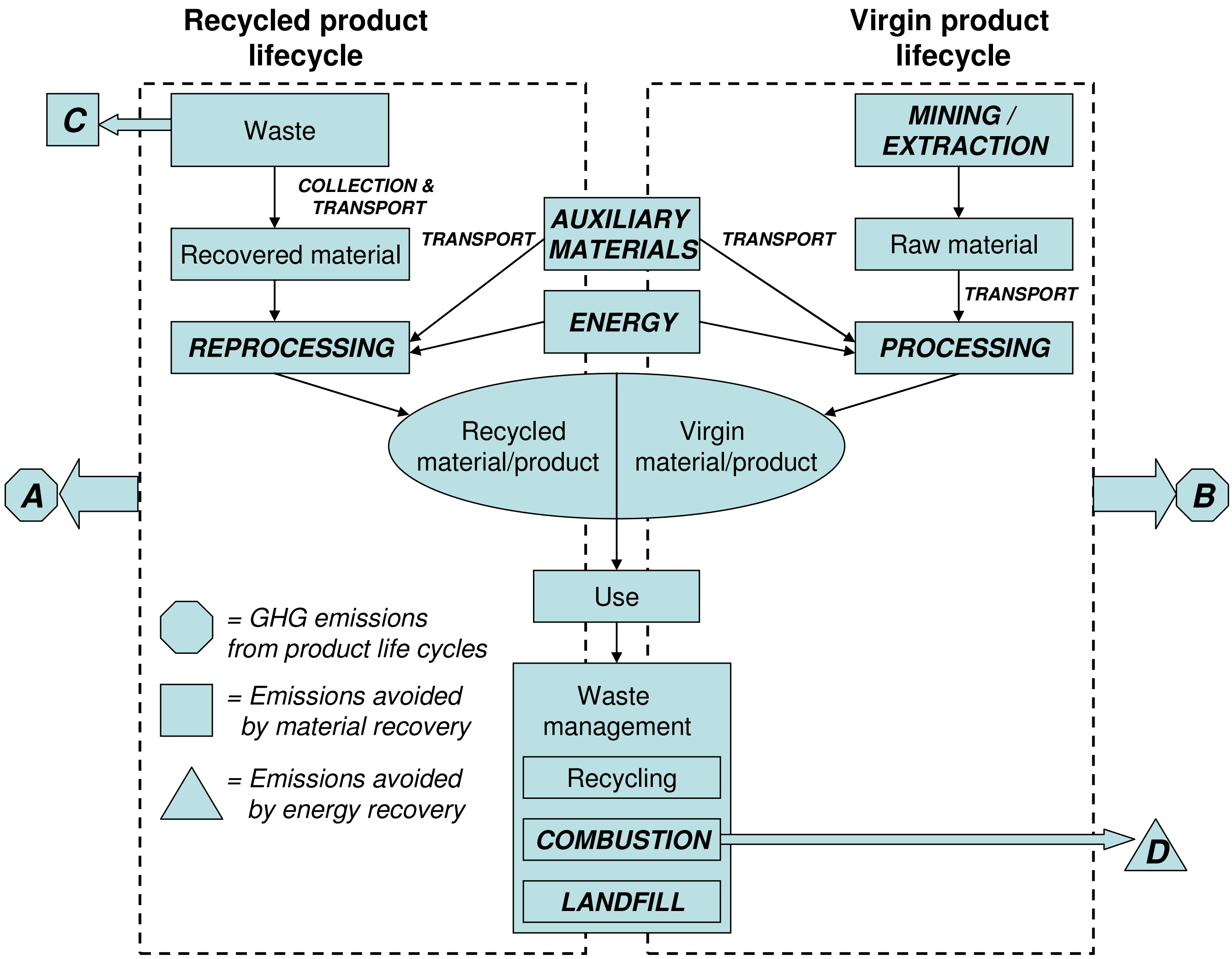


Figure 1 System boundaries of the recycled and virgin product. Capital letters indicate the life cycle stages from which the emission data were gathered. (Modified from McDougall et al. 2001). A = emissions from the recycled product life cycle, B = emissions from the virgin product life cycle, C = emissions avoided in landfills or waste combustion, when the waste is recycled, D = emissions avoided by energy recovery of the cast-off product at the end of the life cycle. Avoided emissions calculated using the fuel mixture of the average Finnish electricity and heat production in 2003.

The product systems studied covered all the processes in the life cycles of the products from raw materials to the disposal of the products (Fig. 1). 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.

RESULTS

GHG Emissions from the Product Systems

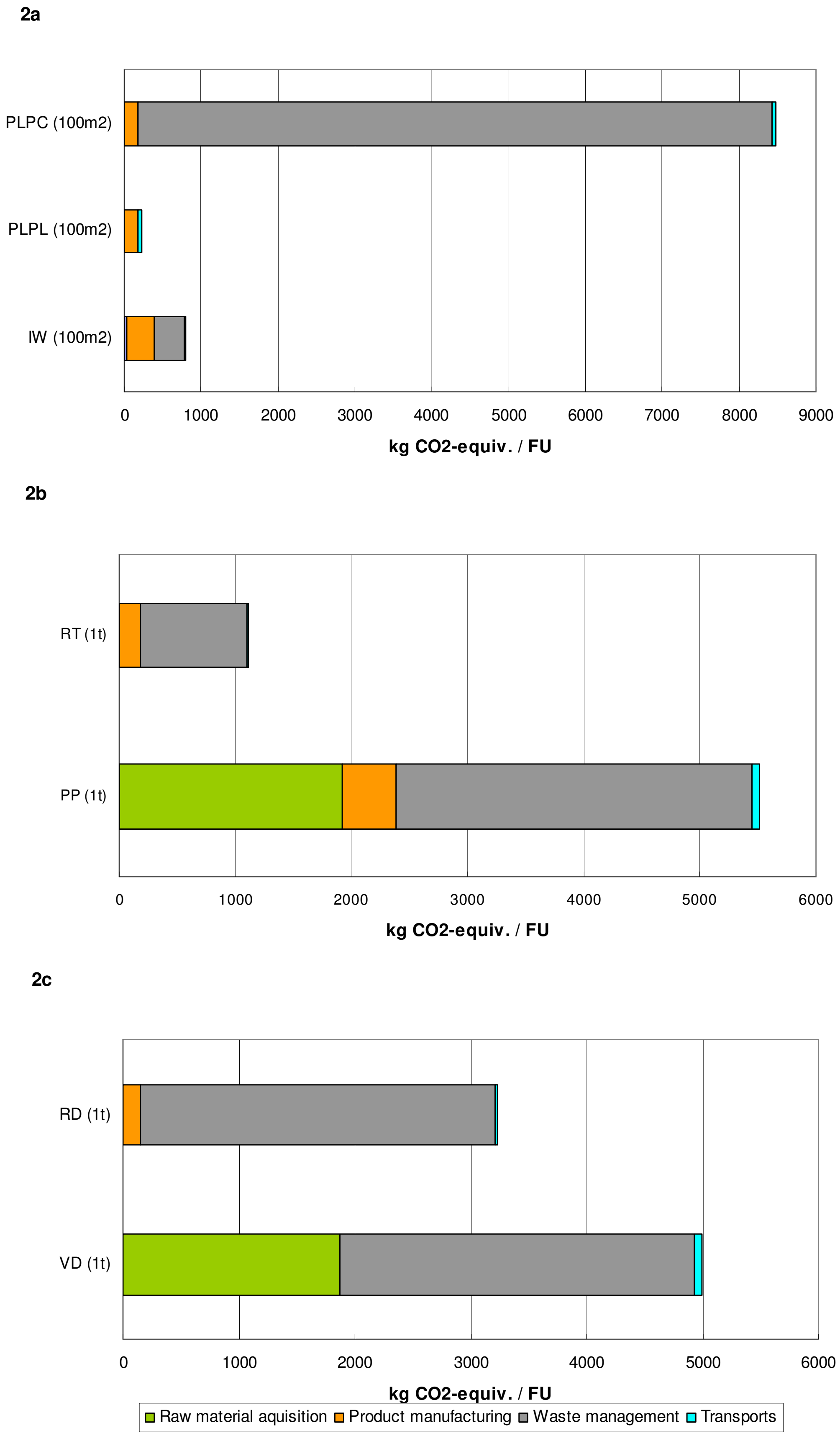
The results of the greenhouse gas emissions from the product systems studied are shown in Figures 2a – 2c. Note that Figure 2 does not include any emissions avoided by energy recovery, these are only included in the results shown in Table 1. For the plastic profile two product systems are presented; in the first one, the cast-off profile is combusted (PLPC) and in the second one it is disposed of at landfill sites (PLPL). Impregnated wood (IW) and cast-off oil absorbent mats (RT, PP) are both classified as hazardous waste, hence combustion was the only waste treatment alternative considered. For the drainpipe concept, the waste management phase could be either combustion or landfilling but the emissions from both would be identical for both the recycled and virgin material. This assumption, however, only holds if the plastic waste used here is clean and of good quality and includes no PVC.

The plastic profile results can only be compared with the results of the impregnated wood (IW) product system (Figure 2a). Similarly the results from recycled textile mat (RT) can only be compared with the results from polypropylene mat (PP) product system (Figure 2b) and the recycled plastic drainpipe (RD) results can only be compared with the results from virgin plastic drainpipe (VD) (Figure 2c).

The results show that if the cast-off plastic profile was combusted (PLPC), the greenhouse gas emissions, expressed as CO_2 equivalents, from the plastic profile life cycle would be multifold compared with the emissions from the life cycle of impregnated wood (IW), because the CO_2-emissions of IW in combustion are considered biogenic and thus left out. But if the profile was disposed of at landfill sites (PLPL), the emissions would be less than from impregnated wood due to CH_4 – emissions generated by the IW.

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, due to the high energy demand of virgin polypropylene manufacturing. Also the drainpipe concept, where fossil resources are compensated with plastic waste, shows great advantage for recycling, because of the same reason. .

Most of the CO_2 emissions are caused by waste management stage in plastic profile with combustion, impregnated wood, recycled textile mat and polypropylene mat. The significance of these emissions may reduce if waste-based-energy is assumed to compensate for energy generated with other fuels.



Figures 2a – 2c 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, RD = recycled plastic drainpipe, VD = virgin plastic drainpipe, FU = functional unit ($100m^2$ or 1t). Note that the pillars do not include any emissions avoided by energy recovery of waste.

Potential for Saving GHG Emissions by Recycling

In calculating the overall greenhouse gas emission saving potential of the product systems, the avoided emissions from material and energy recovery (C and D in Figure 1) were taken into account (Table 1). In all the recycling concepts, subcases 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 profile case the subcases are marked with 1a, 1b, 1c and 1d, in the textile case with 2a and 2b and in the plastic drainpipe case with 3a and 3b.

Table 1 Greenhouse gas emission saving potential (environmental benefits) from waste plastic and waste textile recycling (including credits from material recycling and energy recovery of waste, C and D in Figure 1). 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.

Case 1: Plastic Plastic profile made from recycled plastic vs. virgin impregnated wood		Emission saving potential
Subcase		
1a	Waste plastic is recycled instead of being combusted; plastic profile is combusted.	-
1b	Waste plastic is recycled instead of being landfilled; plastic profile is combusted	---
1c	Waste plastic is recycled instead of being landfilled; plastic profile is landfilled.	-
1d	Waste plastic is recycled instead of being combusted; plastic profile landfilled	+
Case 2: Textile Oil absorbent made from recycled textile vs. oil absorbent made from virgin polypropylene		
Subcase		
2a	Waste textile is recycled instead of being combusted; recycled textile oil absorbent is combusted	++
2b	Waste textile is recycled instead of being landfilled; recycled textile oil absorbent is combusted	+++
Case 3: Plastic Plastic drainpipe made from recycled plastics vs. virgin plastic (high-density polyethylene)		
Subcase		
3a	Waste plastic is recycled instead of being combusted	++
3b	Waste plastic is recycled instead of being landfilled	+

In the plastic profile 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 (subcase 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 causes lower emissions than plastic combustion. And secondly, when the plastic profile is disposed of at landfill sites, no emissions are assumed to be generated.

In all other subcases 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 and combusting the profile at the end of it's lifecycle (subcase 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 subcases 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 subcase 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 subcase 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 subcase 2b.

In the plastic drainpipe concept drainpipe made from recycled plastics replaced the drainpipe made from virgin high-density polyethylene plastic. There are only two subcases in the drainpipe case because the waste management for used drainpipes was assumed to generate identical emissions and credits in both the recycled and virgin plastic life cycle. The results show that if recycled plastic was used to replace virgin high-density polyethylene in drainpipes, greenhouse gas emissions would decrease. This is due to the high energy consumption and thus high emissions in virgin plastic production. Most emission savings would be obtained in subcase 3a, when the waste plastic is recycled instead of being combusted. Here the average fuel mixture of Finnish electricity and heat generation produces lower emissions than energy production with plastic waste and recycling thus generates even more emission savings.

SENSITIVITY OF THE RESULTS

Sensitivity analysis was performed for the plastic profile concept and for the textile concept on some of the issues that were expected to have a major influence on the outcome of the calculations (Hiltunen & Dahlbo 2007). First, the effect of the type of energy substituted by the energy generated within the product systems, 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 favourable over impregnated wood. The key issue in the assessment thus is the reference product and it's origin.

CONCLUSIONS

In this paper the reprocessing of plastic waste into plastic profile or plastic drainpipe 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, polypropylene based oil sorbent for the recycled textile oil sorbent and high-density polyethylene drainpipe for the recycled plastic drainpipe. Focusing only on these 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 were more favourable for plastics recycling when the reference product was of fossil origin as in the drainpipe concept. Here recycling produces high greenhouse gas saving potential. These results are, however, yet preliminary. The assumptions behind these calculations include restrictions on the quality of the plastic material used for recycling. If these assumptions are not met, the efficiency of the process decreases and the quantity of the emission savings may be reduced.

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 might 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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