THE FINNISH ENVIRONMENT 30 | 2007

ENVIRONMENTAL PROTECTION

Reducing Greenhouse Gas Emissions by Recycling Plastics and Textiles into Products

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Helsinki 2007

SYKE

THE FINNISH ENVIRONMENT 30/2007
Finnish Environment Institute
Research Department

Page layout: Ritva Koskinen
Cover photo: Muovix Oy, Dafecor Oy

ISBN 978-952-11-2795-3 (PDF)
ISSN 1796-1637 (online)

FOREWORD

Between 2005 and 2007 the Finnish Environment Institute (SYKE) and the VTT Technical Research Centre of Finland conducted a project titled: "New waste management concepts for reducing greenhouse gas emissions and the development of the concepts towards business in the medium term (UJKON)". The project was funded by Tekes (the Finnish Funding Agency for Technology and Innovation), Kuusakoski Ltd, Vapo Ltd and YTV (the Helsinki Metropolitan Area Council). The project was part of the technology programme organised by Tekes known as "ClimBus - Creating business – mitigating climate change".

The UJKON project was guided by a steering group, composed of the following members: Reetta Anderson (YTV), Alec Estlander (SYKE), Riitta Pipatti (Statistics Finland), Tarja-Riitta Blauberg (Ministry of the Environment), Jatta Jussila (Technopolis), Pia Salokoski (Tekes), Timo Nyrönen (Vapo Ltd) Kai Sipilä (VTT), Antero Vattulainen (Kuusakoski Ltd) and Aimo Aalto (Ministry of Trade and Industry).

The research work was carried out by a project group including the following members from SYKE and VTT: Helena Dahlbo and Marja-Riitta Hiltunen from SYKE; Ilkka Savolainen (project leader), Ulla-Maija Mroueh, Mona Arnold, Margareta Wihersaari, Sirke Ajanko-Laurikko and Tuula Mäkinen from VTT.

The objectives of the project were to find new municipal solid waste management concepts and assess their potential to reduce greenhouse gas emissions in four areas (subprojects): (1) energy recovery, (2) landfill gas collection and utilization, (3) material recovery and (4) biological treatment methods. The implementation costs of the concepts and the business opportunities in Finland as well as in other countries under CDM or JI mechanisms were estimated when possible. From each area one or two concepts were selected for more detailed case studies. SYKE was responsible for the material recovery subproject whereas VTT conducted the other three subprojects.

This report presents the material recovery subproject and more precisely the greenhouse gas emission reduction potential results of two material recycling case studies. The results of the other subprojects will be documented in the final report of the whole project that will be published by the VTT (Mroueh et al. 2007). The project has also produced the report: Kyoto's project mechanisms and the waste management sector - information for companies (Ahonen 2006) (in Finnish). All the reports will be available on the Internet via the web pages of the ClimBus technology programme (www.tekes.fi/climbus)

The authors wish to thank the co-operating companies (Muovix Ltd and Dafecor Ltd) for their favourable attitude towards the project and for providing data for the material recovery case studies. We would also like to express our appreciation to the steering group for their support and expert contributions throughout the project. Finally, the financial contribution of all the funding organisations to the UJKON project is gratefully acknowledged.

Helsinki, July 2007

The authors

CONTENTS

1 Introduction

1.1

Background

Society has always recycled and utilized certain waste fractions as raw materials for new products. Recently, however, the utilization and recycling of waste has become even more important due to the scarcity of unprocessed virgin materials and concerns over the non-sustainable use of natural resources. In addition to this, the increasing cost of waste management, limited landfill space and perhaps most importantly, the climate change impacts of waste decomposition in landfills has also increased interest in recovering waste as either material or energy. Through using waste as the raw material for new products, the wastage of resources can be avoided and energy can be saved. Recycling is also considered as one way to reduce greenhouse gas emissions within waste management and hence it can contribute to the objective of the United Nations Framework Convention on Climate Change (UNFCCC 2006a).

Material recycling is a growing field of activity both globally and in Finland. There is an increasing variety of products that have been produced by using recycled material as the main raw material. The products made from recovered material can either serve the same purpose (e.g. from bottle to bottle) or fall into a different category of application than the primary product (e.g. from glass to fibre).

1.2

UJKON project and objectives of the study

The aim of our study was to identify 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 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, energy recovery technologies, biological treatment methods and landfill gas collection and utilization methods were assessed for their potential to minimise greenhouse gas emissions. The emission reduction potentials of the concepts were assessed against reference cases. In this study the focus was on the main greenhouse gases (CO_2, CH_4, N_2O), and hence, other emissions and environmental impacts were not assessed. The applicability of the technology concepts under the Kyoto Protocol's project mechanisms was also assessed.

The work was carried out in two phases. In the first phase, 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. The purpose was to find concepts in use in Finland which are new and innovative. A number of concepts were identified as relatively innovative and promising, but data for calculating their greenhouse gas emissions were limited to only a very small number of concepts. However, rough estimates of the potential to generate savings in greenhouse gas emissions for one concept in each material category were calculated. If process-specific data was unavailable, we used data for similar processes, or from public databases. A short introduction to the concepts and their emission savings potential is given in Chapter 4. More detailed information can be found in the final report of the UJKON project (Mroueh et al. 2007).

This report concentrates on the second phase of the study, in which two concepts were chosen for a more detailed assessment. The concepts which based on the rough calculations in the first phase showed the most potential to reduce greenhouse gas emissions were chosen as case studies (Chapter 5). The greenhouse gas emissions from these two concepts were compared with emissions from the production of the same products from primary (virgin) raw materials (i.e. reference products). This comparison was performed using the principles of life cycle inventory (LCI) analysis.

2 Material recycling in Europe

2.1

In general

There is growing activity in the field of material recycling in Europe. Material recycling is given high priority in the waste management hierarchy of the European Union. Even so, recycling statistics are still relatively limited and with regard to some material groups, for example textiles, they are completely lacking. Even though the quality of waste recycling data improves every year the data presented here should be treated with caution. In the following short introduction the waste recycling situation in a number of European countries is described.

2.2

Recycling of municipal waste

The municipal waste material recycling data are collected through a questionnaire developed jointly by Eurostat and the OECD (European Commission 2005). The questionnaire is sent to the participating countries every second year. The municipal waste recycling rates by countries illustrated in Figure 1 represent the situation in the year 2002. Material recycling has gained an important role in some Western European countries and accounts for the treatment of up to 33 % (Germany) of the municipal waste total. The average recycling rate of municipal waste in the EU-15 countries (excluding Austria and Luxembourg) was around 19 % in 2002. In some countries (Bulgaria, Cyprus, Lithuania and Malta) municipal waste is almost completely landfilled hence no municipal waste recycling occurred in those countries.

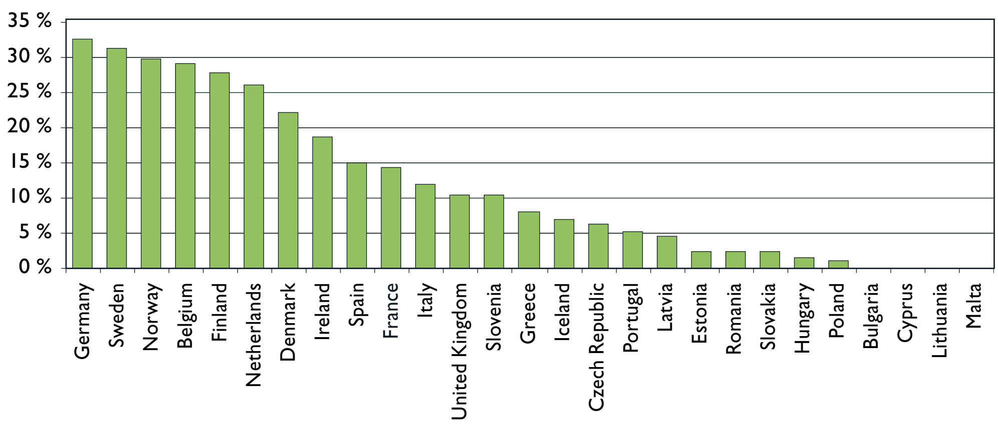

Figure 1. Material recycling rates of municipal waste by countries in 2002

2.3
Recycling of paper, plastics and glass

The figures on the recycling rates of separately collected paper presented in this chapter were taken from the annual statistics of the Confederation of European Paper Industries (CEPI 2005) and they represent the situation in 2004. In Europe about half of the recycled paper total comes from trade and industry sources and the rest comes from households and offices. The data on plastics recycling were obtained from PlasticsEurope (2004) and the figures refer to the year 2002. The data consist of recycled plastics from all sectors; hence it also includes plastics packaging waste. Glass recycling data are for the year 2004 and it is obtained from the European Container Glass Federation (FEVE 2005). The data on separately collected paper, plastics and glass recycling in selected Western European countries are shown in Figure 2.

The figure shows that the recycling rates of different waste fractions differ greatly from one country to another. In several countries like Austria, Finland, Germany, the Netherlands, Spain and Sweden the recycling rate of paper exceeds 60 %. Plastic recycling rates vary from 2 % in Greece to 82 % in Switzerland and glass recycling rates between 24 % (Greece) and 91% (Germany). These shares are not entirely comparable because the definitions of materials may vary between countries.

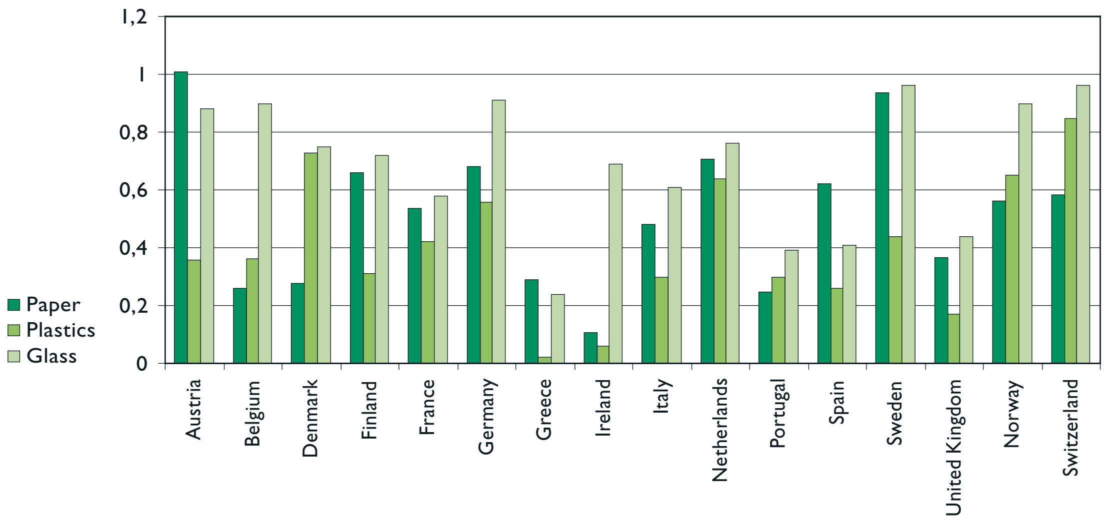

Figure 2. Recycling rates of paper, plastics and glass in selected European countries.

2.4
Recycling of packaging waste

Recycling of packaging waste is regulated in the European Union by the Packaging Directive (94/62/EC). The directive sets percentage targets for packaging recycling in the EU and it also requires the Member States to report the recycling of packaging waste annually. The packaging waste recycling rate data presented in Figure 3 are available from the WasteBase of the European Topic Centre on Resource and Waste Management (WasteBase 2006). The data represent the situation in the year 2002 in the EU-15 countries.

In Germany, the recycling rate of total packaging waste is the highest, reaching over 70 %. Also in Austria, Belgium, Sweden, Denmark, Luxembourg and the Netherlands, the overall recycling target (55%) of the Packaging Directive for the year 2008 has already been achieved. However, there are some countries in which the recycling rate is still relatively low such as Greece, Ireland and Portugal. In most of the countries, recycling rates for paper and glass packaging waste are the highest among all packaging waste fractions. The countries face the most difficulties in plastics packaging waste recycling, since no country has yet reached the 50% level.

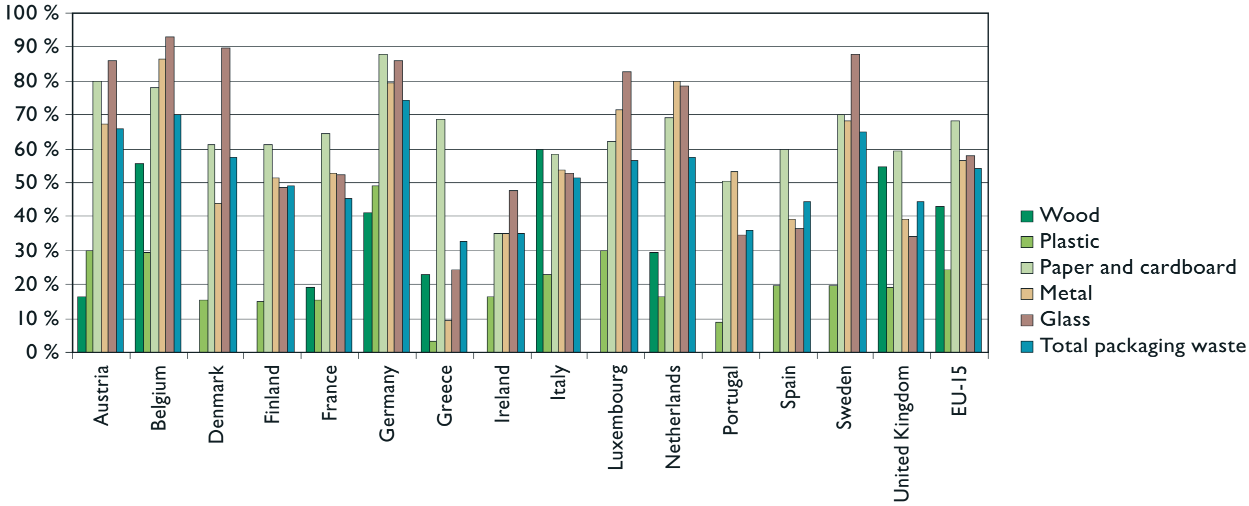

Figure 3. Recycling of packaging waste by materials in the EU-15 countries in 2002.

3 Potential of waste management to reduce greenhouse gas emissions

Waste management generates greenhouse gases both directly and indirectly. Direct emissions are generated

- during waste collection and transportation;
- during waste pretreatment (sorting, crushing etc.);
- in waste utilization processes;
- in landfills during decomposition;
- in waste combustion; and
- in biological treatment

Additionally, indirect greenhouse gas emissions are connected to waste through other functions such as

- energy consumption by the production, transportation and use of the material;
- emissions from production processes (not related to energy consumption); and
- emissions from the production and transportation of the raw materials for the products

The most efficient way to reduce greenhouse gas emissions in waste management is to reduce consumption and thereby reduce waste generation. Material recycling can also 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 cut down 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.

4 Recycling waste into products

4.1
Survey of new Finnish material recycling concepts

In this chapter material recovery concepts for wastes are presented briefly in five material groups. A more detailed introduction can be found in the final report of UJKON project. The information about the concepts was gathered from the Internet and by interviewing the representatives of the companies who deal with the concepts. Rough greenhouse gas emission savings calculations were conducted for one concept from each material group. The estimated greenhouse gas emission savings for different concepts are shown in the summary table (Table 1) directly after the concepts have been presented (Chapter 4.2).

4.1.1
Wood-based waste

Wood-based waste has been recycled and utilized in Finland for several decades. As early as the 1930´s, industry started using recovered paper as a raw material. The paper recovery rate has been increasing continuously and in 2004 it was about 72 % (800 000 t of paper and cardboard) (Finnish Forest Industries Federation 2005). Recovered paper has typically been used as a raw material in newspapers, tissues and core- and packing boards. However, these traditional recovery methods as well as the utilization of wood-based construction waste have been intentionally left out of this study as the focus was on finding new concepts for the recovery of paper.

Paperboard and recycled paper: Urban Mill **-** In the Urban Mill concept, developed by Metso, a small paper mill using recovered fibres is located close to a waste sorting plant and a waste-to-energy plant. The idea is that the waste sorting plant separates paper fibre from solid waste and then the fibre is utilized as a raw material to make paperboard and recycled paper in the paper mill. Other waste fractions are then burned to generate energy, which is used in the nearby paper mill. (Lohiniva et al. 2002). The excess energy is sold outside the consortium. The concept has many environmental and economical advantages. Paper production is located close to large cities, where the existing infrastructure provides good transport connections and sewage treatment. This decreases both the costs and environmental burdens caused by the transportation of the waste and waste paper. The markets for recycled paper are also close. The concept also increases the efficiency of material recycling and decreases the amount of waste disposal at landfills, thereby also reducing greenhouse gas emissions from landfills. (Ristola 2001). Even though the concept has many advantages, further development has been put on hold for the time being (Ristola 2005).

Coreboard: Corenso – Corenso United Oy Ltd’s production plant in Varkaus produces coreboard for different applications mainly in the paper and cardboard industry, textile yarn industry and plastic film industry. The main raw materials of coreboard are mixed waste paper and recycled multi-material packaging such as beverage cartons. In addition to the wood based fibre, plastics and aluminium can be separated in the process. Recycled aluminium is then used in the metal industry and the plastics are gasified into energy. Part of the energy is used in the coreboard production processes and the rest is sold. Coreboard production from recycled fibres requires less energy than its production from virgin wood fibres. (Corenso United Oy Ltd 2005)

Construction and thermal insulations **-** In Finland, there are many companies such as Ekovilla Oy, Suomen SelluvillaEriste Oy and Termex Eriste Oy that produce construction and thermal insulation from waste paper. The companies produce insulations from selected waste paper to which boron minerals are added to increase rot and fire resistance. About 80% of the products weight is recovered newspaper and the rest consists of fire retardants. The insulations are suitable for new and renovated constructions. When a building is demolished the insulations can be reused as they are or they can be utilized in soil enrichment, in recycled paper production or they can be composted. (Ekovilla Oy 2005, Termex Eriste Oy 2005, SelluvillaEriste Oy 2005)

The third concept (construction and thermal insulations) was chosen to represent the wood based waste material group in the greenhouse gas emission savings calculations, because the end product clearly differs from the raw material used in it.

4.1.2
Glass waste

The main raw materials of virgin glass are sand, soda and lime, which are melted into glass at 1500 C. Virgin glass is still used widely but it is increasingly being replaced by recovered glass. In Finland glass recovery has a long tradition. Almost all of the glass bottles belonging to the deposit system are recycled and end up being either refilled or crashed for reprocessing. A part of the municipally collected glass waste is utilized but the rest ends up in landfill. (The Finnish Glass Recycling Association 2005). There are many advantages to glass recycling. Glass can be recycled and used over and over without impairing the quality. Thereby natural resources and expensive raw materials are saved. The use of recycled glass also saves energy, since it is easier to melt than the virgin raw materials. In addition the amount of glass waste disposed of at landfills decreases. However, the impurities in recycled glass (e.g. ceramic materials and porcelain) limit its use. (Suomen uusioaines 2005). Glass can be reused as a raw material for new glass products (containers, glass bottles and -packages and window glass) or glass wool. Recently, TV and PC monitors have also started to be recycled. Monitor glass is mainly reused in the same application but its use as a raw material for the glass and ceramic industry has also been tested.

From the glass waste utilizing concepts that were studied, the production of recycled glass was chosen to represent the glass waste material group in the greenhouse gas emission savings calculations. The recycling concept is not new but it has the potential to be implemented on a larger scale.

Glass products – Karhulan Lasi replaces virgin raw materials with recycled glass in the manufacturing process of different kinds of glass containers. The company manufactures new containers for several product groups such as food, soft drinks, alcohols, drugs and cosmetics. (Karhulan Lasi Oy 2006). The amount of recycled glass in these products is 30-50 %. Most of the recycled glass that the company uses is cleaned and crushed consumer glass obtained from the glass recycler Suomen Uusioaines Ltd. Flat glass can also be used but the share of it in the new products can not exceed 5 %. (Ohlström and Savolainen eds. 2005)

Glass wool – Saint Gobain Isover Oy manufactures glass wool products for thermal insulation and sound rejection. The main raw material of the products is domestic recycled glass (60-80 %). The recycled glass consists mainly of flat glass from glass factories and glass bottles from ALKO, the Finnish alcohol distribution monopoly. Other raw materials are sand, natural minerals and the organic raw materials used in the binder. Isover Oy utilizes about 70 % of the recycled glass total in Finland annually. In the production process the raw materials of glass and recycled glass are melted. The glass is then defibred in a spinner, and the binder is added to bind the fibre together. (Saint Gobain Isover Oy 2003)

Monitor glass – The number of TV and PC monitors removed from service will continuously grow in the future. The monitors include a lot of glass material which could be utilized. CRT-Finland Ltd recycles cathode ray tubes and reprocesses them into the raw material for manufacturing new cathode ray tubes. During the recycling of monitors it is crucial to be able to separate the panel glass from the leaded funnel glass. CRT-Finland Ltd uses a unique laser technique to split the cathode ray tubes and thus the two different glass materials are separated from each other. After the separation process, the glass is crushed and purified and recycled back into the production of cathode ray tubes. (CRT-Finland Oy 2006, Loimi-Hämeen Jätehuolto Oy 2006)

The recycling of cathode ray tube glass into a raw material for the ceramics and glass industry has been examined by the University of Art and Design Helsinki together with the glass using industry (Siikamäki and Leppänen 2003). In the ceramics industry recycled monitor glass material can be used as a raw material in glaze and ceramic mass. In the glass industry monitor glass can be used to replace some or in some cases all use of virgin raw materials. The end products are for example tiles, drinking glasses and vases. The examination revealed that it is possible to use recycled cathode ray tubes as a raw material in the ceramics and glass industry, but no commercial application in this field has yet emerged.

4.1.3
Textile waste

There is a variety of business activities in the textile recycling field both in Finland and in other countries. Even though quite a large amount of textiles are recycled, the processing of the recovered textiles into new products is relatively minor. The use of recovered textiles reduces the amount disposed of at landfills. It also reduces the use of virgin raw materials and thereby decreases the use of natural resources (e.g. water, energy, chemicals). Textile reprocessing can be roughly divided into three categories: sorting and reuse of good quality textiles, industry and machine cleaning cloth (wipers) production and mechanical defibreing (e.g. non-woven fabric products, papers or raw material for yarns). Textile waste reprocessing into cleaning cloths is quite a simple process, hence there are many cleaning cloth manufacturing companies in Finland and elsewhere in the world. In this study the manufacturing of cleaning cloth was not under examination, instead three smaller scale textile waste reprocessing concepts were studied.

Non-woven products for industry, building and construction, gardening and upholstery - Dafecor Oy manufactures a variety of products from recovered textiles for different applications. This concept was chosen for a case study, and it is presented in more depth in Chapter 4.4.

Utility article manufacturing - In principle recycled textiles can also be used as a raw material of utility articles. This idea was developed and tested under the supervision of the Tampere University of Technology in the early 2000’s (Nieminen and Talvenmaa 2003). In the project, cast-off rental textiles were used as a raw material for new products. Firstly the textiles were defibred and then the University of Art and

Design Helsinki designed product models, which were technically easy to produce. The outcome of the project was a range of utility articles such as bags, containers, boxes and different kinds of screens. Despite the promising results the manufacturing of the utility articles from used textiles has not been continued.

Fibre and fibre product manufacturing – SOEX Textil-Vermarktungs GmbH in Germany recycles and reprocesses textiles into new products. The textiles which are not suitable for second hand clothing are pre-sorted according to the colour and type of fabric and are used as a raw material for new products. The end product of the reprocessing plant consists of reprocessed fibres of cotton, wool and acrylic, which are sought for example by the automotive industry for the production of acoustic insulation materials. A large share of the product is used in the company's own non-woven plant. The end products of the plant are used for example as carpet underlay or mattress inlays in the home textiles industry, as insulation material in technical applications or as geo non-woven fabrics for road construction purposes. (SOEX 2006)

The concept in which different kinds of non-woven products are manufactured was chosen to represent the textile material group in the greenhouse gas emission reduction potential calculations. The concept was also chosen for the case study in Chapter 4.

4.1.4
Plastics waste

Oil is the basic feedstock of plastics. About 4 % of crude oil is used in plastics manufacturing (The Finnish Plastics Recycling Ltd 2006). Recycling of plastics can reduce the use of raw materials and energy in the virgin plastic production process and also the greenhouse gas emissions originating from waste plastics combustion. Littering problems arising from waste plastics would also diminish.

The separation of plastics from municipal waste by households is quite rare in Finland except for drinking bottles which are recycled efficiently. Usually separately collected plastics originate from industry, mainly the plastics industry. A large proportion of used plastic could be utilized either mechanically or chemically. In mechanical recycling the plastics are shredded or crumbled to a flake or granule form and contaminants like paper are removed. The flakes/granules are then washed and dried and extruded to pellets or products for sale to the plastics market. In the feedstock (chemical) recycling polymers are broken down into monomers and then re-polymerized to produce a hydrocarbon feedstock for the petrochemical industry. Plastics can also be used as a reducing agent in steel furnaces. (Smith et al. 2001: McDougall et al. 2001).

In Finland separately collected plastics are used as a raw material for example in manufacturing plastic profile (building material). Textiles can be manufactured from plastics but this has not yet been tried in Finland. The production of plastic profile and textiles from waste plastics are presented here. The plastic profile production was chosen to represent the waste plastics material group in the greenhouse gas emission reduction potential calculations and was also chosen for a case study (Chapter 5).

Plastic profile manufacturing **-** Presented in detail in Chapter 5.3.

Textile production **-** Wellman Inc. is one of the world's largest recyclers of plastics and produces polyester fibre made from recycled bottles. The company purchases post consumer PET bottles from soft drinks, water, fruit juices, and sport drinks; it also collects other rigid PET containers as well as post industrial by-products from polyester fibre, resin and film manufacturing processes. From this recycled material it produces polyester staple which is used in pillows, comforters, sleeping bags, scrub pads, furniture (seat backs), mattress pads, automotive trunk liners, grill covers and geotextiles for road bed and pond liners. Wellman has also developed a 100% recycled content fibre (Fortrel® EcoSpun®) that is used in producing manufactured products such as outerwear jackets, bags and T-shirts. (Wellman Inc. 2006)

4.1.5 Metal waste

Metal recycling has a long history. Scrap metal is a valuable raw material and its quality does not degrade during recycling. Almost all scrap metal in Finland is recycled. (Melanen et al. 2000) Nearly 98 % of the cans belonging to the deposit and refund system are recycled (The Association of Environmental Enterprises 2006) but only about half of the metal packaging is recycled (PYR 2006). Recycling of metal waste can reduce the environmental impacts from the mining industry, the space needed at landfill and the emissions originating from landfill sites (Melanen et al. 2000). A lot of energy can also be saved by recycling metals compared with the use of virgin metals. The energy saving in steel- and sheet tin packaging manufacture is 75 % and in aluminium packaging it is 95 % (Mepak Recycling Ltd 2006).

In Finland there are many companies which focus on recycling and refining scrap metals. The processes within companies are identical; hence only one company is presented here. The greenhouse gas emission reduction potential of recycling waste metal is assessed by using one particular company as an example.

Scrap metal recycling –Kuusakoski is the biggest company in Finland which recycles and refines waste metal. The main raw materials of the company are recycled metals and metalliferous cast off products such as vehicles and electric and electronic appliances. The most important end products are iron, stainless steel and aluminium casting alloys to be used as a raw material within the base metal and foundry industry. The recycling process includes the sorting of the recycled material, pre-treatment, crushing, separation and metal refining.

4.2 Estimation of the potential to reduce greenhouse gas emissions using the concepts studied

The following approach was used to calculate the greenhouse gas emission reduction potential of material recovery. First the virgin material that the recycled product substitutes was defined. Then the emissions originating from the production of the recycled product were compared with the emissions from the production of a similar product from virgin material. In many of the concepts the replaced product and its production process are the same as for the recycled product, but it is manufactured from virgin raw materials. In these cases the emission savings consist of the emissions originating from manufacturing the virgin raw material, because the recycled material is considered to produce no emissions. The differences between the energy consumption of the production processes are taken into account. It should be noted that these calculations are approximate and they are not based on life cycle inventories, hence they exclude important processes such as waste management, transports and external processes such as energy recovery from waste management.

The greenhouse gas emission savings, calculated as carbon dioxide equivalents, for different waste recycling concepts are presented in Table 1. The exact calculation procedures for the emission savings of each concept and the emission savings by compounds (CO_2, CH_4, N_2O) can be found in the final report of the UJKON project (Mroueh et al. 2007).

Table 1. Emissions and emission savings of the examined concepts expressed as carbon dioxide equivalents (CO_2-eqv.) per (1) ton of produced product. (Global warming potentials obtained from IPCC 1996[1])

Concept	CO2-eqv. of reference product	CO2-eqv. of recycled product	CO2-eqv. emission savings
Wood based			
– mineral wool vs. thermal insulation made of paper fibre	990	225	*765*
Glass			
– 25 % recycled glass vs. 59 % recycled glass in glass	463	362	*101*
Textile			
– a mat made of virgin polypropylene vs. a mat made of recycled textile fibre	2 182	115	*2 067*
Plastics			
– virgin plastic vs. plastic profile	2 866	172	*2 695*
– concrete beam vs. plastic profile	195	172	*24*
– steel beam vs. plastic profile	498	172	*327*
Metal			
– virgin steel vs. recycled steel	2 174	440	*1 734*

* wood and recyclable paper and cardboard
Totals may not agree because of rounding.

The calculations show that material recycling has the potential to reduce greenhouse gas emission in all material groups. The highest potential for emission savings exists within textiles and plastics recycling. It should be noted, however, that the high greenhouse gas reduction potential for plastic waste recycling only exists when recycled plastics replaces virgin plastics. Replacing other materials produces less significant savings. Metal waste recycling also has high greenhouse gas emission reduction potential.

[1] GWP values from the year 1996 are used when reporting emissions to the UN Framework Convention on Climate Change (UNFCCC).

5 Case studies

5.1

Selecting the concepts for the case studies

Two of the concepts presented in Chapter 4 were selected for more detailed case studies, based on the following six staple criteria:

1. The concepts have the potential to reduce greenhouse gas emissions (based on the estimation reported in Chapter 4).
2. The concepts have enough recyclable material available to be viable, i.e. the amount of the untreated material within municipal solid waste is relatively high.
3. In the chosen concepts the new product serves a different purpose than the recycled material it is made from (e.g. from bottle to bottle was not taken into account).
4. The concepts are already in use in Finland.
5. The concept and the new product also have potential markets abroad.
6. The greenhouse gas emission reduction potential of recycling these materials has not been widely studied before.

On the basis of these criteria, one concept was chosen from the plastics material group and one from the textiles material group. In the plastics concept, the recovered waste plastics are reprocessed into *plastic profiles*, and in the textiles concept, discarded textiles from the textile industry are reprocessed into *oil sorbents (mats)*. According to the approximate estimation (in Chapter 4), the potential to reduce greenhouse gas emissions is high in both concepts. In both concepts, the products made from the recovered material fall into a different category of application than what the recovered material was originally designed for.

Even though the two concepts seem very promising in reducing greenhouse gas emissions there are some disadvantages related to them. Firstly, the products from the concepts are not mass-produced; hence the real potential for reducing greenhouse gas emissions is relatively low globally and in Finland. Secondly, the concepts are still relatively new and underdeveloped, so there is no public data available for the exact greenhouse gas emission savings calculations.

5.2

Method, goal and scope of the study

Life cycle approach

The Life Cycle Inventory (LCI) method was used to assess 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 emissions to the air, water and soil are estimated at each stage of manufacture, use and disposal of the product. These are then related to the potential environmental impacts such as global warming.

A complete LCA is usually very resource intensive and complicated, hence it is common to reduce the scope of an LCA to specific life cycle stages e.g. end of life, or specific environmental issues such as energy consumption or global warming. This is referred to as a streamlined LCA. The scope of an LCA study defines the framework and application of the LCA. (Woolridge et al. 2006). In this study the scope was restricted to greenhouse gas emission savings of different waste recovery concepts. Therefore full LCA was not conducted and the study was 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).

Reference products and the functional units

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 as impregnated wood, because in most applications the plastic profile replaces impregnated wood and less frequently other materials. Polypropylene fibre was chosen as the reference product for the textiles concept due to the fact that oil sorbents are now increasingly made from recycled textile fibres but many are still made from virgin polypropylene.

Functional units, i.e. the reference units against which all the input and output data are calculated to enable comparison of 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 the materials are needed to fulfil the same purpose of use (plastic profile 2 700 kg/100 m^2, impregnated wood 2 250 kg/100 m^2 (Muovix Oy 2006; Prima Group Oy 2006)). For the textiles concept case study the FU was defined as one ton of oil sorbent mat, since there is no significant difference in the absorption capacity between the reference product and recycled product (reference product 13,5-25 times of its own weight, recycled product 18 times of its own weight). Hence, it was assumed that both products have the same absorbent capacity (Dafecor Oy 2006; Sinituote Oy 2006; Suomen Elektrodi Oy 2006).

System boundaries

Defining the system boundaries is important because the emission level is dependent on boundary setting. The system boundaries set for the product systems for this study are presented in Figure 4. In the same figure the sources of emissions from both recycled and virgin product lifecycles are also represented. The letters from A to D refer to the greenhouse gas emissions savings calculations. They are discussed in the next section where the principles of calculations are presented.

The product systems studied covered all the processes in the life cycles of the products from raw materials to the disposal of the products (Figure 4). The product systems were divided into life cycle stages to enable evaluation and comparison of the relative contributions of each stage within the same product system or between the stages within different product systems. The emission data were gathered from the life cycle stages marked with capital letters in Figure 4.

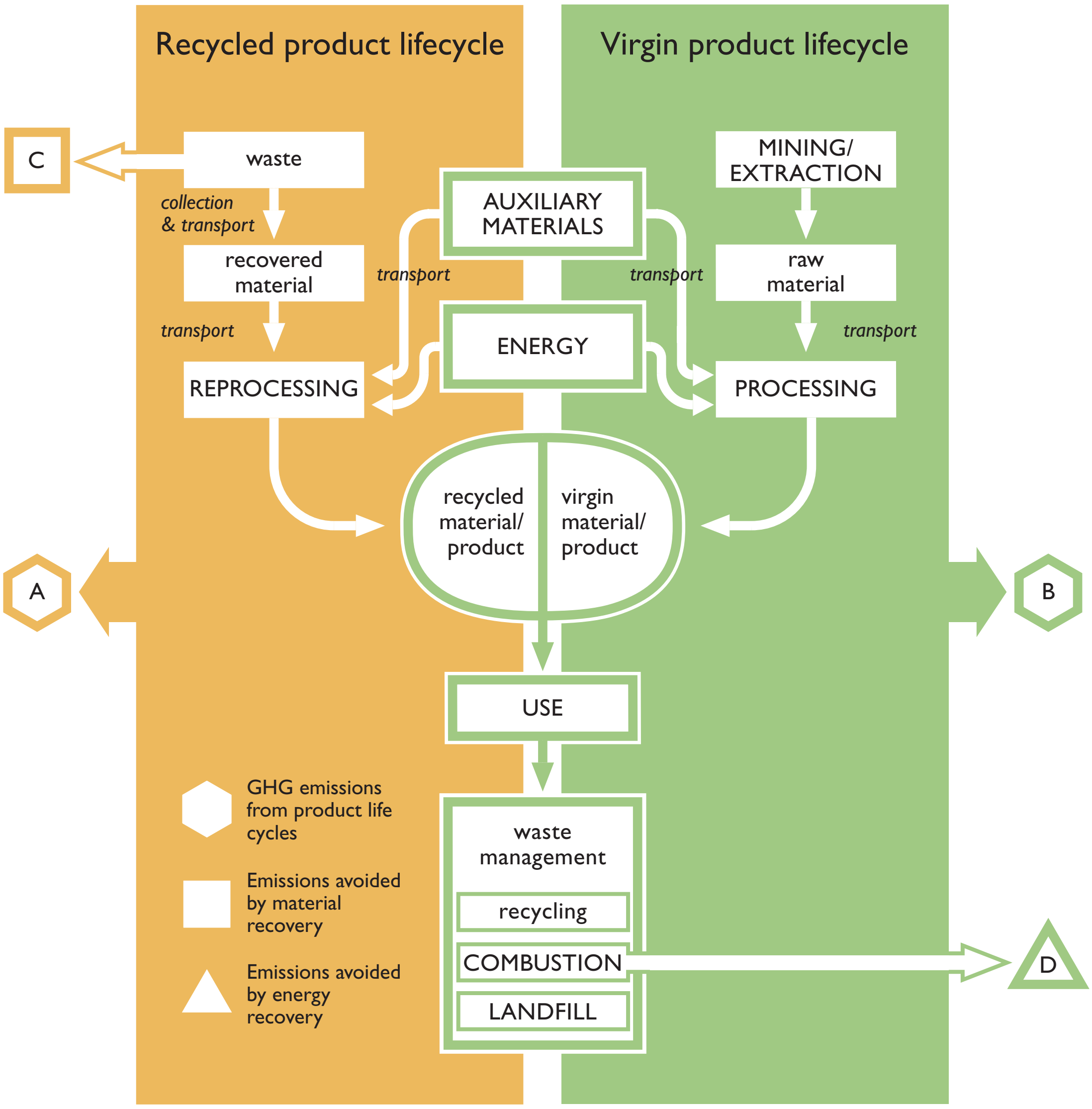

Figure 4. System boundaries of the recycled and virgin product. Capital letters in the boxes indicate the life cycle stages from which the emission data were gathered. (Modified from McDougall et al. 2001). A = emissions from the recycled product life cycle, B = emissions from the virgin product life 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.

In the recycled product case, the life cycle stages for which the emission data were gathered were:

- recycled material reprocessing (including auxiliary materials and electricity);
- waste management; and
- transportation.

For the virgin material lifecycle the stages were:

- raw material manufacturing;
- raw material processing (including auxiliary materials and electricity);
- waste management; and
- transportation.

In the waste management stage the waste is either recycled, disposed of at landfill or combusted. The use of the product was also considered to be a life cycle stage but it was assumed to produce no emissions. The flow charts of the product systems were constructed using the KCL-ECO 4.0 software, which is a calculation programme suitable for life cycle assessments (KCL 2006). The flow charts are presented later in Chapter 5.3 for plastics and in 5.4 for textiles.

The principles of greenhouse gas emissions savings calculations

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 savings calculations. The calculation principles were as follows. (The letters A-D refer to Figure 4).

- Greenhouse gas emissions from the recycled product life cycle (A) were quantified where possible. The manufacturing of auxiliary materials, the energy production, the transportation 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 would be avoided when the waste (=raw material of the recycled product) entering the product system was recovered, instead of being disposed of at landfill or combusted to produce energy.
  If waste was recovered instead of being disposed of at landfill, the avoided emissions would be equal to the emissions that would have been emitted in the landfill due to decomposition of the material. On the other hand, if waste was recovered instead of being combusted, the energy, which could have been gained from combustion, would have to be generated from another energy source. In this study, the other energy source was assumed to be the average Finnish electricity and heat production. Thus the avoided emissions from material recovery is the difference in emissions released between energy produced by the average Finnish electricity and heat production compared with an equal amount of energy from waste combustion.
- Finally, the emissions avoided by the energy recovered from the combustion of the cast-off product in the waste management phase (D) were added. The energy recovered from waste combustion replaces energy generated with other energy sources; which in the basic calculations was the average Finnish electricity and heat generation.
  The energy recovery from waste consists of two elements. Firstly, energy can be generated by combusting the waste from the recycled material product system. This energy and emissions from it were already included in the recycled product life cycle (A), but in addition to these it should be considered that this energy substitutes other energy and emissions from its production. Thus, emissions from producing the energy with the average Finnish electricity and heat production are avoided. These are added to the total emission savings.
  Secondly, energy can be generated by combusting the cast-off virgin product. If the virgin product is replaced by the recycled product, there will be no emissions from combusting the cast-off virgin product. If, however, the cast-off virgin product is not combusted to generate energy, this energy has to be produced by another energy source. The amount of avoided emissions is the difference between the emissions from producing the energy with the average Finnish electricity and heat production and the emissions originating from producing the same amount of energy by combusting the cast-off virgin product. These avoided emissions are not realized when recycled material is used instead of virgin. This is accounted for in calculating the avoided emissions of energy recovery from waste management (D).

The overall greenhouse gas savings result from the equation B - A + C + D. There are 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.

Data quality requirements

For the inventories, site-specific emission data were used when possible; otherwise the data were gathered from the best available sources. The data for recycled material processing and transportation distances are site specific and were obtained directly from the companies. The data for the virgin material production were gathered from different sources such as the Association of Plastics Manufacturers (Plastics*Europe*) and the Finnish Pulp and Paper Research Institute (KCL Datamaster). For the emissions from transportation, the calculation system for traffic exhaust emissions and energy consumption (LIPASTO) developed by the Technical Research Centre of Finland (VTT) was used. Other data sources such as the Ecoinvent database (2005) were also used if site specific data were not available. The site-specific data represent the situation in 2005, but most of the other data originate from the late 1990's or early 2000's.

Structure of the following chapters

In the following chapters (5.3 and 5.4) the plastics and textiles case studies are presented. Both chapters are structured in the same way. They begin with a short description of each examined concept, followed by an inventory analysis by life cycle stages. Finally, a short summary of the avoided emissions is given. The results of the case studies are presented in Chapter 5.5.

5.3 Concept I, Plastics

5.3.1 Description of the concept

Waste plastics can be utilized as a raw material for many different products. In this study the concept of reprocessing waste plastics into plastic profile was chosen to demonstrate the potential of plastic recycling to reduce greenhouse gas emissions. In Finland Muovix Oy manufactures plastic profiles which are mainly used to substitute pressure impregnated wood. Hence impregnated wood was chosen as the reference product against which the emissions from plastic profiles life cycle were compared. The profile can also occasionally substitute other materials such as virgin plastics, concrete or steal but these are not examined within this case study.

Muovix Oy recovers and processes industrial and commercial waste plastics at the Riihimäki, Joensuu and Salo production plants. The end products are a plastic raw material for use in industry and plastic profile for use in construction and agriculture. Plastic profile can either be a ready made product or used as a building material. Profiles can be used for example in horse stalls, fences, gratings, traffic obstacles, embankment structures, sandboxes, tables, benches and consumer products such as sawhorses. The profile is at its best in applications where it touches the ground or water or becomes dirty. The profile, having the form of a plank or pole, can be sawed, planed, nailed, screwed and painted. In contrast to wood, the profile stands up well to wear and tear, does not rot and is easy to wash and disinfect. It is also resistant to insects and fungi. (Muovix Oy 2007)

All plastics (including PVC), even mixed, are suitable raw materials for the profiles. The most common raw materials are remainders from the plastic industry, left over granules, plastic car parts and agricultural plastics. Waste film (e.g. stretch film, package film) and packaging waste (e.g. bottles, reels, canisters and trays) are also used. About 60-80% of the plastics that the company uses consist of HDPE, LDPE, PP and PS plastics and about 10-30% are PET, ABS, PC plastics. PA, PMMA and PVC (0-10%) are used as filling materials. Small contaminants such as tapes, labels, cardboard and small metal parts can be tolerated by the process. However, plastics that contain hazardous waste, sand or gravel, rubber, wood or food can not be used. (Surakka 2006)

The production technology of the profile is based on Julien Environment Technology (2006). The Muovix-profile is the first of its kind in Finland but elsewhere in Europe a similar technology has been in use for sometime. The production process begins with the quality assurance of the received raw material (Figure 5). The material is then grinded and agglomerated or fine grinded depending on the composition of the material. From the grinder the material is moved to a storage bin and then forwarded to a mixing silo. The coloring agents are then added to the mass. In the extruder, the material is melted and then directly finished into the required shape. At the end of the process the product is cooled and packed. (Surakka 2006)

Muovix Oy utilizes about 6 000 tons of waste plastics annually of which about one half are film plastics. The total annual amount of waste plastics in Finland is 140 000 – 160 000 tons of which the company utilizes about 4 %. (Surakka 2006)

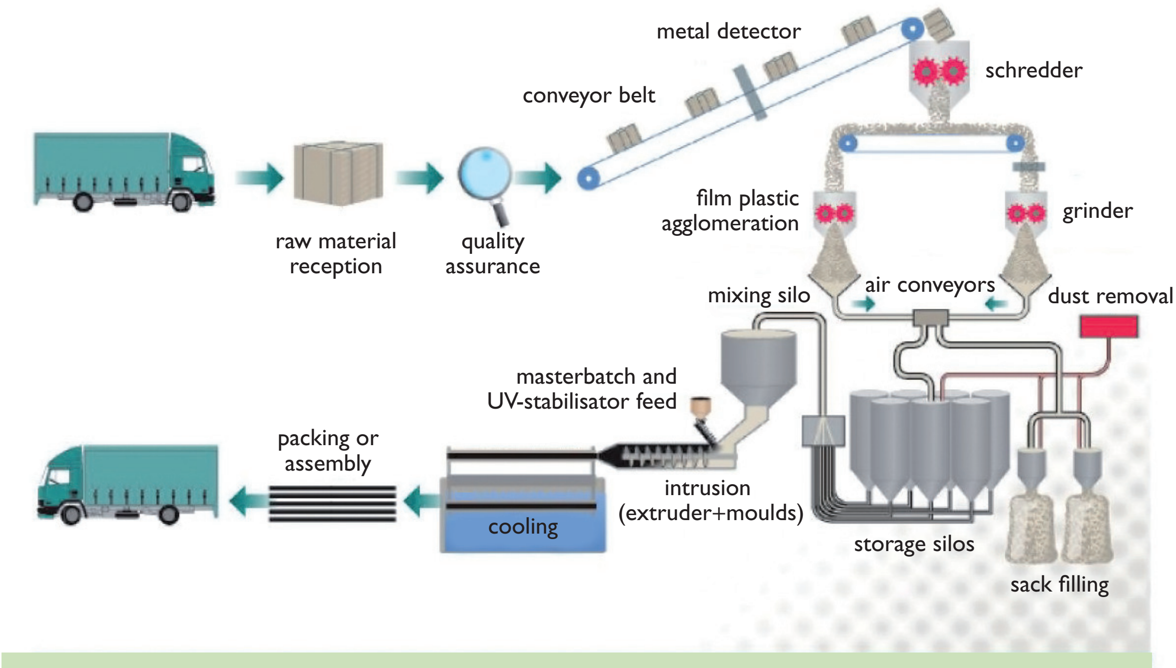

Figure 5. Process chart of the Muovix plastic profile.

5.3.2

Inventory analysis

The study covered the entire life cycles of both the recycled product (plastic profile) and the reference virgin product (impregnated wood) (Figure 6). The KCL-ECO software calculates inventory results per functional unit, which in this case is 100 meters squared (m^2) of board. In the following the life cycle stages and data sources are presented. The use stage was assumed to produce no greenhouse gas emissions and was thus excluded from the calculations. Summarized information of the unit processes is available in Appendix 1 and the transportation modules in Appendix 2.

Raw material acquisition

The main raw material of the plastic profile is waste plastics obtained primarily from industry. The waste itself is assumed to produce no greenhouse gas emissions; hence the raw material for plastic profile is emission free. The emissions avoided by recycling the waste instead of combusting it into energy are discussed in Chapter 5.2.

The main raw material of the reference product i.e. the impregnated wood is pine. The module for the timber (pine) includes emissions from working machines used in two thinnings and in regeneration felling for pine logs (KCL Datamaster). The production of fuels (petrol, diesel, hydraulic oil and chain oil) used in the machines is also taken into account (Fortum Oil and Gas Oy 2002).

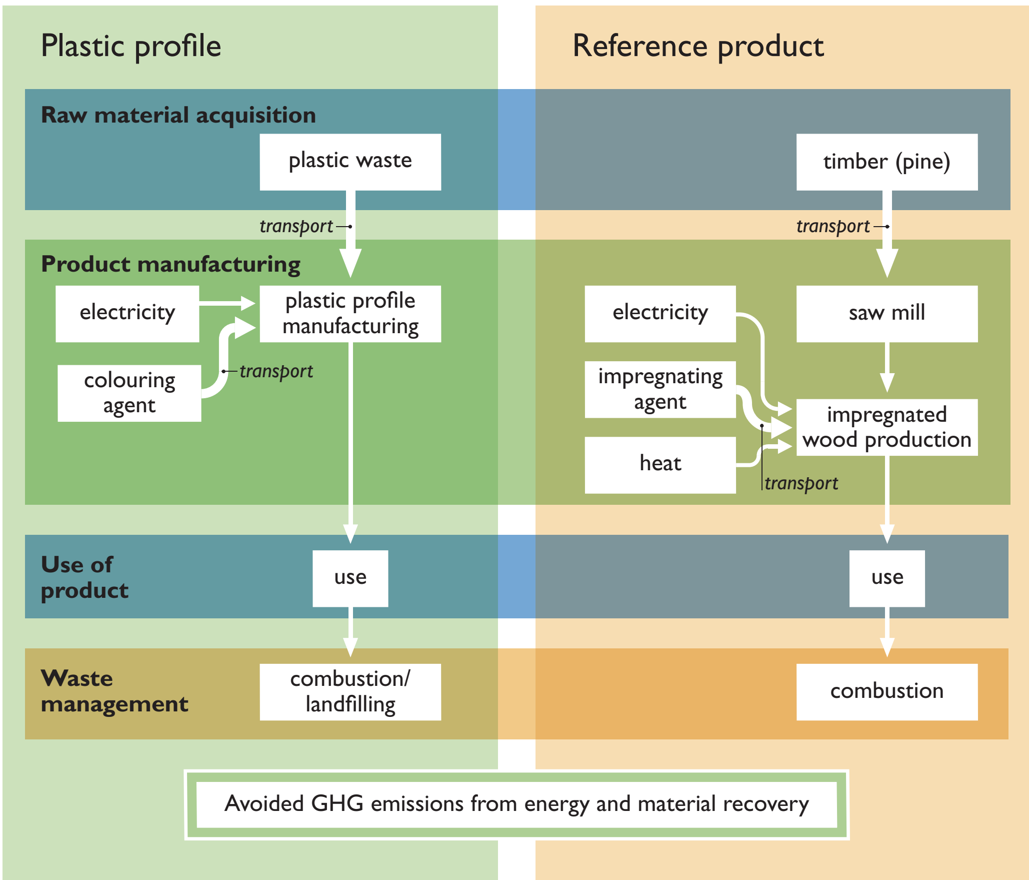

Figure 6. The flowcharts of the plastic profile and the reference product i.e. pressure impregnated wood.

Product manufacturing

The manufacturing process of the plastic profile is presented in detail in Chapter 5.3.1. Besides electricity, the only materials used in the process are waste plastics and the colouring/UV-protection agent. For the purpose of the calculations it was assumed that the process used the average Finnish electricity supply (model presented in Appendix 3a). Emission data for the colouring agent production was not available. However, information about the amount of electricity used in its production process was, received from the producer (Premix Oy 2006). Hence, emissions from producing the electricity were used instead. The agent is manufactured in Denmark, and thus, the electricity profile of Denmark was used (Ecoinvent database 2005).

The production of the impregnated wood begins at the sawmill, where the timber is sawn to the right length and width. The sawmill data (KCL Datamaster) represent the average data on sawmills in Finland based on the level of technology typical for Finland in 1999. The electricity used in the sawmill is included in the sawmill module and is based on the average electricity in Finland in 1999. The main product is sawn timber but simultaneously chips are also produced. However, the chips have been excluded from this study.

After the sawmill the wood undergoes the pressure treatment, which is a chemical wood preservation process where the impregnating agent is penetrated through wood by pressure. The pressure is generated with electricity. Heat is used to speed up and enhance the adhesion of the impregnating agent. (Viitasaari 1991). The wood can be impregnated by using either organic active ingredients, creosote oil or by using water based salt impregnating agents, in which the active ingredient is copper, arsenic or chromium. However, the use of impregnating agents is highly regulated and since 2002 the use of chrome and arsenic in the pressure treatment of board and planks has been prohibited and the use of creosote has been restricted to only certain professional uses (SYKE 2003).

The manufacturing data (including the amounts of raw materials used) for the pressure impregnated wood were obtained from a Finnish medium-sized company, producing wood board and using copper based impregnating agent in the process (Prima Group Oy 2006). The data concerning impregnating agent was obtained from the Ecoinvent database (2005) and it represents an organic salt wood preservative containing no chromium. The data includes all inputs to the production processes and their transportation, but excludes the process emission data. Heat needed in the process is produced using light fuel oil, which is burned in a small boiler. The production data of the light fuel oil was obtained from Fortum Oil and Gas Oy (2002). The emissions from the heat production were calculated using the emission coefficients for fuels prepared by Statistics Finland (2006). Burning light fuel oil produces greenhouse gas emissions of which only the CO_2 emissions were taken into account because the emissions of CH_4 and N_2O are minor from the type of boiler in question (Tohka 2006). For the purpose of the calculations it was assumed that the process used the average Finnish electricity supply (Appendix 3a).

Waste management

After use, the plastic profile can either be combusted to produce energy or disposed of at landfill. In the short term plastics do not degrade, hence the disposal of plastics at landfills was assumed to produce no emissions. Combustion of plastic generates greenhouse gas emissions, but it also produces energy which can substitute other energy sources such as fossil fuels. This energy from plastics was taken into account in the calculations by using methodology that is discussed thoroughly in Chapter 5.2. Here only the direct emissions from the combustion of waste plastics are examined. The data for CO_2 emissions from combusting plastics are from Statistics Finland (2006) and the data for CH_4 and N_2O emissions are obtained from the Ecoinvent database

(2005). The efficiency of energy production in the combustion plant was assumed to be 80 % (Tohka 2006).

The disposal of pressure impregnated wood is highly regulated. Impregnated wood containing arsenic or chromium is classified as hazardous waste and has to be disposed of according to the respective regulations. Currently in Finland all the discarded impregnated wood is stored for later treatment in the hazardous waste combustion plant which is at planning stage (Tähkälä 2006). The combustion of the impregnated wood produces both biogenic (from wood) and fossil (from impregnating agent) emissions but only the fossil emissions were included here. The data for CO_2 emissions from the impregnated wood combustion are obtained from Statistics Finland (2006) and CH_4 and N_2O emissions are from the Ecoinvent database (2005). The efficiency of energy production in a wood combustion plant was assumed to be 80 % (Tohka 2006).

Transportation

Only transportation of the main raw and auxiliary materials to the production plants was included in the inventory. The transportation distance of the waste plastics to the profile production plant as well as the distance of the timber from the forest to the sawmill was assumed to be 100 km, but the transport equipment and the degree of loading differed. The waste plastics are transported using a full trailer and the timber using a timber lorry. Both materials are transported with full loads but waste plastics consume a lot of space relative to weight, hence plastic loads weigh from 3 to 15 tons even though the maximum capacity of a full trailer is 40 tons. It was assumed that both end products (plastic profile and impregnated wood) were used in Finland and the transportation distances of the end products to the consumer were assumed to be equal. Some differences in the emissions might occur due to the different weights of the end products. However, these emissions were assumed to be minor and hence they were excluded from the inventory. The transportation distances to the waste management sites were also assumed to be equal for both discarded products and the difference in emissions from transporting the products were assumed to be minor, thus they were ignored.

The auxiliary materials are produced abroad. The colouring agent is transported from Denmark by ferry and the impregnating agent from England. The transportation of these was included in the inventory due to the large amount of impregnating agent needed in the impregnating process and it's possible significance for the results. The waterborne traffic distances were estimated from Couper (1989).

Emissions from transportation were calculated using the specific emission coefficients by vehicle type obtained from the Unit Emissions of Traffic Calculation System developed by the VTT (2002). Return transport was only assessed for transportation of timber from forest to the mill, since it timber lorries always return to the forest empty. For other materials, the return trip was neglected due to the assumption that other goods were transported on the return trip. The emissions from the production of fuels were included (Fortum Oil and Gas 2002). The transportation modules are presented in Appendix 2.

5.3.3

Emissions avoided by material and energy recovery

If we want to assess the greenhouse gas emission savings potential of material recycling, then only comparing the life cycle stages of the recycled and virgin product systems is insufficient (A and B in Figure 4, flowcharts in Figure 6). In addition to the emissions avoided by material and energy recovery have to be taken into account (C and D in Figure 4). It is essential to include these processes because they might have a significant effect on the overall results when assessing the greenhouse gas emission reduction potential of material recycling.

Emissions avoided by material recovery. In the raw material acquisition life cycle stage the waste plastics are recovered and used as a raw material for the plastic profile. This procedure prevents the waste plastics from being disposed of at landfill or being combusted. Therefore the greenhouse gas emissions from plastics landfilling and combustion are avoided. Plastics landfilling would not generate emissions but if waste plastics were combusted, this would produce both emissions and energy. This amount of energy now has to be produced using another energy source, since in this case study the waste plastics are recovered as material. For the purpose of the calculations, it was assumed, that the energy that would have been produced by the combustion of the plastics would be replaced by the average supply of electricity and heat in Finland.

Emissions avoided by energy recovery from waste. The energy recovered from waste can be considered a by-product of waste treatment. In this study credits were given for the by-products of the production system by deducting the emission data of the product replaced by the by-product from the total life cycle emissions of the product system. In the plastics recycling case study, energy is recovered from waste in the waste management life cycle stage, if the cast-off plastic profile is combusted. The production of this energy decreases the need for other energy sources of the same value. Thus, the fuel that is assumed to have been required for the external energy production determines the amount of emissions avoided. For example, renewable energy sources and natural gas are more environmentally friendly fuels than coal in the context of greenhouse gas emissions. Therefore, the energy generated from waste provides relatively larger reductions in emissions if it is assumed to replace for instance coal rather than when it replaces for example wind energy or natural gas. In this study, the emissions avoided (credits) from the energy recovery of waste combustion are calculated based on the average fuel mixture used in Finnish electricity and heat generation. (Appendix 3b). The data regarding the average Finnish electricity and heat generation includes emissions from all fuels in the appropriate proportions.

The avoided emissions from not combusting the reference product are also taken into account to find out the total greenhouse gas emissions savings from the waste management life cycle stage of the whole system. The methodology is explained in Chapter 5.2.

The data sources of the emissions considered in the above mentioned processes are the same as in waste management life cycle stage presented in Chapter 5.3.2. The information sources for the Finnish electricity and heat generation are presented in Appendix 3b. The data and the main calculation principles for the avoided emissions are presented in Appendix 4.

5.4 Concept II, Textile

5.4.1 Description of the concept

Despite the fact that the amount of textile waste is considerable and that a relatively large amount of this is recycled, the reprocessing of textiles into new products is only done to a minor degree. The concept of producing oil sorbent mats was chosen for a case study to demonstrate the potential for greenhouse gas emission reductions by waste textile reprocessing. Since 1994 Dafecor Oy, Finland, has produced different types of oil sorbent mats from waste textiles. Oil sorbent mats can also be manufactured for example from polyethylene, flax or mineral fibre, hence virgin polypropylene mat was chosen as the reference product of this study.

Dafecor Oy uses recovered textiles for producing various non-woven products mainly for the needs of industry, building and construction, gardening and upholstery. The products for industry include oil adsorption rug (mats), floor protection carpets and wiping cloths for handling and preventing spills of hazardous liquids. Building materials and felting as well as wadding for upholsterers are also produced. Gardening products include irrigation mats for growing seeds, seedlings and flowers. The main raw material of the various Dafecor's products is waste from the domestic textile and clothing industry. Additionally cast-offs from households and hospital laundries are used. The end product contains approximately 50 % wool, which can absorb 18 times more liquid than its own weight. The rest of the product is made up of other materials e.g. polypropylene or cotton. Mineral oil lubricant is also used in the products. (Dafecor Oy 2006, Saha 2006)

Dafecor uses a mechanical ripping and carding process during production. First, the raw material is shredded with the rotational crusher and sorted according to the fibre type. Second, the material is crushed into the correct fraction sizes and treated with the card oil. This is followed by the three-phase mechanical ripping-carding process in which the raw material is defibred. The fibres are then folded and needled into fibre blanket. In the needling phase other materials such as plastic film can also be attached to the product. Finally, the fibre blanket is cut to the correct size and packed. (Saha 2006)

The company´s annual production volume is 120-200 tons. In the late 1990's it was estimated that the Finnish clothing industry produced 7 000 tons of production refuses annually. In the beginning of the 2000's, the textile industry generated 15 000 tons of refuses per year. Additionally, households generate approximately 70 000 tons of refuse textiles annually. Hence the amount of waste textile that the company utilizes is minor in comparison to the volume of annual textile waste in Finland. (Saha 2006)

5.4.2
Inventory analysis

The flowcharts (Figure 7) for both the reference virgin product (from mineral oil) and the recycled product (from textile waste) were constructed according to system boundaries set earlier. In the textile case, the functional unit is one ton of oil adsorbent mat. In the following analysis, the life cycle stages and data sources are presented. The use stage was assumed to produce no greenhouse gas emissions, and was thus excluded from the product system. The summarized information of the unit processes is available in Appendix 1 and the transportation modules in Appendix 2.

Raw material acquisition

The raw material for the oil absorbent mat produced from recycled material is textile waste obtained mainly from industry. The waste itself is assumed to produce no greenhouse gas emissions; hence the raw material for (recycled) oil absorbent mat is emission free. The emissions avoided by recycling the textile waste instead of combusting it into energy or landfilling it are discussed in Chapter 5.2.

Crude oil is the main raw material of the reference product. First, the crude oil is produced, transported and refined. Then it is further processed into polypropylene (PP). Polypropylene is an olefin polymer which can be produced commercially from olefin (alkane) monomers using the following technologies; high pressure technology, solution or slurry processes and gas phase polymerization (Boustead 2005a,b).

The PP production stage is presented here as a part of the raw material acquisition life cycle stage even though it actually belongs to the product manufacturing stage.

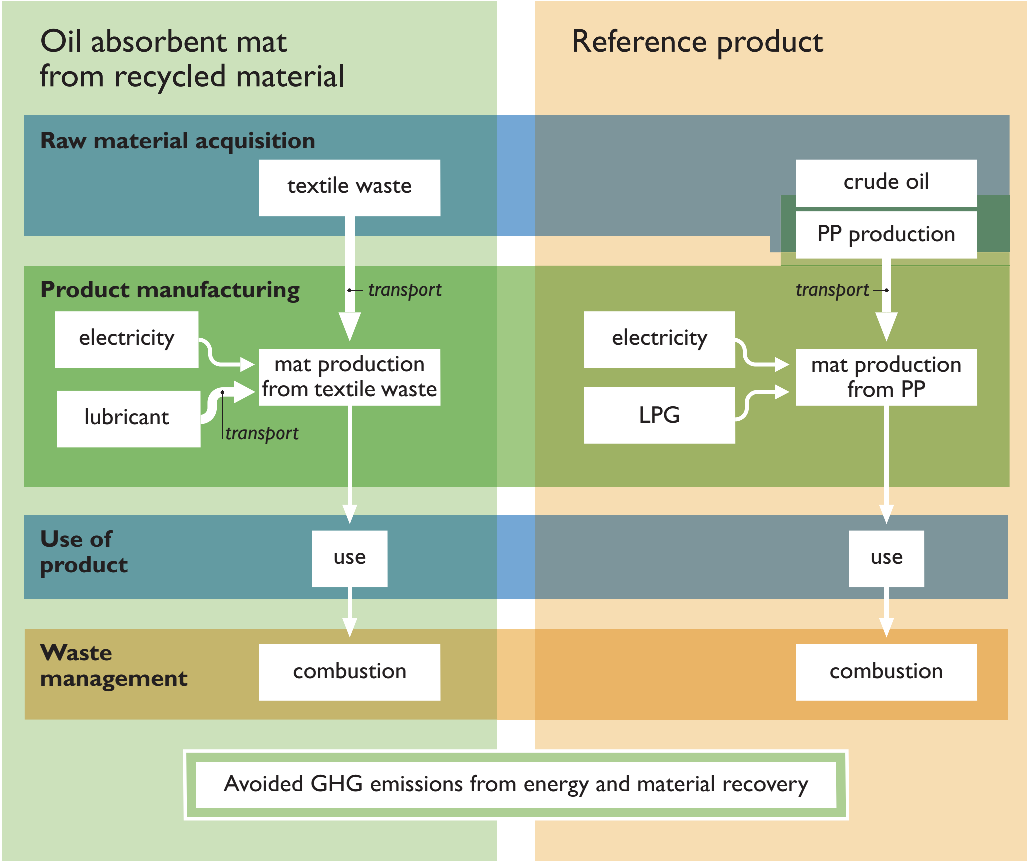

Figure 7. Flowcharts of the oil absorbent mat produced from recycled textiles and the reference product i.e. polypropylene oil absorbent mat.

The reason for this is that the crude oil production and refining data could not be separated from PP production data and so the emission data includes all operations (including transports) from extraction of raw materials to the production of PP. The data originates from the producing companies and it represents industry average data instead of company specific data. It was obtained from the Association of Plastics Manufacturers (Boustead 2005b).

Product manufacturing

The production process of the recycled mat is presented in detail in Chapter 5.4.1. The data concerning the production inputs relative to the amount of the end product are site specific. To produce one ton of oil absorbent mats, 1.05 tons of textile waste is needed (Saha 2006). Process specific emissions were not available; hence the emissions were calculated from the electricity used in the process (average Finnish electricity production, Appendix 3a). The only auxiliary material used in the process is mineral oil lubricant. The lubricant (a combination of hydrocarbons and fatty acid ethoxylates) is needed for the tearing and needling processes (Zschimmer & Schwarz Inc. 2006). No site-specific data were available for the lubricating oil production; hence the data from the Ecoinvent database (2005) were used instead.

The production of polypropylene has already been discussed in the raw material acquisition stage, and thus, only the manufacturing of the oil absorbent mat is covered here. Process specific data regarding the production of polypropylene oil absorbent mats were not available, so energy consumption data of a corresponding process were used. The data used was obtained from a process which uses technology for manufacturing building insulators and wadding from polyester fibres (Toukoniemi

2003). The fibres are produced from recycled PET-bottles. The fibres are bound together with heat, produced by liquefied petroleum gas (LPG). Electricity is also used. Previously carding oil was also used in the process to make the fibre anti-static, but nowadays no auxiliary materials are used. This technology could also be used for producing polypropylene oil absorbent mats (Saha 2006), so the energy consumption data of this technology was used as the basis for the emission calculations of the reference product.

The heat needed in the production process is produced with liquefied petroleum gas (LPG). The LPG is either propane, butane or a mixture of both (Statistics Finland 2006). The production data of the LPG was obtained from the Ecoinvent database 2005. Emissions from the heat production were calculated using the emission coefficients for fuels prepared by Statistics Finland (2006). Burning LPG produces greenhouse gas emissions of which only the CO_2 emissions were taken into account, because the emissions of CH_4 and N_2O are negligible (Tohka 2006).

In Finland there are no companies that produce oil absorbent mats from virgin polypropylene. Therefore the electricity from the Finnish national grid could not be the electricity used in the production process calculations. In this case study the reference product was assumed to be manufactured in Belgium, hence the Belgian electricity profile was used. The Belgian electricity data was obtained from the Ecoinvent database (2005).

Waste management

If the used oil absorbent mats are oily, they have to be treated as hazardous waste (combusted), regardless of which material they are made from. In this study, it was assumed that both the polypropylene-based and recycled textile-based mats absorb the same amount of oil. Therefore the emissions from burning the oil are the same in both cases, and they can be omitted. Burning the mat itself generates emissions which depend on the material of the mat. The recovered energy from the oil absorbent mat combustion was taken into account in the calculations; the methodology is discussed thoroughly in Chapter 5.2. In this section only the direct emissions from the combustion of textile waste are examined.

About 70 % of the recovered textile waste used in oil absorbent mats is biogenic (wool, cotton, viscose) and the remaining 30% is synthetic fibre (polyester) (Saha 2006). The combustion of biogenic fibre does not produce fossil greenhouse gas emissions, thus the fossil emissions from the combustion of the textile-based oil absorbent mats originate from the synthetic fibre and only these are taken into account. Polyester is a plastic based fibre, thus the plastic case study (Chapter 5.3.2) emission data of the waste management phase in which the waste plastics are combusted are applicable. The same data is used for the emissions from the combustion of the reference product i.e. the polypropylene oil absorbent mat. The origins of the data are: CO_2 (Statistics Finland 2006), CH_4 and N_2O (Ecoinvent database 2005) and the efficiency of the combustion plant (Tohka 2006).

Transportation

Transportation of the textile waste and the lubricant oil to the oil absorbent mat production plant and the transportation of the polypropylene oil absorbent mats to the consumer in Finland were assessed in the inventory. The textile waste is transported by delivery lorries and the average transportation distance of the textile waste is 77 km. It was estimated that 30 % of the lorries return empty (Saha 2006). The lubricant that is used in the textile reprocessing was assumed to be imported from the USA by ferry.

Since there is no production of polypropylene oil absorbent mats in Finland, they are imported from Central Europe. In this case study the mats are assumed to be manufactured in Belgium and transported by ferry. Only one way transportation is taken into account, because on the return trip other goods are transported. The transportation of the mats from the manufacturing plant to the harbour and the earlier transportation stages of the polypropylene were excluded from the inventory due to the lack of data.

As in the plastic case study, in this case it is also assumed that both end products (oil absorbent mat made from recycled textile and virgin polypropylene) are used in Finland. The transportation distances to the consumer and from the consumer to the waste management were assumed to be equal for both products; hence they were excluded from the inventory. The transportation emissions were calculated using the specific emission coefficients by vehicle type obtained from the Unit Emissions of Traffic Calculation System by the VTT (2002) and the waterborne traffic distance was estimated from Couper (1989). The emissions from the production of the fuels were included (Fortum Oil and Gas 2002). The transportation modules are presented in Appendix 2.

5.4.3
Emissions avoided by material and energy recovery

In the textile case study, the same boundaries and calculation principles for the emissions avoided by energy and material recovery apply as in the plastics case study reported in Chapter 5.3.3. In this chapter, only the differences from the plastics case study and the data sources for the textile waste case study are presented briefly. In the following calculation principles (except for the emissions from landfills) the basic assumption is that 70 % of the raw material of the recycled oil absorbent mat is biogenic and only 30 % is fossil-originated (Saha 2006).

Emissions avoided by material recovery. Waste textile is recovered and used as a raw material for the recycled oil absorbent mat in the raw material acquisition life cycle stage. Recovery prevents textile waste from being disposed of at landfill or being combusted and therefore the greenhouse gas emissions from textile landfilling or combustion are avoided. In the solid waste disposal sites (SWDS) methane is emitted during the anaerobic decomposition of organic waste. The amount of methane emitted from textile waste in a managed SWDS was calculated following the principles of the Intergovernmental Panel on Climate Change (IPCC 2000) for the National Greenhouse Gas Inventories. The calculation procedure is presented in Appendix 5. Textile waste combustion produces energy. However, in this case textile waste is not combusted but recovered, and thus, the energy has to be produced with other energy sources. The substitute energy source was again the average electricity and heat supply in Finland.

Emissions avoided by energy recovery of waste. Energy is recovered from the waste when the used oil absorbent mat is combusted in the waste management life cycle stage. The use of the recovered energy from the recycled oil absorbent mat reduces the need for energy produced from other fuels and thus the emissions from producing this energy are avoided. The substituted energy in this case was also the average electricity and heat supply in Finland (Appendix 3b). The avoided emissions from not combusting the reference product are also taken into account to find out the total greenhouse gas emissions savings from the waste management life cycle stage of the whole system. The methodology is explained in Chapter 5.2.

The waste plastics combustion data presented earlier in Chapter 5.3.2 were used when the emissions from the combustion of the recycled material oil absorbent mat (30% fossil origin in textile waste) and polypropylene mat were calculated. The data for calculating the emissions of the average electricity and heat supply in Finland are presented in Appendix 3b. The data and the main calculation principles of the avoided emissions are presented in Appendix 4.

5.5

Results

5.5.1

Greenhouse gas emissions according to the life cycle stages

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

Table 2. Greenhouse gas emissions from the product systems. The plastic profile results were only compared with the results of the impregnated wood (IW) product system and similarly the results from recycled textile mat (RT) were compared with the results from polypropylene mat (PP) product system.

Product system	Abbr. + functional unit	kg			
		CO_2	CH_4	N_2O	CO_2-eqv.
Plastic profile: combustion	PLPC (100m^2)	8 456	0.676	0.0350	8 481
Plastic profile: landfill	PLPL (100m^2)	203	0.575	0.0159	220
Impregnated wood	IW (100m^2)	781	0.908	0.0154	805
Recycled textile mat	RT (1t)	1 090	0.601	0.0181	1 109
Polypropylene mat	PP (1t)	5 249	12.275	0.0122	5 511

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 manifold compared with the emissions from the life cycle of impregnated wood (IW) (Table 2). However if the profile was disposed of at landfill (PLPL), the emissions would be less than those from impregnated wood. The results of the textile concept show that there is a great advantage to be gained from recycling textiles. Namely, the emissions from the oil absorbent mat made of virgin polypropylene (PP) are five times higher than those from the mat made of recycled textile (RT).

In Figure 8 the emissions from the life cycle stages of the studied product systems, i.e., raw material acquisition, product manufacturing (including electricity), waste management and transports, are shown. Most of the CO_2 emissions are caused by the waste management stage in all product systems except for the plastic profile (landfill) product system (PLPL). Product manufacturing produces the second most CO_2-emissions in the product systems except for polypropylene mat production product system (PP), in which raw material acquisition produces about 32 % of all CO_2 emissions.

By contrast, most methane emissions originate during 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. The life cycles of plastic profile (PLPC and PLPL) and impregnated wood (IW) produce approximately the same amount of methane emissions per the functional unit each. In the textile case methane emissions from the polypropylene mat concept (PP) are more than tenfold compared with the recycled textile concept (RT). Nearly 97 % of polypropylene methane emissions originate from the raw material acquisition.

Most of the N_2O emissions originate from the waste management and product manufacturing stages and only a small share comes from transportation. The life cycle of the combusted plastic profile (PLPC) produces about twice as much N_2O emissions as the profile disposed of at landfill (PLPL) and the impregnated wood (IW). The recycled textile (RT) produces slightly more N_2O emissions than the polypropylene mat (PP). It should be noted, however, that most of the emissions from the product manufacturing stage actually originate from generating the electricity needed during the manufacturing.

In the calculation of CO_2 equivalents the global warming potentials for CO_2, CH_4 and N_2O from the IPCC (1996)[2] were used. The global warming impacts of CH_4 and N_2O emissions in these product systems are minor compared with the impacts of CO_2 emissions (Figure 8). However, data on the CH_4 and N_2O emissions were not obtained for all unit processes, which reduce their significance in the results. The emissions by life cycle stages are presented in more detail in Appendix 6.

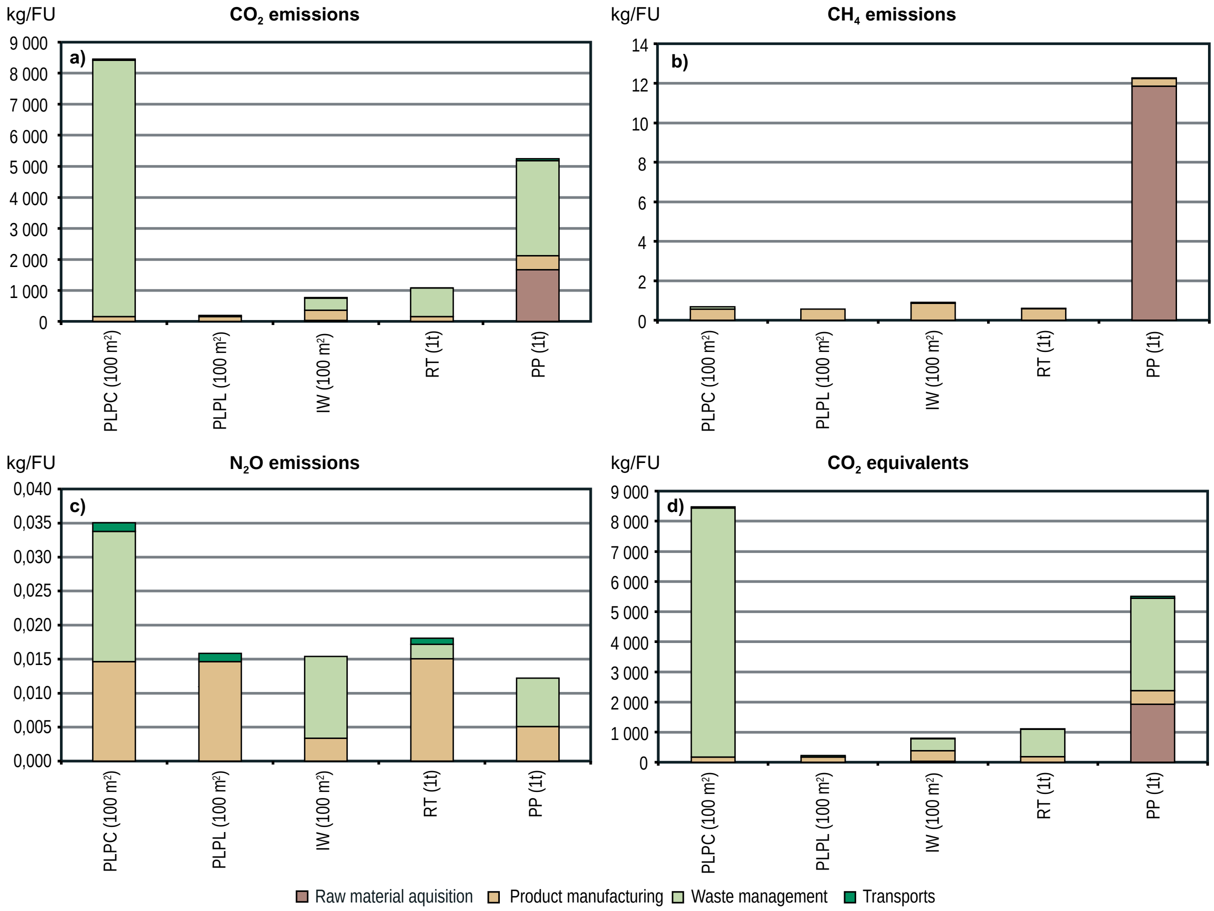

Figure 8. a) CO_2 emissions, b) CH_4 emissions, c) N_2O emissions and d) CO_2-equivalents from the product systems studied. Abbreviations: PLPC = Plastic profile combustion, PLPL = plastic profile landfill, IW = impregnated wood, RT = recycled textile mat, PP = polypropylene mat, FU = functional unit (100m² or 1t).

[2] GWP values from the year 1996 are used when reporting emissions to the UN Framework Convention on Climate Change (UNFCCC).

5.5.2
Overall greenhouse gas emission savings achieved by material recycling

In this study the reduced environmental burden, i.e. reduction in greenhouse gas emissions due to replacing virgin material with recycled material, was calculated following the principles presented in Chapter 5.2. The summarized results per the functional units are shown in Table 3. More detailed results are presented in Appendix 7.

In calculating the overall greenhouse gas emission savings potential of the product systems, the avoided emissions from material and energy recovery were taken into account (Tables 3 and 4). For both case studies, 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 plastics case, the sub cases are marked 1a, 1b, 1c and 1d and in the textile case 2a and 2b (Table 3).

Table 3. Greenhouse gas emission savings potential (environmental benefits) from waste plastic and waste textile recycling per functional units (FU) expressed as CO_2 equivalents. Positive values indicate environmental benefits.

Case I: Plastic **Plastic profile made from recycled plastic vs. virgin impregnated wood**		**Emission savings CO_2 eqv. t / FU** **FU = 100m²**
Sub case		
1a	Waste plastic is not combusted; plastic profile is combusted.	-1.00
1b	Waste plastic is landfilled; plastic profile is combusted.	-2.90
1c	Waste plastic not landfilled; plastic profile is landfilled.	-1.00
1d	Waste plastic is not combusted; plastic profile is landfilled.	0.90
Case II: Textile **Oil sorbent made from recycled textile vs. oil sorbent made from virgin polypropylene**		**FU = 1 t**
Sub case		
2a	Waste textile is not combusted; recycled textile oil sorbent is combusted.	6.00
2b	Waste textile is not landfilled; recycled textile oil sorbent is combusted.	9.20

However, in order to highlight the significance of the results, the potentials for emission savings were also assessed by assuming that the annually landfilled amount of waste material would be reprocessed within the concepts studied (Table 4). This describes a theoretical and highly unlikely situation, due to for example the limited markets for oil absorbent mats and the miscellaneous composition of the materials landfilled. In the plastics case, the potential for emission savings was assessed assuming that all impregnated sawn timber produced annually in Finland could be replaced with the plastic profile. This approach is also theoretical, firstly because the amount of good quality waste plastics is not large enough to substitute all impregnated sawn timber with the plastic profile and secondly, it is not possible to replace impregnated wood with plastic profile in all applications.

Table 4. Greenhouse gas emission savings potential (environmental benefits) from waste plastic and waste textile recycling expressed as CO_2 equivalents in two theoretical situations. First emission savings were calculated assuming that the annual amount of waste disposed of at landfill would be reprocessed within the concepts and second, the annual amount of impregnated wood produced in Finland would be replaced by plastic profile. Positive values indicate environmental benefits.

		Emissions saving CO_2 eqv. t /	
		Plastic[1)]/textile[2)] amount disposed of at landfill	Annual production of Impregnated wood[3)]
Case I: Plastic **Plastic profile made from recycled plastic vs. virgin impregnated wood**		**56 400 t**	**214 000 m^3**
Subcase			
Ia	Waste plastic is not combusted; plastic profile is combusted.	-19 900	-68 000
Ib	Waste plastic is landfilled; plastic profile is combusted.	-59 600	-203 400
Ic	Waste plastic not landfilled; plastic profile is landfilled.	-19 900	-68 000
Id	Waste plastic is not combusted; plastic profile is landfilled.	19 700	67 400
Case II: Textile **Oil sorbent made from recycled textile vs. oil sorbent made from virgin polypropylene**		**65 077 t**	**-**
Subcase			
2a	Waste textile is not combusted; recycled textile oil sorbent is combusted.	390 100	-
2b	Waste textile is not landfilled; recycled textile oil sorbent is combusted.	601 100	-

1) Amount of packaging waste plastics disposed of at landfill in Finland in 2003 (PYR 2006).
2) Amount of combustible textiles disposed of at landfill in Finland in 2003 (Myllymaa et al. 2006).
3) Amount of industrially impregnated sawn timber in Finland in 2003 (Kestopuu Oy 2006).

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 (subcase 1d, Table 3). The emission savings derive from the following: firstly, the energy that would have been obtained from the combustion of plastic waste was assumed to be produced using the average electricity and heat supply in Finland which produces lower emissions. And secondly, when the cast off plastic profile is disposed of at landfill sites, it was assumed that no emissions are 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, Table 3). In theory, the waste plastics do not 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 generates more emissions than the substituted energy source, and 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 (Table 3). 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 principles of the 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 the electricity and heat supply in Finland replaces the energy produced with textile waste, more emissions are emitted and thus the emission savings are smaller than in sub case 2b.

5.6

Sensitivity analysis

Probably the most important issue that influenced the results is the reference product and its origin. Combustion of biogenic material, such as wood, produces biogenic greenhouse gas emissions, which are not taken into account in the calculations. The results of the plastic case would turn out differently if the reference product for plastic profile was of fossil origin e.g. virgin plastic instead of biogenic origin. In the textile case, the production and combustion of the reference product (polypropylene) generates a lot of fossil greenhouse gas emissions, which conversely increase the emission savings from recycled oil absorbent mats.

Sensitivity analysis was performed on some of the other 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 from waste 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 life-time length of the plastic profile was analysed by assuming a three-fold life-time for the profile compared to impregnated wood. Third, the effect of the assumed composition of the recycled material (bio or fossil based) in the textile concept was analysed by using different composition percentages.

In this study the substituted energy source was effectively the fuel mixture used for the average electricity and heat supply in Finland, in which about half of the energy is produced using fossil fuels. Energy generated solely with hard coal produces approximately 45 % more carbon dioxide emissions than energy generated using the average fuel mixture. Energy production with renewable energy sources (e.g. water, wind, solar) is assumed to produce no fossil greenhouse gas emissions. The sensitivity of the plastic case study to changes in the energy supply source and in the lifetime of the plastic profile is presented in Figure 9.

The results of the sensitivity analysis for the plastic case study show that by using energy from coal as the alternative to energy generated from waste (both in the recycled product system and in the reference product system), no emission savings occur and hence greenhouse gas emissions can not be reduced by plastic recycling (Figure 9). Respectively, by using renewable fuels as the alternative to energy from waste makes producing plastic profiles from plastic waste favourable over impregnated wood in sub cases 1a, 1c and 1b. The results in this section are also highly influenced by the bio-origin of the reference product, since the different forms of energy and their emissions are also compared to energy generated from the bio-based reference product. Coal energy produces more emissions than the average fuel mix and if compared with impregnated wood the emission savings decrease. Respectively, the renewable energy produces less emissions than impregnated wood (fossil emissions originate from the impregnating agent) hence the emission savings increase.

The lifetime of the plastic profile can be up to three times as long as the lifetime of the impregnated wood, due to the fact that wood rots. When this is assumed, the emission savings potential gained by plastics recycling further decreases, since the emissions avoided by the energy recovery of the impregnated wood are lost and this energy is produced with the average fuel mixture. Despite the fact that the emissions from producing impregnated wood would be threefold compared to the plastics profile the effect of this on the overall results is smaller than the effect of the avoided emissions when the impregnated wood is combusted.

Textile recycling shows high potential to reduce greenhouse gas emissions. Neither the type of energy substituted by the energy generated within the product systems nor the assumed origin of the recycled material substantially affect the emission savings potential of textile recycling (Figure 10).

The use of renewable energy sources instead of the average fuel mixture slightly increases the emission savings and the use of coal decreases the emission savings potential. The change in the origin of the recycled textile raw material slightly affects the emission savings but nevertheless emission saving potential still exists in all sub cases.

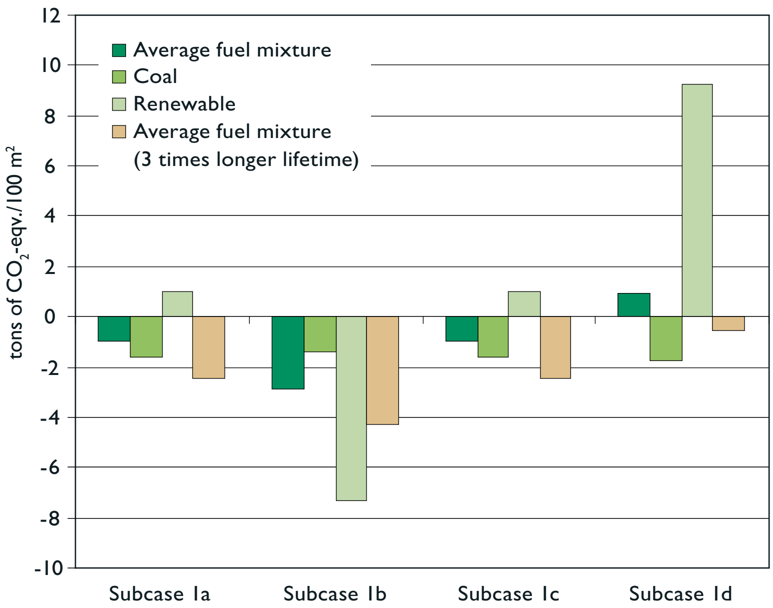

Figure 9. The sensitivity of the subcases 1a - 1d of the plastic case study to the different energy generation forms and to changes in the plastic profiles lifetime. Positive values indicate emission savings.

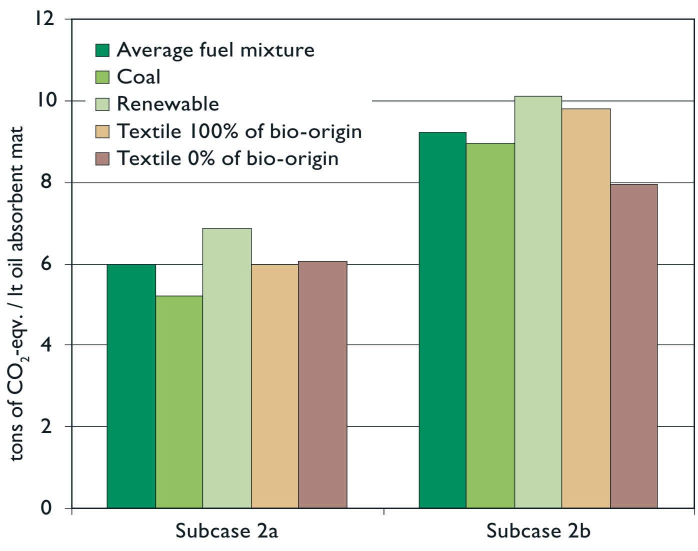

Figure 10. The sensitivity of the sub cases 2a – 2b of the textile case study to the different forms of energy generation and to the change in the origin of the textile.

5.7
Discussion

5.7.1
Waste plastics

There have been many studies on the energy consumption and emissions of virgin plastic production (i.e. eco-profiles conducted by PlasticsEurope). However, studies on the emissions and energy consumption of producing plastics from recycled resin are less common. McDougall et al. (2001) compared the emissions and energy consumption from virgin plastic production (original figures from BUWAL 1998) and recycled plastics production (original figures from Henstock 1992 and Deurloo 1990). The comparison showed that CO_2 emission reductions and energy savings can be obtained by reprocessing the waste plastics. The reprocessing of low-density polyethylene film collected from supermarkets into recycled LDPE granules and then into recycled polyethylene bags reduced the CO_2-emissions by approximately 46 % and energy consumption by 38%. By the reprocessing of rigid plastic bottles (HDPE) into recycled HDPE the CO_2 emission savings were around 83% and energy savings approximately 77%. In another study conducted by the US EPA (2002), the emissions from manufacturing plastics from recycled inputs were compared with the emissions from manufacturing an equivalent amount of the material from virgin inputs. The results showed that emission reductions were possible and varied between approximately 1.4 – 1.7 tons of CO_2 equivalents per ton of material recovered. According to Patel et al. (2000) energy savings and CO_2 emissions reduction have been obtained by mechanical recycling when virgin polymers are substituted. They also found that plastic recycling almost always shows a better performance in terms of CO_2 and energy reductions than waste treatment in an average incinerator.

Wollny and Schmied (2000) have reviewed the ten most important LCA studies on plastics recycling. The purpose of all of the studies was to investigate the environmental burden and benefits of the various waste plastic recycling methods and energy recovery processes, and to compare the different waste management options to find the best solution from an environmental point of view. The majority of the studies concluded that the mechanical recycling of waste plastics under certain conditions is the best solution followed by feedstock recycling, combustion and landfilling. Some of the studies (i.e. Heyde and Kremer 1999 and Patel et al. 1999) also investigated the environmental benefits of mechanically recycled plastic material when it substitutes non-plastic such as wood, concrete or steel. Replacing concrete or wood with mechanically recycled plastic in general produces considerably lower ecological savings than the competing processes. The studies showed that the ecological savings depend strongly on the primary production processes replaced by recycling.

In an LCA study by Graighill and Powell (1996), the environmental impacts of a recycling system (including the kerbside collection and the subsequent use by manufacturers) were compared with a waste disposal system (virgin materials are used in production and waste is disposed of at landfill). The results of the study showed that the contribution of plastic recycling to global warming (CO_2 equivalents) was 40-80 % lower than in the waste disposal system, depending on the plastic type.

Overall, the results from earlier studies showed that the environmental burdens and thus greenhouse gas emissions can be reduced by waste plastics recycling. In the studies where recycled plastic replaced wood, no savings in greenhouse gas emissions were obtained, but if they replaced virgin plastics, the savings were notable. However, the results from these studies should not be directly compared with the results obtained in our study. Every study is unique and the system boundaries usually differ from one study to another. In most studies, the use of waste plastics has been compared with the use of virgin plastics or other waste management processes. In our study the approach was different; a product made from waste plastics was compared with a product made from a different material but with the same purpose of use.

5.7.2 Textile waste

Studies concerning the emissions and energy consumption of textile recycling are very limited. McDougall et al. (2001) present two relatively old studies concerning textile recycling conducted by Lowe (1981) and Ogilvie (1992). The studies indicated that the energy consumption of producing a woven product from virgin wool was approximately double compared to producing the product from recycled material. In a recent study by Woolridge et al. (2006) the energy consumption of reuse and recycling using donated clothing in UK was compared with the energy consumption of purchasing new clothing made from virgin materials. In the study discarded textiles were used for second hand clothing, filling materials, wiping cloths and a small share was utilized in fibre reclamation. A part of the recycled clothing replaced the purchase of garments made from virgin material and likewise a part of the recycled clothing was used in furniture filling or wipers replacing paper or foam products. The study showed that for every ton of virgin cotton displaced by second hand clothing about 65 MWh is saved, and for every ton of polyester around 90 MWh is saved.

The studies mentioned above as well as our study indicate that textile recycling has the potential to reduce energy consumption and thus also to reduce greenhouse gas emissions. Even though the results discussed above are similar to those of this study they should not be directly compared with each other, because of the different research methods and system boundaries used.

5.7.3 Suitability of the concepts for CDM and JI activities

The Clean Development Mechanism (CDM) and Joint Implementation (JI) are two of the so-called flexible mechanisms of the Kyoto Protocol which are designed to increase the cost-effectiveness of emission reduction activities and to promote sustainable development. The CDM and JI are project-based mechanisms, as the reduced emissions originate from individual projects. The mechanisms are designed to promote projects between countries which lead to reduced emissions of greenhouse gases in comparison to what would have happened in the absence of the project. In the case of JI projects, both countries must have a reduction commitment under the Kyoto Protocol whereas the CDM projects are carried out in countries without a reduction commitment (e.g. developing countries). (UNFCCC 2006b; Ahonen 2006)

A considerable amount of the CDM projects are implemented within the waste management sector. This is partly because the emission reductions are fairly easy to verify for biological treatment, thermal treatment and landfilling projects. However, material recycling concepts are not unambiguously suitable for CDM and JI projects mainly due to the difficulties in the complete verification of the emission reduction potential. As shown in this study, the potential for emission reductions consists of both direct and indirect impacts on emissions from processes both inside and outside the waste recovery-reprocessing chain. Thus the methodology for calculating the emission savings may be too complicated and costly for CDM and JI projects, for which a straightforward methodology is needed in verifying the baseline and emission savings.

5.7.4
Costs and business opportunities of recycling

In general, the costs of the reprocessed material consist of the price paid for the recovered material, the transportation costs to the reprocessing plant and the costs of the reprocessing operation. Reprocessing will be cost-effective if the value of the recycled material produced exceeds the transport and reprocessing (including recovered material prices) costs. The recycled material will only sell if it is priced competitively compared to the virgin material. For the recycling industry to expand, it is necessary for the transport and reprocessing costs of the recovered material to be less than the transport and production costs of the virgin material. This holds for materials where a large amount of energy is saved in reprocessing compared to the production of virgin material. However for some materials with high reprocessing costs and low energy savings it may not be possible to produce recycled material at a competitive price. (McDougall et al. 2001)

The economic costs of recycling were not calculated within this study because the costs of material reprocessing could not be obtained from the reprocessing companies and likewise the economic costs of the virgin material production were also difficult to obtain. However, at the moment both of the examined concepts operate well, and the businesses are expanding. The production volume of the plastic profile has increased considerably within the past three years. The biggest problem in marketing the plastic profile has been the bad image of recycled plastics. If the image could be improved the markets for the profile could grow even more. (Surakka 2006). In the recycled textile case the acquisition of the raw material might cause problems in the future, since the easily exploitable material is continuously diminishing. The transportation costs of the end products made from recycled textile are high because the products are light and consume a lot of space (Saha 2006).

6 Conclusions

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. This report presents a selection of the material recycling concepts which are currently in use in Finland and for which information was readily available. However, this study does not reveal all activity within the field of material recycling because new waste recycling / reprocessing concepts are being developed and introduced all the time.

In our study, the reprocessing of plastic waste into plastic profile and the reprocessing of textile waste into oil absorbent mats were chosen as case study examples to demonstrate the potential of material recycling to support 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 products that could be replaced by the waste-based products and they were chosen on the basis of the current market situation. The reference product for the plastics profile was impregnated wood and for the recycled textile oil sorbent it was polypropylene based oil sorbent. Only focusing on these two reference products is definitely a limitation to the study, i.e. choosing 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 plastic is recycled instead of being combusted and the discarded plastic profile is disposed of at landfill sites. The results would have be more favourable for plastic recycling if the reference product was of fossil origin instead of biogenic origin. This is due to the fact that in greenhouse gas emission calculations, the biogenic reference product gained more advantage than the fossil-material-based recycled product in e.g. compensating for fossil fuels in energy production through combustion. The results would also favour plastics recycling if renewable energy sources were used as the alternative energy instead of the average electricity and heat supply in Finland.

The results of the textile case study revealed that when textile waste is used to replace virgin plastic products the greenhouse gas emissions can be reduced substantially. However the results only represent the situation in these case studies hence they cannot be generalized to cover the whole field of material recycling.

In this study the focus was on the 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 could 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 to increasing material recycling. Currently, waste plastic (especially of municipal origin) is often too contaminated and heterogeneous to be used in reprocessing processes and hence ends up in landfills. This presents a challenge in terms of the development of sorting and cleaning technologies for different waste fractions. The leftover textiles from the 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 textile 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 amongst municipal waste. However, plastics and textile recycling is likely to increase in the future, when more experience in this field is obtained.

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Appendix 1. Description of unit processes used in this study.

Module	Description of unit process(es)	Data from year	Data source
In all cases:			
Finnish electricity (not used in the textile reference product case)	Includes the electricity generation in Finland and net imports from Sweden and Russia. Also includes the production of fuels.	2003	Finnish Environment Institute (2006)[1]
Use	Does not produce emissions.		
Plastic profile			
Waste plastics	Does not produce emissions.		
Colouring/UV-protection agent	Site specific electricity demand of producing colouring agent.	2005	*Electricity demand:* Premix Oy (2006) [2], *Danish electricity profile:* Ecoinvent database (2005) [3]
Plastic profile manufacturing	Site specific. Manufacturing of plastic profile.	2005	Muovix Oy (2006) [4]
Combustion	*CO_2-emissions:* Emissions from combustion of plastics. *CH_4 and N_2O -emissions:* Includes emissions from combustion of polyethylene and auxiliary material consumption for flue gas cleaning. *Efficiency:* Average efficiency of electricity and heat production in a plastic combustion plant	CO_2: 2006 CH_4 and N_2O: 1994	*CO_2:* Statistics Finland (2006) [5], *CH_4 and N_2O:* EcoInvent database (2005) [3], *Efficiency:* Tohka (2006) [6]
Landfilling	Does not produce emissions in the short term.		
Reference product: Pressure impregnated wood			
Timber (pine)	Data includes the following forestry operations: 1st and 2nd thinning, regeneration felling as well as the production of petrol, diesel, hydraulic oil and chain oil used in the forestry operations.	Forestry operations: 1998 Fuels: 2002	*Forestry:* KCL Datamaster [7], *Fuels:* Fortum Oil and Gas Oy (2002) [8]
Saw mill	Production of sawn timber. Emissions from electricity production are included in air emissions.	1999	KCL Datamaster [7]
Wood impregnating agent	Mixing of ingredients. Includes the inputs to the production processes and transports of those inputs. No process emission data were available.	2000	EcoInvent database (2005) [3]
Heat	Light fuel oil production (extraction and transportation of crude oil, refining and transportation to an end user) and heat generating.	Fuel production: 2002 Heat generating: 2005	*Fuel production:* Fortum Oil and Gas Oy (2002) [8], *Heat generation:* Statistics Finland (2006) [5]
Pressure impregnated wood production	Site specific. Impregnation of wood.	2005	Prima Group Oy (2006) [9]

Combustion	*CO_2-emissions:* Emissions from combustion of impregnated wood. *CH_4 and N_2O -emissions:* Includes emissions from combustion of chrome preserved pole and auxiliary material consumption for flue gas cleaning. *Efficiency:* Average efficiency of electricity and heat production in a wood combustion plant.	CO_2: 2006 CH_4 and N_2O: 1994	*CO_2:* Statistics Finland (2006) [5], *CH_4 and N_2O:* EcoInvent database (2005) [3], *Efficiency:* Tohka (2006) [6]
Oil absorbent mat from recycled textile			
Textile waste	Does not produce emissions.		
Oil absorbent mat production from textile waste	Site specific. Manufacturing of oil absorbent mat from textile waste.	2005	Dafecor Oy (2006) [10]
Lubricant	Includes raw materials and chemicals used for production, transports, energy, infrastructure and production process (large uncertainty). The emissions to air are rough estimates.	2000	EcoInvent database (2005) [3]
Combustion (70% biogenic, 30% fossil based)	For fossil based textile share: *CO_2-emissions:* Emissions from combustion of plastics. *CH_4 and N_2O -emissions:* Includes emissions from combustion of polyethylene and auxiliary material consumption for flue gas cleaning. *Efficiency:* Average efficiency of electricity and heat production in a plastic combustion plant	CO_2: 2006 CH_4 and N_2O: 1994	*CO_2:* Statistics Finland (2006) [5], *CH_4 and N_2O:* EcoInvent database (2005) [3], *Efficiency:* Tohka (2006) [6]
Landfilling	An estimate of CH_4 emissions originating from degradation process of textiles at landfills.		IPCC 2000 [11]
Reference product: Oil absorbent mat from polypropylene			
PP production	Polypropylene production (production of fuels, fuel use, transports and process). There is no exact number for N_2O in the report, hence it was assumed to be 0.	2005	Boustead (2005b) [12]
Oil absorbent mat production from PP	Site specific electricity and heat demand of manufacturing building insulators and wadding from polyester fibre by binding them together with heat. Fibres are produced from recycled PET-bottles.	2003	Toukoniemi (2003) [13]
Heat	Liquefied petroleum gas (LPG) production (extraction and transportation of crude oil, all processes on the refinery site excluding the emissions from combustion facilities) and heat generation.	LPG production: 1980-2000 Heat generating: 2005	*Fuel production:* EcoInvent database (2005) [3], *Heat generation:* Statistics Finland (2006) [5]
Lubricant	Includes raw materials and chemicals used for production, transports, energy, infrastructure and production process (large uncertainty). The emissions to air are rough estimates.	2000	EcoInvent database (2005) [3]

Other electricity	Belgian electricity: It includes the shares of domestic electricity production by technology at the busbar. Includes the production of fuels. It does not include transformation, transport nor distribution losses. Data apply to public and self producers in Belgium.	2000	EcoInvent database (2005) [3]
Combustion	*CO_2-emissions:* Emissions from combustion of plastics. *CH_4 and N_2O -emissions:* Includes emissions from combustion of polyethylene and auxiliary material consumption for flue gas cleaning. *Efficiency:* Average efficiency of electricity and heat production in a plastic combustion plant	CO_2: 2006 CH_4 and N_2O: 1994	*CO_2:* Statistics Finland (2006) [5], *CH_4 and N_2O:* EcoInvent database (2005) [3], *Efficiency:* Tohka (2006) [6]

Sources:

[1] Finnish Environment Institute (2006). Environmental loads of electricity and heat production. Unpublished.
[2] Premix Oy. 2006. Varis, J. Personal communication 28.4.2006.
[3] EcoInvent Database v. 1.2. 2005. Swiss Centre for Life Cycle Inventories. http://www.ecoinvent.ch
[4] Muovix Oy 2006. Mika Surakka. Personal communication 10.2.2006.
[5] Statistics Finland 2006. Fuel classification. http://www.tilastokeskus.fi/polttoaineluokitus. Read 20.3.2006.
[6] Tohka, A. 2006. Finnish Environment Institute. Personal communication 13.3.2006.
[7] KCL Datamaster. Oy Keskuslaboratorio – Centrallaboratorium Ab, the Finnish Pulp and Paper Research Institute. LCA Database.
[8] Fortum Oil and Gas Oy 2002. Ekotasetiedotteet. (Eco-balance analysis). (In Finnish)
[9] Prima Group Oy 2006. Petri Rajasuo. Personal communication 13.3.2006.
[10] Dafecor Oy 2006. Risto Saha. Personal communication. 16.3.2006.
[11] IPCC 2000. Intergovernmental Panel on Climate Change. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 5: Waste.
[12] Boustead 2005b. Association of Plastics Manufacturers. Eco-profiles of the European Plastics Industry, Polypropylene (PP). PlasticsEurope.
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Appendix 2. Transportation modules used in this study

Modules	Unit processes	Data from year	Data source
Full trailer	Transportation of waste plastics to the plastic profile manufacturing plant. Maximum capacity 40t, here 15% load (6t). Trailer model: average in 2001. One way transport. Average distance 100km. Also includes the diesel oil production.	2002	*Transportation:* VTT 2002 [1)], *Diesel oil production:* Fortum Oil and Gas Oy 2002 [2)]
Full trailer timber lorry	Transportation of timber to the sawmill. Maximum capacity 40t. Full load. Includes empty return trip. EURO 2 (1996-1998) emission level. Only CO_2 emissions. Also includes the diesel oil production.	2002	*Transportation:* VTT 2002 [1)], *Diesel oil production:* Fortum Oil and Gas Oy 2002 [2)]
Cargo ferries (Ro-Ro, Lo-Lo, StoRo)	Transportation of impregnating agent from London to Hanko (1825km). One way transport. Also includes the heavy fuel oil production.	1999	*Transportation:* VTT 2002 [1)], *Transporting distance:* Couper 1989 [3)], *Heavy fuel oil production:* Fortum Oil and Gas Oy 2002 [2)]
	Transportation of colouring agent from Copenhagen to Hanko (875km). One way transport. Also includes the heavy fuel oil production.		
	Transportation of lubricant for Dafecor process from New York to Hanko (7881km). One way transport. Includes heavy fuel oil production.		
	Transportation of oil absorbent mat made from polypropylene from Rotterdam to Hanko (1986). One way transport. Also includes the heavy fuel oil production.		
Delivery lorry	Transportation of waste textile to the oil absorbent mat production plant. Full loaded 3,5t. Lorry model: average in 2001. 30% empty return trip. Average distance 77km. Includes diesel oil production.		*Transportation:* VTT 2002 [1)], *Diesel oil production:* Fortum Oil and Gas Oy 2002 [2)]

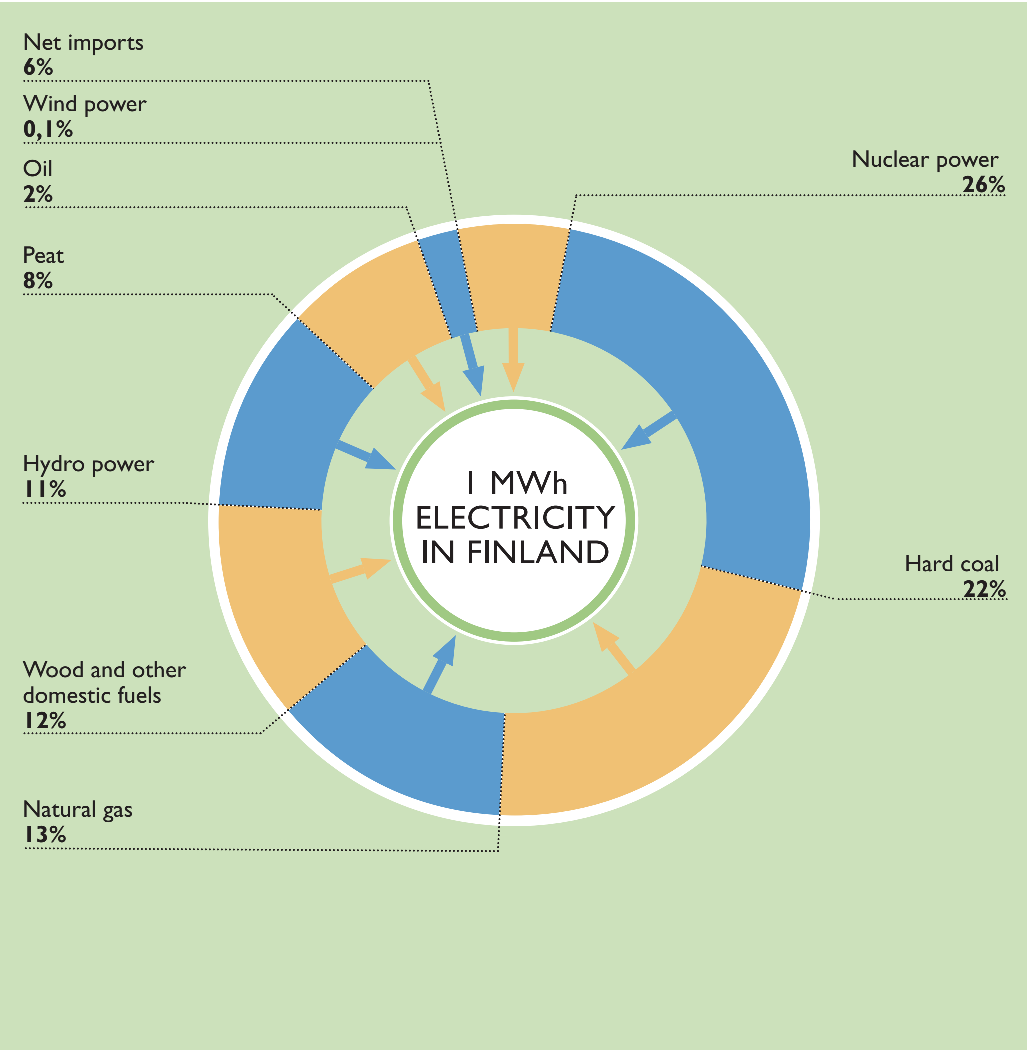
Sources:

[1)] VTT 2002. Lipasto database of traffic emissions. Unit emissions of vehicles in Finland. VTT Technical Research Centre of Finland. http://lipasto.vtt.fi/yksikkopaastot/freight_road.htm. Read 19.4.2006.
[2)] Fortum Oil and Gas Oy 2002. Ekotasetiedotteet. (Eco-balance analysis). (In Finnish).
[3)] Couper, A. (ed.) 1989. Atlas and Encyclopedia of the Sea 1989. Times Books Limited.

Appendix 3a. Finnish electricity generation model

The Finnish electricity generation model was designed by The Finnish Environment Institute (2006)[1]. The Finnish electricity generation profile varies annually mainly depending on the availability of hydroelectric power and on the situation on the international electric market. This model is based on the situation in Finland in 2003[2]. In the year 2003 the main source of energy for electricity generation was nuclear power with a share of 26% (Figure e). The weather conditions in that year were not favourable for hydroelectric power; hence only 11 % of electricity was generated using hydroelectric power. This increased the use of hard coal and thereby it also increased the emissions from electricity generation compared with the electricity generation in Finland between 2000-2002[3]. The model also includes net imports from Russia and the Nordic countries and also takes into account the production of the fuels. The emission coefficients of the average Finnish electricity generation are presented in Appendix 3b.

[1] Finnish Environment Institute (2006). Environmental loads of electricity and heat production. Unpublished.
[2] Statistics Finland 2004. Energiatilasto 2003. Energy statistics 2003. Energy 2004:2.
[3] Dahlbo, H., Laukka, J., Myllymaa, T., Koskela, S. Tenhunen, J., Seppälä, J., Jouttijärvi, T. and Melanen, M. 2005. Waste management options for discarded newspaper in the Helsinki Metropolitan Area. Life cycle assessment report. Helsinki, Finnish Environment Institute. The Finnish Environment 752.



Appendix 3b. Source information used to calculate the greenhouse gas emission coefficients for the average Finnish electricity and district heating generation in the year 2003.

	District heating	Electricity	Global warming potential [2]	Co-generation of electricity and heat
Efficiency of energy production (%)	90 [1]	40 [1]		
Allocation of primary energy and emissions (%)	0.51 [1]	0.49 [1]		
Emission (g/kWh) [3]				
CO_2	292.0	292.0	1	292
CH_4	0.75	1.056	21	0.90
N_2O	0.040	0.027	310	0.03
CO_2-equivalents	320.2	322.5		321

[1] Myllymaa, T. Dahlbo, H., Ollikainen, M., Peltola, S. and Melanen, M. 2005. A method for implementing life cycle surveys of waste management alternatives' environmental and cost effects. The Finnish Environment 750. Finnish Environment Institute. (In Finnish). Available at http://www.ymparisto.fi/julkaisut.
[2] IPCC 1996. Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change
[3] Finnish Environment Institute (2006). Environmental loads of electricity and heat production. Unpublished.

Appendix 4. Source data for the calculation of avoided emissions (credits) (t emissions / t waste) and an example of the calculation procedure.

	Plastics	Impregnated wood	Textile*	Coal (anthracite)
Average default calorific value (GJ/t)	33 [1)]	12 [1)]	15.6 [5)]	33.5 [1)]
CO_2 default emission factor (t CO_2 / t waste) [1)]	2.45	0.14		3.17
CH_4 emission factor (t CH_4 / t waste) [2)]	3.0028E-05	1.9673E-05		
N_2O emission factor (t N_2O / t waste) [2)]	5.6754E-06	4.2877E-06		
Average Finnish heat and electricity production: CO_2 default emission factor (g/kWh) [3)]	292	292	292	292
Assumed efficiency for the energy production [4)]	0.8	0.8	0.8	0.8

* 70 % of textile waste is biogenic = no fossil emissions, 30 % is fossil based = emissions of plastics combustion

Example: Avoided emissions when energy recovered from waste plastics substitutes the energy generated by the average Finnish heat and electricity generation.

A The energy produced from plastics waste (1t) is
*33 GJ/t * 1000/3.6 = 9 167 kWh*

B CO_2-emissions, when the energy amount (A) is produced with average Finnish heat and electricity model is
*9 167kWh * 0.8 * 292 g/kWh / 1000 / 1000*

C CO_2-emissions, when energy amount (A) is produced by waste plastics combustion is
2.45 / 0.8 = ***3.057*** *tons of* CO_2

D Avoided CO_2-emissions when plastics waste substitutes the average Finnish heat and electricity
2.141 *tons of* CO_2 *–* ***3.057*** *tons of* CO_2 *=* ***-0.92*** *tons of* CO_2

The same calculation principles were used when calculating avoided emissions (CO_2, CH_4, N_2O) from energy recovery of impregnated wood, textile waste and the oil absorbent mats.

Sources:
[1)] Statistics Finland 2006. Fuel classification http://www.tilastokeskus.fi/tup/khkinv/khkaasut_poltto-aineluokitus.html. Read 27.6.2006.
[2)] EcoInvent Database v. 1.2. 2005. Swiss Centre for Life Cycle Inventories. http://www.ecoinvent.ch
[3)] Finnish Environment Institute (2006). Environmental loads of electricity and heat production. Unpublished.
[4)] Tohka, A. 2006. Finnish Environment Institute. Personal communication 28.3.2006.
[5)] Williams, P. T. 1998. Waste Treatment and Disposal. Department of Fuel and Energy. The University of Leeds, UK.

Appendix 5. Calculation of the methane emissions from textile waste disposed of at solid waste disposal sites (SWDS).

Default method – Tier 1 [1)]

The method is based on the assumption that all potential CH_4 is released in the year the waste is disposed of.

$$CH_4 \text{ emissions} = [(MSW_T * MSW_F * L_0) - R] * (1-OX) = 0.120 \text{ kg } CH_4 / \text{kg of textile disposed of at landfill}$$

Where:

MSW_T	=	0.12	=	Total municipal solid waste (MSW) generated (Gg/yr) (Dafecors annual production)
MSW_F	=	1	=	Fraction of MSW disposed at Solid waste disposal site (SWDS)
L_0	=	0.1334	=	Methane generation potential [MCF * DOC * DOC_F * F * 16/12 (Gg CH_4/Gg waste)]
MCF	=	1	=	Methane correction factor (fraction)
DOC	=	0.4	=	Degradable organic carbon [fraction (Gg C/Gg MSW)]
DOC_F	=	0.5	=	Fraction DOC dissimilated
F	=	0.5	=	Fraction by volume of CH_4 in landfill gas
R	=	0	=	Recovered CH_4 (Gg/yr)
OX	=	0.1	=	Oxidation factor (fraction)

Source:

[1)] IPCC 2000. Intergovernmental Panel on Climate Change. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 5: Waste.

Appendix 6. Greenhouse gas emissions by life cycle stages

Abbreviations and functional units:

PLPC	Plastic profile: combustion	(100 m^2)
PLPL	Plastic profile: landfill	(100 m^2)
IW	Impregnated wood	(100 m^2)
RT	Recycled textile mat	(1t)
PP	Polypropylene mat	(1t)

	Raw material acquisition	Product manufacturing	Waste management	Transports	Total*
			CO_2 (kg)		
PLPC (100m^2)		159	8 253	44.5	8 456
PLPL (100m^2)		159		44.5	203
IW (100m^2)	34.5	333	384	29.5	781
RT (1t)		163	917	10.5	1 090
PP (1t)	1 668	459	3 057	65.7	5 249
			CH_4 (kg)		
PLPC		0.5744	0.1013	0.00072	0.6764
PLPL		0.5744		0.00072	0.5751
IW		0.8528	0.0553		0.9082
RT		0.5890	0.0113	0.00060	0.6009
PP	11.9	0.3871	0.0375		12.2746
			N_2O (kg)		
PLPC		0.0146	0.0192	0.0012	0.0350
PLPL		0.0146		0.0012	0.0159
IW		0.0033	0.0121		0.0154
RT		0.0150	0.0021	0.0009	0.0181
PP		0.0051	0.0071		0.0122
			CO_2 eqv. (kg)		
PLPC		175	8 261	44.9	8 481
PLPL		175		44.9	220
IW	34.5	352	390	29.5	805
RT		180	918	10.8	1 109
PP	1 917	469	3 060	65.7	5 511

*Totals may not agree because of rounding.

Appendix 7. Calculation procedure and results (per functional unit) of greenhouse gas emission reduction potential (emission savings) of plastic and textile waste recycling.

Equation = B-A+C+D

Where,

A = Emissions from recycled product life cycle
B = Emissions from virgin product life cycle
C = Emission savings, when the waste (=raw material of the recycled product) entering the product system is recovered, not disposed of at landfill or combusted to produce energy
D = Emissions from energy recovery during waste management life cycle stage.

	kg CO_2 eqv. /100m²				
Case I: Plastics	**B -**	**A +**	**C +**	**D**	**Total***
Combustion of waste plastic is prevented and plastic profile is combusted.	805	8 481	1 898	4 824	-954
Disposal of waste plastic at landfill is prevented and plastic profile is combusted.	805	8 481	0	4 824	-2 852
Disposal of waste plastic at landfill is prevented and plastic profile is disposed of at landfill.	805	220	0	-1 539	-954
Combustion of waste plastic is prevented and plastic profile is disposed of at landfill.	805	220	1 898	-1 539	944
	kg CO_2 eqv. / 1 t				
Case II: Textile	**B -**	**A +**	**C +**	**D**	**Total***
Combustion of waste textile is prevented and recycled textile oil absorbent mat is combusted.	5 511	1 109	-596	2 189	5 995
Disposal of waste textile at landfill is prevented of at landfill and recycled textile oil absorbent mat is combusted.	5 511	1 109	2 646	2 189	9 237

* Totals may not agree because of rounding.

DOCUMENTATION PAGE

Publisher	Finnish Environment Institute (SYKE)			*Date* September 2007
Author(s)	Marja-Riitta Korhonen and Helena Dahlbo			
Title of publication	**Reducing Greenhouse Gas Emissions by Recycling Plastics and Textiles into Products**			
Publication series and number	The Finnish Environment 30/2007			
Theme of publication	Environmental pretection			
Parts of publication/ other project publications				
Abstract	Waste management generates greenhouse gas emissions. New waste management concepts for reducing these emissions are continuously being developed. In this study the potential of material recovery to reduce greenhouse gas emissions was assessed. The study was divided into two phases. In the first phase the material recovery concepts used in Finland were identified and approximate greenhouse gas emission savings calculations were conducted for some of the concepts. In the second phase two promising concepts were chosen as case studies for a more detailed assessment, both of which are documented in detail in this report. In the first concept plastic waste is reprocessed into plastic profiles and in the second waste textile is reprocessed into oil absorbent mats. Life Cycle Inventory (LCI) methodology was used for calculating the greenhouse gas emission savings. The emission saving potential was assessed by comparing the emissions from the product made of recycled material with the emissions from the lifecycle of a reference product. The reference product is made for the same application of use but manufactured from virgin raw material. Impregnated wood was chosen as the reference product for the plastic profile and oil absorbent mat made from virgin polypropylene fibre was used as the reference product for the oil absorbent mat made from textile waste. When assessing the overall greenhouse gas emission savings from material recovery, only comparing the emissions from the recycled and the reference product lifecycles is insufficient. Thus, the emissions avoided by material and energy recovery were also included in the calculations. The results show that the greenhouse gas emission reduction potential of material recycling is highly case-specific and emission savings can not always be obtained. In this study recovery of textile waste showed the potential to reduce greenhouse gas emissions. However, plastic waste recycling only generates greenhouse gas emission savings under certain conditions. The emission reduction potential greatly depends on the reference product chosen. This study concentrated solely on greenhouse gas emissions. Thus the results only highlight one aspect of the environmental impacts from material recycling.			
Keywords	recycling, material recovery, greenhouse gas emissions, plastics, textile			
Financier/ commissioner				
	ISBN (pbk.)	ISBN 978-952-11-2795-3 (PDF)	ISSN (print)	ISSN 1796-1637 (online)
	No. of pages 59	*Language* English	*Restrictions* Public	*Price (incl. tax 8 %)*
For sale at/ distributor				
Financier of publication	Finnish Environment Institute (SYKE), P.O.Box 140, FI-00251 Helsinki, Finland *Phone +358 20 490 123, Fax +358 20 490 2190* Email: neuvonta.syke@ymparisto.fi, www.environment.fi/syke			
Printing place and year				

KUVAILULEHTI

Julkaisija	Suomen ympäristökeskus (SYKE)	*Julkaisuaika* Syyskuu 2007
Tekijä(t)	Marja-Riitta Korhonen and Helena Dahlbo	
Julkaisun nimi	**Reducing Greenhouse Gas Emissions by Recycling Plastics and Textiles into Products** (Kasvihuonekaasupäästöjen vähentäminen muovia ja tekstiiliä kierrättämällä)	
Julkaisusarjan nimi ja numero	Suomen ympäristö 30/2007	
Julkaisun teema	Ympäristönsuojelu	
Julkaisun osat/ muut saman projektin tuottamat julkaisut		
Tiivistelmä	Jätehuollosta aiheutuu ilmastonmuutosta kiihdyttäviä kasvihuonekaasupäästöjä. Päästöjä pyritään vähentämään mm. kehittämällä uusia jätteenkäsittelykonsepteja jätehuollon eri osa-alueille. Tässä tutkimuksessa tarkastellaan jätteiden materiaalihyötykäytön mahdollisuuksia kasvihuonekaasupäästöjen vähentämisessä. Tutkimus jaettiin kahteen vaiheeseen, joista ensimmäisessä kartoitettiin Suomessa käytössä olevat uudet jätemateriaalien hyödyntämiskonseptit. Näistä muutamille tehtiin alustavat laskelmat kasvihuonekaasupäästösäästöistä. Toisessa vaiheessa kaksi lupaavan tuntuista konseptia valittiin case-tarkasteluihin, joissa niiden kasvihuonekaasupäästöjen säästöpotentiaalia arvioitiin tarkemmin. Ensimmäisessä konseptissa muovijäte prosessoidaan muoviprofiiliksi ja toisessa konseptissa tekstiilijätteestä valmistetaan öljynimeytysmattoja. Tutkimuksen toinen vaihe raportoidaan tässä julkaisussa. Päästösäästöjen laskennassa käytettiin elinkaari-inventaario (LCI) menetelmää. Konseptien päästösäästöpotentiaali arvioitiin vertaamalla kierrätetystä materiaalista valmistetun tuotteen elinkaaren aikaisia kasvihuonekaasupäästöjä samaan käyttötarkoitukseen valmistetun neitseellisen tuotteen aiheuttamiin päästöihin. Esimerkkitarkasteluissa kierrätysmuoviprofiilin vertailutuotteena oli kyllästetty puu ja tekstiilijätteestä valmistetun öljynimeytysmaton vertailutuotteena vastaava neitseellisestä polypropyleenikuidusta valmistettu matto. Tutkimuksessa haluttiin selvittää materiaalien kierrätyksen mahdollistaman päästösäästön kokonaispotentiaali, joten elinkaarten aikaisten päästöjen lisäksi jätteen materiaali- ja energiahyödyntämisellä vältettävät päästöt otettiin huomioon. Tulokset osoittavat, että materiaalien kierrätyksellä saavutettavat päästövähennykset ovat hyvin tapauskohtaisia eikä kierrätysmateriaalien käyttö aina vähennä kasvihuonekaasupäästöjä. Tässä tarkastelussa tekstiilien kierrätyksellä saavutettiin päästösäästöjä, kun taas muovin kierrätyksellä päästösäästöjä syntyi vain tiettyjen oletusten ollessa voimassa. Päästösäästöpotentiaali riippuu huomattavasti tarkasteluun valitusta vertailutuotteesta. Tässä tutkimuksessa tarkasteltiin vain kasvihuonekaasupäästöjä. Tulokset kertovat näin ollen vain yhdestä osasta jätemateriaalien kierrätyksen ympäristövaikutuksista.	
Asiasanat	kierrätys, materiaalihyödyntäminen, kasvihuonekaasupäästöt, muovi, tekstiili	
Rahoittaja/ toimeksiantaja		

	ISBN (nid.)	ISBN 978-952-11-2795-3 (PDF)	ISSN (pain.)	ISSN 1796-1637 (verkkoj.)
	Sivuja 59	*Kieli* Englanti	*Luottamuksellisuus* Julkinen	*Hinta (sis.alv 8 %)*

Julkaisun myynti/ jakaja	
Julkaisun kustantaja	Suomen ympäristökeskus (SYKE), PL 140, 00251 HELSINKI Puh. 020 490 123 Sähköposti: neuvonta.syke@ymparisto.fi, www.ymparisto.fi/syke
Painopaikka ja -aika	

PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral (SYKE)	*Datum* September 2007
Författare	Marja-Riitta Korhonen och Helena Dahlbo	
Publikationens titel	**Reducing Greenhouse Gas Emissions by Recycling Plastics and Textiles into Products** Minskning av växthusgasemissioner genom återvinning av plast och textiler	
Publikationsserie och nummer	Miljön i Finland 30/2007	
Publikationens tema	Miljövård	
Publikationens delar/ andra publikationer inom samma projekt		
Sammandrag	Avfallshanteringen producerar växthusgasemissioner som ökar klimatförändringen. För att reducera emissionerna strävar man bland annat att ta fram nya avfallshanteringsteknologier för olika avfallshanteringssektorer. Denna utredning handlar om möjligheterna att framkalla besparing av växthusgasemissioner genom att återvinna avfallsmaterial. Utredningen genomfördes i två faser. I den första fasen kartlades nya, i Finland använda återvinningskoncept för avfallsmaterial. För några av dessa koncept utfördes preliminära värderingar för besparingspotential av växthusgasemissioner. I den andra fasen valdes två koncept för en noggrannare granskning av besparingspotentialen. I det ena konceptet processas plastavfall till plastprofil. I det andra konceptet tillverkas oljeabsorberingsmattor ur textilavfall. Den andra fasen av utredningen rapporteras i denna publikation. I utvärderingen av emissionsbesparingspotentialen användes en livscykelinventering (LCI) metodologi. Emissionerna från livscykeln av produkten tillverkad av återvunnet material jämfördes med emissionerna från livscykeln av produkten tillverkad av jungfruligt material. För jämförelsen valdes följande referensprodukter: impregnerat trä för plastprofil och oljeabsorberingsmatta gjord av polypropylen för mattan gjord av textilavfall. Eftersom vi ville få reda på totalpotentialen för emissionsbesparingen som kan uppnås med materialåtervinning, tog vi hänsyn till både emissionerna som genereras inom livscyklerna, och emissionerna som kan undvikas genom material- och energiåtervinning. Enligt resultaten är potentialen för emissionsbesparing ytterst beroende på omständigheterna som antas för materialåtervinningen. Återvinningen minskar inte alltid växthusgasemissioner. I fallstudierna som utfördes i detta projekt, visade det sig att återvinning av textil minskar emissionerna. Återvinning av plast minskar emissionerna däremot bara under vissa omständigheter. Referensprodukten har ytterst stor bemärkelse för besparingspotentialen. I denna utredning fokuserade vi enbart på växthusgasemissionerna. Resultaten beskriver följaktligen bara en del av miljökonsekvenserna som anknyter till återvinning av avfallsmaterial.	
Nyckelord	återvinning, utnyttjande av material, växthusgasemissioner, plast, textil	
Finansiär/ uppdragsgivare		

	ISBN (hft.)	ISBN 978-952-11-2795-3 (PDF)	ISSN (print)	ISSN 1796-1637 (online)
	Sidantal 59	*Språk* Engelska	*Offentlighet* Offentlig	*Pris (inneh. moms 8 %)*

Beställningar/ distribution	
Förläggare	Finlands miljöcentral (SYKE), PB 140, 00251 Helsingfors Tel. 020 490 123 Epost: neuvonta.syke@ymparisto.fi, www.miljo.fi/syke
Tryckeri/tryckningsort och -år	

Waste management generates greenhouse gas emissions. New waste management concepts for reducing these emissions are continuously being developed. In the UJKON-project the objectives were to find new municipal solid waste management concepts and assess their potential to reduce greenhouse gas emissions in four areas (subprojects): (1) energy recovery, (2) landfill gas collection and utilization, (3) material recovery and (4) biological treatment methods.

In this study the potential of material recovery (subproject 3) to reduce greenhouse gas emissions through two case studies are assessed and the results are presented. In the first case study concept plastic waste is reprocessed into plastic profiles and in the second waste textile is reprocessed into oil absorbent mats. This study concentrated solely on greenhouse gas emissions. Thus the results only highlight one aspect of the environmental impacts from material recycling.

SYKE

ISBN 978-952-11-2795-3 (PDF)
ISSN 1796-1637 (online)

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THE FINNISH ENVIRONMENT 30 | 2007