VTT SYMPOSIUM 262

Life Cycle Assessment of Products and Technologies

LCA Symposium

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Keywords: life cycle assessment, life cycle inventory, climate change, ecological footprint

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LCA Symposium

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Foreword

VTT Technical Research Centre of Finland organised a Symposium “Life Cycle Assessment of Products and Technologies” on the 6^{th} of October 2009. The Symposium gave a good overview of methods, tools and applications of Life Cycle Assessment developed and utilised in several technology fields of VTT. The presentations are collected in this publication.

The Life Cycle Assessment LCA is a widely accepted approach to evaluate environmental impacts of products, systems and processes. It considers material and energy flows throughout the life cycle, from cradle to grave. The general principles of the methodology were standardized by the International Organization for Standardization (ISO) in four steps in the latter half of the 1990s (ISO 14040:1997, ISO 14041:1999, ISO 14042:2000 and ISO 14043:2000).

A life cycle assessment procedure evaluates ecological aspects and potential environmental impacts in three main phases: (1) by composing an inventory of essential inputs and outputs of the product or respective system, (2) by estimating the potential environmental impacts of these inputs and outputs, and (3) by the results of inventory analysis and impact analysis with respect to set objectives of the exercise in question. Environmental aspects are considered from the acquisition of raw material to manufacturing, use and consumption, and end use and recycling. The conventional areas of environmental impact analyzed in the valuation stage of LCA are related to the use of natural resources, human health and ecology (e.g. ecological diversity).

VTT was among the pioneers of the development and implementation of this new approach. The first publications and presentations dealt with construction materials and products, by-products, road construction, vehicles and work machines, green energy and methodological valuing issues. In recent years, the development and implementation of LCA methods and tools have mainly been on a sector basis.

LCA is becoming increasingly important, especially in view of the challenge of climate change and the related global policy activities. LCA is taking on a growing and essential role at industrial and policy level. At company level, LCA is applied to customer and stakeholder communication; environmental reporting; product, process and sustainability comparisons; product development and improvement; the development of cleaner processes; environmental management; strategic management; product stewardship; the development of environmental indictors and the assessment of life cycle costs. In government policies, e. g, environmental and innovation policies, LCA is utilized to develop criteria for environmental labelling, in the development of environmental auditing and indicators, in R&D programs of clean technology and clean production, in product policies, in waste management policies, in the management of sustainable supply and value chains, in determining the “Best Available Technologies” (BAT) and in analysing environmental taxes and other public instruments aimed at promoting sustainable production and consumption.

The information based on the anticipatory examination of the requirements of sustainable development is one of the main boundaries for successful global businesses. LCA thereby plays an important role in VTT’s research services for industrial as well as public sector customers.

The 12 Symposium papers deal with recent LCA studies on products and technologies. The scope ranges from beverage cups to urban planning, from inventory databases to rating systems. Topical issues relating to climate change concern biorefineries and the overall impacts of the utilisation of biomass. The calculation of carbon footprints is also introduced through paper products and magazines. One example of LCA tools developed at VTT addresses cement manufacturing. VTT’s transport emission database, LIPASTO, was introduced in detail. The use of LCA methods and life cycle thinking is described in various contexts: product development in relation to precision instruments; selection of materials and work processes in relation to sediment remediation project; and procedures of sustainability rating through VTT’s office building Digitalo. The Climate Bonus project presented a demonstrated ICT support that informs about the greenhouse gas emissions and carbon footprints of households.

The Symposium was an achievement by the internal network of researchers at VTT involved in sustainability issues. The network was supported by the R&D Executive Board. The members of the Scientific Team were Tarja Häkkinen, Tiina Pajula and Sampo Soimakallio.

We want to express our thanks to all the authors of the Symposium papers for their excellent work.

Eva Häkkä-Rönnholm

Vice President, R&D
Patron of the LCA network

Torsti Loikkanen

Senior Research Scientist
Chair of the LCA Symposium

Contents

Climate impacts related to biomass utilization

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1. Introduction

Human-engendered greenhouse gas emissions affect the global temperature. There is a large scientific consensus on that increasing atmospheric concentrations of greenhouse gases have an increasing impact on the global mean temperature (IPCC 2007a). The increase in the global temperature may have serious and irreversible impacts on the ecosystems. These implications are not well known, but are very likely the greater in severity the more the global mean temperature increases, as illustrated in Figure 1.

The current atmospheric concentration of carbon dioxide equals approximately some 380 ppm CO_2 (IPCC 2007a). In addition, other greenhouse gases (mainly methane and nitrous oxide) regulated under the Kyoto Protocol and CFC gases regulated under the Montreal Protocol correspond to some 50 and 25 ppm CO_2-eq. respectively (IPCC 2007a). However, the inertia of many natural processes linked to the climate change is huge (Figure 2). Temperature increase is delayed due to particle emissions, which decrease radiative forcing and the large heat capacity of the oceans. By taking these factors into account the common calculatory concentration of greenhouse gases and other factors equals some 375 ppm CO_2-eq (IPCC 2007b). The current growth of greenhouse gas concentrations in the atmosphere is approximately 2 ppm CO_2-eq.

When assessing the effectiveness of various actions on mitigating the climate change, the fundamental issue to be considered is the target. The ultimate objective of the United Nations' Framework Convention on Climate Change (UNFCCC 1992) is the stabilisation of atmospheric concentrations of greenhouse gases at a level that prevents dangerous anthropogenic interference with the climate system. However, the UNFCCC has not provided any concrete limits for global temperature increase, atmospheric concentrations of greenhouse gases or emission reductions required. The lower the global temperature increase is desired to be limited to, the lower is the stabilisation level of greenhouse gas concentrations in the atmosphere, and the more rapidly greenhouse gas emissions need to be reduced (Figure 2).

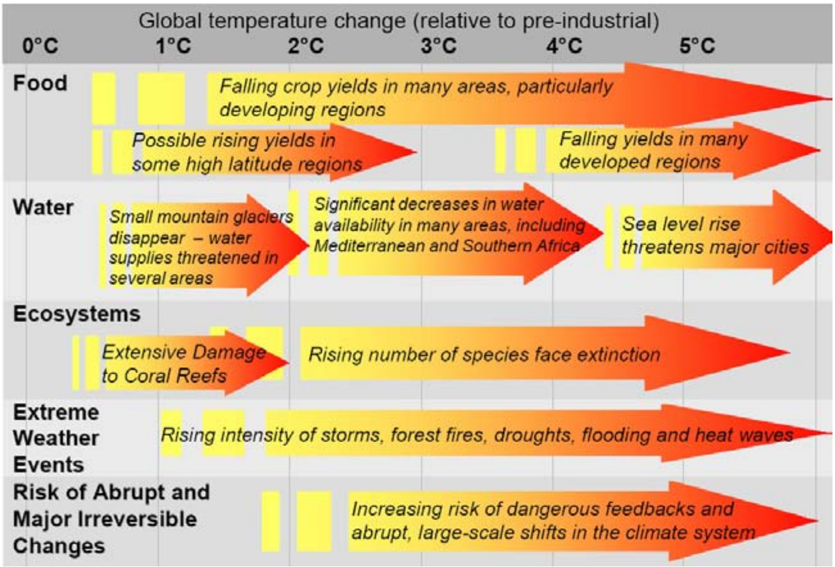

Figure 1. Impacts of global temperature rise (Stern 2006).

The European Union has proposed that the global warming should be limited in maximum to 2 degrees Celsius above the pre-industrial period (EC 1996, 2007). The target for stabilising atmospheric greenhouse gas emissions sets the frames for a time horizon that is relevant to consider when assessing the effectiveness of various actions to mitigate climate change. As regards the 2-degree target proposed by the EU, the time frame for any single emission reduction action should correspond to overall emission reductions required to achieve the target. According to IPCC (2007c), global emissions should peak by 2015 and be reduced by at least 50–85% by year 2050 compared to year 2000, in order to maintain a reasonable likelihood of achieving the 2-degree target. According to

Article 3.1 of the UNFCCC the countries should protect the climate system "on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities". Consequently, industrial countries should do more than the developing countries.

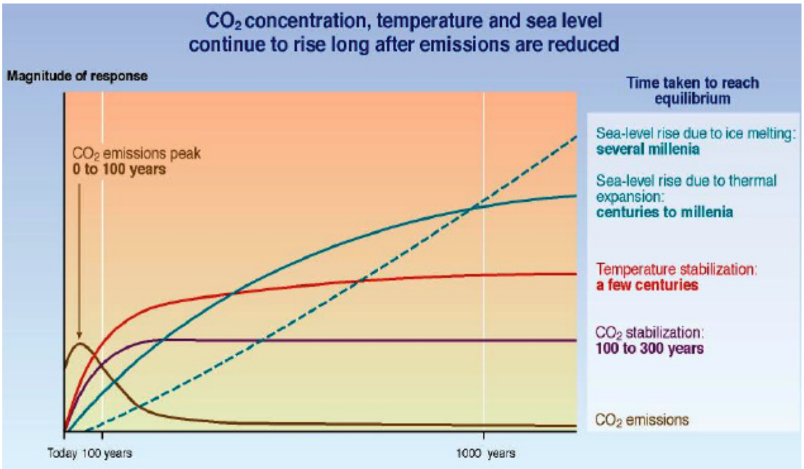

Figure 2. Time frames and inertial factors associated with climate change in principle. Time frames should be considered for illustrative purposes only (IPCC 2001).

The use of bioenergy and other biomass-based products instead of fossil fuels and other emission-intensive products is considered as one of the most important measures to mitigate climate change. The global potentials for bioenergy vary significantly depending on the study. According to UNEP 2009, the most optimistic assumptions lead to a theoretical potential of 200–400 EJ/a or even higher, whereas the most pessimistic scenario forecasts only some 40 EJ/a, and a more realistic scenario considering environmental constraints estimate a sustainable potential of 40–85 EJ/a by 2050.

When biomass is used in a renewable way, the same amount of carbon that is released during biomass combustion or decay is accumulated back into growing biomass. Consequently, biomass combustion is very often considered as carbon neutral in life cycle analysis (LCA). Also, the EU emission trading scheme regards biomass combustion as carbon neutral. However, greenhouse gas emissions are engendered during cultivation, harvesting, transportation, storage, processing and combustion of biomass. The effectiveness of biomass utilisation in climate change mitigation depends on many factors, which are explored in this paper.

2. The role of biomass in climate change mitigation

2.1 Timing issues

The capability of plants to sequester carbon and emit to the atmosphere vary between species. Short rotation biomass such as agrobiomass decays rapidly after growing. Instead, long rotation biomass such as pine or spruce in boreal forests may exceed the rotation period of 100 years and consequently act relatively long as storage of organic carbon. The rotation period of carbon is a very important factor to be considered when assessing the effectiveness of various methods to use biomass in the mitigation of climate change. A large pool of terrestrial carbon is the soil, which is also influenced by the utilisation of biomass. The turnover rate of this pool is usually slow, but human-induced land-use changes can convert soil into a strong source of emissions.

Basically, biomass can be used in three different ways in mitigation of climate change: in carbon substitution, sequestration or conservation. The effectiveness of various methods depends on the time-frame relevant for the target to mitigate climate change, the carbon sequestration rate and the substitution credits available. The dynamics of carbon sequestration and substitution is illustrated in Figure 3.

As illustrated in Figure 2, there are various time-frames relevant for climate change and mitigation of climate change. A specific increase in specific greenhouse gas emission increases the atmospheric concentration of the particular greenhouse gas emission over the atmospheric lifetime of the compound. Increased atmospheric concentration of the particular compound results in an increase in radiative forcing, global mean temperature and the consequences of climate change. The science cannot provide any fixed time-frame for assessing greenhouse impacts of various actions because it is not clear what consequences and how long they should be assessed. Consequently, it is necessary first to select the target of climate change mitigation. According to the 2-degree target proposed, e.g. by the EU, the time-frame for very significant reductions in greenhouse gas emissions should take place within the upcoming few decades. This requirement creates crucial time-frame for assessing the effectiveness of various actions in climate change mitigation. However, due to natural removal of carbon dioxide from the atmosphere in the course of time and delay in the temperature growth due to increased atmospheric concentrations of greenhouse gases, the appropriate time-frame may be somewhat longer, but likely should not exceed 100 years.

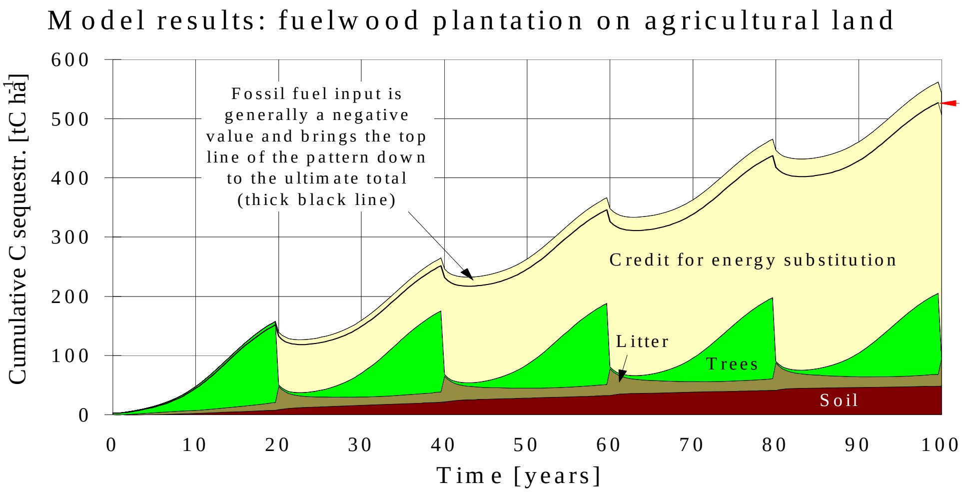

Figure 3. Illustration of net carbon uptake in soil and litter, net carbon increase in trees and saved carbon emissions from the replacement of fossil fuels with bioenergy when one hectare of agricultural land is afforested to produce a biofuel with a 20 year rotation (Joanneum Research 2008).

2.2 The generic alternatives of treating biomass stocks in climate change

In substitution management, biomass is used to displace fossil-fuel-based emissions. Substitution credits may take place directly through fossil energy replacement or indirectly through energy-intensive material replacement in the case of biomass-based products. The most significant substitution credits likely take place when cascading the biomass use: first as products and at the end of their life cycle as energy. However, substitution credits may vary significantly between various biomass utilisation options. The critical issues having influence on the substitution credits are the difference in amount and timing of GHG emissions between caused and avoided emissions due to biomass utilisation. Emissions and avoided emissions may take place directly or indirectly. Direct GHG impacts due to biomass utilisation are related e.g. to the production of auxiliary energy and other resources required, soil-based carbon dioxide, methane and nitrous oxide emissions due to biomass cultivation and harvesting, and to material losses. Indirect GHG impacts due to biomass utilisation are related, e.g. to competition of land, raw materials and other resources, avoided emissions through replaced products, and impacts due to other complex cause and effect relationships. Consequently, when assessing substitution credits the setting of spatial and dynamic system boundary and the choice of other methodological aspects have significant impact on the results. These issues are discussed in more details, e.g. by Soimakallio et al. 2009.

In conservation management significant carbon stocks are protected. These may include e.g. native forests and peatlands including high carbon stocks per land area. For example, tropical peat swamp forests are areas with high terrestrial carbon stocks per land area. They are at the moment hot spot areas of carbon dioxide emissions globally, due to land-use changes. Conservation management of this kind of terrestrial carbon stocks would be an efficient means of reducing greenhouse gas emissions.

In sequestration management atmospheric carbon is accounted into terrestrial ecosystems. The possible methods include e.g. reforestation, increasing of biomass stocks in existing forests and long-living products, and changing of agricultural practices to increase soil carbon balances. In the case of land-use changes, e.g. forestation or plantation, however, the climatic impacts are not only caused by the changes in atmospheric greenhouse gas balances but also by the changes in surface albedo. For example, Betts (2000) found that the change in surface albedo by the planting of coniferous forests in areas with snow can contribute significantly to the radiative forcing. Brovkin et al. (1999) found that cooling due to the albedo change from deforestation was of the same order of magnitude as the increased radiative forcing from CO_2 and solar irradiation. Bala et al. (2007) found that a global-scale deforestation event could have a net cooling influence on the Earth's climate. On the other hand, Matthews et al. (2004) suggest that carbon emissions from land cover changes (deforestation) tend to exceed the cooling that results from change in the surface albedo. However, significant uncertainties are involved in the impacts of the changes in the surface albedo due to land-use changes, but due to the potential significance of the issue, more research work is certainly required.

Typically, alternative biomass treatments are optional to each other. However, when considering the use of certain biomass stock or land area substitution, conservation and sequestration management options may take place at the same time. For example, thinning as a forestry option both provides raw material for substitution (thinning wood) and accelerates the growth of wood left in the forests. Similarly, cultivation practices improving soil carbon balance may play both substitution and sequestration management option roles at the same time.

From the perspective of mitigating climate change, the main advantage of substitution management over sequestration and conservation management is that substitution management creates cumulative credits due to displaced fossil carbon emissions compared to the reference scenario. The biomass stock harvested and used for substitution is compensated by re-growth of new biomass, which can be rapid or take a long time, or in case of unsustainable forest management is not compensated for at all. A major factor to be considered is the time frame that is relevant with the fundamental target to mitigate climate change (e.g. the 2-degree target). There is also a risk that the biomass carbon stock may be lost due to natural disturbances (e.g. forest fires) without any substitution credits. This could make sequestration and conservation managements more uncertain in some cases. However, the more rapidly atmospheric concentrations of greenhouse gases are needed to be reduced the more important the role such options play.

3. Conclusions

Biomass is a limited resource. In addition, the challenge to mitigate climate change will require significant emission reductions in the upcoming few decades. The required reductions in greenhouse gas emissions are not possible to be achieved exclusively by biomass, despite the management options selected. Consequently, from the point of view of mitigating climate change, the biomass should be used as effectively as possible to provide optimal reductions in greenhouse gas emissions within a given time-frame that is relevant with the fundamental target to mitigate climate change (e.g. 2-degree target).

When substitution management is applied and biomass is harvested the effectiveness of various end-use applications to mitigate climate change should be measured by using appropriate indicators. Such indicators should measure objectively the achieved benefits on radiative forcing, compared to a reference scenario, and per-biomass harvested within the relevant time frame. The use of the radiative forcing method taking into account the dynamics of greenhouse gas emissions and sinks is therefore suggested. Such a method does consider the release of carbon dioxide into the atmosphere during biomass decay or combustion, accumulation of carbon into growing biomass, and the timing differences between them. The simplified static consideration of emissions only weighted with GWP factors may also be appropriate with the limitations. First, the possible exceeding of the biomass rotation period compared to the relevant time under consideration should be somehow taken into account. Second, significant pulse emissions compared to annual emissions over the period considered should not take place. Otherwise, the suitability of the GWP method for assessing greenhouse impacts over the life cycle of any action is questionable. For example, Kendall et al. 2009 concluded that climate effects of pulse emissions (e.g. from land-use changes) are significantly underestimated if annualised for many years (e.g. 20–30 a) for static LCA calculations.

The practical problems encountered in defining appropriate indicators to measure the effectiveness of actions in mitigating climate change are associated with the lack of knowledge of the exact time frame and uncertainties of carbon sequestration and storage permanence. In addition, the problems with definition of system boundary, reference scenario, and other methodological issues make any indicator more or less subjective.

In addition to biomass, also suitable land area to produce biomass or money that can be used for climate change mitigation may be limiting factors. Schlamadinger et al. (2005) propose principal indicators appropriate to measure the optimal use of biomass in climate change mitigation as achieved emission reduction per biomass, land area or money depending on the limiting resource. In practice, other factors – such as various environmental or social impacts – may also be limiting factors for biomass use. For this reason, the optimal use of biomass is always a trade-off between various dimensions of sustainability and depends on the weighting of various impacts.

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Assessing the life cycle greenhouse gas emissions of biorefineries

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Abstract

During the next decades there will be a growing demand for new land for food production due to population and economic growth. Simultaneously, global warming has been recognised as one of the most severe environmental problems of our time, and industrialised countries are negotiating on considerable emission cuts for the next decades. Biorefineries are considered by many as one solution for mitigation of climate change and improvement of the future security of food, chemical, forest and energy industries. Since increased use of biomass in biorefineries also implies increased use of land and auxiliary inputs, many have proposed to use by-products of food and forest industries in biorefineries. When assessing the global warming impacts of biorefineries, the setting of the spatial system boundary to include or exclude indirect impacts may significantly affect the results. In this paper, we discuss the life cycle greenhouse gas impacts of a hypothetical forest-based biorefinery by using two different approaches – attributional and consequential life cycle assessment (LCA) – to set the system boundary. The results imply that for those bio-based side-streams for which there presently exists use, the environmental benefits of diverting them to new uses as bio-fuel or bio-material are not straightforward and should be carefully and comprehensively studied before making decisions.

1. Introduction

Population and economic growth are putting an increasing pressure for acquiring new land for food production during the next decades. At the same time, global warming has been recognised as one of the most severe environmental problems of our time. Mitigation of the global climate change will require deep cuts in global greenhouse gas emissions in the near future. Biomass has a vital role in this mitigation. As biomass resources and the available land area are limited, there exists global competition on resources. Increased production of bio-based materials and bio energy are putting considerable pressure on available agricultural land area. Hoogwijk et al. [2003] have estimated that depending on the food demand, the amount of agricultural and degraded land globally available for the production of biomass for energy and materials in 2050 would be between 0.4 to 3.2 Gha [Hoogwijk et al. 2003]. At the same time, the land required for biomaterials production in the same year would be 0.4–0.7 Gha. As there are many problems related to the widespread use of 'new' or 'virgin' biomass for either purpose, it seems rational to first seek for alternatives stemming from existing side-product streams.

Forest industry has traditionally played a central role in the Finnish economy, particularly as a source of export income. However, pulp and paper production is presently undergoing a major structural change with several production units having been closed down [Hetemäki & Hänninen, 2009]. Several authors have mentioned biorefineries as a promising possibility for the future development of the forest, food and chemical industries [Kamm & Kamm 2004; Uihlein & Schebek 2009]. However, increased use of biomass in biorefineries also implies increased use of land and auxiliary inputs, while there already is heavy competition for land for food production.

Life cycle assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts related to the life cycle of a product [Rebitzer et al. 2004, Finnveden et al. 2009]. LCA consists of four iterative steps: goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation.

When assessing the global warming impacts of biorefineries, the setting of the spatial and dynamic system boundary may significantly affect the results. There are two different approaches to LCA: attributional (ALCA) and consequential (CLCA). The attributional LCA only describes the environmental relevant physical flows, whereas consequential approach only reflects the particular change. In this paper, the implications of setting the spatial system boundary for a hypothetical case-study where a pulp and paper plant is changed into a biorefinery are discussed through application of both ALCA and CLCA. In the system, a pulp-based side stream, which is presently used elsewhere, is transformed to new end-uses as a material or fuel in the biorefinery.

2. Attributional and consequential approaches in assessing greenhouse gas emissions

Setting the appropriate system boundary and selecting the approach for LCA depend on the goal and scope of the particular study. There are two primary approaches to LCA: *attributional* and *consequential* [Rebitzer et al. 2004, Finnveden et al. 2009]. ALCA – also referred to as "accounting", book-keeping", "retrospective" or "descriptive" – has been defined as a method for describing the environmentally relevant physical flows of a past, current, or potential future product system [Eriksson et al. 2007]. As the method is static, it cannot reflect the impacts of any change. Instead, CLCA, also referred to as "change-oriented", "market-based", "marginal" and "prospective", can be defined as a method aiming to describe how environmentally relevant flows would have been or would be changed in response to possible decisions that would have been or would be made [Ekvall & Weidema 2004]. ALCA reflects the system as it is, whereas CLCA aims to respond the question: "what if".

Both approaches have different pros and cons, and provide various kinds of perspectives [Thomassen et al. 2008]. In ALCA, environmental impacts are attributed to a given product system over its life cycle. Average or generic data is used where the goods and services stem from a wide mix of producers or technologies. When ALCA is carried out to assess the past or present situation of an existing product system, data is typically relatively well available. The main challenge in ALCA is how to carry out the allocation of environmental impacts between products as there exists no single objective allocation method. ALCA provides useful information on the environmentally relevant physical flows of the product systems, in particular when by-products of a certain main product are used as a raw material of the given product system.

However, as discussed above, ALCA cannot describe the impacts of any change, which often are the main interest of a study. This is the purpose of CLCA: it tries to assess the change between two conditions. The system boundary is extended from the given product system to all those product systems that are influenced by the change. Ideally, all the activities inside and outside the product system's life cycle that are affected are included in the study. As the consequences of a certain change may be very far-reaching in time and space through rebound effects and other secondary consequences, it is very difficult or impossible to carry out a comprehensive CLCA in an objective manner [Finnveden et al. 2009]. The fundamental problem of CLCA is related to the identification of possible changes which are to be analysed and the associated availability of reliable data. The amount of assumptions needed and the uncertainty of the results increase as a function of the completeness of the analysis.

3. A hypothetical biorefinery case study

In this paper, a possible difference in the greenhouse gas emissions resulting from setting the system boundary by using the ALCA and CLCA approaches are studied through a hypothetical biorefinery concept. When conducting an LCA of a production chain, perhaps the most crucial question is how to define the reference system (i.e. what is compared with what) and the system boundary (i.e. what is included in the study) [Soimakallio et al. 2009].

In the present system, a pulp-based side-stream generated at the pulp and paper plant is taken out and refined by a separate actor. The side stream is used as a raw material for several products, which are used for different purposes. It is assumed that the demand on the market is stable and that the by-products have such a small market-share that they could not raise prices. In the new production system, the particular side-stream is taken to the biorefinery and used as a raw material for new biomass-based materials or fuels. As a result, the present refinery is no longer needed. Moreover, other products are needed to replace for the current use of the pulp-based side-stream.

In the attributional assessment, environmentally relevant physical flows (here causing greenhouse gas emissions) directly related to the life cycle of the product are included in the assessment (Figure 1). The assessment is cradle to grave meaning that it covers all the processes from the forest to end treatment. Side-effects on the markets are not taken into account. Greenhouse gas emissions are allocated between co-products using for example mass or economic value as a basis of the allocation (not discussed further in this paper). The ALCA approach represents the ‘carbon footprint’ of the product. The results can be compared to other products providing the same functional unit (the reference system).

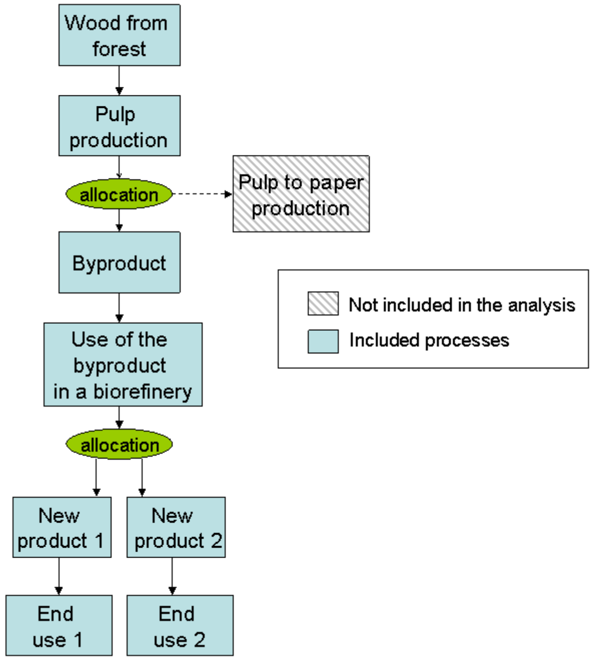

Figure 1. Processes included in the attributional assessment (ALCA).

In the CLCA, greenhouse gas emission impacts caused by the introduction of the biorefinery concept are of interest. All those processes that change as a response to the introduced change are included in the assessment (Figure 2). Thus, the reference system is the present situation. As it is assumed that the present demand stays the same, the products currently produced with the by-product need to be produced with something else. Those processes that do not change are not taken into account. In terms of greenhouse gas emissions, the most important consequences are likely to include the replacement of the side-stream-based raw materials in their present use with other products, and the avoided greenhouse gas emissions due to the avoided refining process and the replacement of fossil fuels by the new biomass-based materials and fuels. In practice, both significant and insignificant secondary consequences may take place. As it is assumed that the demand of products on the market is stable and the by-products have such a small market share that they could not raise prices, only those primary implications described above were considered.

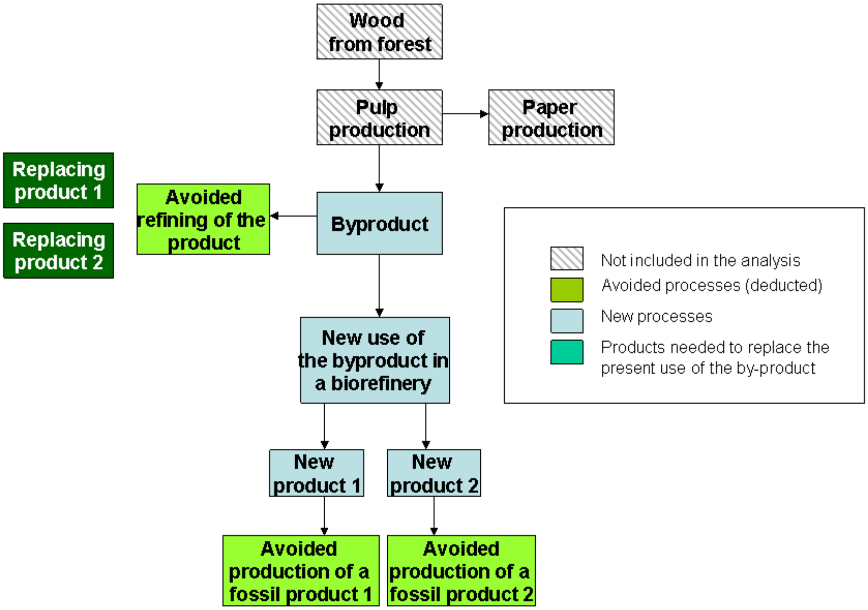

Figure 2. Processes included in the consequential assessment (CLCA).

4. Results

In the hypothetical case study, the greenhouse gas emissions related to environmentally relevant physical flows of the product system (new biomass-based materials and fuels) are lower compared to the assumed fossil reference system (Figure 3). Thus, the attributional analysis illustrates that if the present use of the product is excluded from the assessment, the studied alternative may produce less GHG emissions than the corresponding fossil fuel-based alternative (Figure 3). However, when the present use is taken into account, the introduction of the biorefinery concept results in increased GHG emissions – provided that the production of the replacement alternatives for the raw material yields more emissions than the current system does (consequential assessment) (Figure 4). Consequently, the greenhouse gas emissions of this replacement are assumed to exceed the credits that are achieved through avoided emissions from the avoided refining process and replacement of fossil fuels by the new biomass-based materials and fuels.

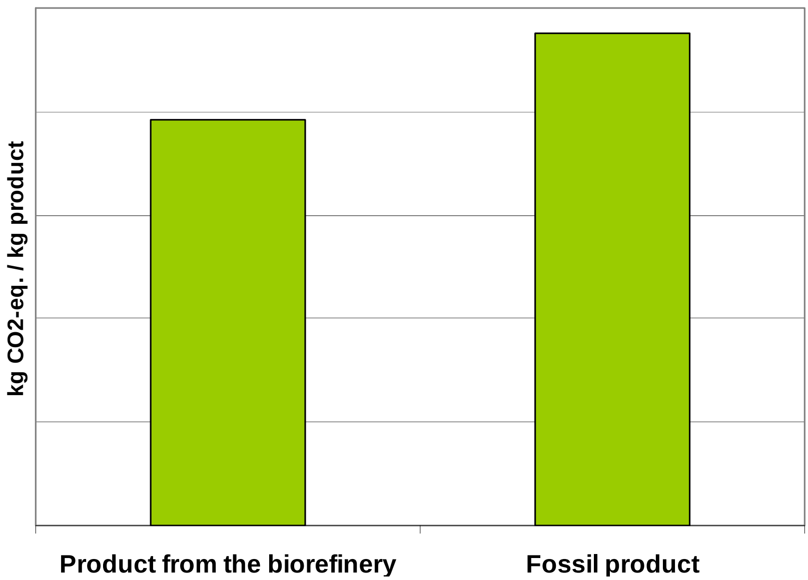

Figure 3. Results from the attributional assessment: product from the biorefinery compared to a fossil product.

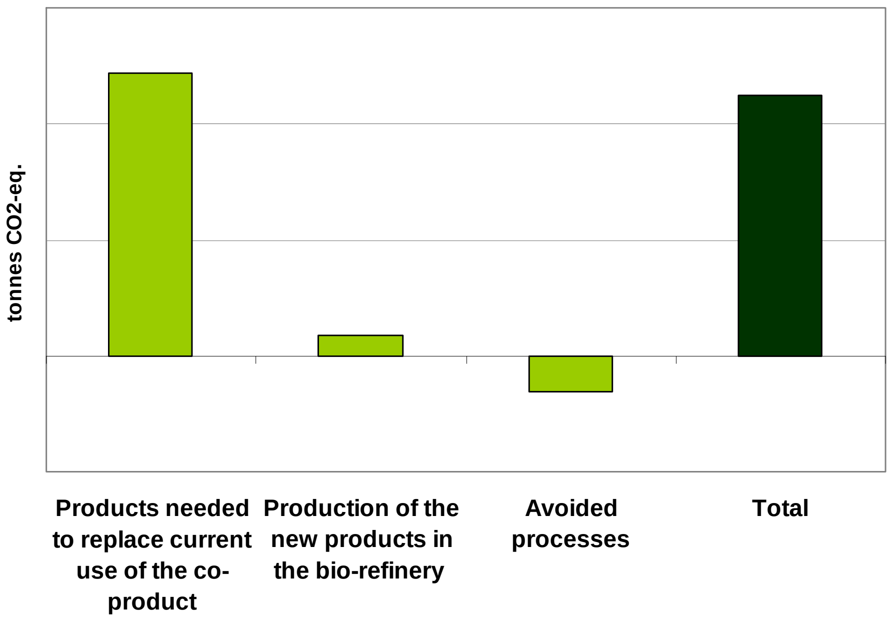

Figure 4. Results from the consequential assessment: emissions compared to the present situation.

5. Discussion and conclusions

The hypothetical case study illustrates that using only the attributional approach may lead to completely different conclusions than applying the consequential approach. The study highlights that for those biomass-based side-streams for which there currently exists use, the environmental benefits of diverting them to new uses as bio-fuel or bio-material are not straightforward and should be carefully and comprehensively studied before making decisions. Applying only the attributional approach may result in completely different conclusions than when attention is paid to indirect impacts, such as competition of available resources. However, it should be noted that the results may also turn out to be different. For example, if the by-product used was presently a waste material, diverting it from landfill to new uses would probably turn out to be a positive solution from the environmental point of view.

Both ALCA and CLCA are relevant, provide different perspectives, have several pros and cons and can be used for assessing the environmental sustainability of all kinds of production systems. ALCA reflects the traditional way of carrying out an LCA and is a suitable approach to study the environmentally relevant physical flows of the product systems. It also provides a good basis for verifying and monitoring greenhouse gas emissions of products or services that are currently more and more claimed for (the so-called carbon footprints). However, as it cannot reflect consequences of any change, it should not be used as a basis for policy-making: for example, when aiming to promote certain actions to reduce greenhouse gas emissions and thus mitigate climate change.

As climate change mitigation requires rapid and effective measures, significant attention should be paid to carrying out the consequential analysis. It is crucial to improve the understanding of the consequences of decisions, i.e. connections between product systems and the implications of various market effects on them. In addition to primary consequences, the knowledge of likely secondary consequences also needs to be improved. Identification of the most relevant consequences is very difficult, and therefore significant impacts may be omitted. Thus, the challenge of the consequential approach is the careful consideration of the possible consequences and the inclusion of those that are the most relevant.

The objective analysis of consequences of any decision is very difficult or even impossible and subject to significant uncertainties. In addition, the consequences may be very far reaching in time and space. Therefore, it is necessary that an appropriate number of scenarios, tools and models reflecting the consequences not only for various product systems but also on the system, sector and economy level are used before making decisions. In order to gain comprehensive understanding and provide adequate perspective on the environmentally relevant physical flows and the related consequences, it is recommended to apply both methods side-by-side but to avoid mixing them up.

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Carbon footprint of a forest product – challenges of including biogenic carbon and carbon sequestration in the calculations

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Abstract

Discussion about the impacts and consequences of climate change has aroused interest in the carbon emissions that are associated with the purchased products. In the methodology development, the inclusion of biogenic carbon has turned out to be problematic. The problems with including biomass carbon are mainly related to forest carbon balance and some methodological issues concerning carbon storage in products. There are several open questions that have to be solved, such as the time frame used in the carbon footprint calculations. Before a generally accepted methodology is available, several varying approaches are applied, depending on who is performing the calculations and what their goal and scope are. The effect of wood raw material harvesting on the forest carbon balance can be calculated in various ways. Three different approaches are presented in this paper. In the first approach, it is claimed that sustainable forest management ensures that the same amount of carbon taken out from the forest is absorbed again by the forest growth. The opposite way is to calculate the lost carbon stock and allocate it to products. The third approach allocates the net carbon sequestration through net forest growth to forest products. Guidance concerning carbon storage in products exist and they are discussed in this paper. The challenges of including the forest carbon balance are expressed with the case calculation examples.

1. Introduction

Due to concern over climate change, controlling and reducing GHG emissions has become an important issue. The carbon footprint concept has been introduced to enable identification and evaluation of GHG emissions as generated by products. The carbon footprint refers to the quantity of greenhouse gases (e.g. CO_2, CH_4 and N_2O) produced during a product's life cycle.

Previously, carbon footprint calculations have included only the GHG emissions originating from fossil sources. This is arguable by the fact that due to the carbon cycle, the biogenic carbon content on earth remains constant in the long run. This assumes that the total volume of forests remains the same. However, the amount of biogenic carbon in the atmosphere varies over time, depending on how much carbon is sequestrating and stored in the forests for the moment, and how much is stored in forest products and landfills. At the regional level, the carbon sinks have also grown, due to sustainable forest management.

Carbon footprint calculation procedure is based on life cycle thinking and the Life cycle assessment (LCA) methodology. However, the impact of the time boundary is not fully stressed in LCA. As a consequence, the attempts to incorporate biogenic carbon in the carbon footprint concept have varied, leading to totally reverse conclusions. Without scientific research and an internationally agreed approach, this range of differing schemes may encourage conclusions with undesirable impacts.

2. Carbon cycle

The most common natural elements in the living world are carbon (C), hydrogen (H) and oxygen (O). The main structural material among living organisms is carbon. Apart from its presence in organic compounds, carbon also occurs in nature in an inorganic crystalline or molecular form, as well as in the form of inorganic compounds. Inorganic carbon compounds include the oxides produced during the combustion of carbon compounds, i.e. carbon monoxide (CO) and carbon dioxide (CO_2), and also carbonates like marble ($CaCO_3$).

The carbon cycle is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere and atmosphere of the Earth. Carbon transport between and among the reservoirs is primarily accomplished via CO_2 gas exchange. The two types of processes that affect the flow of the global carbon cycle are long-term fluxes – the geocycle, e.g.

weathering, or the decomposition of rocks, minerals and soils as well as short-term fluxes driven by natural reactions such as photosynthesis and respiration. In this article, the focus is on short-term fluxes – the biocycle.

The biocycle represents short-term carbon flux varying from minutes to a day, or even centuries. In the biocycle, carbon circulates between inorganic and organic nature. Organisms – such as, e.g. plants and algae containing chloroplasts – bind carbon dioxide from the atmosphere during photosynthesis. Animals eat plants or other animals, thereby obtaining carbon compounds as a building material. As the cycle progresses, the organic material is returned to inorganic nature during cell respiration, a form of combustion in which energy is released for cell functions. Simultaneously, the gas formed by the combustion – i.e. carbon dioxide – is emitted into the atmosphere. The burning of wood also comes into the short-term cycling of carbon, the biocycle. It can be compared to cellular respiration but is a much faster combustion reaction. Carbon dioxide synthesized during photosynthesis is returned to the atmosphere when wood burns (Suomen Metsäyhdistys 1999).

This carbon balance is changed by a phenomenon called *greenhouse effect increase*. This means that the surface of the earth and the troposphere is slowly warming because the normal heat radiation is effected by an increase of greenhouse gases in the atmosphere. The greenhouse gases (normal greenhouse effect) in the atmosphere make the earth warm enough for life to exist, and therefore is absolutely necessary. Most efficient greenhouse gases are water vapor, CO_2, methane (CH_4) and ozone. The CO_2 in the atmosphere is resulting in more than 50% of climate warming. The CO_2 level in the atmosphere is increased by use of fossil fuels. In terms of controlling the greenhouse effect, the most important action is to reduce the geocyclic carbon emissions, i.e. reducing the use of fossil fuels.

The role of forests is significant in terms of the greenhouse effect, because forests regulate the CO_2 concentration in the atmosphere. It is approximated that the living biomass (animals, plants and humans) bind as much carbon as there is free carbon in the atmosphere. Forests in their natural state are in equilibrium, they bind as much CO_2 as they release through breakdown of biomass. When trees from forests are used for production of forest products, the carbon bound in the trees is stored and the removed trees give room for new forest to grow and bind new carbon. In this way, the forest products are carbon storages and the forests carbon sinks (Kantola et al. 2000). However, the carbon stored in the forest products is finally released into the atmosphere as CO_2 from energy production or as landfill gas from the decay of products at landfills consisting of both CO_2 and CH_4. The most important industrial ecosystem feature with regard to the flow of carbon in the forest ecosystem is that the annual cuttings of forests are lower than the annual growth (Wihersaari 2005).

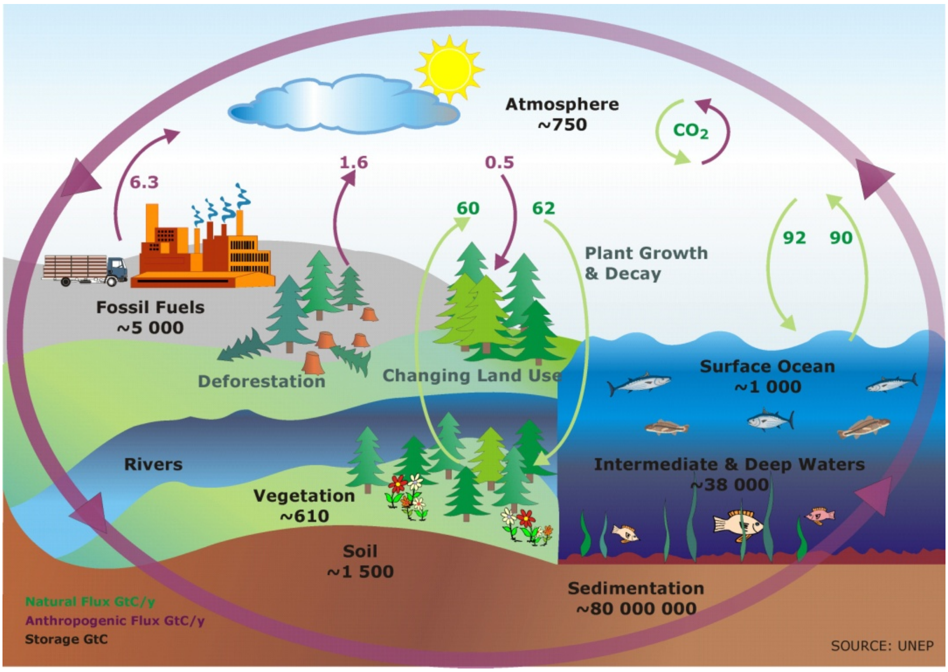

Figure 1. The natural cycle of carbon.

Figure 1 shows the natural and anthropogenic fluxes of CO_2. This article, however, focuses on the anthropogenic fluxes of the forests and land use. How changes in these shall be taken into account and modelled when calculating carbon footprints of forest products is discussed in the following parts of this article.

3. Challenges of including biogenic carbon in carbon footprint calculations

3.1 Forest carbon balance

Including biogenic carbon dioxide in carbon footprint calculations is challenging. Without widely used methodology, biogenic CO_2 can be used in a purpose-oriented way, depending on the product under examination as well as the goal and the scope of the study. PAS 2050 discusses the biogenic carbon but states that biogenic CO_2 emissions should be excluded from the carbon footprints and only carbon storage in products and the impact of land use change can be calculated in carbon footprints.

There are several issues concerning biogenic CO_2 that have to be taken into account when decisions concerning the inclusion of biogenic CO_2 are made. Inclusion of forest carbon balance in the calculations and the time scope are especially relevant issues if biogenic carbon is included in carbon footprints. The question of forest carbon balance is twofold: managed forests sequester carbon dioxide from the atmosphere while growing, whereas in old forests carbon sequestration is closer to zero because the amount of absorbed CO_2 equals to the amounts of released CO_2 via degradation of organic matter (Garcia-Gonzalo et al. 2007). There are several ways of taking forest carbon sequestration into account in carbon footprint calculations. The Confederation of European Paper Industries (CEPI) indicates in its Framework for the development of Carbon Footprints for paper and board products that the forest industry's use of wood fibre provides an incentive to keep land in forest, but admits that it is difficult to determine the exact impact of a single product on forest carbon. CEPI proposes two approaches: stock exchange and flow accounting. When wood is harvested from sustainable managed forest, the stock exchange remains zero because the same amount of wood is growing what is harvested. The flow accounting approach calculates the carbon sequestered while growing and released in the processes. The flow accounting approach is presented in the following chapter (carbon uptake approach) (CEPI 2007).

In Northern Europe, forest growth exceeds harvesting and thus net carbon sequestration takes place. The Swedish Environmental Research Institute IVL is allocating the carbon sequestration from net forest growth to forest industry products, claiming that by using wood raw material, sustainable forest management is ensured and continuous carbon sequestration thereby takes place. (Eriksson et al. 2009). A totally opposite approach is used by the Canadian Environmental Paper Network, which has calculated carbon footprints for various paper grades (Ford 2009). The approach used in their study is adopted from IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003) impacts. The approach calculates the lost carbon sequestration potential as CO_2 emission. Both calculation approaches are presented in the following chapter with case examples.

Calculation of the carbon footprint is usually made for a single product. Recommendations have neglected the predictions of IPCC which state that the amount of greenhouse gas emissions have to be cut down by 60 – 80 percent by 2050 (IPCC 2007). This should mean that the maximum time period examined should be 45 years. In the case of biodegradable material such as wood, it is quite common to ignore wood growth in the calculations as well as bio-based CO_2 emissions. This methodological approach can be explained by the long-term carbon balance – carbon that is released in the burning or decay of bio-based products is captured again during biomass growth. This principle is valid when the same number of growing and burning periods applies during the time period examined. However, if the rotation time of boreal forest is about 90 years and the urgency of mitigating CO_2 emissions is taken into account, the harvested area will not store as much carbon as it did prior to harvesting. The situation is totally different for the eucalyptus tree, which already achieves its ultimate length in 8 years. In addition, it can be argued that forests with long rotation periods would sequester even more carbon if they were not harvested.

3.2 Carbon stored in the product

Other methodological challenges are posed by dealing with carbon stored in products. PAS 2050:2008, which is the first general guidance on dealing with calculating carbon footprints of products, includes biogenic carbon storage of products. PAS indicates that *"if more than 50% of the mass of carbon of biogenic origin in the product remains removed from the atmosphere for one year or more following production of the product"* carbon storage can be included in carbon footprints. The method of calculating the weighted average impact of carbon storage in carbon footprints is presented in Annex C in PAS 2050:2008. The method includes two formulas: one for a product that stores all the carbon for a certain amount of time (e.g. wooden table) and one for the product that loses its carbon slowly (e.g. a product in a landfill). The result is a weighting factor, with which a total amount of biogenic carbon is multiplied in order to find out the weighted average impact of biogenic carbon stored in a product over the 100-year assessment period. (BSI 2008.)

For paper products, carbon storage is insignificant, however, in most cases, because the life span of a paper product is usually relatively short. There are some exceptions, such as books. On the other hand, when wood products are under consideration, biogenic carbon storage is more relevant. The defined time frame is important and determines the significance of carbon storage. In the long run, carbon from wood-based products will be released back to the atmosphere (e.g. via burning or decaying in landfills), but over a short term, carbon stays stored and away from the atmosphere. Because the case calculations in this paper deal with pulp, long-term carbon storage is not studied but rather the amount of carbon in pulp is given. If pulp was used in paper manufacturing for books, carbon storage could have been calculated.

4. Various ways to include carbon sequestration in forests in carbon footprint calculations

Various approaches for including forest carbon sequestration in the carbon footprint calculations are presented in this chapter. In this paper, the flow accounting approach (in this paper called carbon uptake), the lost carbon stock approach and finally the carbon sequestration through net growth are examined. At first, however, the basic cradle-to-gate carbon footprint of typical Finnish softwood pulp is presented, including fossil greenhouse gas emissions alone.

4.1 Baseline scenario

The baseline scenario presents the fossil cradle-to-gate greenhouse gas emissions for an air dry pulp tonne (ADt pulp). In addition to pulp, excess electricity is also produced in a typical Finnish softwood pulp mill. In this paper, excess electricity has been allocated out by using the economical value of electricity and pulp (Nord Pool 2009, Lumme 2009). Pulp is more valuable product for pulp mill and the used allocation factor for pulp was 0.995. The total emissions are 271 kg CO_2eq/adt pulp. Figure 2 shows how the emissions are divided between different life cycle stages.

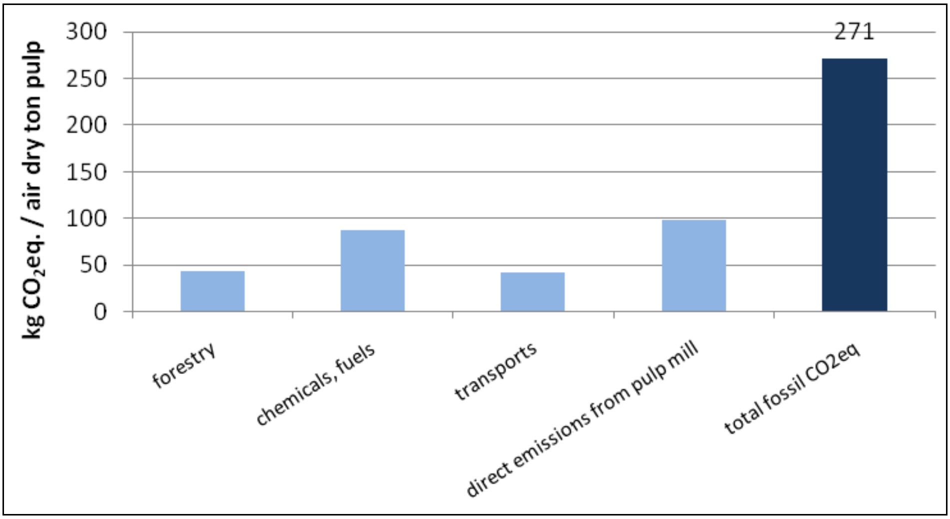

Figure 2. Cradle-to-gate carbon footprint of a typical softwood pulp.

4.2 Carbon uptake

Depending on land use, forest management and environmental conditions, forests and soils can act as major sinks or sources of atmospheric CO_2. Trees absorb carbon in the form of CO_2 from the atmosphere and turn it into the organic matter of their own biomass through the process of photosynthesis. The carbon is removed from forest carbon stocks as emissions from forests to the atmosphere or via harvesting (Miner & Perez-Garcia 2007). The carbon that is sequestrated by growth of the tree stays mostly stored in the wood when it is harvested. Roots, stumps, branches and tops are excluded from the examination. Some of the carbon is released in the pulp mill via black liquor and bark combustion, and part of it stays stored in the product. This approach is called carbon uptake in this paper. A theoretical situation of carbon uptake is presented in Figure 3, showing the real fossil greenhouse gas emissions as well as the idea of the biogenic carbon flows in the pulp value chain. Other biogenic carbon flows, such as emissions from bioenergy production outside the system (e.g. biogenic CO_2 emissions from purchased electricity production) are excluded in the calculation. All the carbon, more or less, is released again to the atmosphere within the life cycle of the forest product. Some carbon might stay sequestrated in the landfills, depending on the decaying rate of the disposed product.

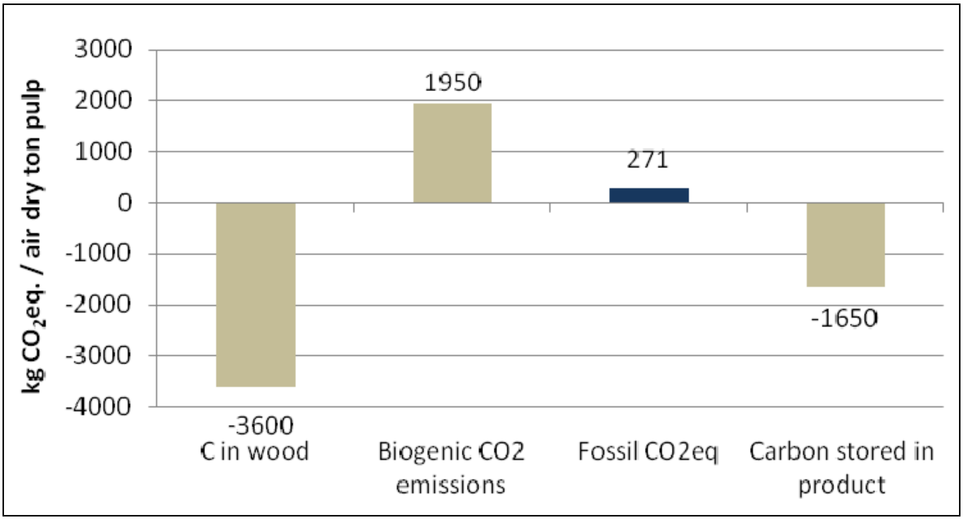

Figure 3. Carbon uptake approach takes into account the biogenic carbon that is bound to the wood used in the system.

4.3 Calculating lost carbon stock as an emission

In this approach, a lost carbon stock is calculated as an emission. This approach is applied in the North-American research (Ford 2009), that studies the carbon neutrality of a paper product and also comparing carbon footprints of the products using virgin and recycled fibre. This approach calculates the loss of carbon sequestration potential when wood is harvested and allocates it to a product in a relation of the amounts wood raw material used. The method is based on IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (IPCC 2003), which sets the rules on how to calculate the lost carbon stock from the harvest of forest products. This approach favours products manufactured from recycled fibre, as the need of virgin fibre is smaller and thus the decreased carbon stock is smaller, too. Figure 4 presents the carbon footprint of the air dry pulp ton in the situation, when lost carbon stock is calculated as an emission and allocated for the product.

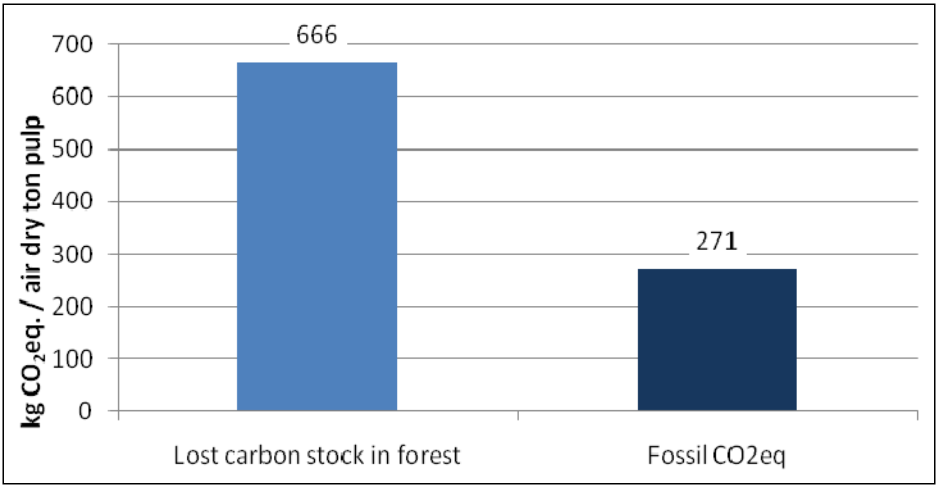

Figure 4. Calculating the lost carbon stock via harvesting in carbon footprints.

4.4 Allocating net carbon sequestration to typical softwood pulp

In Northern Europe, forest growth exceeds harvesting and thus net carbon sequestration takes place. Another calculation approach is to take annual forest net growth into account and allocate part of it to the forest products. Net carbon sequestration is allocated to products in the ratio virgin fibre is used in the manufacturing process. Especially in Sweden this approach is applied when calculating carbon footprints for pulp and paper products. The ideology behind this approach is that using wood as raw material contributes to an economic market for wood raw material, which stimulates a sustainable and efficient forest management. (Eriksson et al. 2009) A calculation example has been calculated in this paper, presenting the carbon footprint with carbon sequestration from net growth. According to the Finnish Statistical Yearbook of Forestry 2008 (Finnish Forest Research Institute 2009), the annual net sequestration of carbon dioxide is (a calculated average of years 2004, 2005, 2006 to minimize the effect of annual changes) -37.97 million tons of CO_2. The total annual removals (average of 2004, 2005 and 2006) are 59.8 million cubic metres (Finnish Forest Research Institute 2009). Thus, carbon sequestration for a cubic metre is 702 kg CO_2/m^3 wood. It is known that a typical Finnish softwood market pulp tonne requires 4.7 cubic metres wood, and therefore a sequestration of -3309 kg CO_2 can be calculated for a market pulp tonne.

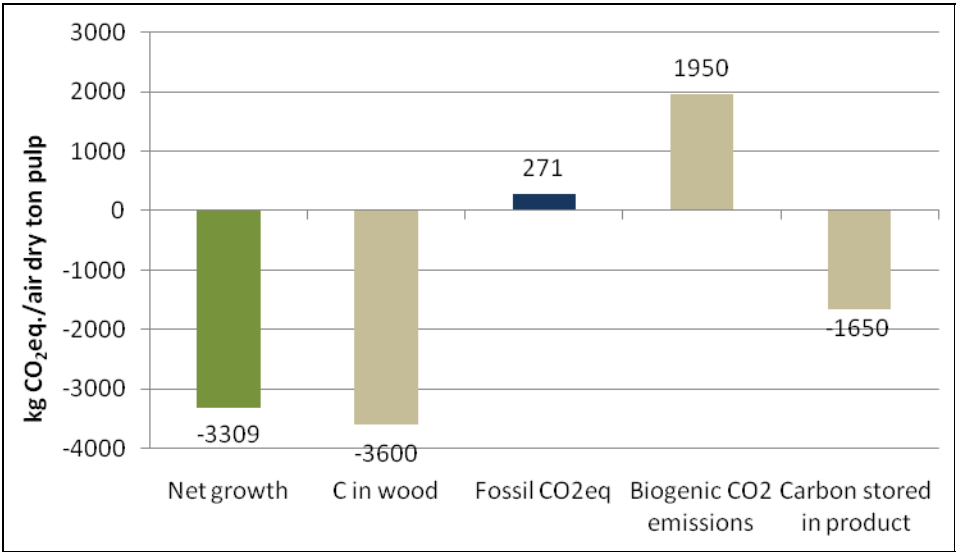

Figure 5. Allocating annual net growth to softwood pulp.

5. Conclusions

In general, carbon footprint has turned out a useful indicator for investigating the possibilities to mitigate the GHG emissions and in evaluating benefits of technological processes in the current prevention of global warming. The primary cause of the increase of carbon concentration in the atmosphere is the fossil carbon. It means that fossil emissions determine when carbon balance is considered in the long term, and thus the mitigation of these emissions is in a decisive role. At the same time, the prevention of global warming will require rapid actions within the next 20–50 years. Therefore, the fundamental question is whether to calculate only fossil GHG emissions when determining carbon footprint, or if the biogenic carbon should also be involved in the actions taken against global warming. As this paper illustrates, various approaches lead to contrary conclusions concerning the use of bio-based material. As a consequence, one can conclude that consuming wood material is beneficial or harmful to the carbon balance. Based on the articles and material published, it is hard to give scientific credit to one approach over another. The standards and guidance have also faced the challenge of assessing the effects of biogenic carbon, since it is dependent on the time frame under examination. Additionally, it is difficult to justify if the net growth of the carbon storages in forests is a consequence of product manufacturing, and it is similarly difficult to say what the carbon balance would be without sustainable forest management.

For the moment, the most reliable and comparable carbon footprint results are those including fossil GHG emissions. More research and methodology development are required with regard to the effects of using material that participate in the biogenic carbon cycle.

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LCA of beverage cups

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Abstract

Environmental impacts of a beverage cup concept were studied with help of life cycle assessment methodology. Carton based products were compared with polymer based products. The carton-based cups were covered either with polyethene (PE) or polylactide (PLA). The polymer based cups were made of polyethylene terephthalate (PET). The paper studies the environmental impacts of production and shortly discusses the alternative end-of-life scenarios. The focus is on global warming potential. The paper shows that significant improvements can be achieved through the choice of raw materials.

1. Introduction

1.1 Objectives

Environmental impacts of a beverage cup concept were studied with help of life cycle assessment methodology. The objective of the study was to compare the impacts of materials choices. This paper focuses on the impacts of the release of green house gases. Carton-based products were compared with polymer-based products. The carton-based cups were covered either with polyethene or polylactide. The polymer based cups were made of polyethylene terephthalate. In both cases the function of the cups is the same. The environmental impacts were calculated with regard to 100 000 pieces of cups over the whole life cycle.

The effects of alternative end-of life scenarios are shortly discussed. When making scenarios for the end-of- life of the products under scrutiny, there are several variables to be considered. The following list shows the variables that can be taken into account:

- recovery of plastics: energy recovery, mechanical recycling and feedstock recovery
- alternative ways of disposal including landfilling, incineration and composting
- the feedstock energy recovery in the case of incineration
- the degree of degradation in the case of landfilling
- the share of CO_2 contra methane in the case of degradation during landfilling; the degree of the oxidation of methane or converting by bacteria to CO_2 before escaping to the atmosphere
- the degree of recovery of methane in the case of degradation during landfilling.

In addition, the system might be extended to cover the substitution of other energy production through recovered energy.

1.2 Background

LCA is a technique for assessing the environmental aspects and potential impacts with a product by (ISO 2006a):

- compiling an inventory of relevant inputs and outputs of a product system
- evaluating the potential environmental impacts associated with those inputs and outputs
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave (ISO 2006b).

The appropriate choices of allocation methods, and system boundaries etc. depend on the purpose of the LCA. A distinction between attributional and consequential LCA has become widespread. Attributional methodology for life cycle inventory analysis (LCI) aims at describing the environmentally relevant physical flows to and from a life cycle and its subsystems. It ideally includes average data on the unit processes. The attributional LCI model does not include unit processes outside the life cycle investigated. Consequential LCI methodology, in contrast, aims at describing how the environmentally relevant physical flows to and from the technosphere will change in response to possible changes in the life cycle. A consequential LCI model includes unit processes that are significantly affected whether they are inside or outside the life cycle. It ideally includes marginal data on bulk production processes in the background system (Russell et al. 2005).

Life cycle inventory analysis is one phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle. Data quality requirements specify in general terms the characteristics of the data needed for the study. Descriptions of data quality are important to understand the reliability of the study results and properly interpret the outcome of the study. The data quality requirements should address the following (ISO 2006b):

- time-related coverage: age of data and the minimum length of time over which data should be collected;
- geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study;
- technology coverage: specific technology or technology mix;
- precision: measure of the variability of the data values for each data expressed (e.g. variance);
- completeness: percentage of flow that is measured or estimated.

The LCIA phase has to include the following mandatory elements:

- selection of impact categories. category indicators and characterization models;
- assignment of LCI results to the selected impact categories (classification);
- calculation of category indicator results (characterization).

2. Methods and background data

2.1 Introduction

Carton-based products were compared with polymer based products. The carton-based cups were covered either with PE or PLA. The polymer-based cups were made of PET. In both cases the function of the cups is the same (cold drink cups). The environmental impacts were calculated with regard to 100 000 pieces of cups over the whole life cycle.

The environmental profiles were calculated on the basis of the collected material and energy data for the chosen alternative units. In addition, the environmental significance of the logistical requirements and options of final disposal were assessed by means of modelling and studying the related environmental loadings.

The life cycle assessment was done following the basic principles of ISO 14040 and ISO 14044. The global warming potential was calculated with using the values of the IPCC Fourth Assessment Report (2007). The results were also analysed with help of the CML-methodology (2001).

The system boundary defines the unit processes to be included in the system. The unit systems included in this study were the following:

- acquisition of raw materials
- inputs and outputs in the main manufacturing/processing sequence
- distribution/transportation
- production and use of fuels, electricity and heat
- manufacture of ancillary materials.

In addition, the study dealt with the disposal of products and the recovery of used products (including reuse, recycling and energy recovery).

The unit systems excluded were:

- manufacture, maintenance and decommissioning of capital equipment.

The exclusion was justified because of the similar significance of these unit systems for all of the alternatives under scrutiny.

The data collection and the LCA study included the following processes:

- forest growth and harvesting.
- board manufacturing covering all operations
- manufacturing of chemicals
- energy generation
- production of reel packing.
- all transportations to site
- waste transport from site
- production of fuels
- cradle to gate data concerning LDPE or PLA
- transport of LDPE and PLA.

and excluded:

- manufacturing of chemicals used <0.1% (weight)
- production of raw materials for packaging
- landfill and waste treatment during the production processes.

With regard to PLA pellets the study included the following processes:

- growth of corn
- transportation of raw materials and ancillaries
- external energy generation.
- production of fuels
- manufacturing of PLA

With regard to PET based cups, the study included the following processes:

- extraction of raw materials
- transportation of raw materials and ancillaries
- energy generation
- production of fuels
- manufacturing of PET

– cup production: thermoforming, regrinding and packing.

For energy consumption the HHV-values (higher heating value) were used (Table 1).

Table 1. Heating values (HHV) used in this study.

Energy type	Value
Coal	30 MJ/kg
Natural gas	55.3 MJ/kg
Heavy fuel oil	42.8 MJ/kg
Light fuel oil	45.4 MJ/kg
Diesel oil	45.5 MJ/kg
Peat	22 MJ/kg

The results were classified and characterised with regard to the following impact categories:

– Depletion of abiotic resources
– Climate change
– Stratospheric ozone depletion
– Acidification
– Eutrofication
– Photochemical oxidant formation.

The following category indicators were used (problem oriented approach, baseline (CML 2001)):

– abiotic depletion, ADP, kg antimony eq
– global warming, GWP100, kg CO2 eq
– ozone layer depletion ODP steady state, kg CFC-11 eq
– acidification, AP, average Europe total, kg SO2 eq
– eutrophication, EP, kg PO4-- eq
– photochemical oxidation, POCP, kg ethylene eq.

2.2 Environmental profiles for coating materials and PET

2.2.1 Environmental impacts of low-density PE

The eco-profile of low-density polyethylene (LDPE) is based on APME (Boustead 2005a). Data have been obtained for the production of 4.48 million tonnes of low density polyethylene. This represents 93.5% of all West European production. The average gross energy to produce 1 kg of LDPE is 77 MJ with a range from 64 MJ to 96 MJ.

2.2.2 Environmental impacts of PLA

PLA is a polymer that can be made from renewable resources such as corn, sugar beets or rice. The life cycle of PLA starts with growing the raw materials. In principle, PLA production comprises the conversion of biomass to fermentable sugars, fermentation of these sugars to produce lactic acid, purification of lactic acid and its polymerisation. PLA is produced commercially from starch crops. However, producing PLA from lingo-cellulose will probably take place in the next 5–8 years because this process has higher efficiencies (Dornburg et al. 2006).

In the USA, the raw material used in the first generation of PLA is corn. In other parts of the world, locally available crops such as rice, sugar beets, sugarcane, wheat and sweet potatoes can be used as a starch/sugar feedstock. After harvesting, the corn is transported to a corn wet mill where the starch is separated from the other components of the corn kern (proteins, fats, ash, and water) and converted by means of enzymatic hydrolysis into dextrose. Dextrose can be fermented into lactic acid at near neutral pH. Through acidulation and purification steps the lactate salt fermentation broth is then purified to yield lactic acid (Vink 2003).

Corn-based polylactic acid resin can be modified to create a material that can be applied to paperboard to create a water-resistant barrier. This material can replace the petrochemical plastic used in standard packaging today. Technologies are available that enable the processing of natural plant sugars to create a proprietary polylactide polymer (marketed for example under the NatureWorks brand name). Cargill Dow's NatureWorks branded PLA is a compostable polymer used in a wide range of packaging, film and fibre applications (Vink et al. 2003). There are two major routes to produce polylactic acid monomer either direct condensation polymerization of lactic acid and ring-opening polymerization through the lactide intermediate or ring-opening through the lactide intermediate. Cargill Dow uses the second route.

Schers (2005) has analysed the risks of the PLA production process. The main identified potentially hazardous substances are the pesticides and fertilizers, concentrated strong base for the fermentation process, and the base and solvents in the first extraction process. In addition, the total primary energy use (roughly 54 MJ per kg of pellets) indicates high emissions. Mainly the same substances that cause emission risks cause risks for calamites. Pesticides, fertilizer, concentrated NaOH and possibly the solvents of the first purification process could cause risks to ecology when suddenly released in large amounts. However, the process conditions are assessed as mild by Schers (2005), and the production system is not assessed to be risky.

Genetic modification is possibly a more powerful tool to change the genome of organisms than traditional breeding and classic mutagenesis. In the case of PLA, GM can be used in the growing of corn to produce better enzymes (for hydrolyses) and better micro-organisms (for fermentation). Genetic modification applications now possibly in use or to be used in the production of PLA seem safe according to Schers (2005). There are contradictory arguments about the risks of GM; and the subject field is not more closely dealt with by Schers (2005). This risk should be compared to other risks of biodiversity. However, this study focuses on LCA. LCA is one of several environmental management techniques including risk assessment. LCIA is different from other techniques, such as environmental performance evaluation, environmental impact assessment and risk assessment, since it is a relative approach based on a functional unit.

Vink et al. (2007) have analysed the environmental impacts of PLA by using the LCA methodology. The study covers the following steps: 1) corn production and transport of corn to the corn processing wet mill, 2) corn processing and conversion of starch into dextrose, 3) conversion of dextrose into lactic acid, 4) conversion of lactic acid into lactide, and 5) polymerization of lactide into polylactide polymer pellets. The study also covers the production and delivery electricity used in the PLA production system. The process uses electricity the energy sources of which include wind power.

Patel et al. (2003) have reviewed LCAs of bio-based polymers. Incineration and composting are options of the waste management of bio-based polymer products. In the LCAs of bio-degradable bags the carbon absorption and release has to be dealt with; assumptions such as the following example are made: 60% of the carbon absorbed in the vegetable material is released to the atmosphere during composting (97% as CO_2, 3% as CH4) and the rest (40%) is sequestered in the compost. This assumption was considered open to doubt by Patel and Marini.

2.2.3 Environmental profile of PET

PET is a thermoplastic polymer. The starting compounds for the commercial production of PET are ethylene ($CH_2 = CH_2$) for the production of ethylene glycol and para-xylene for the production of terephthalic acid. Naphtha cracking produces only very small quantities of xylenes. Most xylenes are produced either from pyrolysis gasoline, an aromatic rich fraction produced during naphtha cracking or directly from naphtha in the process of catalytic reforming. In both cases, the basic feedstock is converted into a mixture of products, the principal components of which are benzene, toluene and xylenes. The result covers Polyethylene Terephthalate (PET) (Bottle grade) production in the EU in 10 plants in 1999. The eco-profile data of PET is based on APME (Boustead 2005b).

Environmental parameters (energy and emissions of CO_2, CH_4 and N_2O) from the production of LDPE, PLA and PET are shown in Table 2.

Table 2. Environmental parameters of LDPE, PLA and PET.

		LDPE	**PLA**	**PET**
Non-renewable energy (including feedstock)	MJ/kg	76.7	27.15	82.0
Renewable energy (including feedstock)	MJ/kg	1.12	31.3	0.450
CO_2	g/kg	1 700	1 783	2 900
CO_2 (biomass)	g/kg	–	–1940	
N_2O	Mg/kg	< 1	0.365	< 0.001
CH_4	g/kg	16.0	13.8	19.0

3. Results

The use of resources and the climate change potential calculated in terms of CO_2 equivalents are shown in Table 3.

Figure 1 shows the overall relative results of the environmental impact potentials calculated on the basis of the alternative production processes.

According to the results PET based cups (100 000 pcs) cause the highest CO2 emissions whereas the CO2 emissions caused by paper based cups for PE coating are only 20 % of that and 23 % of that for PLA coating. Paper based cups with either PE or PLA coatings show also lower potential impacts compared to the PET concept in every impact category except in the impact category of eutrophication.

Table 3. GWP (Global warming potential, emissions into air, mass flows in CO_2 equivalents).

		Carton + 2PE	Carton + 2PLA	PET
CO_2 (bound to biomass)	kg	5 038	4 980	-
Non-renewable energy + feedstock energy	GJ	24	19	119
Renewable energy + feedstock energy	GJ	3.2	9.8	3.9
CO_2 (fossil)	kg	864	925	4 080
CO_2 (biomass)	kg	3 140	3 610	0
N_2O	kg	0.130	0.210	0.031
CH_4	kg	5.00	4.90	25.0
HCFC 22	kg	< 0.0001	< 0.0001	< 0.0001
CFC 11	kg	< 0.0001	< 0.0001	< 0.0001
CFC 12	kg	< 0.0001	< 0.0001	< 0.0001
CFC 13	kg	< 0.0001	< 0.0001	< 0.0001
GWP (CO_2 equ)	kg	1 030	1 090	4 710

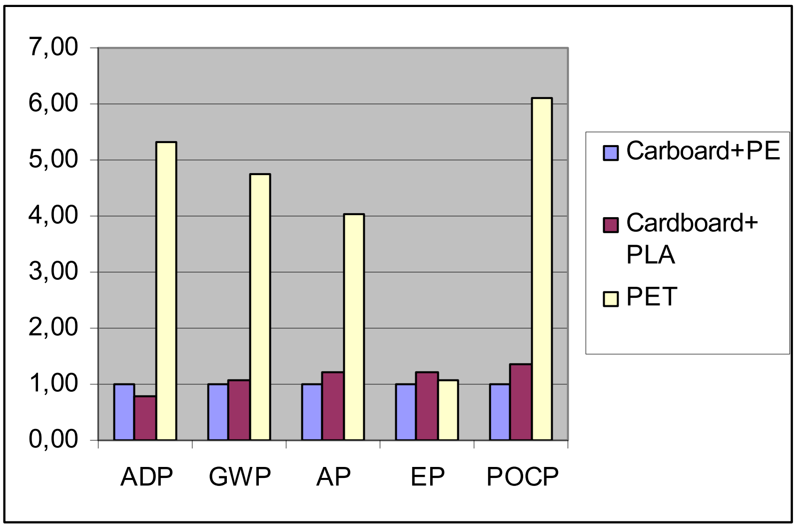

Figure 1. Environmental impact potentials of the studied alternatives compared to the option Cardboard + PE.

4. Discussion

The concept under scrutiny includes cold drink cups. At present, these are mainly PET-based products. The study assessed the environmental impacts of these compared to the corresponding products based on paper and covered either with PE or PLA. In both cases the function of the product remains the same.

On the basis of the overall manufacturing data, the use of resources and the release of harmful emissions are greater for the PET-cups than for paper-based cups. For example the consumption of fossil fuels for PET-based cups (100 000 pieces) was estimated to be 119 GJ whereas the fossil fuel consumption for paper based cups was roughly 20% of that. Correspondingly, as the CO_2 emissions of the PET cups were estimated to be roughly 4 080 kg of CO_2, those were roughly 80% lower for paper based cups. The paper-based cups with either PE or PLA coating showed lower potential impacts (assessed with help of the so called CML method) in all impact categories except in the impact category of eutrophication.

Paper based cups with either PE or PLA coatings show lower potential impacts in every impact category except in the impact category of eutrophication compared to the PET concept (Figure 1). PET production mainly uses electricity and according to the information of the European electricity grid and PET factories the main sources of energy are non-renewable sources, coal and gas. The use of renewable energy resources in PET production is quite a small.

There are several possibilities to deal with recycling within an LCA; the principles that should be followed depend on the scope of the study and the nature of the recycling processes. The essential decisions concern the allocation of the environmental loadings from the manufacturing of primary products and the allocation of the environmental loadings from recycling and final disposal of the recycled products. In the case of incineration, the CO_2 bound in the biomass can be taken into account. According to ISO14044 "reuse and recycling (as well as composting, energy recovery and other processes that can be assimilated to reuse/recycling) may imply that the inputs and outputs associated with unit processes for extraction and processing of raw materials and final disposal of products are to be shared by more than one product system".

The options of waste management are: landfilling, incineration and composting. Recycling is also technically possible. At present, plastics recovery in Western Europe is as follows: 32% energy recovery, 19% mechanical recycling and roughly 2% feedstock recovery (as raw material, Schanssema 2007). The studied alternatives vary with regard to degradation in the case of landfilling, energy recovery in the case of incineration, emissions of fossil CO_2 in the case of incineration and degradation in the case of composting. The end-of-life options may have a significant effect on the overall green house gases and energy of the studied alternatives.

5. Conclusions

The life cycle inventory of the drinking cup concepts was carried out with help the following tasks:

- Defining the units under scrutiny, system boundaries, allocation rules and cut-off rules
- Assessing the material and energy inputs and outputs
- Calculating the environmental loadings (resource consumption and release of emissions) for the chosen units

- Defining the principles of weighting (CML methodology)
- Assessing the significance of the results and summarising the results.

On the basis of the overall manufacturing data, the use of resources and the release of harmful emissions are greater for the PET-cups than for paper-based cups. However, in addition to the production process also the end-of-life options may have a significant effect on the result.

Significant improvements can be achieved through the choice of raw materials.

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Calculating the carbon footprints of a Finnish newspaper and magazine from cradle to grave

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Abstract

Environmental performance of a product in relation to climate change has become an interest among consumers. A carbon footprint is used as an indicator in evaluating the emissions of greenhouse gases of print products. In the following article, results from two case studies define the carbon footprint of a Finnish daily newspaper and weekly magazine throughout their entire life cycle. The significance of the carbon footprint results during the print product's life cycle is discussed.

Energy needed in the pulp, paper and printing processes creates the main part of the emissions. Furthermore, transporting the product to the customer and the end-of-life phase contribute to the total result as calculated from cradle to grave. However, current methodology involves open questions and, e.g. landfill data estimations introduce variation. The calculations provide a baseline against which the development can be measured and communicated. The total carbon footprint should be expressed as a range of values rather than as a single figure.

1. Introduction

Pressures to reduce greenhouse gas emissions have led to the development of the carbon footprint concept. The EU strategies strongly emphasise actions concerning climate change. The reduction aim in greenhouse gases is at least 20% by 2020 (compared with 1990 levels), a rise in the share of renewable energy to 20%, and a cut in overall energy consumption by 20%. Carbon footprint refers to the amount of greenhouse gases produced during the life cycle of a product. The calculation can be done for with, e.g. a product, a process, a company and a person. The scope and system boundaries of the calculation are different, depending on the subject.

The carbon footprint calculation has become widely used in business communication and companies have reported their carbon footprint results. Concerning fibre based print products, the Carbon Trust (2006) has reported the carbon footprint of a British newspaper. Moberg et al. (2007) have completed a study concerning GHG emissions and the global warming potential of a Swedish newspaper, web-based newspaper and electronic paper based on screening LCA.

Nevertheless, the studies covering the whole life cycle of print products are still few to be found.

In this article, the results of carbon footprint case studies for a local newspaper and a weekly magazine are presented. The main sources of GHG emissions are highlighted. In addition, main differences between the two cases are analyzed. The carbon footprint case studies are used as examples, but the point of view presented is relevant for print products in general. Furthermore, specific characteristics of fibre-based products are presented (e.g. the print products' ability to store biogenic carbon). All the results concerning magazine products in this article have been presented before in the Iarigai conference 2009 (Pajula et al. 2009).

The results are from a Finnish industry consortium project, Lean Development with Renewable Resources (LEADER, 2007–2010) (Nors et al. 2009). It has been coordinated by KCL, which was integrated to VTT on June 2009. Cooperation in research is conducted with the Finnish Environment Institute, Metropolia University of Applied Sciences, FinnMedia, printing companies and suppliers as well as logistics and paper manufacturers Stora Enso, UPM-Kymmene, Myllykoski and Metsäliitto. The research has been funded by the Finnish funding agency for Technology and Innovations, the Graphic Industry Research Foundation, Metsäliitto, Myllykoski, StoraEnso and UPM-Kymmene.

2. Methods

A few carbon footprint guidelines have been published since year 2007. The Confederation of the European Paper Industries (CEPI) published a framework in 2007 concerning life cycle phases to include in a carbon footprint calculation for fibre-based products. British Standards Institute (BSI) announced in 2008 a

PAS2050 on a specification for the assessment of the life cycle greenhouse gas emissions of goods and services. The International Standardization Organization ISO started the development of a carbon footprint standard in 2009. The main purpose of such guidance is to ensure uniformity, comparability and reliability of calculations. However, the experts developing standards have faced severe challenges especially in relation to recycling, allocations, biogenic carbon and inclusion of time frame. As a consequence the current standards and guidance allow different approaches and assumptions as long as they are transparently reported. This complicates making concluding recommendations out of results or comparisons of different studies.

In the case studies, the carbon footprints were calculated based on life cycle inventory (LCI) and according to the LCA standards' ISO 14040-44. The life cycle of the local newspaper and weekly magazine were covered from wood harvesting until the end-of-life phase (disposal or recycling). In the carbon footprint, greenhouse gas emissions (carbon dioxide CO_2, methane CH_4, and nitrous oxide N_20) from fossil sources are expressed as carbon dioxide equivalents (CO_2 eq.). CO_2 equivalents were calculated according to the factors presented by the IPCC (Forster et al. 2007). The life span of the case products was assumed to be less than one year. Due to short life span assumption, the bio-based carbon stored in the product was not included in the carbon footprint calculations. This approach is in accordance with the PAS 2050. However, it is not exceptional for the readers to store special magazines for several years. The carbon content of the print products was calculated to provide additional information.

The life cycle inventories were calculated through the aid of KCL-ECO software. LCI data was collected directly from actors in the print products value chain and can be considered reliable. Additional process data was acquired from the KCL EcoData database. The KCL EcoData database is continuously updated and covers pulp and paper industry-related data from harvesting, chemicals production, energy production, transport and pulp, paper and converting processes.

3. Definitions and assumptions for the cases

The case studies cover the carbon footprint of a Finnish local newspaper and a weekly magazine from cradle to grave. The cases are fictious but represent a typical situation that could take place in Finland. Case definitions were decided together with the representatives of Finnish paper and printing industry. The Finnish average energy production profile is utilised in calculation. The local newspaper was printed on 40 gsm newsprint paper (DIP 40%) by means of the coldset offset process. Recycling accounted for 79% of the product, 16% was land-filled and 5% was incinerated. The weekly magazine was printed on 150 gsm coated fine paper (cover) and on 80 gsm LWC paper (inner sheets) by the heatset offset printing process (Pajula et al. 2009). The product was recycled 83%, 16% was land-filled and 1% was incinerated.

In both cases, the editorial work is not included in the calculation. The print products are assumed to be delivered to readers (households). This is a typical situation in Finland since newspapers and magazines are commonly ordered on subscription. The end-of-life phase was covered with the sensitivity analysis of two different landfill data modules. Furthermore, the main sources of electricity profile are presented in Table 1.

Table 1. Finnish average electricity production profile (source: OECD 2004).

Fuel	Electricity production (%)
Coal	Approx. 27
Natural gas	Approx. 15
Biomass	Approx. 12
Nuclear	Approx. 26
Hydro	Approx. 18
Others: Oil, Peat, Waste	Approx. 2

There is some uncertainty related to the greenhouse gas emissions coming from the product’s end of life. In particular, the sensitivity analysis concerning landfill emissions were regarded as important. The estimations for methane production and release in landfill concerning the fibre-based products introduce large variation (Micales and Skog 1997, Mann and Spath 2001, Bingemer and Crutzen 1987). In the case studies, data from various sources are applied to understand the influence of the end-of-life phase to the results. The data comes from research by IPCC and the Danish University of Technology. Landfill data module A was formed in accordance with the recommendations of the IPCC (IPCC 2000) to provide the baseline. Landfill data module C was formed using values based on the model constructed for LCA on waste management by the Danish University of Technology (Kirkeby et al. 2007; Manfredi & Christensen 2009; Dahlbo at al. 2005). Module A provides a higher level of GHG emissions from paper disposed to landfill than module C.

4. Results

Based on the case study for a local newspaper, the carbon footprint for one tonne of printed newspaper is between 750−940 kg CO_2 eq, depending on the estimations related to landfilling. Accordingly, the carbon footprint for one tonne of magazines is between 1,140−1,350 kg CO_2 eq (Pajula et al. 2009).

The energy consumed in pulp and paper production is 43–66% of the total carbon footprint and has the greatest influence on the carbon footprint. The result of the carbon footprint contains the production of all the paper needed for one tonne of printed products including maculature. The load of maculature is part of the carbon footprint, even if recycled. The printing phase incurs 12–17% of the greenhouse gases. This comprises all electricity and fuels (propane in heatset) required during the printing phase. In addition, the transport has a notable share in these cases because of the home delivery of the products 8−17%. The effect of disposal of the print products to landfill varies between 1−21%. The carbon footprint results and distribution of the GHG sources are presented in detail with regard to print products of newspapers and magazines in Figure 1 and Figure 2.

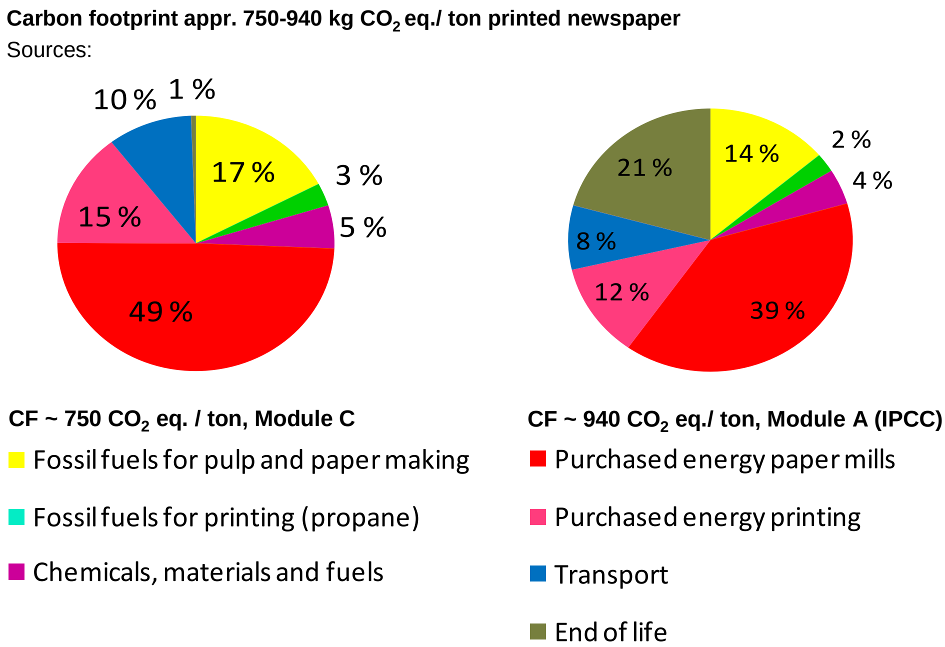

Figure 1. Carbon footprint and GHG sources of printed newspaper.

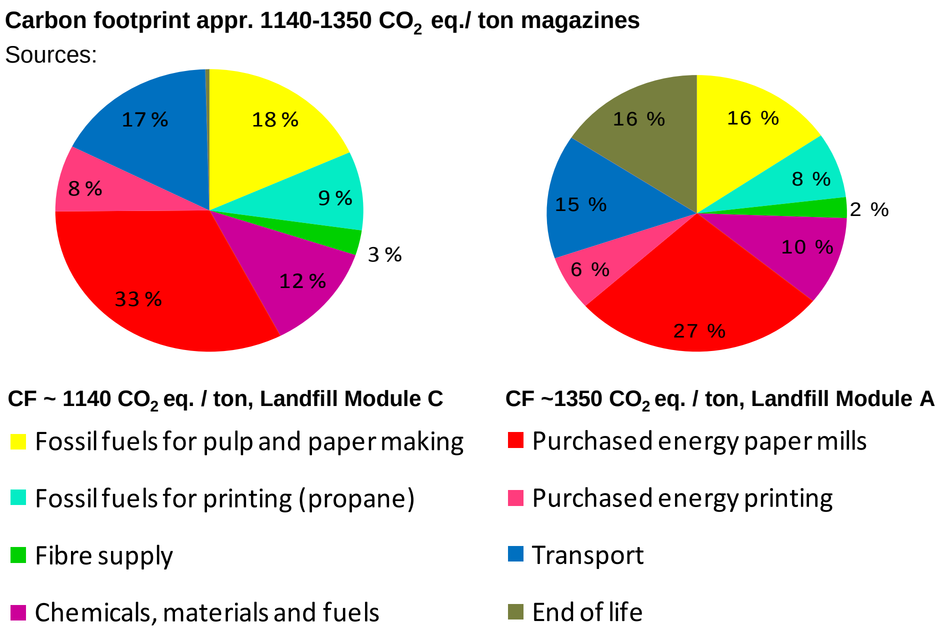

Figure 2. Carbon footprint and GHG sources of magazine.

The carbon footprint of one printed newspaper and one magazine in addition to the carbon footprint of the yearly subscription of the products are presented in Table 2.

Table 2. Carbon footprint of daily newspaper copy and weekly magazine copy with the yearly subscription figures (from cradle to grave).

Case	Life cycle phases	Carbon footprint for one copy (kg CO_2 eq.)	Carbon footprint for yearly subscription (kg CO_2 eq.)
Daily newspa-per	Cradle to grave	0.15–0.19 kg	53–66 kg
Weekly magazine	Cradle to grave	0.19–0.23 kg	9–11 kg

In the carbon footprint case studies, the cradle to gate approach was calculated also as cradle to customer study. In a cradle to customer study, the life cycle of the print product was followed until the product was distributed to the reader's (end-user) home. With these calculation boundaries the carbon footprint results from cradle to customer are presented in Table 3.

Table 3. Carbon footprint results from cradle to customer.

Carbon footprint from cradle to customer	One ton of printed product (kg CO_2 eq)	One copy of newspaper (kg CO_2 eq.)	For yearly subscription (kg CO_2 eq.)
Newspaper	760 kg	0.15 kg	53 kg
Magazine	1 130	0.19	9

To provide additional information, the carbon content for print products was calculated. The carbon content of the local newspaper is 1,520 kg as CO_2/tonne of printed newspaper. Accordingly, the carbon content is 1,080 kg as CO_2/tonne of magazines for the magazine. The share of wood fibres in print products is based on the paper furnish where the carbon content of wood is assumed to be 50%. The carbon is converted to CO_2 in accordance with the molecular masses.

5. Discussion

The case results point out that carbon footprint is quite sensitive for the chosen system boundaries and assumptions. Highly significant choice is the definition of the system boundaries, i.e. which phases of the product's life cycle are included in the calculation of the carbon footprint. Distinctly, the emissions taking place in the end-of-life phase are difficult to evaluate but may influence significantly on the total carbon footprint of the product. The carbon footprint for one tonne of printed newspaper varies between 750–940 kg CO_2 eq and varies between 1,140–1,350 kg CO_2 eq for one tonne of magazines, depending on the estimations related to landfilling. The difference between two value ranges is significant. Due to uncertainty related to emissions from the end-of-life phase, it is recommended that the carbon footprint is reported as a range of values rather than as a single value, when the whole life cycle is considered (from cradle to grave). Furthermore, the possibilities of manufacturer or publisher to influence the final way of using the product are limited. Consequently, sufficient information about the possible impacts of the end-of-life phase is needed in consumer communications. GHG emissions from the end-of-life phase of products are clearly an area that requires further research.

Despite the fact that the life cycle of the two printed products is quite similar, there are many differences that explain the carbon footprint result. Firstly, in general the physical size, appearance and weight of the print products differ.

Secondly, they are printed on a different kind of paper. Thirdly, the coldset offset process is utilised in newspaper printing and the heatset offset process is utilised in magazine printing. In the delivery phase, the newspaper was delivered to readers separately from other mail (early in the morning), and the magazine was delivered together with other mail. Finally, during the end-of-life phase, the recovery and incineration rates of magazines and newspapers were assumed to be slightly different. The landfill sensitivity analysis was conducted equally in both cases, and the share of products disposed to landfills was the same.

In both cases, the largest role in the carbon footprint applies to energy production and the use of fossil fuels. Thus, the energy production profile utilised for the production of purchased energy has a great impact on the results. The companies cannot always control indirect emissions resulting from purchased energy in various countries and how the situation influences their real reduction possibilities. Improving energy efficiency with novel solutions becomes important.

One important factor is the choice of fuels that are utilised in production phases of paper and print products. The improvements in energy efficiency and reducing the use of purchased energy are the most efficient ways to decrease the carbon footprint. In addition, the utilisation of renewable energy sources can be considered. Furthermore, improvements in material usage during the printing phase would have positive influence. The challenge to keep a very low maculature level during the tight production schedule, complicated print jobs and shorter print runs remain.

Paper contains carbon sequestered in the forests and wood is renewable raw material. According to the PAS 2050 guideline, the carbon stored in the print product can be credited within the carbon footprint calculation if the product life span is one year or more. The largest credit is gained when the life span is 100 years or more. In this study the carbon content was calculated separately to provide additional information due to the assumption in the case studies that the life span is less than one year. This figure reflects to the carbon stored in the product for a period of time. It will be released back to the carbon cycle at some point of time, and cannot be subtracted from the carbon footprint result. However, it reveals the potential renewable energy content in the product.

Renewability as such is not part of the footprint. However, being part of the natural carbon cycle a renewable raw material gives better performance compared to fossil materials, and generates no fossil emission. Additionally it is noteworthy that no carbon emissions take place during the use phase of a printed product.

6. Conclusions

Case studies provide useful information about the utilisation of the carbon footprint as an indicator for GHG emission amounts through the print products life cycle. It is important to find out the critical points where most reduction potential is and address objects where resource efficiency can have environmental and, concurrently, economic impact. The calculations provide a baseline against which development can be measured and communicated. However, many open questions remain, and the importance of communicating the results should be remembered.

The evaluation and comparison of different calculation results is difficult if the calculations are not performed in identical ways. The selection of system boundaries are important with respect to whether the carbon footprint result has included the end use and disposal of the product (cradle to grave) or whether the life cycle phases were included until the end user i.e. reader’s home (cradle to customer) or some other boundaries were used (e.g. cradle to gate). For example the end-of-life phase can have a remarkable impact on the results, and it is recommended to express the result as a range of values rather than as a single figure. Therefore, the boundaries, assumptions and calculation methods utilised should be mentioned.

In general consumer products in daily use have very different kind of purpose in the use as well as time of use and life expectancy. Furthermore, they do have different kind of manufacturing processes, dissimilar raw materials and specific characteristics. Already the two case studies calculated concerning print products highlight that despite of the similarities of these two media products, there is also such differences that the comparison of them to each other becomes challenging.

While carbon footprint can be a useful tool in evaluating GHG emissions and reducing the impact on climate change, it ignores all other environmental impacts. As a consequence, the environmental sustainability of a product should not be evaluated as based on GHG emissions and the carbon footprint alone: rather, other aspects should also be considered. For this reason, further research to also cover other environmental aspects is important.

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Cradle-to-customer life cycle assessment for environmental conscious operations and product development: case study of two precision instruments

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Abstract

New emerging regulations and market rivalry has forced electronic manufacturers to assess their environmental impacts in order to decrease their environmental burden. The Life Cycle Assessment (LCA) method has been used widely in industry to assess the product scale environmental impacts in order to enhance the environmentally conscious product design and product planning. However, the LCAs including product specific data collection can be resource extensive due to the complexity of electronic systems, which hinders the usability of LCA in the dynamic product planning process.

This paper aims to present the main findings and challenges of an LCA of small-sized electronic products through a case study. Furthermore, the usability of LCA as a tool for eco-design is discussed. The LCA method was applied for two electronic products with the scope bounded to the cradle-to-customer phases through the life cycle. Due to the complexity of the products' end-of-life system and limited time for the study quantitative assessment of end-of-life was left with less attention in LCA. However, during the LCA process the end-of-life aspects of the case study products were studied separately on a qualitative basis.

1. Product description

Wristop computers assist the end-user in observing the surrounding environment, for instance air pressure, or their own body signals, such as the heart rate. The computers are used mainly for outdoor activities and are fastened around the wrist. The products chosen for the study have altimeter, barometer and compass functions. Two wristop computers were chosen for the study. Only one published LCA was found for products similar to wristop computers (Yung et al. 2008).

The case study products are manufactured by Suunto Oy. Assembly of both products takes place at Suunto headquarters in Vantaa, Finland. Plastic parts are manufactured in Finland whereas metal parts are manufactured in Asia. Products have a life time of over 10 years but battery change is needed several times during use depending on the end-user’s activities. Both of the products have similar functions and both include mechanical parts, electronic parts, paper user manual and product package. The two case study products differ by their manufacturing materials: one has a housing of steel, the other of plastic The steel-based product (B) has three-times more weight than the plastic-based (A). For the product (A) the actual wristop computer covers 16% of the total weight of the product package whereas the corresponding number for product B is 24%. The rest of the product package consists of paper manual (50% of the total weight for A and 21% for B) and a package box with a cardboard sleeve (34% for A for 55% for B). The heavier product (B) has a 4 times bigger weight compared to the lighter one (A). However, the product B’s package was left outside the LCA study due to the lack of Life cycle inventory (LCI) data. The products are thus comparable only without packages in terms of LCA results.

2. Goal and scope of the study

The main goal of the LCA was to give the manufacturer information about environmental impacts of the products. Also the aim was to produce environmental product development scenarios during the LCA process. Realizing that transportation was having a significant impact it was examined at a more detailed scope. The life cycle scope of the study was set to cradle-to-customer. Use and recycling phase were left outside the study because due to lack of LCI data. Mass-based cut-off criteria were applied for mechanical components due to the large number of parts.

3. Data collection

In the case study a commercial LCA software package GaBi 4.3 was employed in order to manage the inventory data, to model and visualise the product system. Software was use also used to build the product development scenarios, and to conduct inventory and Life cycle Impact Assessment (LCIA) calculations. The actual data collection started by compiling a material balance based on the bill-of-materials (BOM) list. The case study products were disassembled into pieces and weighted. Data was collected from each component separately by sending inquiry to the manufacturers. Data collection was conducted with simple data forms based on ISO 14044 (2006) model. 2008 was chosen as the reference year. Transportation distances and capacities of vehicles were tracked from the transportation companies, however due to the limitations of available data sets some simplifications were made in the LCA.

Mass-based allocation was used for transportation processes. Transportation processes of GaBi 4.3 Professional were used though they some have limitation, e.g. there is a lack of vessels operating in the Baltic Sea. Consequently another database (VTT Lipasto 2009) was used to make comparisons between data sets.

Electricity consumption of work machines was evaluated either by machine specific methods with throughput and given power consumption or by roughly starting from the factory-level using the electricity bill with allocation according to the product volume. Machine-specific energy consumption evaluation proved to be challenging. More accurate measurements and energy audits are needed to see the environmental impact of idle running times and waste generated between the production lots. Also refining the data from factory to product level requires efforts that are applicable for the contractor SMEs. Observation was that material wastes are well documented but tracking of the supply chain for different waste types needs significant man hour effort.

Database data was obtained mainly from the data sets of GaBi 4.3 Professional software with electronics extension database. The version of GaBi in use included databases of EPA (US Environmental Protection Agency), ELCD (European Life cycle Data), Ecoinvent and PlasticsEurope. Additionally data was imported manually from IISI (International Iron and Steel Institute) LCI database and product declarations for specific paper types.

4. Modelling and visualisation

Database data and site-specific data collected from the contractors were used as input data for the product system modelling. The product systems models are seen in Figures 1 and 2.

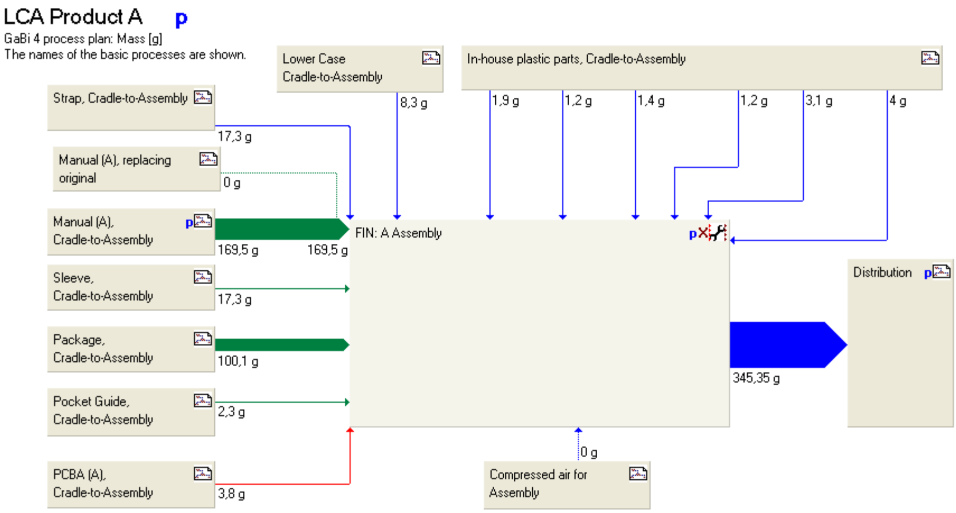

Figure 1. Top-tier LCA process model for product A (GaBi 4.3).

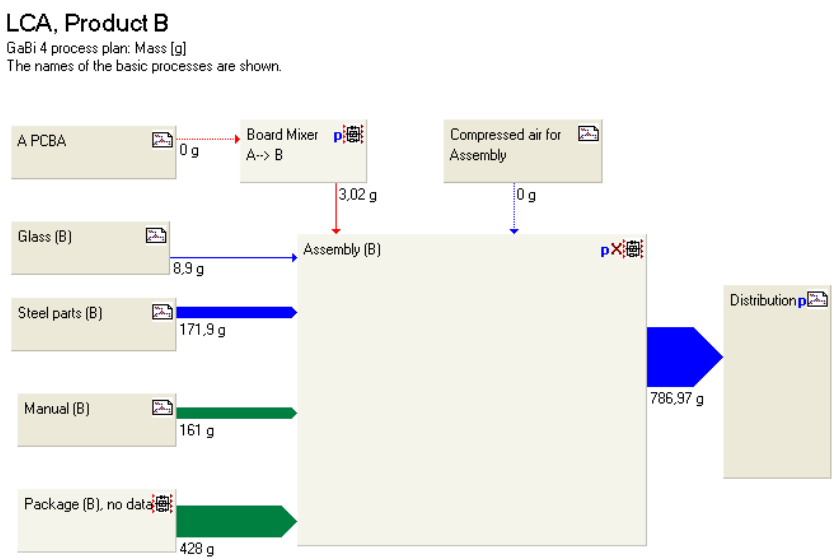

Figure 2. Top-tier LCA process model for product B (GaBi 4.3).

5. Results

Life cycle Impact Assessment (LCIA) was made with Eco-indicator 99 (EI99), an endpoint-level LCIA-method. EI99 aims to present the aggregated results in a single score (Goedkoop & Spriensma, 2001) which supported the aim of the study to be used in product development purpose.

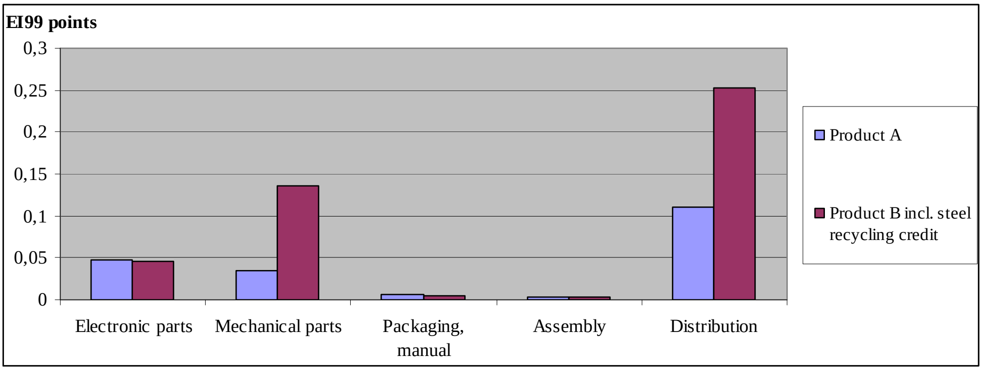

Figure 3. LCIA-EI99 points between Cradle-to-Gate and Gate-to-Customer stages for the case products A (plastic housing) and B (steel housing) in order to identify the life cycle hot spots.

The total amount of EI99-points results for product B 2.2 times bigger than for product A.

The product distribution net from gate to customer was divided and simplified into three geographical areas: 49% to North America, 9% to Asia and 42% to Europe. Products were transported to Europe by ship and to the other continents by aircraft. Aviation was pre-assumed to have a dominant environmental impact consequently short-distance (< 100 km) truck transportations were negligible thus ignored. As Figure 4 illustrates, more than 60% of the distribution-related EI-99 points came from kerosene refining.

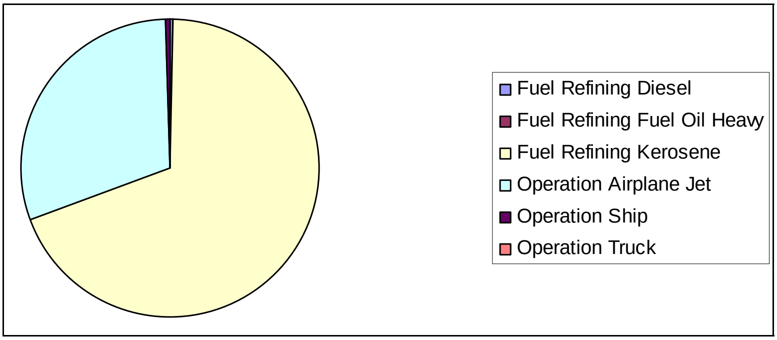

Figure 4. Distribution of EI99-points in Gate-to-Customer phase based on the highest score pillar in Figure 3.

6. Incorporation into product and operations development

Weight reduction of paper user manual was seen as the most potential product development scenario. The process model (Figure 1) for product A includes possibility for a scenario analysis of Compact Disc (CD) manual substituting the paper manual. According to the scenario analysis made for product A, a 22% reduction in the Eco-indicator 99-points will be gained by substituting the CD manual for the paper manual, basically due to the impact of weight loss in air transportation. Besides the product development scenarios, additional outcome of the LCA process was a list, reviewed by the case company, with product and operations development proposals.

7. Discussion and conclusions

The case study confirmed the pre-assumption of aviation being the dominant phase in terms of environmental burden for the case study products. However, data from the use and end-of-life phase will be needed to complement the case study to a full scale LCA. End-of-life aspects can have a significant role in the environmental impacts.

The main challenges of LCAs is data collection, which has been brought up in numerous studies (Muños et al. 2009, Valkama & Keskinen 2008) and in literature (Wenzel et al. 1997, Baumann & Tillman 2004) and further highlighted by this study. An important decision in LCA study is whether to use already produced or site-specific data. The site-specific data is preferred to already produced data but in site-specific data collection resources are needed.

Certain electronic components lack of site specific and readily produced LCI data in certain materials noted in this study and also in a recent LCA study (Muños et al. 2009). Data gaps cause uncertainties in aggregated LCIA-results. In this study some components were lacking data e.g. LCD (Liquid Chrystal Display) and batteries. A wide range of data sets are available for plastics but surprisingly no data sets were available for thermoplastic polyurethane (TPU), the material for the wristband of product A.

Not always is the availability of the data a problem but the inconsistency and quantity of the data. In LCAs the data already documented in the enterprise resource planning systems can be utilised and more important will be not how to get the data but how to manage and structure the already available data. As one finding of the case study, BOMs were seen as an ideal starting point for attaching environmental life cycle data into the existing IT-systems. Information system should include a hyperlink to the data from the contractors, made e.g. within LCA data collection.

The case study showed that LCA is useful method in eco-design purpose as a supportive tool for decision-making and as a tool for producing new ideas. LCAs of electronic products is challenged by time and resources, globally wide spread supply chains, high amount of small components and materials used in the product. Thus gaining site-specific data for the whole product system will be too demanding. Based on the case study, LCA demonstrated that it can be used in eco-design for producing product development ideas. Finally, a check-list for designer who needs to make quick decisions based partially on LCA results was considered as a potential tool for eco-design.

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The CLIMATE BONUS – demonstrating the climate feedback service

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Abstract

In the Climate Bonus project, a demonstrative GHG-monitoring, reporting, consumer feedback & reward system for households was developed by the research consortium. The created application enables consumers to follow up accumulated GHG-emissions of their household’s purchases and to compare results with several reference levels and other users of the system. They can also acquire “bonus points” on the basis of a reduction of emission intensity. The demo version of the service covers foodstuffs, transport fuels and services, home energy and the “other consumption” category, and utilises multi-approach methodology – i.e. combines several data sources and approaches (LCA, I/O, ETS-data) to seek emission factors for a very wide range of product categories. Foodstuffs were registered automatically for the service through a Nutrion Code system (www.nutritioncode.com) that uses the PLUSSA-key card and the information systems of Kesko and Tuulia International Oy. The rest of a household’s purchases can be entered manually via a computer interface directly to the Service or by using the optical barcode recognition capabilities of the Nokia mobile phone. Based on the pilot tests, the authors believe that the climate-feedback system could activate notable voluntary emission reduction potentials, provided that the feedback system is widely used.

1. Background and introduction

The EU's agreed objective is to limit the average global temperature increase to less than 2 °C compared to pre-industrial levels. To have a reasonable chance of staying below the 2 °C threshold, global GHG emissions must be reduced to less than 50% of 1990 levels by 2050. The 4th Assessment report by the Intergovernmental Panel on Climate Change (IPCC) indicates that this would require emission reductions for developed countries in the range of 25–40% by 2020 and 80–95% by 2050 (EC 2009).

GHG emissions will have to already peak before 2020. Finland is committed to reducing its own emissions to the sustainable level, i.e. 80% of 1990 levels by 2050 and also to the transition process towards the low-carbon economy (VN 2009). The optimal strategy will necessitate significant changes in all sectors of the society – both in the production and consumption of goods and services.

The implementation of ambitious medium- and long-term targets presumes new instruments and approaches that go beyond the current portfolio of policies and measures. The production-oriented emissions trading scheme (EU-ETS) should be expanded to cover all relevant economic activities. If it is not possible in practice, it could be supplemented with other market- and consumption-oriented approaches to alleviate emerged multitude carbon leakage problems and promote the required transition processes. Reduction of greenhouse gas (GHG) emissions in energy- and material-intensive industries will remain very important, but if household consumption is not addressed, aggregate demand for energy and material intensive products and services could be curbed insufficiently, if at all (Perrels et al. 2009a) .

Further steps – both technological and regulative – could be taken to encourage various parties to adapt their operations and behaviour towards "low-carbon direction". GHG-information disclosure policies might be effective to incite low-carbon investments and innovation both in production and consumption side processes. An important underlying philosophy of the Climate Bonus project is that credible and structured information provision regarding external environmental impacts of production processes and systematic feedback for consumers constitute essential elements for the correction of market failures. The availability of product-specific GHG data and easy access to it from the demand side are important issues to be considered and developed. Information disclosure policies can be operationalised by means of hybrid-media solutions designed, e.g. for "personalized emission management".

In the Climate Bonus project, a demonstrative emission monitoring, aggregation, reporting, feedback + reward system for households was developed by the consortium (5 Finnish research institutions and 6 companies). The study as a whole can also be regarded as a form of implementation of the transition facilitation process.

The introduction to the climate feedback system is presented in the article (Hongisto et al. 2008). The ordinary project consisted of several work packages. The first work package concerned a material scan of carbon footprinting applications, voluntary emission offset services, loyalty cards with an environmental focus and emission data systems related to carbon footprinting (Perrels et al. 2009b). In the second work package, three dialogues were organised to discuss interim results with the partner companies. In Work Package 3, the basic structure of a system that could produce strict and reliable data needed for generating product-oriented carbon footprints in Finland is illustrated. It also represents a road map for developing the system for the energy and food sectors. Steering and quality assurance mechanisms, standards and possible data sources central to the system are also reviewed (Usva et al. 2009). In Work Package 4, the ICT application utilising Internet and mobile phone capabilities and user interfaces was developed for the consumer piloting phase (reported in Finnish, Hyvönen et al. 2009). Also, a review of earlier studies and experiences with consumer feedback was carried out in this section (Perrels et al. 2009d). Work Package 5 concerned the testing of a monitoring and feedback system for households, such that participating households could follow the accumulating greenhouse gas emissions embodied in the purchases made during the time period. Results of the pilot were published in the report (Hyvönen et al. 2009). Work Package 6 dealt with the environmental and economic effectiveness of the overall system (Perrels et al. 2009c).

This article describes the *Climate Feedback ICT system* developed by VTT and refers to some key findings regarding the piloting phase made by the consortium. Further information and all project publications are available at http://extranet.vatt.fi/climatebonus/.

2. The demonstration version of the climate feedback system

A demonstration version of an Internet-based GHG emission monitoring and reporting service for households was developed at VTT Technical Research

Centre of Finland (Figure 1). This "research tool" was developed to test, in practice, how various media interfaces, quantity or amount registration strategies, emission estimation approaches (LCA, I/O-models, EU-ETS data etc.) and their results can be combined, processed and finally reported and visualised to create an "operative emission management system for households". In the end, the system was piloted in practice to obtain valuable information not only on how consumers perceive this kind of ICT service and its information content but also how the system should be further developed.

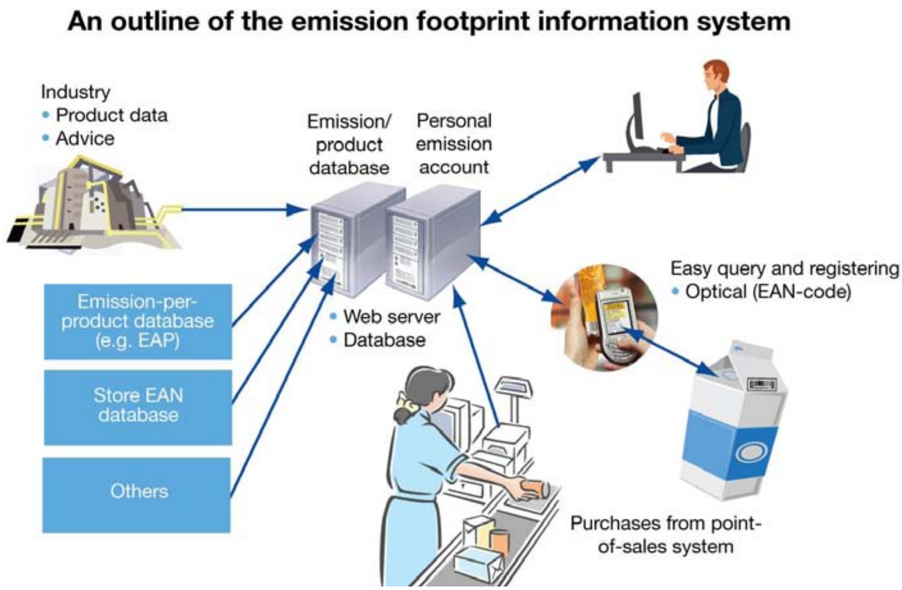

Figure 1. An outline of the carbon footprint information system (demonstration version) from the Climate Bonus project (original sketch; Södergård 2006).

The key purpose of the Climate Bonus project was to assess the possibilities and effectiveness of a feedback and bonus system for households, which incites them to consume in such a way that greenhouse gas emission are reduced, inciting retailers to offer a product portfolio that advances the choice for low emission products by households.

2.1 The design of the monitoring system and features of the interface

In the first step, we focused on overall cumulative emission trends instead of product level comparisons, due to the lack of quality-assured product specific GHG emission data. The central "service function" for the user of the software is "the aggregation capability of otherwise fragmented data of purchases".

The demo system created allows households to monitor their cumulative greenhouse gas emissions (CO_2 equivalents) at various levels of aggregation of their purchases (i.e. four consumption sectors and product groups) as well as compare emissions and intensity indicators with time windows and statistics-based reference levels and those of a peer group. The consumption sectors covered include foodstuffs, energy use at home and transport fuels (for a private motor vehicles) and public transport services. In addition, a remaining sector – "other consumption" – was included, comprising 18 expenditure groups (for example, this included clothing and footwear, furniture, leisure products and free-time services, etc.). The system was designed to enable register and process emission offset transactions, and account for that in the net emissions. The system also includes a simple reward system – 'climate bonus' points which can be earned on the basis of a reduction of calculated emission intensity of accumulated purchases in comparison to a pre-assessed personal reference level.

2.2 Registration of "activity data"

The goal was to track the overall amount of personal consumption in as user-friendly a manner as possible and link this "quantity data" reflecting "activities" to applicable "emission data" (category-specific "life cycle-based emission factors or carbon footprints") to process aggregated behaviour-dependent personal GHG emission figures and trends.

Choices regarding purchase registration strategies and product categorisation systems (taxonomical structure) are central: both automatic and manual quantity/amount registration routes were investigated in the study. In principle, the amount of consumed products and services of a user was registered, based on applicable functional units (FU) in the considered consumption sector or product category. E.g. foodstuff purchases were automatically registered in physical quantities (X kg per category), and then category-specific life cycle-based emission factors (Y kg CO_2eq per category) were applied to register the emission of the transaction to the time axis (stored in the database). The applied system boundaries were designed to fit as well as possible with shared economic responsibilities and reliable monitoring.

Even though a large degree of automation of purchase entries is the objective for this first demo version, automatic and "verified" activity data was received only for foodstuffs.

To improve coverage of the feedback system, the piloted automatic (verifiable) registration route was supplemented by means of manually entered data based on consumption expenditures, invoices, trips and measurement devices. E.g. consumed fuels are registered on the basis of the number of refuelling (purchased litres + entering cumulative km figures).

The demo version received data on purchased foodstuffs (in grams) via the existing Nutritional Code system (www.nutritioncode.com) developed by Tuulia International in cooperation with VTT. In the Nutritional Code system, the information of products purchased is transferred from the cash register system of the retailer company to a database. A few key data per product – e.g. the type of product and its weight – were automatically registered by checking in a key card at the cash desk. To enable this procedure, the participants received a dedicated key card that could only be used in designated supermarkets (in this case, K-Supermarkets). These registered purchases are treated as "real and verified" and formulate a subgroup of activities acceptable for "bonus incentive" developments.

Alongside fully automatic registration of product purchases, direct entry by the consumer is also possible, such as in the VTT HyperFit system (www.vtt.fi/hyperfit, Järvinen T. 2005a and 2005b, Järvinen P. et al. 2008). The secondary route for activity data registration utilised product specific bar codes (or EAN numbers) of the product packages and camera interface of the mobile phone (Figure 2) or manual entry of the EAN-number using PC or mobile phone. This route is capable of linking and registering "brand-specific" product information, but cannot "verify" that an actual purchase was realised.

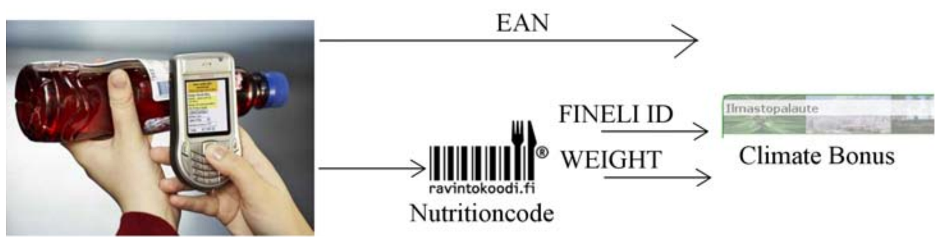

Figure 2. Optical registration of the product using a directly entered EAN number or the barcode recognition capabilities of the mobile phone.

The last route is manual. Users register their own activity data (e.g. kWh, litres, km, euros spent annually, etc.) directly into the demo interface. These data entries were designed in most cases to comply with the "billing boundaries", in order to make it easier for consumers to fill in details or estimate the required activity data (as well as verify data using commercial documents).

It is important to note that only the first "Nutrition code route" to register consumer purchases enables the creation of automatic, verified and user-friendly monitoring capabilities. The reliability of other activity data depends more or less on the user, and thus for the time being the emissions of those product groups cannot be included in the financial incentive system.

The technical challenge for the future is to facilitate this process as much as possible by automation through verifiable linkages, e.g. with the various payment systems or measurement devices. The idea to combine several supplementary automatic "amount registration strategies" to cover various consumption sectors (food, housing, mobility, other invoicing, etc.) emerged during the study.

2.3 Other features of the developed software

The demo version of the service includes user registration procedures, conditions of use, guidance, specification of user profiles (number of persons, type of residence, car model(s), option to specify recurrent trips). Summary reports can be obtained for overall emissions (and %-shares by sector) as well as inside sectors (% shares by product groups) during the monitoring period. The system also provides an option to check every consecutive entry, i.e. a kind of logbook.

In addition to "activity data" and corresponding "emission factors", users can import data generated by means of other (e.g. company-specific) web-based carbon footprinting calculators to obtain more reliable estimates in specific cases.

The software includes background information on emission intensity per product group and references (links) to more information for interested users. In addition to quantity (purchased amounts in kg) and emission estimates (kg CO_2 equivalents per kg), emission intensity indicators (kg CO_2-eq./€, product category) were formulated. Euro-based information is partly collected through direct entries from users and partly from inferred unit prices per kg based on the 2006 Consumption Survey of Statistics Finland. Emission intensity indicators are useful for various kinds of comparisons, as they are scale-neutral and less sensitive to temporal and inter-personal variations in purchased or registered amounts. Among other things, the system provides a comparison of the accumulated emission of the participating household with those of similar participating households during a certain period.

Regarding the display of results in summary tables, the monthly time windows were assumed to fit households' own monitoring purposes. Feedback information must be available in a sufficiently short period of time: otherwise, consumers experience difficulties in linking particular actions to particular results – hence, the incitement for behavioural change may get spurious. An annual reporting window is assumed to be important within a commercial service context. Energy inputs for housing and the sector "other consumption" are registered only at an annual level, but translated into amounts commensurate to the length of the accumulating monitoring period. Purchases (and emissions) on other consumption sectors are registered on a case-by-case basis, according to the date of purchase. On the basis of the annual reporting window aggregate, emission reductions reported by the whole system could be linked to the overarching climate policy framework.

2.4 Applied programming tools

The demonstration version was developed by VTT-utilizing open source software to make further development of the system easier. Common web technologies such as (X)HTML, CSS and JavaScript were used for the web interface. The dynamic web pages were implemented using JSP and a Java back-end relying on the Stripes MVC framework. MySQL was used for permanent database storage, and Apache Tomcat handles the web server functionality.

3. User experience and results of the preliminary pilot

In particular, we were interested in the possibilities and effectiveness of inciting changes in consumer behaviour with the aim to reduce the embodied emissions of household consumption. We studied consumers' experiences and judgements of the feedback and bonus features respectively, with the aim to infer whether such systems in principle can promote the desired behaviour and what features in the design and services provided seem to affect actual responsiveness and the continuation of interest on the part of consumers.

Even though four weeks of purchasing information from 35 households does provide some interesting quantitative information, the number of participants is too small and the first-time experience possibly too experimental to allow for elaborate quantitative analysis of the recorded purchase patterns and resulting accumulated emissions. The account below focuses on the feedback from questionnaires and group discussions. It should also be kept in mind that the pilot predominantly tested user experiences of pre-selected participants.

On a general level, the participants found the idea of the monitoring and feedback system interesting. They were of the opinion that it was a new, innovative and thought-provoking idea that aimed to tackle an important and topical problem. They liked the idea of personal monitoring of GHG emissions, and thought that it could be a concrete, everyday service for following the consequences of one's consumption. If the consumers had any doubt about the idea of the system, they had to do with realising the system: for example, the kind of investments trade and industry are willing to make for the climate and environment.

Most participants also thought that the monitoring and feedback system would be quite useful for them and their households. They thought that it could assist in evaluating the consequences of one's consumption, and even when making everyday purchase choices. In contrast, some consumers aired doubts about the usefulness of the system. Some said that emission information should be available in shops, within the context of the choice-making situation(s).

The participants had many ideas as to how to develop and improve the system. In particular, they stressed the importance of user friendliness, usefulness, reliability of the figures, and the way the service would be priced. On a general level, they demanded that it should be easy-to-use and free-of-charge, and that the information the system provides should be useful "to me and my household". The consumers argued that in order to improve the usability, the system should be simpler and more logical and that information of all the purchases should register automatically into the system.

The participants' views concerning the required levels of information within the system (i.e. product level, product sub-group level, etc.) were split. Some of the participants thought that in principle the information should be more detailed than in the demo version they tested, i.e. it should include accurate GHG emission data on each product-brand. The others were content with the information level of the demo version, or accepted even rougher estimates of GHG emissions. Food products and transportation were the consumption categories where more accurate and detailed information was needed. The pilot is presented and discussed more deeply in the report by Hyvönen et al. 2009.

4. Conclusions

An Internet-based demonstration version of "climate feedback service" was developed in the Climate Bonus project, which was carried out by five Finnish research institutes with support from business partners.

The utilised Nutrition Code + K-Plussa key card platforms enable practical development of automated commercial systems. Automatic registration of purchased products was found to be a key factor when improving the usability and easiness of the climate-related personalized feedback service.

The demonstration system was tested in practice in a consumer pilot. Consumers tried out the system and evaluated its acceptability and potential impacts. The pilot was planned and carried out in close cooperation with the research group and business partners of the project.

The results showed that a monitoring and feedback service interests consumers. They regarded the demonstration service as rather useful to their households. Further development of this kind of service was regarded as desirable. In order to be widely used, the service should be functional, user-friendly, reliable, free-of-charge and appealing. Personalizing the service and rewarding for emission reduction could motivate consumers to use the service continuously. Consumer feedback obtained is to be used for the further development of the service towards commercial use. The issues that receive special attention and further development are usability, utility and accessibility of the system.

Most of the participating consumers believed that using a fully functional monitoring and feedback system could help people to change their consumption habits into a more climate-friendly direction.

In practice, the accuracy and tractability of carbon footprint data should be adequate in order to maintain credibility among consumers, retailers and the operators of production chains. Consequently, the approval of carbon footprints should be based on transparent and comparable methods as well as impartial 3rd party verification if used for crediting purposes. On the other hand, a wide range of product categories should be covered to create meaningful consumer applications.

Up-to-date, reliable carbon footprint data of products (e.g. compatible with PAS 2050) are seldom available in the public domain, restricting the rapid commercial introduction of these kinds of ICT services. Due to the challenges relating to emission monitoring of international real world supply chains, expansion of these systems is expected to happen step-by-step, starting from certain products, product categories and sectors where public product specific emission factors are already available or can be generated using existing activity data and monitoring mechanisms. The integration of LCA principles and EU-ETS monitoring approaches and reporting to support the systematic production of certified carbon footprints of products is an important future challenge.

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LCA in contaminated sediment remediation

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Abstract

The criteria used in selecting products and materials are increasingly related to environmental impacts during the life cycle. Life cycle thinking is well suited for remediation of contaminated sediments. It can be used in selecting most environmentally friendly options for dredging, treatment and disposal of sediments. In this work, assessment and comparison procedure (SEDU) was created to identify environmental impacts during a sediment remediation project.

Sediment contamination is recognized as a widespread and serious problem and the management of contaminated sediments presents significant challenges. However, with optimal selection of dredging and treatment technologies, costs and environmental effects can be minimised.

1. Introduction

Millions of tons of sediments are dredged each year (Samira et al. 2009). Dredging is normally used in the construction of harbour structures and to safeguard navigation and provide stable navigable depth (Bhattacharya et al. 2006). The majority (90%) of dredged sediment is clean, but in some cases sediments may contain large quantities of various pollutants (OSPAR 2004). Major sediment contaminants include: metals, mercury, PCBs, dioxins, DDT, PAHs, tributyltins, bacteriological contaminants and toxic phytoplankton. These contaminants remain in the environment long after their sources have been removed (Kachel 2008).

Contaminants enter the marine environment from spills, point sources such as industrial discharges or from nonpoint sources such as runoff, as well as from ship waste, ballast water or antifouling paints (Kachel 2008). According to

NAVFAC (2002), the goals of sediment remediation are to: “remove contaminated sediments from the environment, obstruct contaminant migration into the environment, and/or minimize the exposure of ecological and human receptors to sediment contaminants”. When the characteristics of the dredged sediment are such that its disposal into the sea is not an option, treatment or other management options should be considered (HELCOM 2007).

In Finland, dredged sediments are occasionally contaminated, e.g. with metals and organic compounds. TBT, copper and nickel are particularly problematic, since they are used or have been used in antifouling paints to prevent fouling in ship hulls (Vahanne et al. 2007). These compounds are biocides in nature and when released into the environment may pose a serious threat to marine or lake ecosystems (Dubey & Roy 2002).

Sediment contamination is recognized as a widespread and serious problem, and the management of contaminated sediments presents significant challenges (NAVFAC 2002). These challenges involve a number of technical issues, including the means of identifying contamination, understanding contaminant behaviour in the environment and mitigating the potential adverse affects to human health and the environment as well as the technical issues of dredging and management of contaminated sediment. Treatment and valorisation of contaminated sediment will be even more important, because in the future there will be a lack of appropriate disposal sites (e.g. landfills and designed disposal sites such as artificial islands). With optimal selection of dredging and treatment technologies, environmental effects and costs of sediment dredging and remediation project can be minimised.

One way to do the optimisation is to utilise life cycle assessment (LCA), which is well-suited for remediation of contaminated sediments. It can be used in selecting most environmentally friendly options for dredging, treatment and disposal of sediments. In this work, assessment and comparison procedure (SEDU) was created to identify environmental impacts during sediment remediation project. The procedure is based and relies on the same principles as VTT’s MELI-LCA program, which was developed to assess the environmental impacts of road construction (Eskola 2002).

2. Life cycle assessment procedure

The basic phases of life cycle assessment include goal and scope definition, inventory analysis and estimation of impact (ISO 14040, ISO 14044). The procedure created in this study covers only the first two, and traditional impact assessment is not included. However, the user can evaluate the significance of the environmental impacts, and apply the final weighting, expressing how harmful the impacts are in relation to each other. This procedure or tool was developed particularly for organic contaminants, such as tributyltin or polyaromatic hydrocarbons. Metals can be easily added to the assessment

In life cycle assessment, material flows and emissions are specified for all phases of the life cycle of a product or procedure (FAO 2002). The most significant risks and factors influencing them are identified. The main phases of a life cycle that were assessed in this case were dredging, pre-treatment, treatment and disposal/utilisation of sediments and transportation in the various phases.

2.1 Background data

Background data for the assessment was gathered from various Finnish data sources, including data from construction and dredging companies, contractors, planning and consulting companies and literature. Only some of the treatment methods are covered by this procedure. These techniques were chosen because 1) they are suitable for organotin removal, 2) the technique has been proven to work in Finland, and 3) the technique is already in use in Finland.

2.2 Assessment steps

The first step in the assessment is to specify the dredging method for contaminated sediment. This is then followed by the selection of various pre-treatment and dewatering options. Finally, the most suitable treatment method is chosen. These dredging, pre-treatment and treatment options are then combined into a treatment chain, and the environmental impacts of the individual work phases as well as the treatment chain as a whole are defined.

2.3 Assessment boundaries

The work phases which have remarkable impact during the life cycle were included in the assessment, as described in Figure 1.

INCLUDED	NOT INCLUDED
Work phases which have significant impact during the life cycle	• Work phases which are not important or lack data
• Dredging • Barge transportation • Treatment • Manufacturing of materials and chemicals used in the treatment • Land transportation • Disposal/utilisation of treated sediment	• Water treatment • Landfill construction • Leaching of contaminants

Figure 1. Assessment boundaries.

In order to set the boundaries for the assessment, only the most important negative environmental impacts were considered. These include

- renewable and non-renewable energy consumption, MJ
- consumption of renewable and non-renewable natural resources, t
- amount of utilised by-products, t
- emissions to the air, including CO_2, NO_x, SO_2, VOC, particles, CO, N_2O, CH_4, kg
- amount of waste produced, t.

Selection of dredging methods is specified for three types of dredging sites, including small-, medium- and large-scale sites where different dredging methods can be applied. Treatment methods for organotin-contaminated sediments include *in situ* capping, unconfined and confined disposal facilities, landfill disposal, stabilisation, geotube treatment and capping, isolation/encapsulation and thermal desorption. This procedure also covers the following pre-treatment and dewatering techniques: screening, sieving, flotation, belt filter pressing, centrifugation and geotube treatment. An example of a treatment chain for a confined disposal facility is described in Figure 2. Different work phases such as the construction of a disposal facility, dredging, pre-treatment of material by sieving, pumping of sediment into the facility, clarification, and dewatering options to remove the excess water are included. Water treatment is illustrated here but is not included in the assessment itself, and is therefore separated with a dash line.

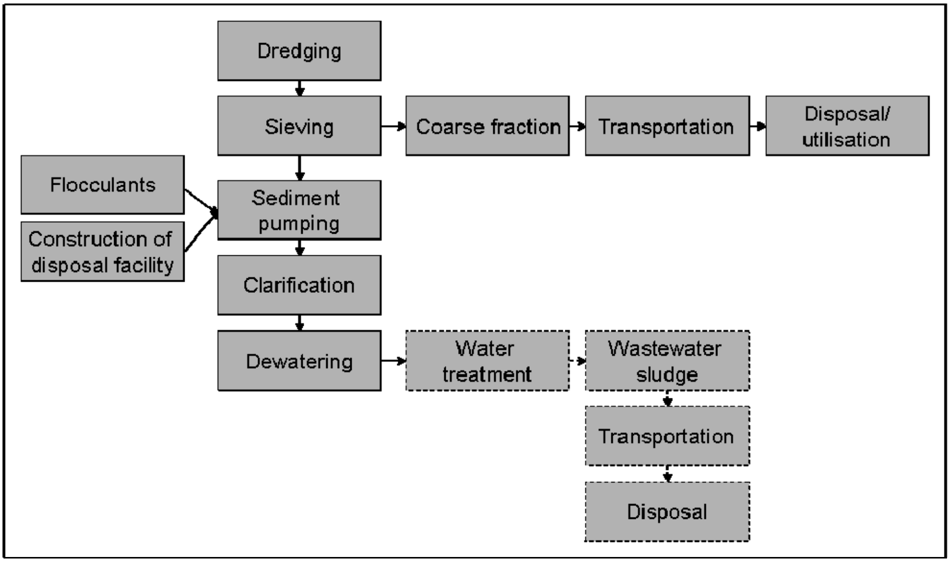

Figure 2. Treatment chain for a confined disposal facility.

3. Calculation program (SEDU)

The information gathered from various data sources was processed into a database that facilitates later calculations and comparisons. Currently, only *Excel*-based calculation sheet data exists, but a Java-based calculation program called SEDU is currently under construction. In this program, the user enters the amount of contaminated sediment and singles out possible and desirable pretreatment, treatment and disposal/placement methods and transport distances as initial data (Figure 3). The total environmental loads from one work phase to another and the whole dredging and remediation project are then calculated by the program.

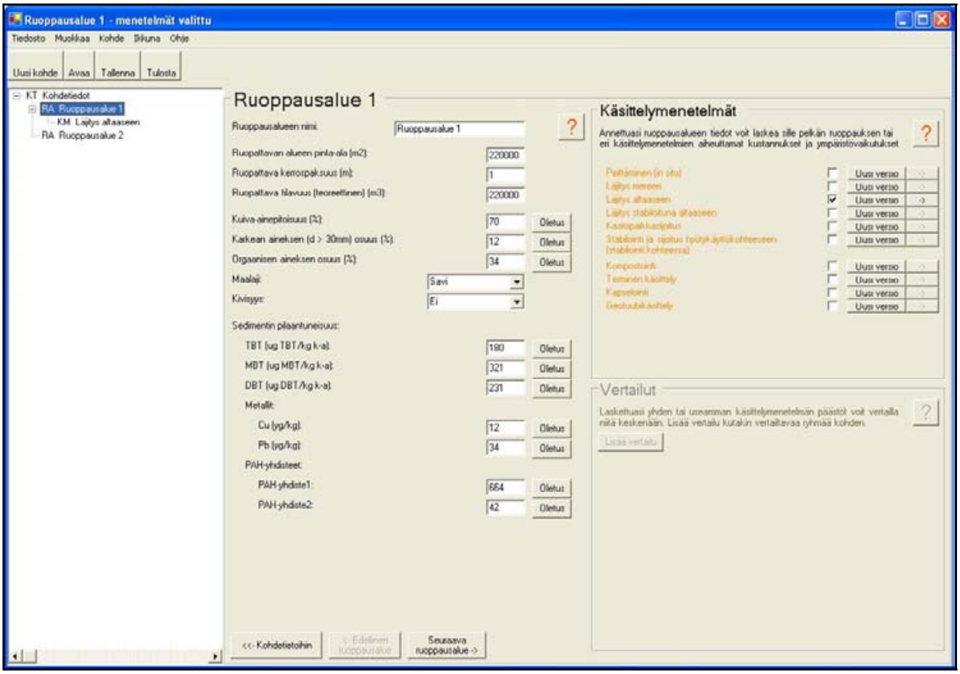

Figure 3. Demo version of the calculation program. In the first page, the user enters initial data such as the quantity of dredged sediment, contaminant concentrations and sediment type, and singles out desirable treatment methods.

SEDU adapts basic principles of life cycle assessment, and only the most significant environmental impacts of the dredging and remediation project are included. These include emissions to the air and water, consumption of renewable and non-renewable natural resources, the utilisation of by-products, the amount of waste produced, land use and energy consumption.

The final version of the SEDU is still incomplete. For the time being, gathered data and *Excel*-based calculation sheets can be used for a rough estimation of the environmental impacts of the sediment remediation project.

4. Discussion

Life cycle assessment is a useful tool when the environmental impacts of contaminated sediment remediation project are assessed. This type of procedure enables adequate comparisons between different remediation options and can be used in planning the dredging and treatment project, for marketing purposes, or as a decision-making tool for the authorities.

However, it needs to be addressed that there are always assessment uncertainties, mainly because average values and data are used to assess various environmental impacts during the life cycle. Therefore, results from this assessment are only indicative, and performing risk assessment and economic analysis in order to complete the results is recommended.

Many ports in Europe look for standardized processes, procedures and tools for sediment management in order to meet the challenges of future demands such as stricter legislative requirements and regulations. Various innovative dredging, treatment and valorisation methods have been developed, but there is still a lack of information about their performance, feasibility, limitations, possible risks and environmental impacts, not to mention their cost effectiveness. One way to reduce this information gap is to use LCA to assess and compare environmental impacts from one sediment management option to another.

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Sustainability assessment of facilities – a comparative analysis of rating schemes Case VTT Digitalo

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Abstract

The building sector contributes about a third of all energy-related emissions worldwide. Taking into account the emissions caused by land-use change impacts caused by urbanization, the manufacturing of building elements and the production of building materials, the share becomes even larger. According to the World Watch Institute, if the current trend continues the entire global community will run out of raw building materials by approximately 2030. Moreover, the building sector consumes water – a scarce resource in many parts of the world – for domestic use, landscapes and cooling towers. The building sector also generates a large variety of waste in construction, operation, renovation and, finally, demolition. Consequently, finding an effective way to transform the way we plan, design, build, operate, renovate and demolish buildings in the direction of sustainable practices has been the goal of many environmental assessment tools. In addition, there are co-benefits from this effort such as decreasing air and environmental pollution, improving health and productivity, and enabling sustainable economic development by promoting new sustainable technologies and behavior. Due to rising environmental concerns many local and global assessment tools have been developed. Because of the varying perspectives of the assessment tools the weighting factors applied to the various issues differ to some extent.

The aim of this study was to understand the similarities and differences between various rating schemes currently applied in our market and to analyze

their relation to LCA-based assessment and the new SBA system, which is still under development. The commercial rating tools studied were BREEAM, LEED and PromisE.

1. Introduction

Environmentally harmful activities differ from one industry to another, but it is well-known that the single largest contributor to greenhouse gas (GHG) emissions is the built environment, accounting for up to 50% of global carbon dioxide emissions [1]. In addition, the embodied environmental impacts generated by the building during the other periods of its life cycle can be of the same order of magnitude as those generated during the utilisation stage [2]. The construction industry consumes 40% of the materials entering the global economy and generates 40–50% of the global output of GHG and acid rain causing emissions [3].

Significant research efforts have already focused on specific aspects of buildings such as material properties, equipment performance and simulation of building physics. Much research has also explored building-related environmental performance in areas such as energy consumption, daylighting, recycled materials and air quality. However, as owners, designers, regulators and occupants increasingly desire that the entire building should provide improved environmental performance, integration of these individual research fields is required.

Generally, integrated approaches to understanding environmental impacts falls under the description of environmental assessment. Assessment has the dual goals of documenting environmental impacts and communicating those impacts to an intended audience. Any given party may conduct an environmental assessment for internal purposes, such as examining processes, or it may be part of a larger effort to communicate environmental information to consumers, regulators or investors. Currently, there are several methods that attempt to assess environmental impacts related to buildings. Each system has its own set of assumptions and limitations, each is designed to address certain aspects of environmental impacts and further, each system is designed for utilization by various participants in the building process, a condition that can "profoundly influence the outcome."

Life cycle assessment, LCA, has been widely used in the building sector since 1990. It is an important tool for assessing buildings, it is still less developed than in other industries, including perhaps the engineering and infrastructure sector. The building industry, governments, designers and researchers of buildings are all affected by the trend of sustainable production and eco-green strategies. The importance of obtaining environment-related product information by LCA is broadly recognized, and LCA is one of the tools that help achieve sustainable building practices.

Applying LCA in the building sector has become a distinct working area within LCA practice. This is not only due to the complexity of buildings but also because of the following factors, which combine to make this sector unique compared to other complex products. First, buildings have long lifetimes, often more than 50 years, and it is difficult to predict the whole life cycle from cradle-to-grave. Second, during its life span, the building may undergo many changes in its form and function, which can be as significant, or even more significant, than the original product. The ease with which changes can be made and the opportunity to minimize the environmental effects of changes are partly functions of the original design. Third, many of the environmental impacts of a building occur during its use. Proper design and material selection are critical to minimize those in-use environmental loads. Fourth, there are many stakeholders in the building industry. The designer, who makes the decisions about the final building or its required performance, does not produce the components, nor does he or she build the building. Traditionally, each building is unique and is designed as such. There is very little standardization in the whole building design process, so new choices have to be made for each specific situation.

One way to apply LCA to the building industry is to use rating tools, even though LCA is only one part of the tool. The objective of this study was to compare various rating tools currently applied in our market and to analyze their relation to LCA based assessment and the new Sustainable Building Alliance (SBA) system, which is still under development.

2. Approach to the comparative analysis

2.1 Data collection

The different rating tools require lots of information about different issues: management, technical maintenance, cleaning, catering, procurement, invoicing department, real estate management etc. The collaboration between the owner’s and user’s different departments and service providers is crucial if success is to be achieved in the rating assessment project. Here the main sources for information were the real estate manager and maintenance manual.

Every new building in Finland (constructed after the year 2000) must have a maintenance manual. This kind of manual can be a very good source of information. However, there is often only information that has been included there right after the implementation. Sometimes maintenance manuals are used more extensively and they include preventive maintenance programmes as well as the actual tasks and status of the actions. Digitalo had been as a target of similar kind of assessments earlier and information was relatively easily available in the maintenance manual and in other documents provided to the project group [4, 5].

This assessment is based on the existing documents, i.e. if some criteria will most likely be filled based on the current level of regulation and construction practices. However, credits were generally not granted if no documentation existed. The existence of the material, which can be used as evidence of the fulfilment of the requirement, is a major challenge in the existing building stock. Much information is lost when the builder hands over the property to the user or the new owner.

2.2 Use of rating tools and comparison

The assessment of Digitalo was conducted based on different rating schemes: BREEAM Offices 2008 [6], LEED 2009 for Existing Buildings [7], and PromisE Existing building [8]. Each tool was used by a different expert and the results, as well as assessment details, were discussed among the group during and after the assessments.

The BREEAM Office Assessment Tool assumes by default that some kind of a development project is undertaken. Moreover, the assessment tool is meant for buildings in the UK. BREEAM takes into consideration the local conditions inside the UK, but also in other countries. When BREEAM is used outside the UK, it is possible to use a localised version of BREEAM. The evaluation of Digitalo was done based on the available documentation of the building and the regulations of the Finnish building code. The assessment was conservative in the sense that where no confirmation was available, no points were awarded. Moreover since there is no development project ongoing in Digitalo, it received no project management and execution related points.

For LEED assessment, the first question to be solved was the fact that there are several other buildings on the same site. Different buildings have the same owner but different users and in practice it would be useful to apply LEED certification to the whole site (campus). However for this assessment, Digitalo was treated as if it had a smaller plot of its own. The existence of process guidelines is a prerequisite for many categories, for example energy efficiency best management practices, sustainable purchasing policy and solid waste management policy. Contrary to the BREEAM evaluation, these prerequisites were assumed to be fulfilled even if no exact documentation was available. In the practise, the service providers have guidelines, but some modification is needed to modify this to fit the LEED documentation requirements.

PromisE Existing building rating tool is aimed for older buildings since they form the majority of the building stock. The evaluated building was rather new and thus, with some indicators, rather easy points were collected. In some cases the assumptions were not that well suited to the current situation. For indoor climate assessment the A-rate was really the-state-of-the-art in such a new building.

The SBA system (see Figure 1) is based on LCA and ongoing international standardization work, such as CEN TC350 [9]. Sustainability assessment contains environmental, social and economic dimensions. The first SBA core indicators relate with environmental aspects (primary energy, water, GHG and waste) and human health (thermal comfort, indoor air quality) which is often considered as a social aspect. Some social aspects are also included into existing “environmental” rating schemes BREEAM, LEED, and PromisE. However, these are included into categories of Indoor environment quality, IEQ, materials and resources.

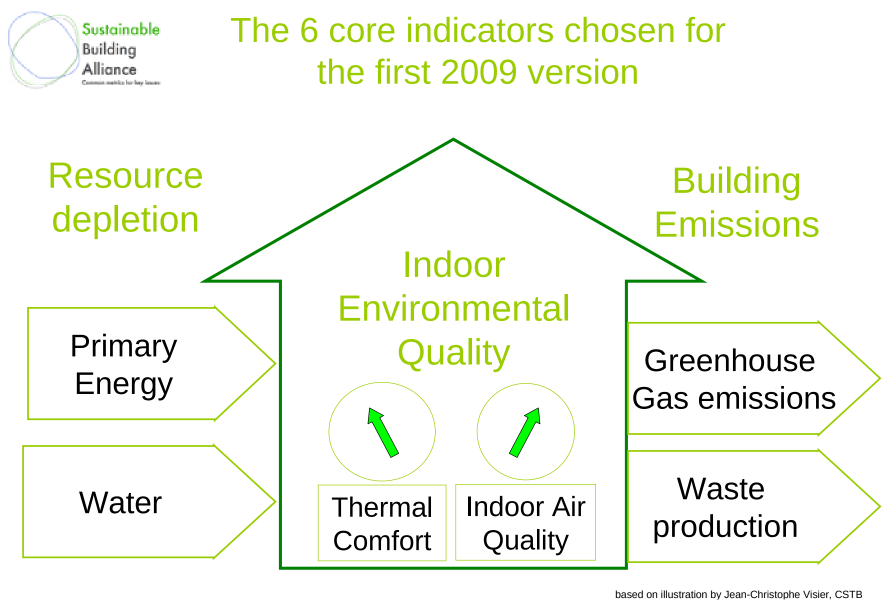

Figure 1. The approach and core indicators of the SBA 2009 system.

The assessments with different tools were conducted separately. After the assessment work the results were discussed together with the assessment group and similarities and differences were collected into Table 1 in the next chapter.

3. Results

3.1 Differences and similarities between assessment tools

The objective of this study was to understand the similarities and differences between various rating schemes currently applied in our market and to analyze their relation to LCA-based assessment and the new SBA system.

Digitalo is situated in the northern hemisphere, where the share of heating energy is high. Drinking water does not have as important a role as it has in many other countries. On the one hand there is a need for a uniform scheme that can be used in different parts of the world to prevent global warming. On the other hand, the local climate – even the micro climate – has a considerable impact on energy consumption within a single property, among other things.

In the BREEAM evaluation, even though Digitalo suffered from the lack of an improvement project and unavailable documentation in some instances, enough points could be accumulated to achieve certification, and the BREEAM Good level was within reach. With proper documentation, it seems that the BREEAM Good level could be attained.

Based on the general regulations for construction in Finland, the property could achieve the LEED Certified level. The biggest challenges would be to actually collect the information from the various service providers as well as develop and compile the process improvement documentation. An optimistic assessment was conducted, where it was assumed that all existing information will be produced as documents. This showed that even the LEED Gold level would be possible to achieve.

PromisE is being developed for the Finnish built environment and as such is very well-suited for the Finnish building stock. However, since the rating was done for an existing building and the tool is designed for the average building stock, the tool does not take the advanced technology available well into account in our case. This enabled some points to be collected rather easily.

3.2 Localisation and weights

Local conditions have affected to the development of to the tools. Originally the development started based on local needs, but afterwards the use of assessment tools has grown internationally. The weighting is fixed to make introducing the tools easier. However, this diminishes the relevance of the results. Currently there are no local versions available of BREEAM and LEED. BREEAM can be localised, but it needs extra knowledge which is not that easy available.

The assessments refer to different types of regulations and guidelines. The lowest level of reference is the existing norms. When the regulations differ from country to country, some extra credits might be awarded even if just the local norms have been fulfilled. Also the credits are rewarded mainly if the requirements have been achieved using current systems and solutions. International assessment schemes (BREEAM and LEED) have separate categories for innovativeness and they reward the use of innovative solutions.

3.3 Categories

The assessment tools include very similar categories relating to environmental issues. The tools used in this assessment are similar in a way that they do not take into consideration other factors of sustainability, like social and economic issues.

The following Table 1 presents the differences and similarities between the rating systems.

Table 1. Differences and similarities between rating tools.

Category	BREEAM UK		LEED USA		PromisE Finland	
Site	Transport Pollution Ecology Land use	5/10 3–4/9 - -	Sustainable Site	13–15/26	Land use Pollution Ecology Transport	A A B–C A
Energy	Energy	12–15/23	Energy and Atmosphere	20–24/35	Energy and Atmosphere	B–C
Materials and resources	Water Materials Waste	0/6 1–2/7 1/3	Materials and Resource Water Efficiency	3–4/10 3–5/14	Water, Materials and Resources Moisture performance	B–C B–C A A
IEQ	Health and Wellbeing	9–12/13	Indoor Environment Quality	5–13/15	Indoor Environment Quality	A
Other Issues	Management Innovation	- 0–1/10	Innovation and Design Process	0–1/6	Commissioning Adaptability	A–B
Total	35,56% (Pass) – 45,44% (Good)		44 (Certified) – 61 (Gold) /110		B–C	

The total points in Table 1 should be interpreted so that the lower value shows the level of certification available with the current documentation and the higher value shows the level of certification possible with documentation that could fairly easily be produced with no changes in the building itself. In BREEAM the difference is much lower than with others.

The levels in BREEAM are Pass ≥ 30%, Good ≥ 45%, Very good ≥ 55%, Excellent ≥ 70% and Outstanding ≥ 85%. In LEED assessment the existence of the documents have a great role. The levels for certification are Certified 40 to 49 points, Silver 50 to 59 points, Gold 60 to 79 points and Platinum 80 to 110 points. In PromisE the levels are from A to F. The best score is A corresponding to high quality level with respect to environmental issues. The tool developers estimate that roughly 1–2% of Finnish buildings are at this level. Also a B score is rather ambitious for the current building stock, roughly 10% of Finnish buildings correspond to that score. Score E corresponds to the current state of the art.

3.4 Comparison to SBA

The systems as compared (BREEAM, LEED and PromisE) have fixed weights and benchmarks, reflecting the fact that they have been developed within a particular region. This offers simplicity and facilitates marketing of the brand, since the product is always constant. It also appears to be good for comparative assessments, but not when the assessed buildings are located in different regions with widely different conditions, which is often the case. A structure that allows the relative importance of parameters to be explicitly changed to reflect differences in priorities in various regions can therefore ensure that the system produces results that are locally meaningful. For example, the importance of water consumption or conservation relative to other performance issues is surely different in southern Spain compared to Scotland, and if a system cannot reflect this, its results will be less relevant. It is no use to say that no weighting at all should be used, because a system that gives equal importance to all parameters is one kind of a weighting in itself.

SBA is an international LCA based system that has a common core and locally applicable supplement. It aims at avoiding multiple rating and in-comparable results. It contains at present a proposition for six core indicators, a methodology to assess them, a method to report on the indicators and links between SBA indicators and assessment schemes. The next steps are to agree on rules for establishing local benchmarks, to discuss the weighting methodology, to define a small number of additional core indicators, such as economic performance, visual comfort and acoustic comfort. The objective is to implement these indicators in different assessment schemes so that local rating will be based on LCA, to have a universal core methodology and thus improve the sustainability of buildings in a more reliable way than current schemes.

4. Discussion and conclusions

All studied rating tools had similar categories even though there were differences in the weighting systems and indicator values. Even so, the studied tools highlighted some common issues in the building's environmental performance, which can be summarized as five key issues of the building sector throughout the whole lifecycle: site, water, energy, material, and IEQ. The other issues can be regarded as the technological and strategic innovation to improve the environmental performance within the above five issues. A benchmarking system must identify best practices under specific climate conditions and development stages.

The systems compared (BREEAM, LEED and PromisE) have fixed weights and benchmarks, reflecting the fact that they have been developed within a particular region. However, the tools gave similar results, and were basically in good agreement with each other.

Currently, there is a market need for rating; many international investors demand certification of the buildings that they invest in. Even though the Finnish building industry has widely adopted BIM (building information models) for the design and construction phases as well as in some scale to maintenance, the information is not suitable for rating tools. This often leads to a new workload when certification is completed. The information exists but is scattered and not in a form that would allow it to be directly used for certification. Thus, a certification currently requires an extract effort and in many cases leads to underestimated scores, since all necessary information is not properly documented. It is evident that current rating systems could benefit remarkably if BIM could be used to transfer the information directly to the rating tools. It is important that the tools are used for the continuous improvement of sustainability in a built environment and not just for their own sake.

Holistic life cycle assessment is not that deeply and widely used in building sector than in other industries [10]. The main problem is the buildings, whose production process is complicated, and whose life span is long with future phases on assumptions. However, LCA and LCA-based rating schemes, such as the SBA system, are powerful for the evaluation of sustainability of buildings. They have the potential to make a strong contribution to the goal of sustainable development.

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Assessing ecological sustainability in urban planning – EcoBalance model

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Abstract

Urban planning solutions and decisions have large-scale significance for ecological sustainability, eco-efficiency, the consumption of energy and other natural resources, the production of greenhouse gas and other emissions, and the costs caused by urban form.

The EcoBalance Model was developed to assess sustainability of urban form and has been applied at various planning levels: regional plans, local master plans and detailed plans. The EcoBalance model estimates the total consumption of energy and other natural resources, the production of emissions and wastes and the costs caused directly and indirectly by urban form on a life cycle basis. The results of the case studies provide information about the ecological impacts of various solutions in urban development.

Planning solutions may impact on greenhouse gas emissions by 10% at the regional level, 60% at the local community level, and even 200% at the local dwelling area level. Impact on emissions caused by transportation is even bigger: at least double compared to the impact on total emissions. Similarly, large impacts can be seen concerning the consumption of energy and other natural resources, as well as costs.

The most important factors in sustainable urban planning are at the dwelling area level – location, structure, building density, house types, space heating systems; at the community and regional level – area density, energy consumption and production systems, location and distances between dwellings, working places and services, transportation systems, possibilities for walking and cycling, availability of public transport and necessity for the use of private cars.

1. Introduction

An ecologically sustainable area can be described as an area which requires the supply of as little energy and raw materials as possible (especially non-renewable materials), and which produces the minimum of harmful emission and wastes from all building and operating processes on a life cycle basis. A sustainable area should also offer people a good living environment and be economically affordable. (Lahti & Harmaajärvi 1992.)

In order to evaluate the ecological sustainability of urban form it is necessary to develop appropriate assessment methods. Methods for sustainability assessment are described, for example, in COST Action C8 "Best Practice in Sustainable Urban Infrastructure" (Towards Sustainable Urban Structure 2006).

The EcoBalance model has been developed and used in several cases in Finland for evaluating the impacts of different solutions in urban planning at various planning levels: residential area (detailed plans), municipality (master plans) and regional (regional plans) levels (e.g. Harmaajärvi 1992, 1998, 2002; Harmaajärvi & Lyytikkä 1999; Halme & Harmaajärvi 2003; Halme et al. 2003, 2005; Wahlgren & Halonen 2006; Wahlgren 2007a, 2008; Kuismanen & Wahlgren 2009). Results of the case studies show how ecologically sustainable various areas are, which impacts appear from area to area and from one urban form level to another, the essential choices of urban planning and transportation, and how to act to promote ecological sustainability in land use planning.

2. The EcoBalance model

The EcoBalance model estimates the total consumption of energy and other natural resources, the production of emissions and wastes and the costs caused directly and indirectly by urban structures and transportation on a life cycle basis (e.g. Harmaajärvi 1995, 2000a; Wahlgren 2007a) (Figure 1).

The EcoBalance model is divided into three sub-models: production, operation and transportation models. The ecological balance sheet has the following dimensions: consumption of energy (primary energy), consumption of natural resources (building materials, fuels, water), emissions, wastes and costs. All effects are measured with their natural dimensions (tonnes, kWh, m^3, euros).

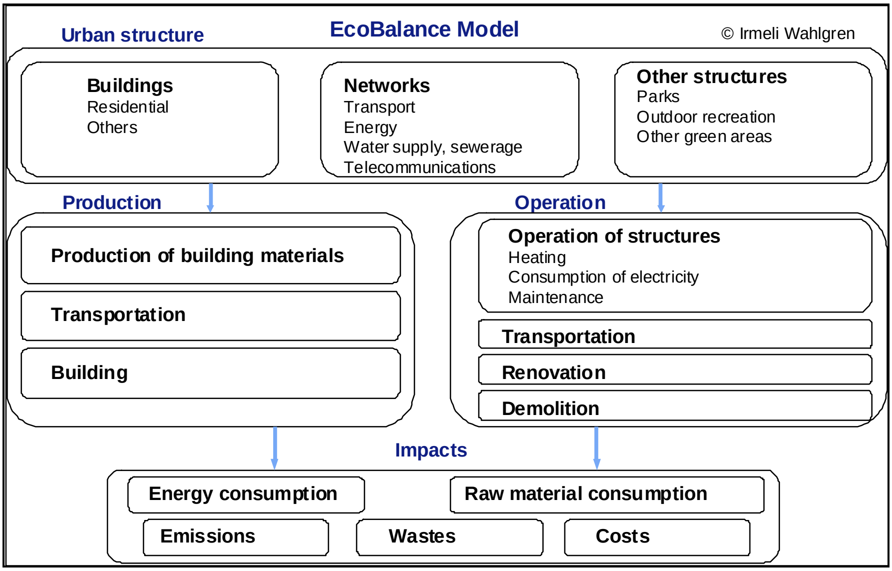

Figure 1. Structure of the EcoBalance model (e.g. Harmaajärvi 1995, 2000a; Wahlgren 2007a).

The EcoBalance model includes all urban structures: buildings, technical infrastructure and green areas. The model covers the whole life cycle of urban structures, starting from the production of building materials and fuels and continuing through maintenance and the use of the structures, as well as transportation in the urban structure, and finally to the demolition of the structures.

The input for the model is the volume information about all the structures of the area and transportation. The details of the information depend on the planning level.

The EcoBalance model calculates

1. total energy consumption (primary energy, kWh)
2. consumption of building materials (tonnes of wood, concrete, other stone materials, metals, glass, oil and plastic products)
3. consumption of fuels (tonnes of gasoline, diesel oil, fuel oil, coal, gas, peat, wood, etc.)
4. production of emissions (tonnes of CO_2, CO, SO_2, NO_X, CH and particles; greenhouse gas emissions CO_2-eq. calculated from CO_2, CH_4 and N_2O)
5. water consumption and waste-water production (m^3)
6. production of wastes (tonnes for recycling, compost, dump, etc.)
7. total costs of construction, operation as well as transportation (euros).

All these impacts of an area are evaluated during various phases of the life cycle: production, operation and transportation. Continuous impacts (operation and transportation) are evaluated using, for instance, a period of 50 years. The output of the EcoBalance model consists of total and relative figures (for instance, CO_2 eq. tonnes per inhabitant) for each ecological dimension.

3. Examples of assessment results – case studies

The results of the case studies offer information about the ecological impacts of various solutions in urban development. This paper introduces the results of some of the case studies in which the EcoBalance model has been used to assess eco-efficiency – ecological and economic impacts – of differing urban planning solutions at varying planning levels (Figure 2). Examples of results introduced in this paper focus on greenhouse gas emissions.

Figure 2. Case study areas. Rural "eco-villages": 1 Ekolehtilä, 2 Pellesmäki, 3 Puutosmäki, 4 Vuonislahti. Urban residential areas: 5 Sodankylä (mixed area), 6 Kotka (mixed area), 7 compact small house area, 8 loose small house area, 9 mixed area, 10 area with blocks of flats. Municipal and regional level: 11 Sipoo (9 structure models, draft and proposal for master plan), 12 Kuopio (2 structure models), 13 Kuopio Region (5 structure models). (Source of the map: Google Earth.)

3.1 Residential area level

Eco-efficiency of residential areas is introduced by 10 case study areas in various parts of Finland. Study areas have varying solutions with regard to location, structure, building efficiency, housing types and heating systems, etc. Two of the studies concern already-built areas, and two of them concern plans of the areas: studies have been made at the planning phase and assessment has been utilised in planning.

The study areas are

1. four typical Finnish residential areas: a compact small house area, loose small house area, mixed area with blocks of flats and small houses and compact area with blocks of flats (Harmaajärvi 1992)
2. two relatively new areas: Ravirata (former race track) in Sodankylä and Hirssaari in Kotka. They are mixed areas with a majority of small houses (Harmaajärvi 1998, 2002)
3. four "eco-villages" (rural areas that have been planned or are being developed with environmental interests as a priority): Ekolehtilä in Uusikaupunki, Pellesmäki in Kuopio, Puutosmäki in Vehmersalmi (nowadays a part of Kuopio) and Vuonislahti in Lieksa. The first two are relatively new areas with new technical or other solutions intended to lead to environmental conservation. The others are old villages where sustainable solutions for their future development are sought. (Harmaajärvi & Lyytikkä 1999.)

Greenhouse gas emissions account for 3.5–6.7 tonnes of CO_2-eq. per square metre in a 50-year period (Figure 3). The production phase is responsible for only about 10% of total energy consumption and greenhouse gas emissions. Most of the total energy consumption and greenhouse gas emissions are due to heating and the use of electricity in buildings.

Energy is consumed most in rural "eco-villages" and small house areas, because of long distances and the widespread use of private cars. The least energy is consumed in areas which have district heating and an efficient energy production system and which are located close to the city centre, and walking/ bicycling as well as public transport are widely utilised.

Greenhouse gas emissions caused in the operation phase are less in rural "eco-villages" than in other areas, due to the use of wood heating. Greenhouse gas emissions caused by transportation nevertheless eat away at the savings obtained by wood heating. Transportation draws the greatest differences between areas.

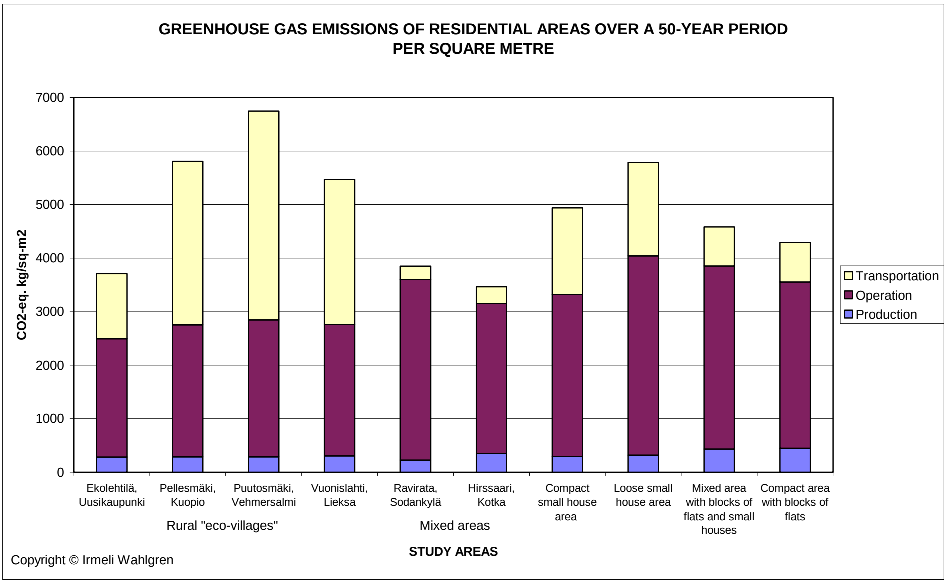

Figure 3. Greenhouse gas emissions of residential areas over a 50-year period. Emissions are produced most in rural areas by transportation (Harmaajärvi 1992, 1998, 2002; Harmaajärvi & Lyytikkä 1999; Wahlgren 2007a).

The results of the case studies show that there are big differences in the ecological impact of different areas. Eco-villages are not necessarily very sound from an ecological point of view. On average, eco-villages require more energy and raw materials, as they produce more emissions and cost more than urban areas. One of the most important explanations for the differences is transportation, especially in the use of private cars. This is strongly affected by the location of the area, the availability of public transport and individual preferences. Another important explanation for the differences lies in the consumption of heating energy, especially electricity. It would be most desirable to minimize electricity consumption.

3.2 Municipality level

Two research studies are introduced at the municipality (master plan) level: Municipality of Sipoo (Wahlgren & Halonen 2006; Wahlgren 2007a, 2008) and Southern City of Kuopio (Halme & Harmaajärvi 2003).

3.2.1 Structure models of the Master Plan (2025) of Sipoo

The structure models of the Master Plan (2025) of Sipoo differ from each other by the share of rural housing in addition to the transportation system, location of new areas and building efficiency.

Structure model A has the most scattered structure and low density and is strongly based on the use of cars. Structure models B and F have virtually the same features as model A but have less housing in rural areas and slightly higher area density than model A. Structure models C, D and E are based on public rail transport and new areas are more compact. Structure models C1 and D1 have the same structure as models C and D, with a significantly higher number of new inhabitants and a slightly higher area density.

Structure model V is a combination of models C1 and D1 and is, by decision of the municipality, the basis for the Master Plan. Distances between dwellings, work places and services are shortest. Public transport is based on rail transport connections. Housing is located in urban areas and villages.

Greenhouse gas emissions account for 224–364 tonnes of CO_2-eq. per inhabitant over a 50-year period (Figure 4). Most of the energy consumption and greenhouse gas emissions are due to heating and the use of electricity in buildings, but the greatest differences between models come from transportation. Effective public rail transportation clearly results in fewer emissions than a transportation system based on private cars.

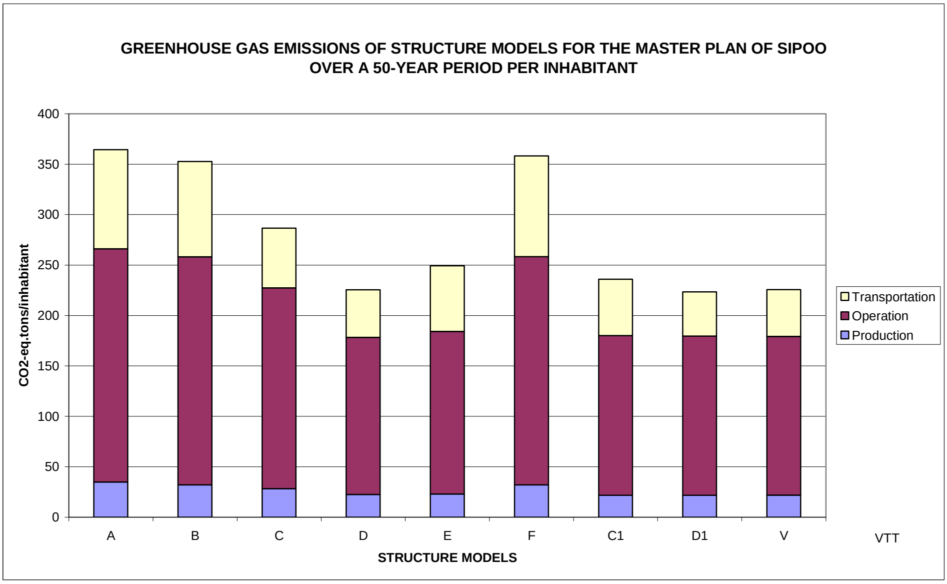

Figure 4. Greenhouse gas emissions of the structure models of the Sipoo Master Plan 2025. Emissions are produced most in models with scattered structure and a transportation system based on private cars. (Wahlgren & Halonen 2006; Wahlgren 2007a, 2007b.)

3.2.2 The southern city of Kuopio

City of Kuopio is planning and implementing a district ("Town of Islands"), which consists of a chain of new neighbourhoods. A new special street ("Street of Islands") connects the new district directly to the city centre. It promotes cycling and bus transit and integrates the southern parts of the existing urban area with the Inner City. The street crosses a lake and passes several small islands. Due to the aesthetic landscape, the street has been designed for slow driving. It includes a good path for cyclists and pedestrians. The street shortens distances considerably. (Figure 5.)

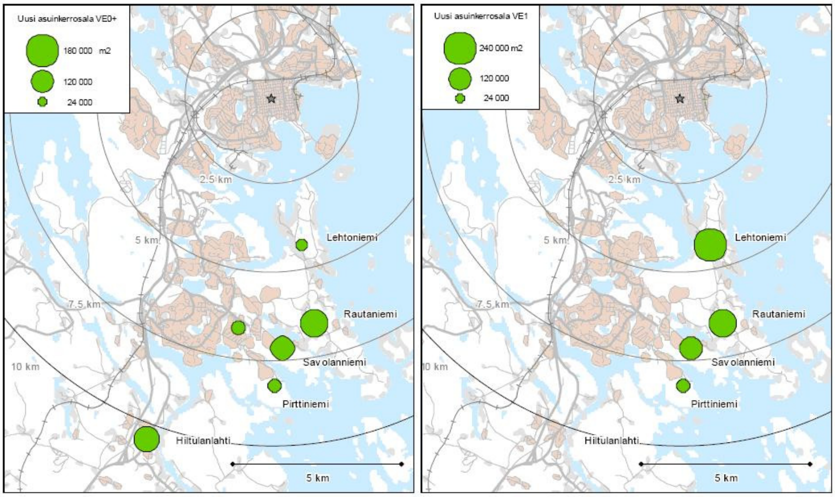

Figure 5. Town structure alternatives in the southern city of Kuopio. Location of new residential areas and amount of new residential floor area. Alternative 1 on the right includes the “Street of Islands”. (Halme & Harmaajärvi 2003.)

The study shows that the greenhouse gas emissions of the new “Town of Islands” will be substantially lower as compared with the alternative urban structure without the “Street of Islands” (Figure 6). The same result also concerns other impacts: energy and raw material consumption and other emissions as well as costs.

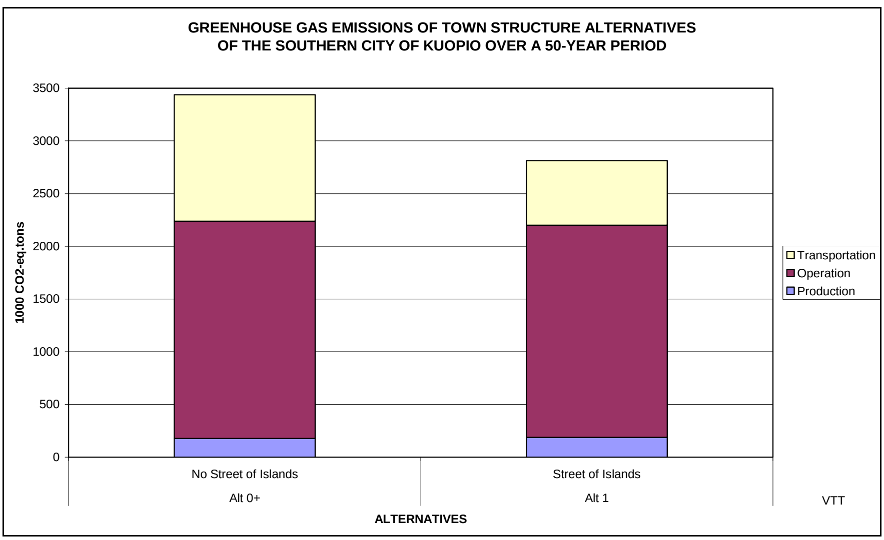

Figure 6. Greenhouse gas emissions of the structure alternatives of Kuopio. The “Street of Islands” shall halve emissions from transportation. (Halme & Harmaajärvi 2003.)

3.3 Regional level

3.3.1 The structure models of the Regional Plan of the Kuopio Region

Five structure models of the Regional Plan of Kuopio Region were studied with the EcoBalance model (Harmaajärvi et al. 2005, Halme et al. 2003). The study showed that the best structure model has the shortest distances between functions, the share of complementary building and infill development is relatively large, the share of rural housing is relatively small, area density is relatively high, and district heating possibilities are exploited. Greenhouse gas emissions are lowest and other impacts are most advantageous in the Kuopio model (Figure 7).

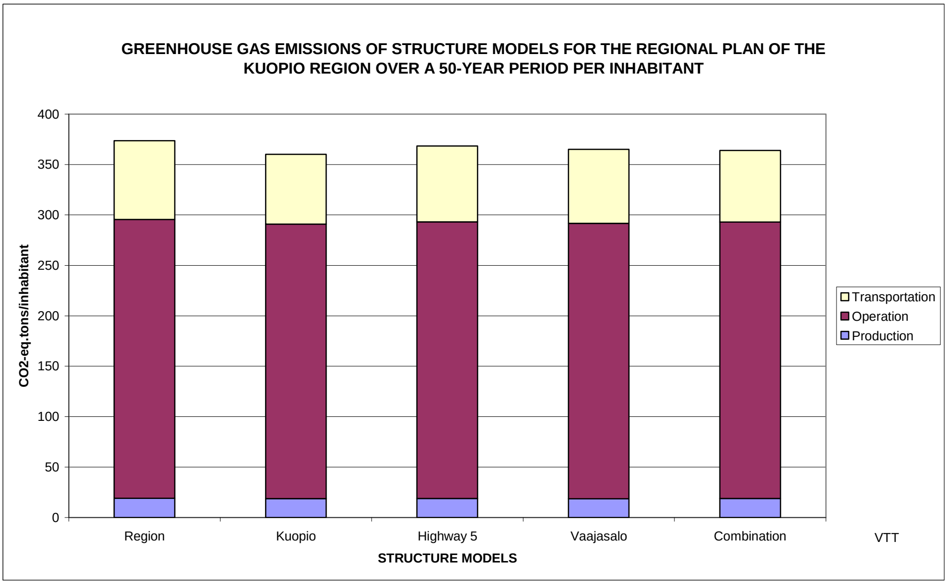

Figure 7. Greenhouse gas emissions of the structure models of the Regional Plan of Kuopio Region. The biggest differences are caused by transportation. (Harmaajärvi et al. 2005.)

3.3.2 The structure models of the Helsinki Metropolitan Area

Greenhouse gas emissions of urban form alternatives have been studied at the regional level, also in the Helsinki Metropolitan Area (Harmaajärvi & Huhdanmäki 1999, Harmaajärvi 2000b). The study showed that urban sprawl increases emissions even 50%, and more infilling decreases emissions 20% by comparison to the basic model.

3.4 National level

Greenhouse gas emissions at the national level were studied when preparing the National Climate Programme of Finland (Harmaajärvi et al. 2001, 2002; Harmaajärvi 2003, 2004). The study showed that it is possible to reduce greenhouse gas emissions by 2.3 million tonnes in 2010 by developing the urban form in a target-oriented way. This amounts to 15% of Finland's target in accordance with the Kyoto protocol for greenhouse gas emissions reductions.

3.5 Conclusions

The most important factors in sustainable urban and transportation planning are at the residential area level – location, what forms the transportation basis, structure, building density, house types and space heating systems as well as at the municipal and regional level – area density, energy consumption and production systems, location and distances between dwellings, working places and services, transportation systems, possibilities of walking/cycling, the availability of public transport and the necessity for use of private cars.

4. Effectiveness of urban planning

Effectiveness of urban planning to eco-efficiency of urban areas at various planning levels is assessed by considering the relative differences of urban form choices (Figure 8) and the reduction potential of greenhouse gas emissions of urban form choices (Figure 9). The same kind of assessment can also be made with regard to other impacts of urban development. This consideration concerns greenhouse gas emissions calculated per inhabitant.

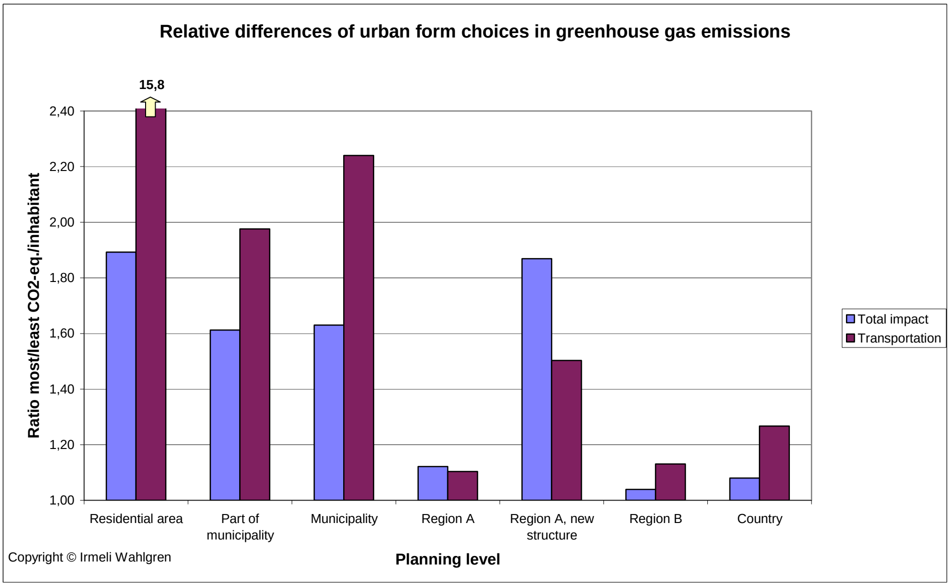

Figure 8. Relative differences of urban form choices in greenhouse gas emissions. Ratio between the best and worst solution at various planning levels.

This consideration shows that there are big differences between impacts of various urban form and transportation solutions. The differences are largest at residential area or local levels: the worst solution causes about twice the total of greenhouse gas emissions per inhabitant as the best solution – emissions from transportation even 16-fold compared to the best solution. At the regional level it is, however, also important to consider those parts of the future structure which have differences (the new part of the whole future structure). The study shows that it is possible to influence future impacts of urban form by urban planning and transportation decisions.

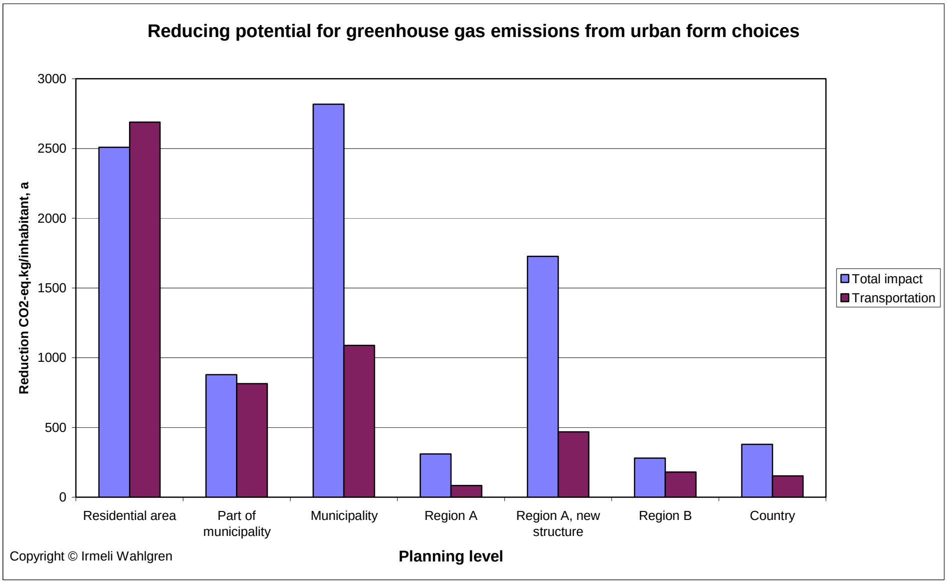

Figure 9. Reduction potential for greenhouse gas emissions from urban form choices. Reduction of greenhouse gas emissions (CO_2-eq kg/inhabitant, a) from the worst to the best solution at various planning levels.

5. Conclusions

Important choices in urban planning concern: the location of areas, distances, share of urban and rural development, complementary building, building density, structure – extent of networks, consumption of heating energy and electricity, heating system, energy production system, building systems and materials, living space, transportation system, possibilities to walk and bicycle, availability of public transport (especially rail traffic) and the need for the use of private cars.

Existing buildings should be utilised when necessary with change of purpose. Existing infrastructure should be applied when necessary with change of purposes, utilising complementary building. New areas should not be implemented before utilising complementary building and infill possibilities. New areas should be located favourably within the urban structure, with no necessity for the use of cars. Possibilities for walking, bicycling and the use of public transport – especially rail transport – should be created. Areas should have a good structure and a decent density.

Urban planning solutions and decisions have large-scale significance for eco-efficiency, the consumption of energy and other natural resources, the production of greenhouse gas and other emissions, and the costs caused by communities.

Planning solutions may impact on greenhouse gas emissions by 10% at the regional level, 60% at the local community level and even 200% at the local dwelling area level. Impact on emissions caused by transportation is even greater: at least double compared to the impact on total emissions. Similarly, large impacts can be seen to concern the consumption of energy and other natural resources as well as costs.

Most favourable urban planning and transportation solutions also have positive impacts, e.g. on the quality of the environment.

Planning alone cannot stop urban sprawl. When considering and assessing various measures on the national level with regard to legislative and fiscal issues, citizen participation and other background forces should be taken under serious consideration. Better cooperation between researchers, politicians, civil servants and citizens is required to find deeper understanding concerning economic, social and environmental long-term impacts of decisions related to urban development.

Cooperation, interaction and dissemination of information are essential to contribute to sustainable urban forms.

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LCA tool for cement manufacturers for system optimization and for environmental reporting

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Abstract

A tool was developed for life cycle assessment of cements. This tool aids the manufacturer to consider environmental aspects in product development and environmental reporting (for example environmental product declaration). Attention was paid especially to the energy efficiency in the manufacturing processes. This affects not only energy use but also environmental impacts such as the carbon footprint.

Cement is an essential material increasingly needed in the production of concrete structures, buildings and the modern infrastructure. However, the production of cement is an energy-intensive process which requires a lot of fuels and releases process emissions, especially CO_2 in the calcination process. On the other hand, as calcination is an inevitable process in cement production, attention should be given to energy use – especially the use of recovered energy and combustible wastes. Manufacturing process optimisation and life cycle management are the key issues with regard to lowering environmental impacts caused by cement production.

Cement industry belongs to the EU's emission trade systems; they must track and report the CO_2 emissions annually. The role of manufacturer is also to identify and improve the CO_2 and other environmental impacts incurred by production processes. This can happen with the help of life cycle assessment tool, target-setting, process development and monitoring. The LCA result should be provided for designers, contractors, and users. This information aids them to design eco-efficient use of products and buildings.

1. Introduction

1.1 Life cycle approach

Life cycle approach is emphasised in EU policies and legislation. All products and services have environmental impacts during their production, use and disposal. Integrated Product Policy (IPP) (COM 2003) seeks to support sustainable development by reducing the negative environmental impacts of products throughout their life cycle “from cradle to grave”. It addresses the importance to ensure that environmental impacts are considered throughout the life cycle in an integrated way. It will be more and more important for the European industry to understand the meaning of the life cycle approach and the necessity to adopt it. The sustainable use of resources, involving sustainable production and consumption, is highly important for the EU as well as the world as a whole (COM 2005). The sustainable consumption and production action plan emphasises the importance to create a virtuous circle: improving the overall environmental performance of products throughout their life cycle, promoting and stimulating the demand of better products and production technologies, and helping consumers to make better choices through more coherent, simplified labelling (COM 2008).

1.2 Cement, concrete and building industry

Building construction needs durable and sustainable building materials with the efficient use of resources: energy, water, and materials. In the building context, it also means reduced building impacts on human health and the environment during the building’s lifecycle – through better design, construction, operation, maintenance and end-of-life options.

Concrete is the most used building material in the world with annual use is approximately 5 billion tonnes; in Finland the annual use is 5 million m^3. There is a wide range of products made from concrete: load-bearing structures, elements, bridges, dams, roads, pipes and blocks, etc. In Finland 40% of the load bearing structures and 15% of facades are made from concrete (measured from building cubic meters).

Based on its performance, cement is the main raw material in concrete, binding together sand, aggregate, and water into a concrete material. Although the cement content in concrete is low (12–15%), it is an energy intensive substance thus, the sustainable production is extremely important. World cement production in 2008 was 2,830 million tonnes (Cembureau 2008). Each produced ton of cement emits nearly 900 kg of CO_2, from which ~500 kg comes from limestone calcination and the rest from the energy-intensive process. Cement production causes 2,500 million ton of CO_2 emission annually, which is 5% of global man-made CO_2 emissions (Natesan et al. 2003).

1.3 LCA and life cycle management

Life cycle assessment (LCA) is a quantitative tool for Life cycle Management (LCM) of cement. LCA helps to identify and understand all significant environmental impacts throughout the product or building life cycle.

Life cycle design aims to integrate environmental issues and parameters into product development throughout the life cycle of a product (Westkämper et al. 2000). Life cycle design approaches represent systematic approaches for design of the environment, aiming at the reduction of the adverse impact on the environment by considering the product’s entire life cycle (Roy 2000). This challenge has led to the concepts of sustainable product design, in which the function of products formulate the starting point and which aims at creating alternative, environmentally more sustainable, means for providing the desired functions. Maxwell and Vorst (2003) also address the concept of functionality in sustainable product design. They define that sustainable product development means the process of making products in a more sustainable way throughout their entire lifecycle, from conception to end of life. The goal is to produce products which are sustainable and achieve their required functionality, meet customer requirements and are cost effective; sustainable product development is about assessing the life cycle of a function to be provided and determining the optimum sustainable way of providing that function.

Environmental innovation can be defined as the use of production equipment, techniques and procedures, products and product delivery mechanisms that are sustainable (Dewick and Miozzo 2002). Takata et al. (2004) argue that as attention to environmental problems grows, product life cycle management is becoming a crucial issue in realizing a sustainable society (Takata et al. 2004, Herreborg 2008). The objective of sustainable product development is to provide the functions necessary for such a society, while minimizing material and energy consumption.

LCA is a procedure which offers instruments and bases for environmental management. It helps to make conclusions, recommendations and decisions about

- environmental performance
- use of natural resources, reduction of emissions and wastes
- process optimisation
- production of information for environmental reporting.

The role of the product manufacturer is, in the point of view of sustainable development, to identify and reduce the CO_2 and other environmental impacts induced from the production processes. This can occur through the aid of life cycle assessment, target-setting, process development and monitoring. Ultimately, the LCA result should be provided for designers, contractors, and users to assist them in designing the eco-efficient use of products and buildings.

However, an LCA may be an overly complex process for manufacturers because

- the assessment requires information on many other product systems. A broad material, energy and resources database is needed for calculations.
- environmental impacts of the product and processes often depend on factors that are variable
- model creation and LCA assessment is a knowledge-based and time-consuming process, so any help is beneficial.

Manufacturers need simple tools for life cycle assessment. VTT is responding to the Finnish cement industry need, and the “LCA-CEMENT” tool for cement factories and various cement type assessments was developed.

2. LCA method for cement calculation

Calculation principles within the LCA-CEMENT tool are based on Life cycle assessment (LCA) and follow the basic principles of ISO 14040 (2006) and ISO 14044 (2006). Calculation also takes into account the national assessment method prepared under the guidance of the Confederation of Finnish Construction Industries RT for environmental product declarations in 2004 (Anon 2004). This national method describes commonly accepted methodology and procedure for EPD of building materials also in addition to the principles of using this information in building design.

According to the definition, LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition, production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave). In cement assessment, as the cement is a raw material for the concrete industry, the life cycle cut-off was completed at the cement factory gate, i.e. the assessment was cradle-to-gate assessment.

The cement production process is shown in Figure 1.

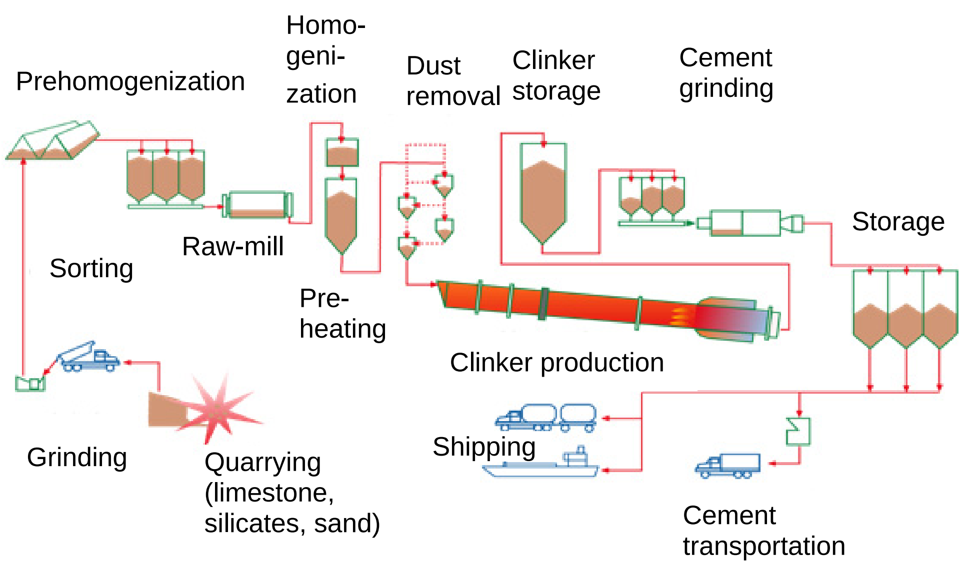

Figure 1. Cement production process.

3. LCA cement tool, background

This Excel-based and Visual Basic coded tool contains environmental profiles for various energy sources, transportation modes and raw materials used in cement production as background data.

The main raw material of cement production is limestone. Limestone and other raw-material mining, acquisition, grinding, homogenisation and calcination of calcium carbonate at high temperatures are needed to produce the clinker. To produce cement, the clinker is ground or milled together with gypsum and other additives. Calcium carbonate decomposes during calcination and CO_2 emissions release. To produce 1 tonne of clinker, the typical average consumption of raw materials in the EU is 1.57 tonnes (IPCC 2001). Most of this is lost from the process as carbon dioxide emission to air in the calcination reaction ($CaCO_3 \rightarrow CaO + CO_2$). The tool deals with this amount of CO_2 (CO_2 from calcination) as a calculated value which depends on the limestone used, and is an input value for the tool.

The environmental impacts of other mineral raw materials are assessed on the basis of the energy consumption used in acquisition. When the mineral raw materials are industrial by-products like fly ash and blast furnace slag, no environmental loads from the production are considered: only the product transportation is taken into account.

A small amount of clinker is purchased from abroad by the Finnish cement industry. The environmental profile for this clinker is estimated to be the same as that produced in Finland. However, the transportation distance for purchased clinker is taken into account as realised values.

During the clinker burning process, sulphur oxides, nitrogen oxides, particles, and heavy metals are released. The quantity of these emissions is based on the measurements and used as tool input values.

4. Tool for optimisation and reporting

It is known that cement production is an energy-intensive process; depending on the process, 60 to 130 kg fuels and ~100 kWh of electricity are used to produce 1 tonne of cement (http://www.cembureau.be/). Various fuels like coal, metallurgic coke, and petcoke can be used to provide the heat required for the process. Besides these, waste and many other by-product fuels could also be utilised in the cement kiln. In cement production, limestone decarbonation results in CO_2 emissions which are inevitable and unavoidable: because of this, attention should be given to the reduction of energy use, the use of renewable energy sources and particularly the utilisation of recovered energy and combustible wastes. In the seventies, the Finnish cement industry made a significant decision on behalf of decreasing energy consumption and emissions by changing the cement production method from wet to dry. This radical change in the technique applied is not an everyday option. Only continuous development of production processes and economic use of natural resources could reduce environmental impacts.

Manufacturing process optimisation and life cycle management are the key issues to lowering environmental impacts caused by cement production. What the impact of using different types of fuel or varying raw material composition is could be studied by means of the LCA Cement tool.

This tool enables the analyses of various factors to do with the environmental profile of the cement type or the whole factory operation. The variables which could be studied are composition, raw material and ingredient types and amounts, energy used in production processes and raw material transportation volumes and modes. Material variables within the tool are limestone, sand, slag, gypsum, fly ash, black rust, diabase and ferrous sulphate. The energy sources, concerning which assessments could be provided are coal, petro-based and spillage coke as well as renewable and waste materials such as bone meal, rubber chaff, waste slurry and oils. For production data feed, the Visual Basic forms have been established, and these are shown as examples in Figure 2.

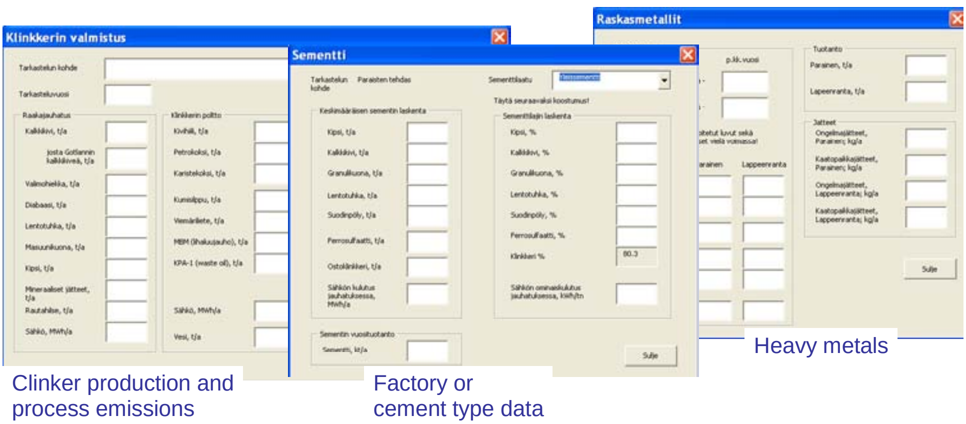

Figure 2. Visual basic forms for data inputs.

The cement production must follow the national and European legislation. The cement industry should account for environmental effects in the excavation of natural raw materials. It is responsible for the rehabilitation of quarries as well as the recovery of energy and material from wastes and caused emissions. The cement industry belongs to the EU's emission trade systems (ETS), and industry must annually follow-up and report CO_2 emissions from production. According to the Cement type assessment, it could be seen that cement production in Finland causes less substantial CO_2 emissions than on the average in the EU or in general production (Figure 3).

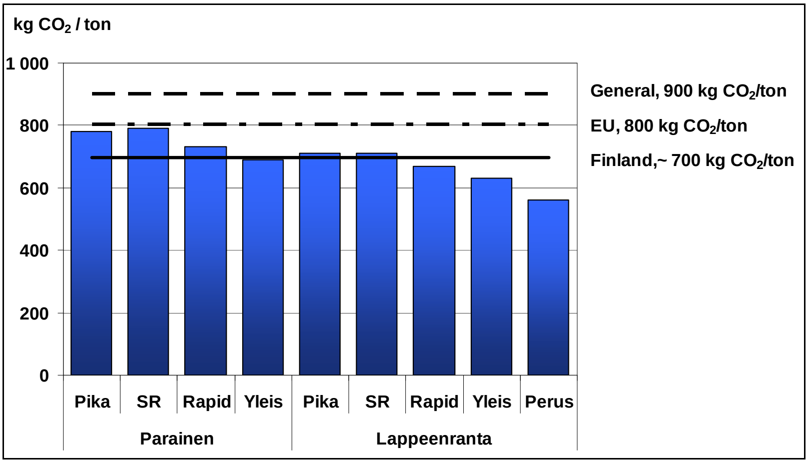

Figure 3. CO_2 emissions from decarbonation, combustion of fuels and electrical consumption in different types of cement production.

Environmental product declaration (EPD) procedure have been put up internationally (ISO 21930, ISO 14025) and in Finland for environmental reporting. VTT together with the Finnish building industry and the Confederation of Finnish Construction Industries RT worked out principles, methodology and format for compiling environmental declarations and for assessing environmental impacts of buildings (Anon 2004). The LCA-CEMENT tool could be used for environmental reporting. The tool provides the results in two environmental product declaration formats, national format (Ympäristöseloste) and format proposed by the European Cement Association (Cembureau). Cembureau is the representative organisation of the cement industry in Europe, which is responsible for cement producers in Europe and also has been collecting information about cement production for business-to-business use.

The EPD's information can be used as an input for the assessment of a specific application of cement-based products with regard to its entire life cycle. This information is essential for the BERTTA LCA tool, where life cycle assessment of various concrete products is calculated (Vares and Wirtanen 2004, 2005). Ultimately, the environmental profiles of concrete products could be utilised in building assessments.

Environmental Product Declarations will play a crucial role as Business-to-Business communication. EU Commission have mandated CEN TC 350 to develop a set of horizontal European standards for sustainability construction work. The standards already under development in the field including

- framework for assessment of buildings,
- assessment of environmental performance of buildings – calculation methods
- use of environmental product declarations
- environmental product declarations – product category rules
- environmental product declarations – communication formats.

In the near future, these standards will promote the use of EPDs in the environmental assessment of buildings.

5. Discussion and conclusions

Cement production is an energy-intensive process which releases emissions into the environment. An option to reduce environmental impacts is to reduce clinker content in cement by using additives like fly ash and slag. This leads to smaller total energy content, and when the clinker content is smaller the CO_2 emissions from limestone calcination are also smaller. Air emissions from fossil fuel can be reduced by using alternative energy sources such as the combustion of tires, municipal wastes, bone meal, biofuels and other alternatives. The optimal choices can be studied by means of the LCA-CEMENT tool.

The basic principles, environmental profiles used and calculation procedure are relevant and form the basis for the conformity of the calculations. However, the validity of the results also depends on the quality of input data.

Every manufacturer should have a tool which aids in considering environmental aspects in product development and environmental reporting. Target-setting and process development based on identified environmental performance and continuous monitoring can help manufacturers reduce environmental impacts from the products produced.

According to the World Business Council for Sustainable development (WBCSD), cement production has become more efficient over time. The Cement Sustainability Initiative (CSI) and cement action plan (sectoral approach for managing environmental impacts) have had an important role. CSI outlines a pathway towards a more sustainable cement sector by tracking action according to six main issues (WBCSD 2005):

- CO_2 and Climate Protection
- Responsible Use of Fuels and Raw Materials
- Employee Health and Safety
- Emissions Monitoring and Reduction

- Local Impacts on Land and Communities
- Concrete Recycling.

According to this, cement producers report their baseline emissions, develop a climate change mitigation strategy, publish their targets and progress and report CO_2 and other emissions annually.

Cement plays an important role in the development of sustainable concrete, buildings, and infrastructure. Although existing clinker-making technologies do not provide significant potentials for further improvements, massive energy and CO_2 savings can be achieved in cement-based products because of their durability and long life span. Environmental impact verifications in the building level cannot be carried out without EPD information on used products and materials. This is one reason why material industries should have an obligation to produce authentic and publicly available data about their processes and environmental performance.

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LIPASTO – transport emission database

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Abstract

LIPASTO is a calculation system for transport energy consumption and emissions in Finland. The system comprises two separate units, the emission inventory part and the unit emission database part. This article is an introduction to the LIPASTO system, the main focus being on the unit emission database. The database contains energy consumption and emission figures for both passenger and freight transport, expressed as grams per passenger kilometre or tonne kilometre. These types of data are needed, for example, when calculating the carbon footprint of a transport service or when assessing the life cycle emissions of a consumer product. The LIPASTO system has been developed by VTT, and all main results are published on a free website www.lipasto.vtt.fi.

1. Introduction

The demand for information and data on transport energy consumption and emissions is growing. Extensive knowledge is needed, for example, by individuals and companies that want to assess the environmental impacts resulting from their activities. Transport emission data are also needed for comparing different choices and for monitoring the total amount of emissions on a regional, national or global level. National emission inventory reports serve decision makers as a valuable source of information.

Transport emissions cannot be directly measured in practice. A set of calculations are required, some of which may be rather complicated. Some emission compounds are generated in proportion to fuel consumption, whereas others are very much dependant on other factors, such as motor characteristics and the surrounding environment. A number of methodologies are currently used, but harmonisation is needed in order to ensure better comparability between different sources. Standardisation work for transport unit emissions has only started, and the most comprehensive instructions concerning emission inventories are given by the Intergovernmental Panel on Climate Change (IPCC 2006).

2. LIPASTO system

The LIPASTO calculation system consists of two parts: the emission inventory and the unit emission database. The results of both of these units are published in Finnish and in English on a free website: www.lipasto.vtt.fi. The LIPASTO system is a unique source of information containing the annual emission inventory data for all transport modes, the development and forecast for total national transport emissions, and emission factors for hundreds of vehicles and working machines. The most similar information to the LIPASTO unit emission database has been released in the UK, where a guide for calculating corporate and individual carbon footprint has been published (AEA 2009). The work for the LIPASTO calculation system started in the 1980s, and apart from VTT's own contributions, financing has been received from the main transport authorities in Finland.

The focus in the LIPASTO calculation system is on the Finnish transport system. Vehicle types and their performance reflect the situation in Finland, though international transport is covered especially in the case of waterborne and air transport. All data for energy consumption and resulting emissions deal with the operational phase of transport, meaning the energy consumption and emissions while a vehicle is being used. The only exception to this rule is the electric train, whose energy consumption is defined as electricity used and emissions are defined as emissions from electricity production. In order to broaden the scope to the total environmental impacts of transport, the entire life cycle should be studied – including, for example, the entire production chain of fuels, production of vehicles, construction of the infrastructure, maintenance and disposal of vehicles and infrastructure. The life cycle approach for transport has been studied, for example, in the United States (Chester 2008) and Norway (Berntsen & Fuglestvedt 2008).

2.1 Emission inventory

LIPASTO emission inventory covers the four transport modes: road, railway, waterborne and air transport, and additionally working machines. The total annual emissions from each transport mode in Finland are calculated using separate mode-specific sub models developed by VTT, except for the air transport model developed and maintained by Finavia. The results from each of the calculation models include mode-specific energy consumption and emission compounds CO, HC, NO_X, PM, CH_4, N_2O, SO_2 and CO_2. All models generate results for Finland as a whole, but the more detailed models for road and railway transport also enable inventory calculations on the municipality level. The most recent calculations were carried out for the year 2008, and the calculations reach back as far as year 1980. In addition, a forecast for twenty years ahead – i.e. presently up to 2028 – is given. Figure 1 is an illustrative example, showing the developments and future trends for carbon dioxide emissions from road transport in 2008.

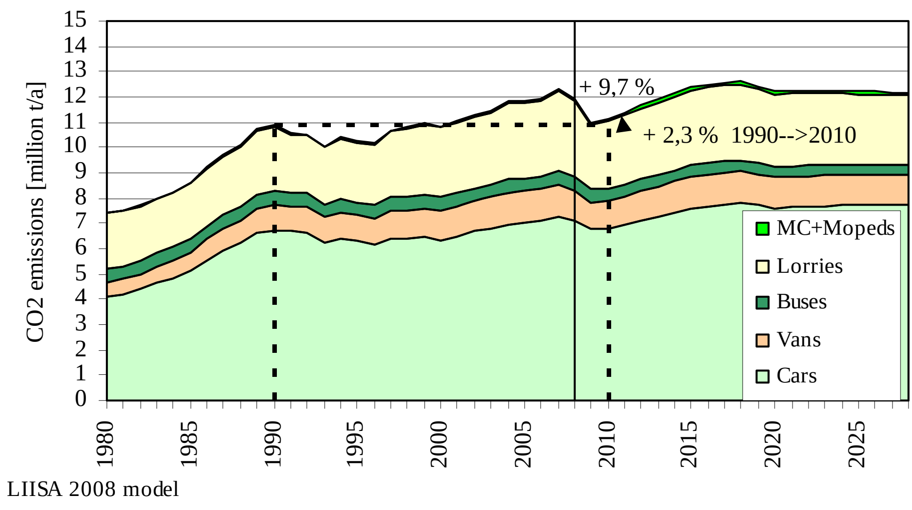

Figure 1. Carbon dioxide emissions from road transport in Finland.

The results of the emission inventory calculations are displayed on the LIPASTO website. The results are widely used by different parties such as municipalities and provinces wanting to assess the regional environmental impacts from transport. The emission inventory figures do also serve as a valuable source data for air quality studies. Furthermore, the LIPASTO model forms the basis for the official reporting of the national transport emission calculations submitted to the EU and the United Nations Framework Convention on Climate Change (UNFCCC).

Besides the traditional four transport modes, LIPASTO emission inventory includes two special features. Firstly, a fifth sub model for calculating energy use and emissions of working machines has been set up. Covering about 50 different machine types, the model offers information that is collected only in a few countries. Secondly, an additional element accounting for all motor-driven leisure boats has been added to the sub model for waterborne transport.

2.2 Unit emission database

Within the LIPASTO system, transport unit emissions are defined as emissions allocated to the transport of a transport unit over one kilometre. While both passenger transport and freight transport are included, the term transport unit may refer to, for example, one passenger, one tonne of freight, one container, one trailer or the entire vehicle in question. Most commonly, unit emissions are expressed as grams per passenger kilometre (g/pkm) or grams per tonne kilometre (g/tkm). All transport modes and working machines are represented in the LIPASTO unit emission database, and the results consist of data for energy consumption and emissions of the following compounds: CO, HC, NO_X, CH_4, PM, N_2O, SO_2 and CO_2. In addition, a value for carbon dioxide equivalent is calculated, combining the warming effects of carbon dioxide, methane and nitrous oxide.

Unit emission figures are needed, for example, in companies that want to calculate emissions resulting from their transport services. Transport unit emission figures are also needed when calculating carbon footprints for consumer products, an activity that is becoming increasingly important. The LIPASTO unit emission database is the only one of its kind regarding the extensive amounts of data free of charge on the Internet (see Figure 2). Presently the unit emission database gives unit emission figures for the year 2007 or 2008, depending on the transport mode. Updates are planned on an annual basis.

Figure 2. The LIPASTO unit emission database home page.

Whilst the need for unit emission data is growing, a standardised methodology for calculating them is, for the time being, missing. One of the biggest questions is how to allocate energy consumption and emissions when both passengers and freight are transported in the same vehicle. Various approaches exist: some of them are based on the masses of the passengers and freight or the volume or surface area required by them. Another challenge is how to promote public transport as an environmentally sound option, when the unit emission figures for public transport some times are high because of the relatively low occupancy rate.

Unit emissions of passenger **road transport** are presented for passenger cars, buses, two-wheelers and all-terrain vehicles, whereas freight road transport covers vans, lorries and trucks of a different size. The vehicle types have been chosen to best reflect the vehicle fleet in Finland, and thus full trailer combination up to 60 tonnes is included. The resulting data tables are compiled for each vehicle type and Euro emission category and thereto vehicles using different types of fuels are separated. As a basic rule, unit emissions are calculated and allocated to the average number of passengers or amount of freight transported. However, for road freight transport, unit emission figures are also given for empty- and full-loaded vehicles.

Calculation procedures for electric **railway transport** differ significantly from those for other transport modes, as the driving power is produced in power stations. Therefore, the unit emissions for electric trains are defined as emissions released while producing the amount of electricity needed. Emission factors for electricity production are derived from the Finnish power production statistics as a ten-year average. Electric trains are dominant in Finland, but figures are also given for diesel-driven trains. Passenger railway transport covers intercity, Pendolino, local and diesel trains, and freight transport covers container and trailer trains and freight trains on average.

Waterborne transport is the transport mode that has been given special attention in the most recent update. More ship types typical to waterborne transport in Finland have been added, comparisons between ships travelling at various speeds are now possible, and a lot of effort has been put on defining actual load factors. A special characteristic concerning the ship types used in the north is the need for ice strengthening, which in turn requires additional power reserves. The problem with load factors is that traditionally they are calculated from the total weight of freight carried over the loaded leg. However, the approach chosen for the LIPASTO system takes into account both legs, the latter of which may in some cases be an empty return trip. Also, the LIPASTO unit emission figures are calculated for the actual net freight tonnes, excluding the weight of containers and trailers. This approach leads to lower loading factors and higher unit emission figures, but also to more realistic results and better comparability between different modes. Data tables are given for ship types such as container ships, bulk carriers, tankers, general cargo ships, ferries and ropax ships. For freight transport, emissions are allocated not only to net tonnes but also to entire containers and trailers. Table 4 shows, as an example, energy consumption and emissions from a ropax ship travelling at the speed of 24 knots.

Table 4. Energy consumption and emissions from a ropax ship with trailer capacity of 300. [g/trailer km] is calculated as emissions of the ropax ship per trailer onboard and kilometre.

	Ropax, 24 knots, trailer capacity 300		
Compound	[g/ship km]	[g/trailer km]	[g/tonne km]
CO	376	1.3	0.11
HC	77	0.27	0.023
NOx	9 384	33	2.8
PM_{10}	219	0.77	0.065
$PM_{2,5}$	176	0.61	0.052
CH_4	37	0.13	0.011
N_2O	13	0.044	0.0037
SO_2	3 999	14.0	1.2
CO_2	454 182	1 590	134
CO_2 equivalent	458 907	1 606	135
Fuel consumption	142 504	499	42

Unit emissions of **air transport** are provided for various zones in terms of flight distances. Both domestic and international flights are included. Passenger air transport figures are calculated from the information received from Finnish airlines, but in the absence of information on freight transport, best available international source was chosen for reference (AEA 2009). In the case of passenger transport, energy consumption and emissions are allocated to the actual number of passengers, resulting in very accurate results specific to Finland. Flight distances in the LIPASTO system are defined using the concept of great circle distance, which is the theoretical minimum distance between two points.

The LIPASTO unit emission database also offers figures for less conventional objects. Off-road traffic contains energy consumption and emission data for all-terrain vehicles and snowmobiles operated outside the road network and the section for working machines provides the same data for about 50 different machines, such as forklifts, tractors, chain saws and lawn movers.

3. Discussion

The demand for accurate environmental knowledge in the transport sector is growing, and to meet this demand, emission factor databases and tools for calculating the environmental impacts are being set up. The LIPASTO system, consisting of the emission inventory part and unit emission database part, is one of the first and most comprehensive emission data sources. The results are displayed on a free, public website serving individuals, companies and decision makers. On the national level, the database with regular updates and easy access has established itself as an important information source and on the international level as a reference database.

The lack of harmonized definitions and calculation methods for transport emission calculations has been recognised by the EU, and the European Committee for Standardization (CEN) has established a working group for the preparation of standard CEN/TC 320/WG10 "Energy consumption and GHG emissions in relation to transport services". A VTT representative is taking part in the working group.

Besides harmonisation of the methodology, other future challenges in the field include the growing use of biofuels and how to handle them in emission calculations. Another challenge will be to broaden the scope to full life cycle assessments that will enable better comparability between modes. For these and many other future challenges, the common nominator is the growing need for detailed base data. More and more data needs to be collected concerning the transport services: fuel consumption, accurate load factors and occupancy rates, net freight weight, fuel and vehicle characteristics, infrastructure and maintenance used, et cetera.

Eventually, the information gained from transport energy consumption and emission calculations should lead to environmental assessments that in turn lead to improvements, such as more efficient use of the existing vehicle fleet and better grounds for policy-making. Weak points – such as inefficient capacity use and unfavourable impact of high speed in freight transport – can be pinpointed and addressed.

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Title
Life Cycle Assessment of Products and Technologies LCA Symposium

Abstract
VTT Technical Research Centre of Finland organised a Symposium "Life Cycle Assessment of Products and Technologies" on the 6th of October, 2009. The Symposium gave a good overview of methods, tools and applications of Life Cycle Assessment developed and utilised in several technology fields of VTT.

The 12 Symposium papers deal with recent LCA studies on products and technologies. The scope ranges from beverage cups to urban planning, from inventory databases to rating systems. Topical issues relating to climate change concern biorefineries and the overall impacts of the utilisation of biomass. The calculation of carbon footprints is also introduced through paper products and magazines. One example of LCA tools developed at VTT addresses cement manufacturing. VTT's transport emission database, LIPASTO, was introduced in detail. The use of LCA methods and life cycle thinking is described in various contexts: product development in relation to precision instruments; selection of materials and work processes in relation to sediment remediation project; and procedures of sustainability rating through VTT's office building Digitalo. The Climate Bonus project presented a demonstrated ICT support that informs about the greenhouse gas emissions and carbon footprints of households.

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