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# Assessment of media and communication from a sustainability perspective

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# Abstract
This thesis aims to assess potential environmental impacts of media and communication and to contribute to the development of methods for sustainability assessment. Although the main focus is on printed and electronic media products and environmental impacts, a broader sector analysis is also included and social aspects are discussed. The thesis provides a review of different environmental assessment tools in order to better understand their relationships and the appropriateness of different tools in different situations. Life cycle assessment (LCA) is used to assess printed and electronic versions of newspapers, books and invoices. Results of the screening LCAs of newspapers and books indicate that when comparing printed and electronic versions there are benefits and drawbacks for both. For news and books read on e-reading devices with energy efficient e-ink screens, the main environmental impacts in the studies stemmed from the production of the device and partly from disposal, with the latter having the potential to reduce some environmental impacts through recycling of materials. However, there are data gaps regarding the production of the e-reading devices, most notably for the e-ink screen and the waste management of obsolete e-reading devices. Existing data on internet energy use are uncertain. The potential impacts from a hypothetical total change from paper invoices to electronic invoices in Sweden were assessed through a screening consequential LCA regarding greenhouse gas emissions and cumulative energy demand. The results indicate that emissions and energy demand could decrease as a result of a change. The screening LCAs performed indicate that users' practices could substantially influence the environmental impacts. Key factors which can influence results and comparisons of printed and electronic media products are total use of electronic devices, total use of printed media, amount and type of paper, energy use of electronic devices, potential printing of electronic media, electricity mix, and the system boundaries set for the assessments.

To get a wider perspective, a sector study of the ICT sector and media sector concerning global greenhouse gas emissions and operational electricity use was performed. It was estimated that the contribution to global greenhouse gas emissions in 2007 was roughly 1-2 % for each sector. To assess media and communication products from a sustainability perspective, social aspects should also be covered. The author participated in an international project group on social aspects and LCA, one outcome from which was guidelines for social LCA (S-LCA). In addition to providing guidance for S-LCA, another important role of the guidelines is to facilitate discussions, criticism and proposals for improvement and development of the methodology being developed.

The LCA and sector studies in this thesis are limited to direct and to some extent indirect environmental impacts. Further studies of the environmental impacts of more long-term changes in practices and potential structural changes, as well as potential social impacts, could provide important additional insights. This could increase the possibility of facilitating sustainable practices related to ICT and media.

Keywords: electronic media, e-reading device, print media, newspaper, book, invoice, information and communication technology (ICT), environmental assessment, life cycle assessment (LCA), social life cycle assessment (S-LCA), sector analysis.

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I have written a PhD thesis, amazing. There are many people I would like to thank for making this possible. First of all, my supervisor Göran Finnveden. When I came to fms in 1998 to inquire about a suggested Master thesis subject Göran answered the door and convinced me to take on a subject of his instead; 12 years later this has lead to a Doctoral thesis as well. Thanks Göran for a lot of support and considerable encouragement. I have learnt a lot from you. My co-supervisor Maria Enroth has meant a lot to me too. Previously as colleague and mentor at Innventia (formerly STFI-Packforsk and Framkom); teaching me about the environmental aspects of media and introducing me to inspiring practical work and research in collaboration with companies. The last year Maria also acted as my co-supervisor giving good advice, comments and support which I have very much appreciated. As Centre Directors, Charlie Gullström, Helene Wintzell and Mattias Höjer made this thesis possible by letting me dig further into the environmental aspects of media and communication within the framework of Centre for Sustainable Communications. Mattias, thanks also for valuable comments on draft papers and on the cover essay.

There are many colleagues who have inspired, supported and encouraged me during the years. I would like to thank all colleagues at fms, at Innventia and at Centre for Sustainable Communications (CESC), but also mention some in particular. Jessica, I much appreciated our collaboration at fms in Gamla Stan. I am very glad that you have also supported me during the writing of the cover essay of this thesis. Maria and Martin, I enjoyed our intense work, interesting discussions and other inspiring activities while working at Innventia. Clara, I really appreciate working with you; special thanks for 'graphical support'. Minna, thanks for inspiring collaboration introducing new perspectives and also for relevant comments on the cover essay. Also, thanks Bernhard for your assistance.

I would like to thank all the company representatives who have made the research possible; especially Dag at TeliaSonera, Jens at Ericsson and Malin at TU who much participated in the work underlying a large part of this thesis. I have learned a lot regarding environmental assessment and information and communication technology (ICT) from discussions with Dag and Jens both of whom have substantial knowledge and experience in the field. These experiences form part of the discussion section. Thanks Jens also for reviewing parts of the cover essay. In addition, I would like to thank all other co-authors of the Papers included in this thesis.

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# Preface

As a graduate student in systems ecology at Stockholm University I performed my Master thesis at fms (at that time a research group associated to Stockholm University and the Swedish Defence Research Agency). The Master thesis (Moberg 1999) formed a basis for Paper I of this thesis; a review of environmental systems analysis tools. Paper I was also included in my licentiate thesis (Moberg 2006) and some of the text regarding Paper I in this cover essay has its origin there. However, the other papers of the licentiate thesis (Finnveden et al. 2005; Moberg et al. 2005; Finnveden et al. 2003) are not included here, as I have since then changed focus from waste management to media and communication. Still, the assessment of environmental impacts remains as research area, starting to broaden now to cover also the assessment of social impacts.

The environmental performance of printed media became my work area as I got employed at Innventia in 2002 (formerly STFI-Packforsk and earlier Framkom). I was working with indicators, labelling, life cycle assessment, etc. related to products and companies mainly related to printed media, but also packaging. The scope was later broadened to also cover electronic media. Since I started working at the Division of Environmental Strategies Research at KTH Royal Institute of Technology most of the projects have been and still are within the framework of the Centre for Sustainable Communications (CESC). CESC is a Vinnova Centre of Excellence and its mission is “to enable innovative media and communication services for sustainable practices” (CESC 2009). The projects in which I am involved mainly concern development of methods for sustainability assessment and use of these within the field of media and communication. Much of my analytical work is based on project work and inspiring discussions at CESC with researchers of different backgrounds and representatives of partner organisations.

The research and PhD studies which this thesis is based on was partly funded by the Centre for Sustainable Communications, which is funded by Vinnova and Centre partners, among them Bonnier Group, Ericsson, Swedish Media Publishers' Association (TU) and TeliaSonera were actively involved in the research. In addition, the research was enabled through funding provided by Innventia, Itella Information, Mistra and the Swedish Environmental Protection Agency. All funding is gratefully acknowledged.

# List of papers

Paper I — Finnveden G. and Moberg Å. (2005). Environmental systems analysis methods - an overview. *Journal of Cleaner Production* 13:1165-1173.

Paper II — Moberg Å., Johansson M., Finnveden G. and Jonsson A. (2010). Printed and tablet e-paper newspaper from an environmental perspective- a screening life cycle assessment. *Environmental Impact Assessment Review* 30:3:177-191, doi:10.1016/j.eiar.2009.07.001.

Paper III — Borggren C., Moberg Å. and Finnveden G. Books from an environmental perspective - Part 1: Environmental impacts of paper books sold in traditional and internet bookshops. Submitted to *International Journal of Life Cycle Assessment*.

Paper IV — Moberg Å., Borggren C. and Finnveden G. Books from an environmental perspective - Part 2: e-books as an alternative to paper books. Submitted to *International Journal of Life Cycle Assessment*.

Paper V — Moberg Å., Borggren C., Finnveden G. and Tyskeng S. Environmental impacts of electronic invoicing. Accepted with minor revisions by *Progress in Industrial Ecology*.

Paper VI — Malmodin J, Moberg Å, Lundén D, Finnveden G. and Lövehagen N. Greenhouse gas emissions and operational electricity use in the ICT and entertainment & media sectors. Submitted to *Journal of Industrial Ecology*.

Paper VII — Benoit C., Norris G.A., Valdivia S., Ciroth A., Moberg Å., Bos U., Prakash S., Ugaya C. and Beck T. (2010). The Guidelines for Social Life Cycle Assessment of products: Just in time! *International Journal of Life Cycle Assessment*, DOI 10.1007/s11367-009-0147-8.

# Errata

In Paper II on p. 180

"Thus, in the base scenario the energy use of servers and data storage is not included in the internet energy use and the energy use is 3 Wh/MB (based on the higher figure in the span suggested by Taylor and Koomey (2008)."

should be

"Thus, in the base scenario the energy use of servers and data storage is not included in the internet energy use and the energy use is 3 Wh/MB (based on the lower figure in the span suggested by Taylor and Koomey (2008)."

# Abbreviations

| | |
|---|---|
| ADP | Abiotic depletion potential |
| AP | Acidification potential |
| CBA | Cost-Benefit Analysis |
| CESC | Centre for Sustainable Communications |
| CSR | Corporate Social Responsibility |
| DMC | Direct Material Consumption |
| DMI | Direct Material Input |
| DSLAM | Digital Subscriber Line Access Multiplexer |
| EF | Ecological Footprint |
| EIA | Environmental Impact Assessment |
| EMAS | Eco Management and Audit Scheme |
| EMS | Environmental Management System |
| EN | Energy Analysis |
| EP | Eutrophication potential |
| E&M | Entertainment and Media |
| FAEP | Freshwater aquatic ecotoxicity potential |
| GRI | Global Reporting Initiative |
| GWP | Global warming potential |
| HIA | Health Impact Assessment |
| HTP | Human toxicity potential |
| ICT | Information and Communication Technology |
| IOA | Input-Output Analysis |
| ISO | International Organization for Standardization |
| LCA | Life Cycle Assessment |
| LCC | Life Cycle Costing |
| LCIA | Life Cycle Impact Assessment |
| MAEP | Marine aquatic ecotoxicity potential |
| MFA | Material Flow Accounting |
| MIPS | Material Intensity Per Unit Service |
| ODP | Ozone depletion potential |
| POCP | Photochemical ozone creation potential |
| RA | Risk Assessment |
| S-LCA | Social Life Cycle Assessment |
| SEA | Strategic Environmental Assessment |
| SEEA | System of Economic and Environmental Accounts |
| SETAC | Society of Environmental Toxicology and Chemistry |
| SF | Social Footprint |
| SFA | Substance Flow Analysis |
| SIA | Social Impact Assessment |
| SocA | Social Accountability |
| TEP | Terrestrial ecotoxicity potential |
| TMR | Total Material Requirement |
| UNEP | United Nations Environment Programme |
| VCA | Value Chain Assessment |

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# 1 Introduction

## 1.1 Research background

Society and the private sector are increasingly acknowledging the aim of sustainable development. Different actors are showing an interest in contributing by decreasing negative environmental and social impacts and/or increasing positive impacts. However, in many cases it is not directly apparent how to contribute to sustainable development and justify the relevance of an activity. Learning more about environmental impacts has been facilitated by development and application of tools for environmental assessment although there are still many questions to address regarding the development of methodology, the performance of assessments and the use of outcomes (Finnveden et al. 2009; Owens et al. 2004). The interest in assessing environmental impacts has increasingly been followed by a demand for assessment methods and more information on negative and positive social impacts (Benoît and Mazijn 2009).

Rapid development is taking place within the field of media and communication, sometimes supported by arguments about new solutions contributing to sustainable development. In order to steer such development in the direction of sustainability, we need to learn more about the impacts of different products, processes, plans, policies and practices related to the information and communication technology (ICT) and media sectors.

## 1.2 Aims and delimitations of the thesis

The main aims of this thesis were to assess environmental impacts of media and communication and to contribute to the development of methods for sustainability assessment. In order to achieve these aims, life cycle assessments (LCAs) and a sector study were performed; methods for assessing environmental and social impacts were studied and analysed; and; possibilities and difficulties of assessing media and communication from a sustainability perspective were explored. The main objectives of the Papers included in the thesis were:

to characterise different methods for environmental assessment to better understand their relationships and the appropriateness of different tools in different situations;

to assess potential environmental impacts of a newspaper read on paper and on an e-reading device respectively;

to assess potential environmental impacts of a novel read on paper and on an e-reading device respectively;

to compare the printed and electronic versions of the newspaper and the novel respectively;

to assess the potential impacts on energy use and greenhouse gas emissions of a transition from paper invoices to electronic invoices;

to assess the respective greenhouse gas emissions of the ICT sector and media & entertainment sector;

to identify possible data gaps, major uncertainties or methodological development needs in the environmental assessments performed;

to present and discuss guidelines for social LCA developed within the UNEP/SETAC Life Cycle Initiative Project Group on integration of social impacts into LCA.

The focus of the thesis is on products (goods and services) and the emphasis is on environmental impacts. The social aspects have been approached from the environmental assessment field. The thesis does not attempt to use or develop methodology for a complete sustainability assessment, but addresses parts thereof. Media and communication is a large field. The main parts studied in this thesis were printed media and related electronic media. Content, distribution and end-consumer platform (such as paper, PC or e-reading device) are defining the media products studied. In addition, the ICT and media sectors were included in a sector study. In Papers II-V, the perspective is Swedish, and in Paper II also European. The discussion and conclusions in this thesis are intended to be broadly applicable for media and communication.

Other types of products could have been assessed as well as other objects related to the ICT and media sectors, such as policies, plans, projects or companies. There are also other perspectives that need to be addressed, e.g. testing the social LCA in practice. However, it was not possible to cover all angles of the overall aim in this thesis; some issues which are lacking are addressed in the section on Future research needs, 5.3.

## 1.3 Outline of the thesis

The thesis consists of this cover essay and the seven Papers appended. The cover essay serves the purpose of summarising the Papers and putting them into context. In Chapter 2 a background to the research is given. Tools for assessment of environmental and social impacts are shortly described and thereafter the field of media and communication is presented in an environmental perspective. Here some previous environmental assessments are presented and some methodological issues are noted. In Chapter 3 the research performed is put into a scientific context and the methods used are described. Some details on the aim and scope of the environmental assessments are presented as well. The results of the respective Papers are summarised in Chapter 4. In Chapter 5 the results of the Papers are analysed, discussed and related to other relevant research. Finally, Chapter 6 closes the thesis with a presentation of conclusions.

# 2 Background

## *2.1 Assessment of environmental and social impacts*

There are a large number of assessment methods and tools available to provide learning and decision support. Some of these focus on assessing sustainability or aspects of sustainability (in this thesis the terms tool and method are used synonymously). Examples include strategic environmental assessment, life cycle assessment and ecological footprinting, (see e.g. Pennington et al. 2004; Rebitzer et al. 2004; Partidario 1999; Wackernagel and Rees 1996). Tools are continually being developed. Some are used internally in organisations where decisions are to be made or where knowledge is requested for other purposes. Others are used by researchers or consultants providing the decision-makers and others with information.

In some cases the assessments are made within a decision-making process, with the aim of providing support. Decision-making occurs within a context (Nykvist and Nilsson 2009; Hilding-Rydevik and Bjarnadottír 2007; Wrisberg et al. 2002). This context may influence the practice and usability of assessment tools. Wrisberg et al. (2002) explore how context can influence the need for environmental information in business decision-making. They suggest that the need for more detailed, complex and integrated types of analyses increases as for example if more complex system changes are considered, if the decision-makers have high ambition for environmental improvement and high power in the supply chain, if decisions are more unique and with greater bearing on the public (Wrisberg et al. 2002, p 92). Wrisberg et al. (2002) acknowledge that the cultural context will ultimately influence the usability of deeper analyses and Tukker (2000) describes different value frames (precautionary, strict control and risk assessment) which will use environmental information differently and will have different needs regarding the level of detail and complexity. When the stakeholders have different value frames (Tukker (2000) takes the PVC debate as an example), the use of the information provided by environmental assessments to support decision-making in the different frames leads to different interpretations of the results. Hilding-Rydevik and Bjarnadottír (2007) emphasise the importance of context awareness when performing strategic environmental assessment (SEA), as the context defines the role of the SEA in each specific case and which type of contribution is expected.

However, as decision-making is often not entirely rational, even with the same value frames the outcome of the decision may not be directly affected by the decision support provided. Nevertheless, the process of performing the assessment may lead to various kinds of learning which can be an aim in itself (Owens et al. 2004).

Within the field of planning and policy-making, the benefits of environmental assessment have been questioned and different ideas on performance and use of assessments are proposed. Owens et al. (2004) review a number of different ideas. In business decision-making and in the field of product and company assessments, this discussion has not been as extensive and the reasons for performing environmental assessments may be different. Owens et al. (2004) argue for a strategy where deliberative approaches are combined with more technical approaches.

Environmental aspects have been of interest for some time regarding the assessment of sustainability, but a lack of tools covering social issues, especially product-related tools, has earlier been noted (Ness et al. 2007; Levett-Therivel 2004). The life cycle perspective is gaining acceptance for assessing the environmental impacts of products. The LCA methodology is continuing to undergo development (Finnveden et al. 2009) and there are international initiatives to support further development and use of the methodology (European Commission 2010; UNEP-SETAC 2010). According to Pennington et al. (2007), barriers to the broader implementation of LCA include the suspicion that experts conducting the assessments will influence the outcomes and that the end-consumers and businesses in a buyer's position are not fully aware of the benefits of life cycle thinking. Pennington et al. (2007) conclude that life cycle thinking is "moving from its academic origins and limited uses primarily inhouse in large companies to more powerful approaches that can efficiently support the provision of more sustainable goods and services through efficient use in product development, external communications, in support of customer choice, and in public debates".

Recent reports on child labour, impacts of mining, corruption, health issues from e-waste handling, etc. have given rise to an increasing awareness of negative social impacts and during recent years social aspects of sustainability have increasingly been raised and addressed. In the context of companies, corporate social responsibility (CSR) is now widely applied by businesses and organisations. There are a number of definitions of CSR, most of which include the notion of stakeholders, social issues, economic issues, environmental issues and voluntariness (Dahlsrud 2006). CSR work on social issues to date has mainly concentrated on social responsibility at the company, e.g. ensuring that working conditions are satisfactory and that employees are treated fairly, but the scope is broadening. There has been relatively limited discussion in the past on the definition of social sustainability and there are few scientific articles specifically dealing with social sustainability (Dempsey et al. 2009). According to Geibler et al. (2006) generally accepted standards of measurement for social performance of companies or products have been lacking, creating problems in handling social sustainability in practice. However, there are assessment or management methods that cover social aspects, including the global reporting initiative indicators for sustainability reporting (GRI 2007), social impact assessment in relation to projects, plans, programmes and policies (Vanclay 2002) and the SA 8000 standards for working rights at company level (SAI 2008). Guidelines for social responsibility of companies and organisations are under development within the International Organization for Standardization (ISO 2009).

Difficulties have been experienced when trying to promote the use of LCA in developing countries, partly due to the inability to address issues such as poverty eradication, employment opportunities, working conditions and human rights (UNEP-SETAC no year). The need for including social aspects into LCA gave rise to the task force on integrating social aspects into LCA within the UNEP-

SETAC Life Cycle Initiative (UNEP-SETAC no year), which has published guidelines for social life cycle assessment (Benoît and Mazijn 2009). Development in the field of social LCA is in progress (Jørgensen et al. 2010; Parent et al. 2010; Jørgensen et al. 2008).

With the many assessment methods available, there is a continuous need for sorting and characterisation in order to clarify differences and similarities and relate them to different decision contexts. Reviews of environmental and sustainability assessment methods have been presented by e.g. Jeswani et al. (2010), Gasparatos et al. (2008), Unger et al. (2008), Ness et al. (2007), EEA (2003), Wrisberg et al. (2002), Baumann and Cowell (1999), Moberg et al. (1999) and Petts (1999).

Although the use of assessment methods is intended to provide increased learning and possibly more informed decision-making, assessment methods are limited by uncertainties, some of them inherent (Finnveden 2000). By definition, the system assessed is a *model of* reality. Assumptions and simplifications are always made and these will influence the results to differing degrees. As methods are applied these limitations should be made transparent and the results interpreted with this in mind. Generally, when a group of products, a sector or a company is assessed several times using different approaches and methods, more is learned about the object and about the assumptions and simplifications that can influence the results. This knowledge, together with other results of specific assessments, can then indicate the key areas that need to be considered with care. The practical use of assessment methods should be carried out in parallel to development work aimed at making the methods as accurate as possible, and at the same time making them easy to use and providing possibilities for satisfactory interpretation of results.

## 2.2 Media and communication in an environmental perspective

There is a continuous process of change in the media field (Hvitfelt and Nygren 2005). There are economic, organisational and technical reasons for these changes (Hvitfelt and Nygren 2005; Picard 2005); the print media industry has for example split into printing industry and publishers (Vermeulin et al. 2006). The printed media and especially the daily newspapers have been considerably affected and in many cases damaged by electronic alternatives for news consumption, even though the effect in Sweden is still comparatively small. The challenge for media companies previously concentrating on printed media is to make electronic editions financially viable.

Media is a means of communication, and the term is commonly used in reference to for example radio, television, newspapers and magazines. All media involves, simply put, a process including senders, messages and receivers (Briggs and Cobley 2002, p. 1). The messages, i.e. the content, are distributed and consumed using different channels and platforms. *Content* may be news, information, entertainment, advertisement, etc. This content can be in the form of text, images, audio and/or moving images. To distribute the content it may be printed on paper or sent in the format chosen. *Distribution* is then performed physically by truck, railway, car, plane, etc., as radio waves, or to an increasing extent electronically via the internet or other networks. The *platforms* used for consuming the media content have typically been TVs, radios and paper, but now similar content may also be accessed on PCs, mobile phones and other electronic devices such as e-reading devices. In this thesis, where environmental impact is a key issue, the physical devices and networks used are an important aspect, as use of material and energy is crucial. In addition, a life cycle perspective is preferred here. In comparison Oittinen (2009) claims that media technology should be separated from the hardware and software it makes use of and that the media sector should be defined as content and value-adding operations. Lindqvist et al. (2003) consider the main components of the media sector to be print media, electronic media and recorded media, thus characterising based on means of distribution. How the media sector is defined and framed depends on the context and aim.

As a sector with immaterial products and services, the media sector has become a pioneer regarding use of ICT (Lindqvist et al. 2003) and content is today to a large extent digitalised. TV and radio were the major electronic media during the 20th century, but during recent years the electronic distribution of media content has increased and diversified. In statistics on the daily use of different media in Sweden (Nordicom-Sverige 2009a), it can be noted that the proportion of the population that uses 'old' media such as TV, radio and daily newspapers on an average day in Sweden has remained relatively stable during the last 30 years (1979-2008); the proportion watching TV has slightly increased, the proportion reading a daily newspaper has slightly decreased and the proportion listening to radio has fluctuated over the years. However, the proportion of people using the internet has drastically increased. In 2008, the average Swede spent 6 hours per day on media use (gross time), which has been similar for the last few years according to Nordicom-Sverige (2009a). TV and radio represented 25% each of the use time during 2008, internet 19% of the time and printed media 18% (Nordicom-Sverige 2009a). According to Nordicom-Sverige (2009b), daily newspapers are read on paper by 72% of the Swedish population and on the internet by 17%. The latter was only 6% in 2002, but the increase has slowed down since 2006. According to the same survey, younger people use the internet for social media, music and video (sound and moving images), whereas older people tend to use it for text and image, such as e-mail, information and daily newspapers. It can be noted that an interview study by Arjas-Kauranen and Sesito (2009, p. 142) concluded that ”those media that dominate time-wise were not necessarily emotionally the most important ones”.

The ICT sector and media sector are starting to overlap. What was previously understood as 'radio, TV, newspapers and magazines' is now starting to become less clear-cut as regards the content, distribution, platform or combinations thereof. The statistics, e.g. those presented above from Nordicom-Sverige (2009b), illustrate changes in the use of media such as TV, radio and daily newspapers compared with changes in the use of internet, where the internet can be used to watch TV, listen to radio or read the daily newspaper. As the companies providing TV and newspapers start using the internet channel, the definition and characterisation of different media will change and parts of the ICT sector is clearly involved in the media sector as well. For example, PCs are generally considered part of the ICT sector but are also becoming a major platform for accessing media content. The use of mobile phones is heading in a similar direction. The internet, which is regarded as part of the ICT sector today, is a major channel for distribution of media content.

The possibilities of ICT to contribute to sustainable development have been much discussed (Hilty et al. 2006; Berkhout and Hertin 2004; Plepys 2002). The media sector is one potential area where ICT could enable dematerialisation, but also for example increase access. Hilty et al. (2006) suggest that there is a high potential related to a product-to-service shift (virtual goods) as freight transport, waste and the energy used by the industrial sector can all be affected. In a global perspective, Kuhndt et al. (2006, p. 20), in their study related to the Millennium Development Goals, list factors that will to some extent determine the possibility of ICT to contribute to societal benefits. The factors listed are whether people have access to technology; are prepared to use the technology; the regular use patterns; and whether the application in a concrete context actually contributes to the relevant goal. Berkhout and Hertin (2004, p. 916) also believe that ICT offers opportunities for sustainable practices, but that "Economic, social, institutional and cognitive barriers are likely to prevent technical potentials for resource efficiency from being fully exploited". The risks of rebound effects have been pointed out (Hilty et al. 2006; Berkhout and Hertin 2004; Plepys 2002). There are a considerable amount of studies on a micro scale, assessing potential impacts related to specific products and companies. Some of those relating to printed and electronic media are presented below; there are also several studies regarding other ICT goods and services (e.g. see Scharnhorst 2006 for a review of LCAs in the field of telecommunication). Studies considering potential impacts on a macro scale are fewer, e.g. Hilty et al. (2006) present a future study performed for the European Union considering the potential of ICT. There are a number of more commercial reports considering the potential benefits of ICT as well. Even though global sector assessments only roughly indicate environmental impacts, these would be beneficial complements to the micro studies in order to get a broader perspective and review the consequences of increased total consumption and use.

Turning to product-level studies on printed and electronic media, products studied include news, scientific articles, scholarly books, telephone directories and mail (Enroth 2009; Toffel and Horvath 2004; Gard and Keoleian 2003; Kozak 2003; Reichart and Hischier 2003; Yagita et al. 2003; Zurkirch and Reichart 2000). There are also several studies focusing on printed media only (e.g. Nors et al. 2009; Larsen et al. 2009). Some of the comparative studies indicate a preference from an environmental perspective for electronic versions (Toffel and Horvath 2004; Kozak 2003) or printed versions (Enroth 2009), whereas others conclude that parameters such as frequency of use, size of content, electricity mix and the possible printing out of electronic content will influence the preference (Gard and Keoleian 2003; Reichart and Hischier 2003; Yagita et al. 2003; Zurkirch and Reichart 2000).

Some previous studies have examined energy and/or greenhouse gas emissions (Enroth 2009; Gard and Keoleian 2003; Yagita et al. 2003). Kozak (2003) performed an impact assessment for global warming, ozone depletion and acidification. Toffel and Horvath (2004) calculated energy and water use for the electronic newspaper and compared emissions of $CO_2$, $N_2O$ and $SO_2$ with the printed version. However, the toxicological impacts have not been considered in these studies, even though toxic materials are frequently used in the production of different components for electronic devices (Plepys 2002). In the studies by Reichart and Hischier (2003) and Zurkirch and Reichart (2000), the results are presented as weighted aggregates. Reichart and Hischier (2003) in one figure show the contribution to the total environmental impact of different impact categories weighted using Eco-indicator 99. For the electronic media extraction of fossil fuels and respiratory effects were the main contributors and for the printed media extraction of fossil fuels and carcinogenic effects (water) (Reichart and Hischier 2003).

Reichart and Hischier (2003) stress the lack of inventory data for electronic devices and data on energy use for internet and telephone networks. Toffel and Horvath (2004, p 2963) had no specific inventory data for the personal digital assistant with LCD screen that they assessed, but studied the available data on use of energy and water for "production of its memory chip, processor, display, and battery".

For the printed media, paper production has been shown to exert the main environmental impacts (Enroth 2009; Toffel and Horvath 2004; Kozak 2003; Reichart and Hischier 2003; Zurkirch and Reichart 2000). Other activities in the life cycle of printed media that have been shown to be important are partly dependent on the system boundaries of the studies. In two studies (Gard and Keoleian 2003; Kozak 2003), personal transportation, to the library and bookshop respectively, was included within the system boundaries and this was shown to be an important activity from an environmental perspective in this case. Different studies have resulted in varying results regarding the importance of the environmental impacts of the printing process. Larsen et al. (2009) in their LCA study of sheet-fed offset printing show that printing can contribute a large fraction of the total toxicological impacts from printed matter. In their study toxic emissions were thoroughly handled for printing and related processes, but less emphasis seem to be placed on handling all toxic emissions related to pulp and paper production.

New electronic devices are continually being developed, with new functions and new techniques. In some cases, such development may lead to improvements from an environmental perspective, as operational energy use is decreased or hazardous substances are no longer part of the product. In the studies mentioned above, the end-consumer devices (media platforms) studied were PCs, personal digital assistants and e-reading devices with LCD screens. Energy use during operation was one of the main contributors to the environmental impacts in these studies. New e-reading devices with displays using E Ink technology, electrophoretic displays, have reduced the energy use for operation considerably (Senarclens de Grancy 2008). The electronic paper displays using this technology are intended to share many of the qualities of paper, such as reading using reflective light, high resolution, 180° viewing angle and high contrast (Ihlström Eriksson et al. 2007; Moberg et al. 2007). The electronic paper display differs from traditional display technologies, such as LCD, OLED, CRT or plasma screens (Senarclens de Grancy 2008). Apart from the display itself, an e-reading device with such a display consists mostly of standard components, such as plastic housing, electronic components of different kinds and a rechargeable battery.

Environmental assessments of devices with e-ink displays include a German study that examined the cumulative energy demand for three editions of a newspaper (printed, on-line and e-reader) using a life cycle perspective (Kamburow 2004). A Canadian LCA covering printed newspaper and newspaper read on an e-reading device was presented by Trudel at a life cycle management conference in 2007 (Trudel 2007), but the study has not been published so far.

The distribution of electronic content, together with the differing platforms, is the main difference compared with the printed media. In many cases the internet is used as the distribution channel. Assessing the environmental impacts of distributing content via the internet is not straight-forward. There is not one single way in which data are transmitted from point A to point B. This is one reason why the energy use for a specific transmission of data cannot easily be calculated. In addition, the allocation of operational energy and manufacturing of components and cables is not easy. Resource use and emissions can be split between the various uses of the network based on the size of data transmitted, the use time or perhaps some valuation of the activity for which the data are transmitted (e.g. for company use the amount allocated could be doubled compared with home use). Estimates on the operation of networks (e.g. internet and telephone networks) are based on energy use of the system and the total use of that system (Toffel and Horvath 2004; Zurkirch and Reichart 2000) or the energy use of selected components of the internet (Reichart and Hischier 2003). The total use may be in units of time (hours) or size (MB). The internet energy use figures used in the studies have varied and so has the internet impacts on the results. Telephone networks and in some cases internet operation have been shown to be significant contributors to the overall environmental impact of electronic media (Kamburow 2004; Toffel and Horvath 2004; Hischier and Reichart 2003; Zurkirch and Reichart 2000). The results of Kozak (2003) and Gard and Keoloeian (2003) indicated that network operation was non-significant in relation to the overall impact, but in these studies the network was an internal university system. In the study by Trudel (2007) the distribution of newspapers to e-reading devices did not contribute to the greenhouse gas emissions of the studied systems, although it is not clear how the distribution was modelled.

As mentioned above, there have been environmental assessments of printed and electronic media, but there are still areas where knowledge is lacking. Earlier studies have clearly suffered from a lack of data and in general, not all impact categories are addressed. Differences in scope will clearly affect some outcomes and to date there have been no general conclusions regarding printed and electronic media. Social impact is another important issue related to media and communication in a sustainability perspective. The bad working conditions in raw material acquisition (Pöyhönen and Simola 2007), production of electronic devices (Chan et al. 2007) and disposal of e-waste (Kuper and Hojsik 2008) reported by NGOs underline the importance of considering the social impacts with a life cycle perspective when assessing the sustainability of media and communication products. Some studies have aimed to assess the potential social impacts of ICT products, but have only concentrated on parts of the life cycle (Manhart 2007; Manhart and Griesshammer 2006).

# 3 Methods

## 3.1 Scientific context

This thesis starts with environmental assessment and proceeds to touch upon the broader concept of sustainability assessment by considering assessment of social impacts. Many scientific disciplines can be involved in the field of sustainability assessment. Environmental assessment has a strong relationship to natural sciences, building on methods to assess impacts on ecological systems and in some cases on health. In addition, environmental assessment is closely related to technological science as defined by Hansson (2007). Characteristics of environmental assessments include that the focus of the study are *human-made objects* (policies, plans, products, etc.), which are often *functionally defined*, and that the assessments depend on *value-laden* concepts, thus sharing at least three of the characteristics of technological science as suggested by Hansson (2007). In addition, Hansson suggests that sufficiently good approximations will suit the purpose in technological science, which is indeed the case here too. In the same way, assessment of social sustainability can be related to technological science if the assessment is framed in a similar way; assessing functionally defined human-made objects and depending on value-laden concepts. However, assessing the impacts on social rather than ecological systems requires a social science perspective. A social science perspective can also contribute to the environmental assessment as the objects of study are most likely affected by social practices in some way. By involving natural, technological and social sciences the process is clearly multidisciplinary, with an ambition for interdisciplinarity.

Robinson (2008) describes issue-driven interdisciplinarity, which includes strong participation of non-academic parts and addresses real societal problems. Robinson (2008, p. 72) exemplifies this with the sustainability field, with "its inherently complex, multi-faceted and problem-based focus". Much of the research presented in this thesis was performed within the framework of the Centre for Sustainable Communications (CESC), with active participants from academia, industry and authorities. CESC research is based on the interests and needs of these participants. In this way the research aims to focus on areas where there are knowledge gaps and where there is a practical need for research. The aims of CESC and its research appear very much in line with the issue-driven interdisciplinarity presented by Robinson (2008). Difficulties experienced are also discussed by Robinson, including the need to define problems which can be formulated as research questions and at the same time be satisfactory for the non-academic partners, and the considerable need for time and resources to start and maintain good collaboration. Issue-driven interdisciplinarity as suggested by Robinson (2008) is problem-based, interactive and participatory, with a need for reflexivity, and builds on strong collaboration and partnership. Emphasising collaboration, interactivity and emergence at the same time as addressing a problem relevant to the participants leads to increased possibilities for learning, whether or not the final outcome will give direct effects. This is in line with the discussion by Owens et al. (2004) on the potential importance of learning from assessment processes.

The post-normal science perspective (Ravetz and Funtowicz 1999; Ravetz 1999) is applicable to this thesis as it emphasises the inherent occurrence of uncertainty and the influence of value-choices within science. The results of the environmental assessments presented in Papers II-V are largely dependent on the assumptions made (as tested in sensitivity analyses) and there are uncertainties and data gaps in some of the underlying data. However, these kinds of studies can still be justified as information may facilitate learning and more informed decisions. By making the post-normal science perspective clearer, the use of outcomes could be improved, as the user could consider the results in a more appropriate perspective. As Ravetz (1999, p. 649) notes "most problems in practice have more than one plausible answer, and many have no answer at all".

In this thesis, the role of science in decision-making is considered as mainly providing possibilities for increased learning, filling in knowledge gaps. The work process preceding Papers II-VII was aimed at collaboration, but in many cases only achieved this to a limited degree, mainly due to lack of resources and to being performed during the start-up phase of CESC. In some cases the company employees involved in the project found the work difficult to prioritise in relation to other tasks and it was not always easy to achieve a good balance between the academic research and the interests of participating companies and organisations in direct results.

## 3.2 Life cycle assessment (LCA)

LCA is a tool to assess the resources used and potential environmental impacts (inputs and outputs) throughout a product's life from raw material acquisition through production use and disposal (i.e. from cradle to grave) (Baumann and Tillman 2004). The term 'product' can include not only product systems but also service systems. The term *potential* environmental impacts is used to express the fact that actual impacts cannot be assessed. Neither the time and place where resources are extracted and emissions occur, nor the state of the environment at this place, are well defined within an LCA and thus the actual environmental impacts cannot be assessed (Baumann and Tillman 2004). Throughout the thesis, the word potential is not always explicitly stated when describing resulting environmental impacts, but it is potential rather than actual impacts that are meant also when "environmental impacts" or e.g. "acidification" are handled.

An ISO standard has been developed for LCA providing a framework, terminology and some methodological choices (ISO 2006a; b). The framework according to this ISO standard (Figure 1) consists of four iterative steps:

1. *Goal and scope definition*, where the goal of the study is defined, system boundaries are set and the functional unit is defined.
2. *Inventory analysis*, where all relevant inflows and outflows of the system are identified and quantified.
3. *Impact assessment*, aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts. Including
    a. selection of impact categories, indicators for the categories and models to quantify the contributions of the different inputs and emissions to the selected impact categories,

   b. *classification*, assignment of the inventory data to the impact categories, and
   c. *characterisation*, quantification of the contributions to the chosen impact categories.
4. *Interpretation*, where inputs from all three previous steps should be considered.

There are also some optional elements that may be included in an LCIA (life cycle impact assessment). Weighting may be included to convert and possibly aggregate indicator results across impact categories resulting in a single result. Normalisation is another optional element whereby the magnitudes of the impacts are related to reference values, e.g. total contribution to an impact category by a nation. (ISO 2006b)

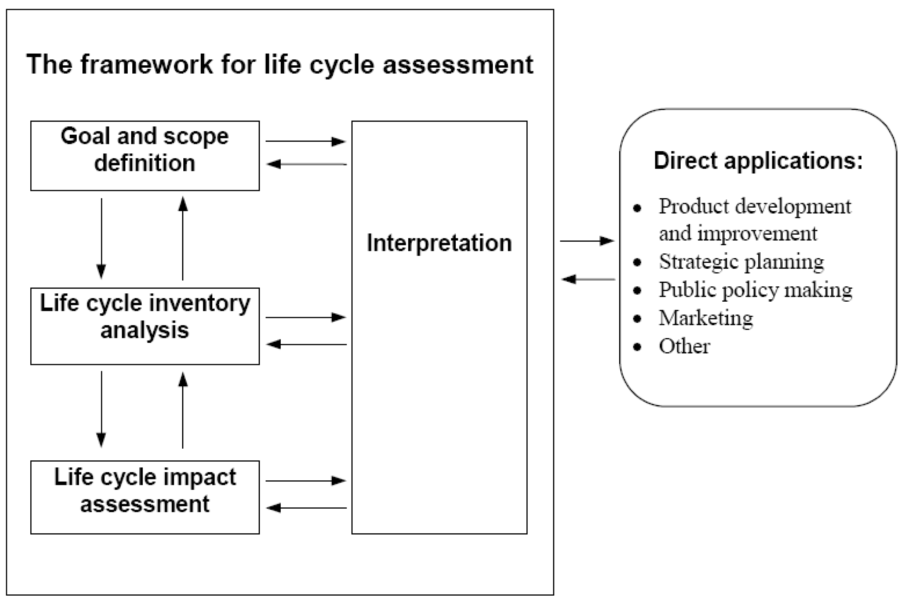


**Figure 1.** The phases of a life cycle assessment (based on ISO 2006a).

The goal and scope definition sets the context and framework for the study. The reasons for carrying out the study and the intended application are defined. The function of the product studied is described and the functional unit formulated. The exact formulation of this unit is especially important when the study is comparative, and two or more product systems are considered. The inputs, outputs and resulting impacts are related to the defined functional unit, thus providing the possibility for comparison. (Baumann and Tillman 2004)

There are two different types of LCA, attributional or accounting LCA and consequential or change-orientated LCA (Tillman 2000). In attributional LCA a system is described as it is, as it was or as it is assumed to become. In consequential LCAs, the consequences of a choice are modelled. These two types of LCA use different types of data (Tillman 2000; Ekvall and Weidema 2004). The attributional type of LCA uses data for all processes of the studied product life cycle system. Average data should be used, for example for the energy system. In consequential LCAs data reflecting processes affected by the changes should be used. This normally means some form of data referring to marginal changes, marginal data.

The setting of system boundaries is important for an LCA (Baumann and Tillman 2004). An LCA should cover all processes throughout the life cycle of a product and the system boundary should ideally be between nature and the technical system. The input should be resources, such as metal ores, and the output should be emissions to air, water or soil. When studying a defined system the boundaries within the technical system may sometimes be less clear. This can occur when there are several goods or services provided by the same process, e.g. the use of a PC for different purposes, or when there are several inputs to a process, e.g. the incineration of mixed waste. In these cases it may not be clear-cut how the inputs and outputs of the process should be allocated between the different goods or services provided. Such an allocation problem can be handled through partitioning or system expansion (Baumann and Tillman 2004). Partitioning means that the environmental impacts are split between the products provided. This could be based on e.g. physical causation, time of use or economic value. One example is that when a PC is used for several purposes, the environmental impacts of producing and treating the discarded PC can be partitioned between the different uses based on time of use. System expansion solves the problem by including all products provided within the studied system boundaries. As the functional unit should still be the same, the additional products then need to be 'eliminated' or added to the functional unit. Elimination is done by including the same products, but produced in an alternative way. It is then assumed that the alternatively produced products are 'avoided' and the related environmental impacts are subtracted. System expansion is recommended in the ISO standard (ISO 2006b). An example of system expansion is when waste newspapers are incinerated with energy recovery. In this case the studied newspaper product system will provide three functions, the newspaper as such and the production of heat and electricity from the incineration facility. This can be handled by expanding the studied system to include the avoided heat and electricity from other sources, subtracting the environmental impacts related to the relevant amount of energy avoided.

When data have been gathered in the inventory phase, the next step is the impact assessment. The inventory data are aggregated using different methods for characterisation of impacts into categories, such as climate change, eutrophication and acidification (Baumann and Tillman 2004). These methods provide possibilities to account for e.g. all emissions contributing to climate change in a common unit. The result of an impact assessment may be presented as such, describing results in terms of climate change as an amount of carbon dioxide equivalents, eutrophication as an amount of nitrogen dioxide equivalents, etc. Weighting is an optional step in the impact assessment phase and may be based on e.g. expert panels, monetarisation or so-called distance to target methods (Baumann and Tillman 2004). There is no consensus on how weighting should be performed and it naturally refers to value choices (Finnveden 1997). When making a decision, weighting is done more or less consciously. In most cases different alternatives are preferable from different viewpoints and thus some kind of value choice, weighting, is inevitable. The final step in an LCA is the interpretation where the results need to be reflected upon in the context provided by choices made during scoping, inventory and assessment of impacts, limitations perceived, etc. One of the main challenges of an LCA is to transparently communicate the results and their interpretation. An LCA can often be demanding regarding time and resources. An alternative approach can be to perform a screening LCA with the aim of identifying the most important aspects of the system under study. More detailed studies can be directed to these important aspects (Lindfors et al. 1995). Easily accessible data are often used in a screening LCA.

There are of course limitations to LCA. These limitations are related to the method as such and to how it is used. As a method for assessing environmental impacts of products using a life cycle perspective, it is delimited and associated with considerable uncertainties and complexity by definition.

Reap et al. (2008a; b) and Finnveden (2000) elaborate upon problems and limitations of LCA. Problems which may occur when performing an LCA include difficulties in the definition of the 'right' functional unit when making assumptions on use scenarios, setting system boundaries, deciding on allocation, finding relevant data and choosing impact categories and impact assessment methods (Reap et al. 2008 a; b). Furthermore, problems regarding the possibility to handle 'spatial variation and local environmental uniqueness' and time perspectives are discussed by Reap et al. (2008b). The choices made and data used may lead to different kinds of uncertainties (examples are given in Finnveden et al. 2009). The problems and limitations of LCA are in many cases due to the fact that complex systems are under study, and as Finnveden (2000) suggests, are inherent and common to all environmental systems analysis tools. Finnveden et al. (2009) suggest that the problem of uncertainty regarding methodological choices can be reduced as understanding of the connections between the aim of the study, questions posed and choices made increases and as consensus is built and best practices suggested.

The performance of sensitivity analyses or the use of different scenarios within a study as well as the performance of several studies of the 'same' product by different people can illustrate the possibility of differing results of assessments, as there can be several answers to a question (Ravetz 1999). Assessments have the potential of providing "a better basis for the decision-making process" (Finnveden 2000, p. 236).

Product-level assessment generally results in a micro scale perspective. However, as illustrated in Paper VI, micro scale assessments can be used in order to get a macro perspective. A macro scale perspective can be important in order not to sub-optimise by missing out on the wider consequences of e.g. increasing overall consumption.

Papers II-V are based on life cycle assessments (LCAs). Life cycle thinking was also used to some extent in Paper VI, while in Paper VII social LCA guidelines are presented. Details are presented for each Paper below.

## Attributional LCA

Environmental assessments can be made for different purposes. The screening LCA studies presented in Papers II, III and IV were performed in order to learn more about the potential differences between the environmental impacts of paper and electronic media. Screening, comparative, attributional LCAs were performed for a newspaper (Paper II) and a book, a novel, (Papers III and IV). Major assumptions had to be made, as in both cases the electronic versions were not in practical use on a relevant scale. These assumptions were tested in sensitivity analyses. The products studied were defined as 'general' newspaper and book products and did not represent specific existing products.

The functional unit in Paper II was 'the consumption of a newspaper during one year by one unique reader' and in Papers III and IV 'one specific book bought and read by one person'. In both studies the end-consumer/reader was assumed to be located in Sweden, while in the newspaper study a 'European reader' was studied as well. The book study covered a paper book sold in a traditional bookshop and in an internet bookshop, as well as an e-book.

The assessments performed were of a screening type. Data available in the databases provided in the LCA software were used for background processes and also for foreground processes when other data were not easily available. As general products were assessed, the inventory of data was to some extent complicated as the product system did not exist in reality and average process data were not available in many cases.

Here only the main processes of the respective life cycles are briefly described and more information on inventory data can be found in Moberg et al. (2007), Borggren and Moberg (2009) and Papers II-IV. The processes described here are those shown to contribute most to the environmental impacts; for the printed media pulp and paper production and for the electronic media production, and for some impact categories waste management of the e-reading devices. In addition the internet use is described as this is regarded an interesting part of the systems studied.

The data used for pulp and paper production for the newspaper were for a deinked pulp containing 45 g/m2 newsprint. The data were taken from Ecoinvent 1.2, as provided in GaBi version 4.112 (PE International no date) and are based on several European LCA studies performed 2000-2002. In the book study the inset and soft cover consisted of wood-free uncoated 80 g/m2 paper, the cover of wood-free coated paper and the hard cover of cardboard. The data used to model the impacts relating to these paper grades reflected average European values and were taken from Ecoinvent 2.0 (Frischknecht et al. 2007a) as provided in SimaPro 7.1.8. (PRé Consultants 2008). In the book study a sensitivity analysis was performed to consider the effect of using wood-containing paper instead, as books are mainly printed on uncoated wood-free or wood-containing paper (A. Linder, pers. comm. 2009). As there were no data available for wood-containing paper in the database, data concerning a specific paper from a Swedish mill were used. Information from the environmental product declaration (Holmen 2008) was complemented with information from the same source about transportation of supply material to the paper mill (R. Nilsson, pers. comm. 2009). Some data were lacking on production of the wood-containing paper (for example forestry was not included).

The electronic device used for reading the electronic versions of both the newspaper and the novel studied was an e-reading device with e-ink screen. However, the specific device used as a basis for the data inventory was not the same. Instead, one specific type of device per study was used as the basis for modelling production processes, use and waste management. In the newspaper study an iRex iLiad was used and in the book study a Sony PRS-505 device. For the latter a more detailed assessment was possible thanks to the new database on electronics provided in Ecoinvent 2.0 (Hischier et al. 2007). The Sony device was disassembled and the components were matched with the components available in the database, with the help of P. Dai Javad (pers. comm. 2009). In the study on newspapers, the data for the e-reading device were based on screening modelling of information provided by iRex Technologies (P. Leurs, pers. comm. 2006 and 2007). In this case the component mix for the printed wiring boards (PWBs) was estimated based on the configuration of a personal computer motherboard, and thus the production data were more uncertain in the newspaper study.

In both studies, information on production of the e-ink screen could not be obtained, resulting in a major data gap. The production process may be energy intensive and thus contribute to the overall environmental impact of the device. The waste management of the obsolete electronic devices is an area where data are lacking or uncertain. In Paper II there were no data on recycling of the device, the waste management modelled was only the fraction of the device that was assumed to be incinerated and thus there was a data gap for the recycling of material. Data on incineration of plastics from consumer electronics were taken from Ecoinvent 1.2. In Paper IV, both material recycling and incineration were modelled, based on information from S. Sjölin (pers. comm. 2009) and P. Dai Javad (pers. comm. 2009), using available data in Ecoinvent 2.0. However, 25% of the devices were assumed to never reach the waste management system. This fraction was not modelled at all in the study, giving neither negative nor positive impacts.

The electronic distribution of the newspaper studied is made via internet. The e-reader edition is published directly to the device using wireless LAN, not via a computer. The newspaper was 2.5 MB and was sent twice a day. In the book study the internet and a computer was used to buy and download an e-book (and to buy a paper book from an internet bookshop). The time spent on the website, including downloading the e-book was approximated to 8 minutes, and the amount of data transferred was approximated to 2.2 MB; the amount of data included information on the website (0.7 MB) and the actual e-book down-loaded (1.5 MB).

The inventory of data regarding the electronic distribution in both studies included energy use for operation of a modem (9 W), as well as energy demand for hubs, routers and switches of the internet infrastructure (based on Taylor and Koomey 2008). The estimates on internet energy use made by Taylor and Koomey (2008) reflect internet use in the U.S. during 2006 and suggest a span of

9–16 Wh/MB information sent, covering hubs, routers, switches, servers and data storage, but excluding end-use equipment (e.g. modem and PC or e-reading device). Energy use of servers and data storage are covered separately in the newspaper and book studies and thus the energy use of servers and data storage is not included in the figure used. In the newspaper study 3 Wh/MB is used (based on the lower figure in the span suggested by Taylor and Koomey 2008). In the book study this figure is halved to estimate 2008 values (J. Malmodin, pers. comm. 2009). Production of cables and carbon dioxide emissions related to construction work and dismantling were included in the book study (D. Lundén, pers. comm. 2009).

In the newspaper study the inclusion of energy use for servers and data storage was tested in a sensitivity analysis (using 16 Wh/MB) as the specific data already included was very uncertain.

Some major assumptions regarding the products and their use are presented in Table 1, while more details on these assumptions and references are given in Papers II, III and IV and the underlying reports (Moberg et al. 2007; Borggren and Moberg 2009).

**Table 1.** Assumptions in the base scenarios in the newspaper and book studies (Papers II, III and IV)

| Assumption regarding | Newspaper study | Book study |
|---|---|---|
| Printed media | | |
| Type of paper | Newsprint, 45 g/m$^2$ | Inset, woodfree uncoated paper, 80 g/m$^2$ |
| Number of readers of printed copy | 2.4 people/newspaper | 1 person/book |
| Number of pages | 40 pages/newspaper | 360 pages/book |
| Personal transportation | - (subscription) | 2 km by car/book |
| Electronic media | | |
| Size | 1.5 MB/e-book | 5 MB/day$^{(1)}$ |
| Life time of e-reader | 1 year | 2 year |
| Total use of e-reader | 365 hours/device | 17 000 pages/device |
| Specific use of e-reader | 30 minutes/ newspaper reader and day | 1 loading of battery/ book read |

(1) 2.5 MB/newspaper sent twice a day.

CML impact assessment methods (Guinée et al. 2002) and a method for cumulative energy demand (Frischknecht et al. 2007b) as provided in the GaBi and SimaPro software respectively were used for characterisation of the inventory results. For the global warming impact category the biotic carbon dioxide uptake and emissions were excluded. The newspaper results were weighted using Ecotax02 (Finnveden et al. 2006) and Eco-indicator 99 (Goedkoop and Spriensma 2000) weighting methods. Ecotax02 is a monetary weighting method using Swedish taxes and fees for monetarisation of the different impacts. There are two versions of Ecotax02 which are based consistently on minimum and maximum values of taxes and fees, which means that no weight is put on resources in the min version and that a lower weight than in the max version is used for photochemical ozone creation, fresh water aquatic ecotoxicity and marine aquatic ecotoxicity (Finnveden et al. 2006). Eco-indicator 99 is a panel method where experts were asked to weight environmental impacts in terms of human health, ecosystem quality and resources against each other.

Sensitivity analyses were performed to consider the robustness of the results of the LCAs performed and whether choice of data or assumptions made has a significant effect on the final results.

The sensitivity analyses presented in Papers II, III and IV concerned:

- Different paper type (Paper III)
- Alternative goods distribution (Paper III)
- Personal transportation (Paper III)
- Total use of electronic device (Paper IV)
- Life time of electronic device (Paper II)
- Energy intensity of the internet (Paper II)
- Total use of the printed media (Paper IV)

In the newspaper study in Paper II the sensitivity analyses mainly concerned the e-reader version of the newspaper. One reason for this was that the assumptions on the e-reader versions were more uncertain. In addition, Paper II covers a Swedish and a European scenario where electricity mixes, distribution distances and waste management options differ; all relevant to the printed newspaper. However, other sensitivity analyses would have been interesting as well but were not prioritised.

In the book study (Papers III and IV) we wanted to test different paper types as books may be printed on different paper and because the paper is in general a main reason for the total environmental impact of printed media. Alternative distribution was tested as the paper books ordered via the internet can be delivered by different modes of distribution and the distribution was a main difference between the studied systems. The personal transportation assumption as well as the assumption of total use of the electronic device were very uncertain and thus were tested. Finally, the effect of an additional reader of the paper book was illustrated as this, naturally, decreases the impacts per reading.

### Consequential LCA

The screening LCA study presented in Paper V was performed in order to learn more about the potential environmental consequences, positive and negative, of a hypothetical transition from all paper to all electronic invoices in Sweden. As the aim was expressed as assessing the consequences of a change, a consequential LCA was considered a relevant choice. The study is presented briefly here and more information can be found in Moberg et al. (2008) and Paper V.

The functional unit used illustrates the total amount of invoices in Sweden during one year, and is defined as: the distribution of 1.4 billion invoices, whereof 70% business to consumer (B-to-C) and 30% business to business (B-to-B).

Data available in the databases provided in the LCA software SimaPro 7.1.8 (PRé Consultants 2008) were used for background processes and also for foreground processes when other data were not easily available. Aiming for a consequential LCA the processes affected by a change were included, i.e. processes that are the same irrelevant of the change were excluded and system expansion was made to include processes outside the respective product system that are assumed to be affected by the change. Consequences may appear in the short or longer term. In this study, the aim was to consider consequences in the long term. This means that the possibilities for new investments and major changes were included. With a short-term perspective, the consequences are limited by investments already made and current conditions.

As the study covered invoicing in Sweden generally, it was not relevant to use specific data for transport distances, computer types used, invoice handling time at companies, etc. and information on average conditions was often not available. Information and data were in some cases obtained from specific companies or reports. These may not always illustrate the generic techniques and systems in Sweden and are not marginal data as ideally used in a consequential analysis. However, these data were regarded as sufficient for this screening study when ideal data were not readily available. Some major assumptions regarding the products and their use are presented in Table 2, while more details on these assumptions and references are given in Paper V and in the underlying report (Moberg et al. 2008).

**Table 2.** Assumptions in the base scenario in the invoice study (Paper V)

| Assumption regarding | Invoice study |
|---|---|
| Printed invoices | |
| Number of pages | 2 A4 pages/paper invoice |
| Type of paper | fine paper (wood-free uncoated), 80g/m$^2$ |
| Internet use, consumer | 10 sec extra internet use/paper invoice |
| Electronic invoices | |
| Size | 3.5 kB/electronic invoice |
| Local environments (software for converting format and e-archive) | 5.2 Wh/electronic invoice |

The consequences for internet use are increased use for sending electronic invoices business to business. For business to consumer invoices the internet use would decrease as more time is needed to pay paper invoices via internet. When this study was performed the study by Taylor and Koomey (2008) was not available, and thus the energy use of internet was estimated based on other information. For the B-to-B invoices the amount of data sent (3.5 kB/invoice) was used to estimate the extra energy needed, together with an estimation of 6 Wh/MB which was based on information provided by Malmodin (pers. comm. 2008). The latter figure was based on global estimates of energy use and data traffic and covers fixed network operation and transport network. The estimation is quite rough and gives an energy use of 0.02 Wh/invoice (Moberg et al. 2008).

For B-to-C invoices the extra internet time assumed to be needed, 10 sec. /paper invoice, was used to estimate the consequences for internet energy use together with estimations on energy demand per subscriber for modem, DSLAM (digital subscriber line access multiplexer), internet operator, transport and transmission. The extra internet energy use for B-to-C invoices was calculated to 0.45 Wh/paper invoice for the internet use and 0.35 Wh/paper invoice for the desktop computer use related to the internet use. In addition production of copper cables and carbon dioxide emissions related to construction work and dismantling were included (D. Lundén, pers. comm. 2009).Energy use of servers was not included in the figures for internet energy use, but was separately accounted for based on company specific, 5.2 Wh/electronic invoice (based on information provided by T. Wikström, pers.comm. 2008).

The marginal electricity was assumed to be a marginal mix for the Nordic electricity market over a longer time period. Two different marginal electricity mixes, based on Mattsson et al. (2003), were tested in different scenarios as suggested by Finnveden (2008). The two scenarios were based on different assumptions concerning the development of the energy market and represent extreme cases in terms of $CO_2$-emissions (Finnveden 2008). The scenario '$CO_2$cap' was based on the assumption that political decisions are effective, leading to a cap on $CO_2$ emissions and low emissions on the marginal electricity. The scenario 'High gas price' was based on the assumption that no policy measures beyond the Kyoto Protocol are introduced and that the gas prices on the market are relatively high. The electricity mixes were used in all cases where data were collected specifically for this study. When existing data from the Ecoinvent 2.0 database were used, the electricity was changed to the suggested mixes in cases where this was possible, and where major amounts of electricity were used.

The study was narrowed down to only cover energy use and greenhouse gas emissions. To assess the cumulative energy demand (CED), a method provided with Ecoinvent 2.0 (Frischknecht et al., 2007b) was used. This method assesses the total energy demand based on figures for the intrinsic values of the energy carriers and describing the amount of energy withdrawn from nature (primary energy). The CED is measured as TJ-equivalents. Greenhouse gas emissions are assessed using the method provided in the CML Baseline 2000 (as provided in the SimaPro software), which calculates the total carbon dioxide equivalents ($CO_2$-eq.) of the system studied. The method in SimaPro was modified for the study. The characterisation factors for $CO_2$ uptake by plants and the subsequent emissions of biogenic $CO_2$ were set to zero, i.e. uptake equals emissions in the long term.

The sensitivity analyses presented in Paper V concerned:

- Number of pages per paper invoice
- Type of postal distribution for B-to-B paper invoices (i.e. economy or first class mail)
- Transportation distances
- Extra internet time needed for B-to-C paper invoices
- Extra computer time for B-to-B invoices
- Printing of electronic invoices

The sensitivity analyses regarded amount of paper and printing of invoices, since paper is in general a main reason for printed media environmental impacts. Another main difference between the two options is the distribution and transportation and thus assumptions regarding these were tested. The assumptions regarding differences in computer and internet time for handling the invoices were uncertain and thus they were tested as well.

## *3.3 Additional methods*

### Literature review

In order to characterise different tools for environmental assessment and relate them to aspects of decision context in Paper I literature on different tools was reviewed. The first part of this work was done in a Master's thesis and a subsequent study (Moberg 1999; Moberg et al. 1999). Further literature studies were then made to obtain further knowledge. The tools covered in Paper I were chosen after discussions with a reference group with members from the Swedish Environmental Protection Agency and industries. Criteria for which tools to cover were to some extent assumed use frequency, but the aim was also to get a good mix of tools capturing different angles and values. Quantitative analytical tools and procedural tools were selected. Qualitative analytical tools were excluded. Comparisons of some qualitative tools can be found in e.g. Johansson et al. (2001) and Byggeth and Hochschorner (2005).

The tools all focus on environmental impacts and share the systems analysis perspective, so it is of interest to characterise the different tools in order to better understand their interrelationships and the appropriateness of different tools in different applications. There are many ways of characterising methods. Based on earlier studies (Moberg 1999; Moberg et al. 1999) we found that these following four aspects were useful:

- Procedural or analytical
- Types of impacts considered (resource use, environmental impacts, or environmental and economic impacts)
- Object of study (policies, plans, programmes or projects; regions or nations; organisations or companies; products; substances)
- Use in attributional or consequential studies

Originally these characteristics were part of a larger set used to characterise different tools by Moberg (1999). The basis for this larger set of characteristics was a framework presented in SETAC (1997) and further developed by Baumann and Cowell (1999). Other aspects and characteristics may also be used to structure the tools.

### Sector study

Sector studies provide information on a macro scale. This perspective complements information from e.g. product-related studies such as LCAs. Different approaches can be chosen for assessing the environmental impacts of a sector in a life cycle perspective, a top-down (e.g. Engström et al. 2007) or a bottom-up perspective (e.g. Seppälä et al. 2002). In the first the starting point is generally data on a national or international level, whereas the second aggregates product-level data to achieve information on a sector level. When defining sectors, a main issue is whether only the processes within the sector should be regarded or whether a life cycle perspective should be used, or something in between.

In the sector study presented in Paper VI, a bottom-up perspective was mainly used. The aim was to assess global operational electricity use and greenhouse gas emissions in the ICT sector and the entertainment and media (E&M) sector. This was done by considering the main product groups or processes giving rise to such operational electricity use and emissions.

The definitions used for the sectors studied in Paper VI were the following:

*ICT is defined as mobile and fixed telecommunication networks including broadband, data centres, data networks, and end-user equipment such as phones, PCs and modems.*

*E&M is represented by TV, TV peripherals, printed media and a range of consumer electronic products (hereafter referred to as other E&M hardware). TV peripherals include set-top boxes, DVD players, game consoles, VCRs and home theatre systems. Other E&M hardware includes audio devices, mp3/media players, digital cameras and camcorders, portable gaming devices, and also different computer HW peripherals.*

The entertainment and media sector is wide and distribution options are many. We did not cover live access to entertainment, content production or business overheads for music, theatre and sports, despite the fact that today such events are accessed using TV or PC solutions. The life cycle activities except for the disposal phase were covered for the greenhouse gas emissions. The operational electricity was assessed only for the operation of end-user equipment and operation of networks.

Greenhouse gas emissions were broadly covered as far as possible, although in some cases only $CO_2$ emissions were available and therefore used. The emissions from electricity generation, which constitutes a major part of total emissions, include all greenhouse gases. A global electricity mix was mainly applied for the use phase, but also in the manufacturing and distribution phases where possible and relevant. For production located in specific parts of the world, the electricity mix from that region was used. The greenhouse gas emissions of the global mix were estimated at 0.6 kg $CO_2$-eq/kWh.

Data related to specified products within the defined sectors were gathered from previous studies of products (different electronic devices and printed media) and in addition Ericsson performed a telecom operator investigation which provided information on the network operational electricity use as well as operators overall energy use for buildings, vehicle fleet and other activities. The operator survey results and manufacturing and deployment data for telecom network equipment were scaled up to global level based on number of subscribers (Eskilsen et al. 2009).

For the end-user devices total operational electricity and greenhouse gas emissions during use were based on average energy use and emissions per device and year, and number of devices used mid-year 2007 (installed base). Manufacturing was accounted for as emissions per device produced and total amount of devices sold in 2007. The scaling up was made based on number of subscribers, devices produced and devices in use when possible (e.g. Eskilsen et al. 2009) and in other cases e.g. the U.S. to world PC ratio (Eskilsen et al. 2009; Britton and McGonegal 2006) was used to scale up U.S. figures. Further information on assumptions and calculations made can be found in Paper VI. For printed media, the total amount of graphics paper produced globally in 2007 was used as a basis for calculations (Crèvecoeur 2009; CEPI 2008). Further, information from different earlier studies on environmental impacts of graphic paper production, printing and printed media were used to estimate global greenhouse gas emissions of printed media (for references see Paper VI). No operational electricity use was assumed for printed media.

### Meetings with experts

Within the UNEP-SETAC Life Cycle Initiative, a Project Group (formerly Task Force) is working on the integration of social aspects into LCA. The aims of the project group include suggesting a framework for inclusion of social aspects into LCA, determining implications for life cycle inventory analysis and impact assessment and providing an international forum for sharing experiences on social LCA. (UNEP-SETAC no year).

The Project Group has been working on a methodology for social LCA (S-LCA) since 2004 and the author of this thesis has taken part in the work since June 2006. The group is multidisciplinary with experts from universities, businesses, consultants and public authorities coming mostly from Europe, but also from North and South America, Asia and Africa. The group is chaired by Bernard Mazijn, Ghent University, Belgium. The activities performed in developing guidelines for S-LCA of products as presented in Paper VII can be described as meetings with experts. Since the start 12 meetings have taken place. The meetings provided possibilities for discussion; methodological issues were raised, inventory indicators were suggested and formulated and case studies were presented. Between the meetings literature reviews were made and draft documents prepared. International agreements, such as ILO Conventions and the UN Declarations of Rights, and other international initiatives on social responsibility were used as a basis, providing as general and trustworthy a set of social criteria as possible. (Benoît and Mazijn 2009)

Producing a common guideline for S-LCA has involved a lot of discussions and compromises. There are 22 authors to the guidelines for S-LCA published in 2009 (Benoît and Mazijn 2009). Draft guidelines were presented to stakeholders who gave feedback and thereafter an international peer review process was organized by UNEP and SETAC (Benoît and Mazijn 2009). The development of S-LCA is an ongoing process and the work in the Project Group, including writing the guidelines, has formed a part of this process which will continue.

# 4 Results

## 4.1 Environmental performance

### Characterisation of methods for environmental assessment

Paper I reviews some 15 methods, which are listed in Table 3 together with the acronyms used. The review provides basic knowledge on the characteristics of the methods, and in addition a comparison of the methods regarding selected relevant aspects. Linking methods and aspects of decision context, the object of study and the impacts of interest are suggested to mainly influence the choice of method, whereas other aspects are suggested to affect how the methods are used. In addition, aspects such as the actor, the complexity, the uncertainty, level of improvement, aspirations of the decision-maker and the cultural context are suggested to influence what is regarded as important questions. Such aspects will thus guide the decision-maker regarding the impacts that are relevant and how the object of the study should be defined.

**Table 3.** List of tools covered in Paper I and their acronyms

| | |
|---|---|
| CBA | Cost-Benefit Analysis |
| DMC | Direct Material Consumption |
| DMI | Direct Material Input |
| EF | Ecological Footprint |
| EIA | Environmental Impact Assessment |
| EMAS | Eco Management and Audit Scheme |
| EMS | Environmental Management System |
| EN | Energy Analysis |
| IOA | Input-Output Analysis |
| LCA | Life Cycle Assessment |
| LCC | Life Cycle Costing |
| MFA | Material Flow Accounting |
| MIPS | Material Intensity Per Unit Service |
| RA | Risk Assessment |
| SEA | Strategic Environmental Assessment |
| SEEA | System of Economic and Environmental Accounts |
| SFA | Substance Flow Analysis |
| TMR | Total Material Requirement |

The tools and their characteristics are illustrated in Figure 2, where objects of study and impacts considered by the respective tools were used to structure them.

Figure 2 shows, a spread of the tools, suggesting that the two chosen characteristics, object studied and impacts included, are suitable for describing and characterising different tools. Some of the tools focus on natural resources, either energy, materials or space, and can be used as assessment or evaluation methods for a wide range of objects. For tools that focus on both the use of natural resources and environmental impacts, it seems that for each object there is a tool that is the most suitable. For example, if the object under study is a project, EIA is the most suitable tool and cannot easily be replaced by other tools if the focus is on the use of natural resources and environmental impacts. However if the focus is on other impacts of the project, other tools would be more relevant, for example CBA or social impact assessment (SIA) (Vanclay 2002) (although social aspects were not covered in Paper I). This suggests that there is indeed a need for a large number of different assessment tools.

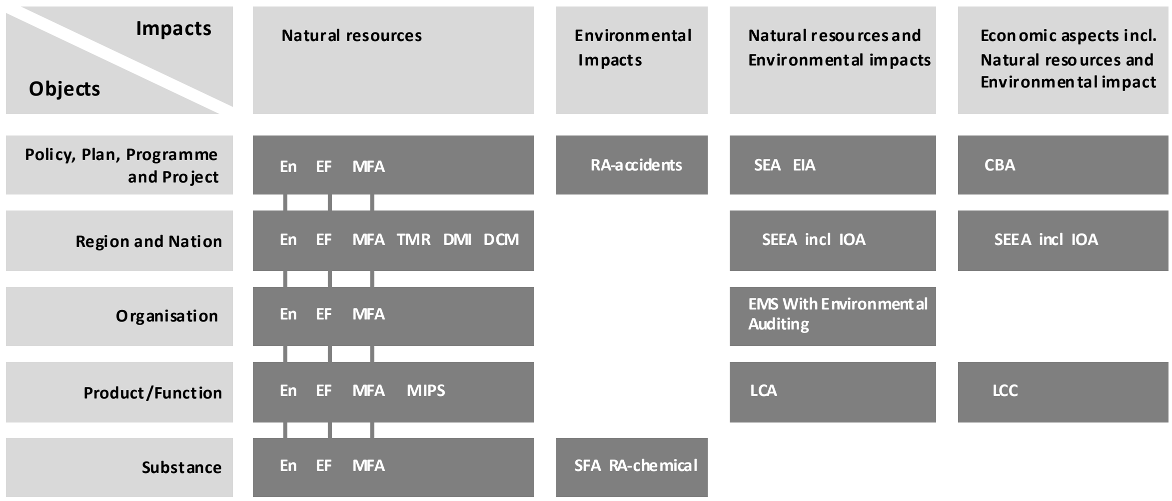


**Figure 2.** The tools shown in relation to their focus, i.e. the object of study and the impacts covered (explanations to abbreviations can be found in Table 3). Modified diagram from Paper I.

Figure 2 suggests that there are tools available for most objects discussed in Paper I. Different tools have been developed and used mainly for attributional purposes, describing a situation as it is, and others for consequential studies, considering the consequences of a choice. In, Figure 3 a tentative classification of tools as attributional and consequential is made in relation to how the tools have normally been applied. Within the LCA world it is now generally accepted that there may be a need for different sets of data and methodology depending on whether the tool is used for attributional or consequential studies (see e.g. Ekvall and Weidema 2004 for a discussion of consequential LCA). Figure 3 suggests that there may be some tools lacking when matching object of study and the attributional or consequential approach. When the focus is on nations and regions, some economic methods are available for consequential assessments, whereas other methods used within the systems of economic and environmental accounts (SEEA) are mainly used for accounting studies. For organisations and companies too, there seems to be a lack of methods for consequential studies, but for the goods or services supplied by organisations and companies consequential LCA may be used.

An apparent lack of tools could indicate a need for development of new tools, no need for such tools, or the tools not being covered in this assessment. There are a large number of tools and it was not possible to cover them all. Some are also less available for study as they are internally developed and used and not presented in scientific papers.

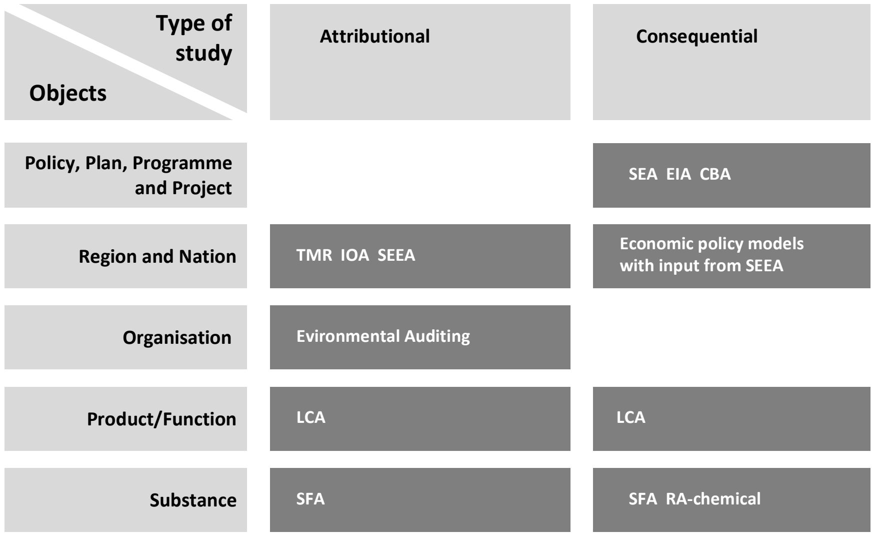


**Figure 3.** Approximate classification of some tools as attributional or consequential in relation to how they have been used and to what extent attributional or consequential data and methodology are used (explanations to acronyms can be found in Table 3. (Modified diagram from Paper I).

## Assessment of printed and electronic media

Papers II, III and IV are based on screening LCA studies. Some results are presented below and more can be found in Papers II, III and IV and underlying reports (Moberg et al. 2007; Borggren and Moberg 2009). As the systems studied have been expanded to include avoided processes some 'negative' results appear; these indicate avoided emissions or resource use.

In all three studies, the main environmental impacts of the printed media largely resulted from the production of pulp and paper (an example is shown in Figure 4 were the relative contribution of different life cycle stages to the impact categories are illustrated). Distribution related to the printed media was also a major part in some cases. In the study on newspapers (Paper II), the Swedish case was defined as demanding more transport work for delivering the newspapers and the results for potential greenhouse gas emissions showed that the paper in this case gave rise to 40% of the total and the distribution 30%. In the study of books (Papers III and IV), a sensitivity analysis showed that the personal transportation related to buying or picking up the book was crucial for the overall impact in that study. Driving a car 5 km to the bookshop and 5 km back only to buy the book studied would lead to more environmental impacts from the car trip than from the rest of the book life cycle activities, as modelled in the study. In the newspaper study, printing was for many impact categories the process second to the paper in giving rise to environmental impacts (Paper II).

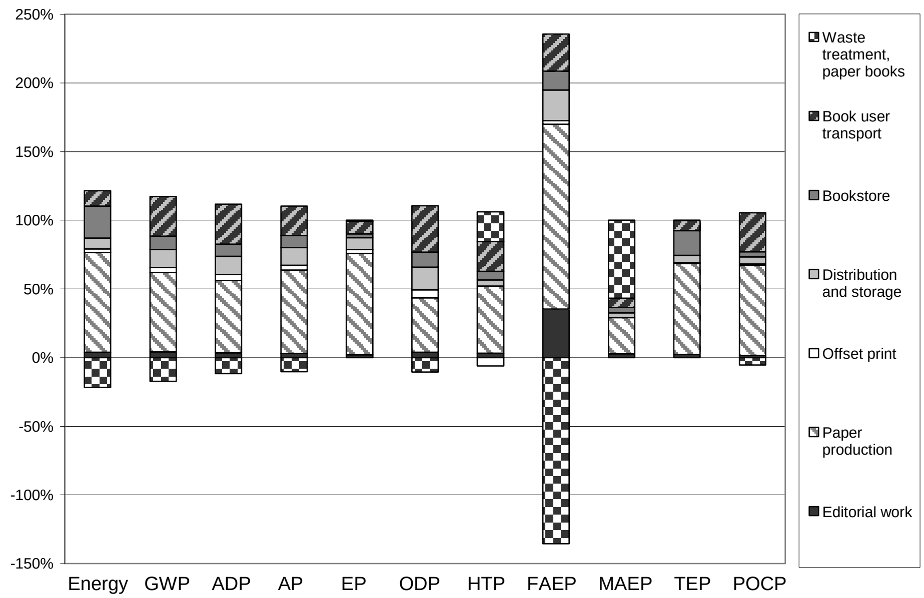


**Figure 4.** Relative contribution to different impact categories of the different life cycle stages of a paper book distributed via a traditional bookshop. It should be noted that the different size of the pillars are not illustrating a difference between them. This effect is due to that the 100% reflects the absolute value resulting for the respective impact category and when a life cycle stage contributes with a negative value, an avoided impact, this leads to a larger pillar as the summing the positive pillar minus the negative should be 100%. The impact categories are: Energy: Cumulative energy demand; GWP: Global warming potential; ADP: Abiotic depletion potential; AP: Acidification potential; EP: Eutrophication potential; POCP: Photochemical ozone creation potential; ODP: Ozone depletion potential; FAEP: Freshwater aquatic ecotoxicity potential; HTP: Human toxicity potential; MAEP: Marine aquatic ecotoxicity potential; and TEP: Terrestrial ecotoxicity potential. (Diagram from Paper III).

For the electronic media using e-reading devices as the platform in the use phase, the production and for some impact categories the waste management of the device influenced the environmental impacts the most (exemplified with the e-book results in Figure 5). As the e-reading devices studied use e-ink screens with low energy draw during use, this result was not surprising. However, it can be noted that in the newspaper study (electronic version of the newspaper in the European scenario), the activities editorial work, production of the e-reading device and incineration of parts of the waste e-reading device resulted in similar amounts of weighted impact using the Ecotax02 min. This could indicate the potential of increasing relative importance of the editorial work if major changes are suggested for distribution and consumption of newspapers.

In the newspaper study (Paper II), weighting methods were used and the results regarding the relationships between the processes within the life cycle of the newspaper read from an e-reading device were similar when using Ecotax02 max version and Eco-indicator 99, but differed considerably when weighted with the Ecotax02 min version. For the processes within the life cycle of the printed newspaper, paper production was weighted highest by all three methods, but thereafter the results differed (see Paper II). Using the different versions of Ecotax02 gave considerable differences in the absolute results; the difference was 100-fold.

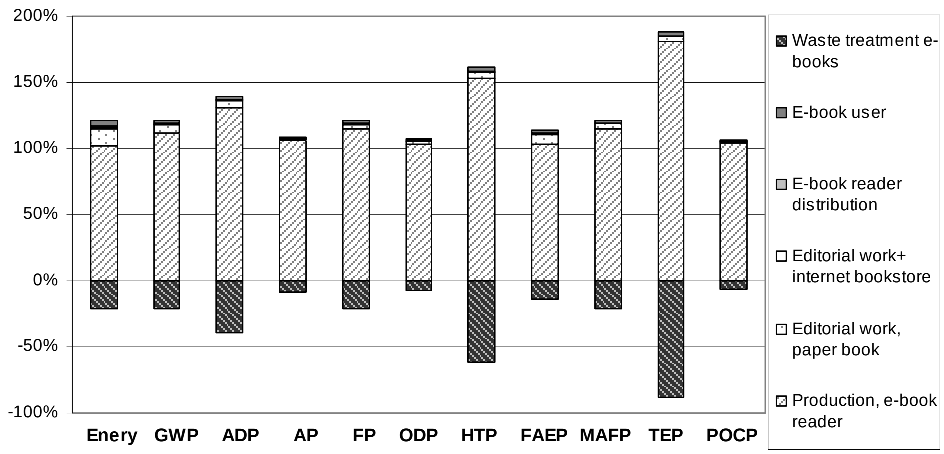


**Figure 5.** Relative contribution to different impact categories of the different life cycle stages of an e-book read on an e-reading device. It should be noted that the different size of the pillars are not illustrating a difference between them. This effect is due to that the 100% reflects the absolute value resulting for the respective impact category and when a life cycle stage contributes with a negative value, an avoided impact, this leads to a larger pillar as the summing the positive pillar minus the negative should be 100%. The impact category abbreviations are listed in Figure 6. (Diagram from Paper IV).

## Comparison of printed and electronic media

Comparing printed media to electronic media from an environmental perspective, the results of the screening LCA studies in Papers II, III and IV indicate that there are benefits and drawbacks for both.

One year of newspaper reading, as assessed in Paper II, resulted in higher environmental impacts for the printed version compared with reading the newspaper on an e-reading device. This was true for all impact categories studied in the European and the Swedish scenario, except for the marine ecotoxicity in the latter (Figure 6). The weighted results also indicated that reading the printed newspaper led to higher overall environmental impact, except in the Swedish scenario when the Ecotax02 max weighting method was applied. In this case the printed newspaper gave rise to 90% of the environmental impact related to reading the newspaper from the e-reading device during one year. In the Ecotax02 max weighted results, toxicological impacts were a major part. As can be seen in Figure 6, the magnitude of the differences varied between the impact categories, with larger differences for e.g. eutrophication and photochemical ozone depletion and smaller for e.g. acidification. Sensitivity analyses were performed regarding the life time of the e-reading device and the energy consumption in internet use. The results confirmed that increased life time of the e-reading device would lead to larger differences between the printed and electronic version of the newspaper studied and that the energy intensity of the internet network, including servers, and how this is allocated to the different uses can be important. Figure 7 and Figure 8 show that the high internet energy use assumed in the sensitivity analysis gave significantly smaller differences between the potential environmental impacts of the printed and electronic versions of the newspaper studied. For a few impact categories, the printed version resulted in a similar or lower level of impact.

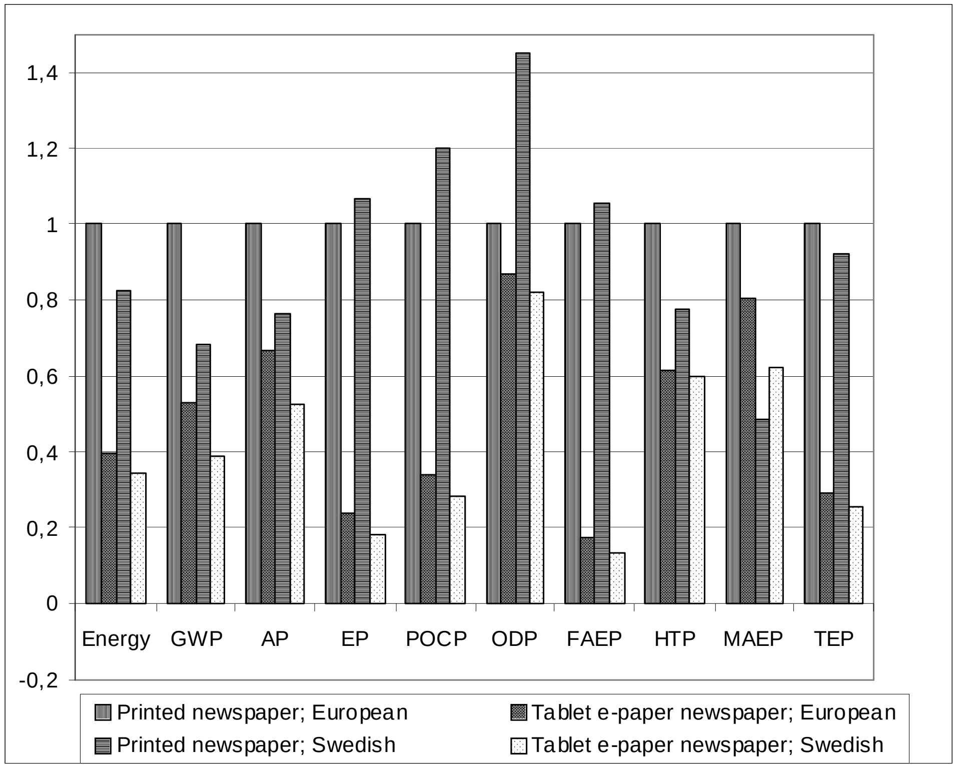


**Figure 6.** Comparison of the two different media (a printed newspaper and a newspaper read from an e-reading device) in a European and Swedish scenario. The environmental impacts of the printed newspaper in the European scenario are set to 1 and the environmental impacts of the other product systems are illustrated in relation to that. Impact category abbreviations are listed in Figure 4. (Diagram from Paper II).

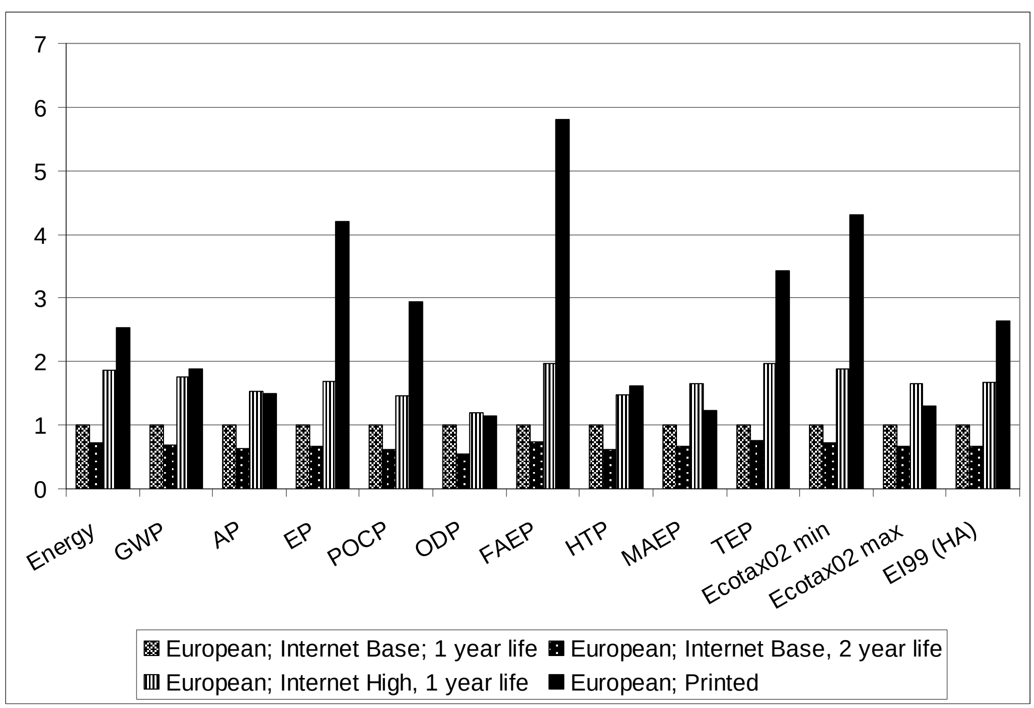


**Figure 7.** Sensitivity analysis concerning life time of the e-reading device and energy demand of internet use in the European scenario. The resulting figures for the newspaper read on an e-reading device in the base scenario are set to 1. (Diagram modified from Figure 22 in Paper II).

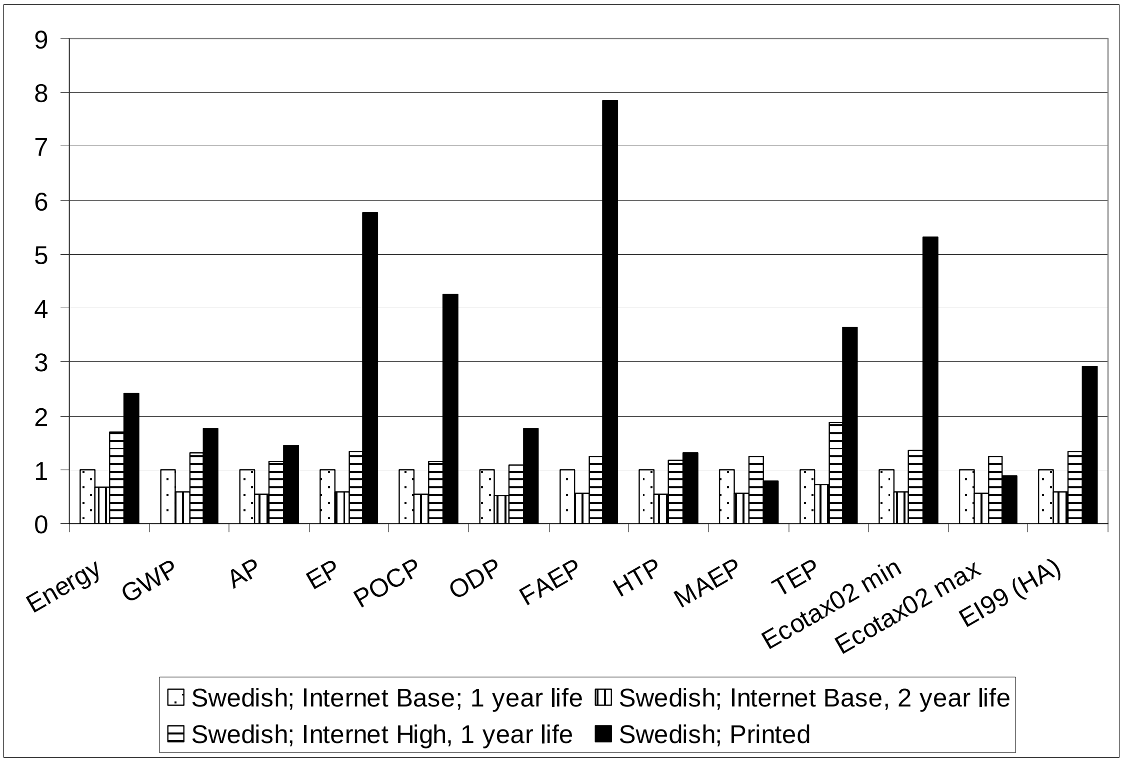


**Figure 8.** Sensitivity analysis concerning life time of the e-reading device and energy demand of internet use in the Swedish scenario. The resulting figures for the newspaper read on an e-reading device in the base scenario are set to 1. (Diagram modified from Figure 23 in Paper II).

In the comparison of a literary hardback and an e-book read from an e-reading device the results, based on the assumptions made, indicated that the e-book was preferable to the hardback paper book in terms of energy, abiotic resources used, global warming, eutrophication, human toxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity (Figure 9). However, the paper book was preferable in terms of acidification, ozone depletion, freshwater aquatic ecotoxicity and photochemical ozone creation (Figure 9). The results were sensitive to variations in assumptions on the total use of the e-reading device and the number of readers per hardback book.

In addition, different distribution options and personal transportation influenced the resulting potential impacts of the printed book. Not surprisingly, the change of assumption from driving a car to the traditional bookshop or the pick-up place (in the case of buying the paper books via an internet bookshop) to walking decreased the total potential greenhouse gas emissions related to the paper book. However, the choice of distribution from the internet bookshop to the door by public mail resulted in a similar decrease in emissions in the study.

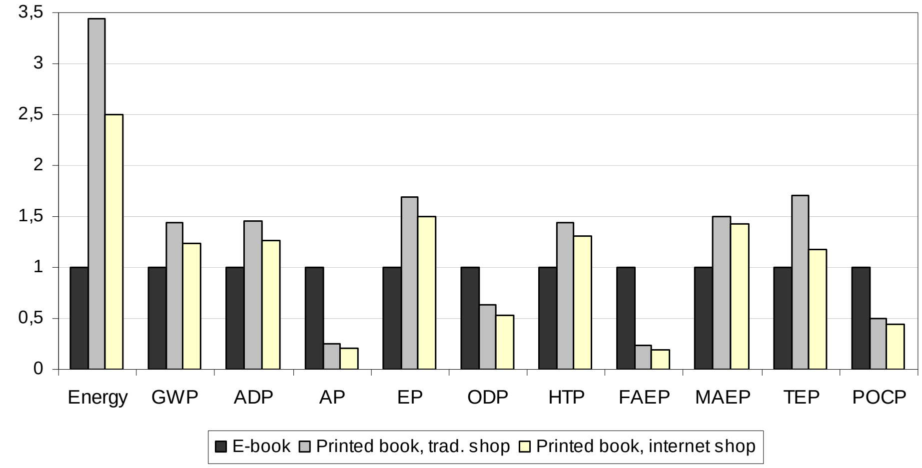


**Figure 9.** Comparison of an e-book and a paper book distributed via a traditional bookshop and internet bookshop respectively. The environmental impacts of the e-book are set to 1 and the environmental impacts of other product systems are illustrated in relation to that. Impact category abbreviations are listed in Figure 4. (Modified diagram from Paper IV).

## Assessment of a transition from printed to electronic invoices

In Paper V a consequential LCA was performed considering the potential environmental impacts arising from a hypothetical total change from all paper invoices to all electronic invoices in Sweden. Thus, the results of this study were not absolute figures of the potential environmental impacts of the printed and electronic media systems respectively, but illustrate potential consequences of a change. Negative values describe a benefit, primary energy use or greenhouse gas emissions avoided.

The results of Paper V indicate the potential benefit regarding cumulative energy demand and greenhouse gas emission of a hypothetical total change from all paper invoices to all electronic in Sweden. In this case too, pulp and paper production was the main reason. The study base scenario resulted in potential savings regarding cumulative energy demand of 1 400 TJ-eq./year and between 39 000 and 41 000 tonnes of $CO_2$-eq./year depending on the electricity mix assumed. According to the results of the sensitivity analyses made, the benefit remained independent of the changes in assumptions made, but the magnitude differed. The largest difference in resulting benefit occurred when assumptions regarding the amount of paper used for the paper invoices and printing of electronic invoices were changed. This is illustrated for greenhouse gas emissions in Figure 10 for the two base scenarios.

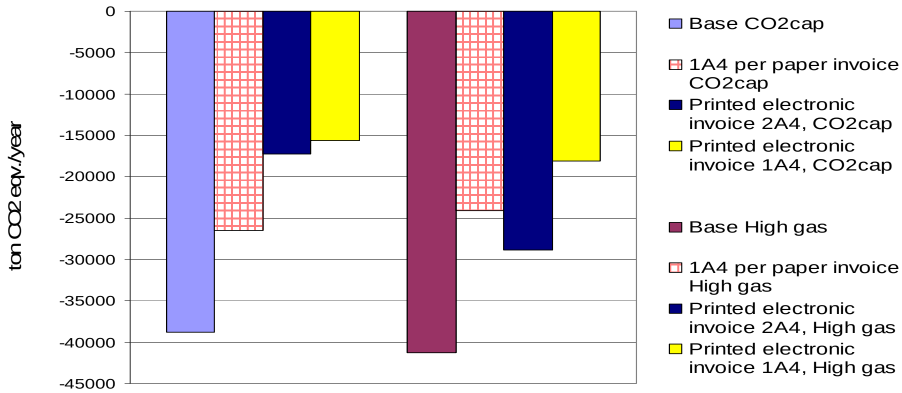


**Figure 10.** Potential consequences of a change to electronic invoices in Sweden. Results of sensitivity analyses considering variations in paper use and printing of electronic invoices. The base scenario is compared with a case where paper invoices consist of one A4 sheet, a second case where electronic invoices are printed on two A4 sheets and a third case where paper invoices consist of one A4 sheet and electronic invoices are printed on one A4 sheet. (Diagram from Paper V).

## Assessment of the ICT sector and the E&M sector

Considering the impacts of the ICT sector and the entertainment and media (E&M) sector globally adds another perspective to the environmental performance related to media and communication solutions. In Paper VI, the ICT sector was estimated to contribute 630 Mton $CO_2$-eq. during 2007 and the operational electricity used was estimated at 710 TWh. The contribution of PCs was 40% and telecom 30%. Data networks, centres and transports contributed the remaining 30%. For PCs the operation phase was responsible for 60% of the greenhouse gas emissions, while for telecom the operation phase of networks contributed 50% of the emissions (Figure 11).

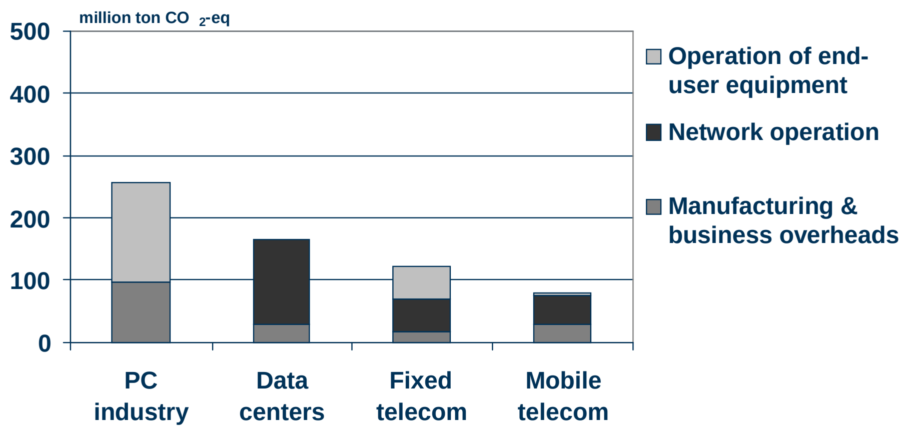


**Figure 11.** Greenhouse gas emissions for the different ICT subsectors in 2007. Data centres also include data and transport networks. (Diagram from Paper VI).

The E&M sector was estimated to give rise to emissions of 820 Mton $CO_2$-eq during 2007 and the operational electricity used was estimated to 580 TWh. The TV and related peripherals contributed 50% of the greenhouse gases, the printed media 40% and other hardware 20% (Figure 12). TV operation was the main reason for the emissions from TVs.

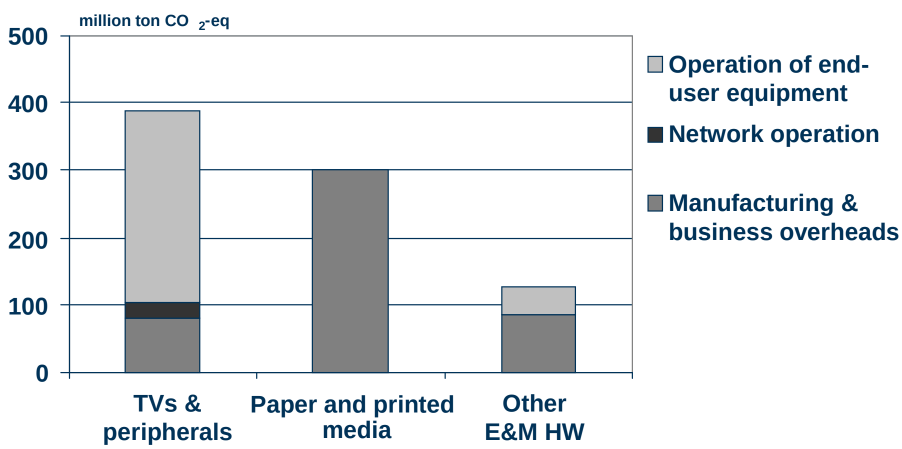


**Figure 12.** Greenhouse gas emissions for the different entertainment and media sub-sectors in 2007. (Diagram from Paper VI).

Overall, Paper VI estimated that the ICT and media sectors contributed to roughly 1.4% and 1.7%, respectively, of global greenhouse gas emissions in 2007. Overall, manufacturing and operation of end-user products were the main reasons for the emissions. For the ICT sector the network operation and data centres were at the same level as operation of PCs globally. For PCs and TVs, operation gave rise to more GHG emissions than manufacturing. The opposite was true for mobile phones, laptops, other E&M hardware and, of course, printed media.

## 4.2 Towards social LCA

One of the outcomes of the UNEP-SETAC Life Cycle Initiative Project Group on integration of social impacts in LCA was Paper VII, where guidelines for social life cycle assessment (S-LCA) are described. The guidelines are also presented in a longer report edited by Benoît and Mazijn (2009). S-LCA is suggested to be used for learning, informing choices, and supporting improvement of social conditions throughout the life cycle of a product.

In many ways S-LCA is similar to environmental LCA (in this thesis generally called LCA, but also E-LCA). The aim is to use the ISO 14040 standard (ISO 2006a; b) as a basis for the S-LCA method. The framework suggested for S-LCA is thus similar to E-LCA (see phases in Figure 1). Within the phases there are some differences that need to be handled. The goal and scope phase consists of similar activities as E-LCA, with some additions; e.g. specification of the stakeholders that should be addressed and the activity variable to use. The activity variable is used to provide a first indication of the important processes in the studied systems and is also a means of relating attributes or other information to the unit of process, which is then related to the defined functional unit. Activity variables could typically be worker hours or value added.

In the inventory phase, the information and data to be gathered may to a larger degree be qualitative in S-LCA and in many cases attributes or characteristics of companies or processes could be assessed throughout the life cycle. In addition, the information and data may not be linked to the production processes to the same degree as physical flows of resources and emissions often are. Social data can be more related to the company management and relations with different stakeholders, as well as regional or political conditions setting the framework. In S-LCA the data collection includes opinions and experiences of employees and other stakeholders. In contrast to environmental LCA, positive impacts may be considered to a larger extent in S-LCA. The inventory of data is to be based on a set of inventory indicators suggested for each subcategory of impact. The subcategories are defined in relation to a specified stakeholder group. This means that e.g. inventory indicators for health and safety are to be used both for the stakeholder group worker and consumer. Information gathered for the subcategories can be further aggregated into impact categories. There is no recommended set of impact categories, but it could typically include human rights, work conditions, cultural heritage, etc.

**Table 4.** Stakeholder categories and subcategories suggested for S-LCA

| Stakeholder | Subcategory |
|---|---|
| Worker | Freedom of association and collective bargaining<br>Child labour<br>Fair salary<br>Working hours<br>Forced labour<br>Equal opportunities/discrimination<br>Health and safety<br>Social benefits/social security |
| Consumer | Health and safety<br>Feedback mechanism<br>Consumer privacy<br>Transparency<br>End of life responsibility |
| Local community | Access to material resources<br>Access to immaterial resources<br>Delocalisation and migration<br>Cultural heritage<br>Safe and healthy living conditions<br>Respect of indigenous rights<br>Community engagement<br>Local employment<br>Secure living conditions |
| Society | Public commitments to sustainability issues<br>Contribution to economic development<br>Prevention and mitigation of armed conflicts<br>Technology development<br>Corruption |
| Value chain actors<br>(not including consumers) | Fair competition<br>Promoting social responsibility<br>Supplier relationships<br>Respect of intellectual property rights |

Both environmental LCA and S-LCA impacts may be dependent on location. Site-dependent, or stakeholder-dependent, impact assessment will in many cases be useful in S-LCA, as the context may influence the impacts to a large extent. For example, employment opportunities and provision of education may be much more crucial in one country or area than another and the impacts will be more significant for certain groups of stakeholders. This is similar to environmental LCA, where the difficulties with site-specific impacts are handled through the assessment of 'potential' environmental impacts and by the development of site-dependent impact assessment methods (Finnveden et al. 2009; Pennington et al. 2004). The impact assessment in S-LCA is a field where there is considerable need for further research and testing of methods.

# 5 Discussion

## 5.1 *Environmental assessment of media and communication*

### Analysis of assessments results

In line with previous studies on printed media, Papers II and III give results indicating that pulp and paper production are main reasons for the environmental impacts. Distribution and personal transportation related to the delivery of the printed media to the end-consumer/home may also be significant (Gard and Keoleian 2003; Kozak 2003; Papers II and III). Weber et al. (2009) report similar importance of personal transportation for delivering music on disc. Thus, apart from the environmental impacts of the industrial processes, use of buildings, personal transportation and distribution may be important activities when assessing the environmental performance of printed media. Another general reflection is that the environmental impacts related to each unit of benefit provided by the printed media, e.g. 'one person reading a book' or 'yearly news consumption by one person', decreases considerably if people share their books, newspapers, magazines, etc. This practice may not be as desirable for the graphic media industry.

The results of the attributional LCA studies can to some extent, as above, be qualitatively applied more broadly to printed media, even though it is hard to generalise as many parameters are very specific for each case (e.g. number of pages, type of paper, type of printing and users' practices). As different studies have different scopes including different system boundaries and functional units, they are not easily compared. In order to try to make use of earlier efforts and experiences, some reflections are made while trying to frame some different studies of printed media in a comparative way. Emissions of greenhouse gases are in Table 5 presented related to the weight of the printed media rather than the varying functional units used in the respective studies. In this way the differences in amount of paper used (paper weight and number and size of pages) and numbers of users are omitted. Greenhouse gas emissions were chosen as this parameter is included in most studies. As seen in Table 5 the greenhouse gas emissions for the respective printed product accounted for as kg printed product ranged from 0.5 kg $CO_2$ to 9.5 kg $CO_2$eq. per kg printed media among the studies and scenarios listed. The difference can be explained by different factors. One is the geographical scope, with Scandinavia, especially Norway and Sweden, having electricity mixes that give rise to lower greenhouse gas emissions per MWh produced than that in the US. This would influence both pulp and paper production and the printing process. Furthermore, different printing processes may be more or less energy demanding. In addition, some studies use life cycle data on pulp and paper production including e.g. forestry and transportation (e.g. Larsen et al. 2009; Nors et al. 2009; Toffel and Horvath 2004; Kozak 2003; Reichart and Hischier 2003; Papers II and III), whereas at least one use data that only consider the emissions and energy use of pulp and paper production (e.g. Enroth 2009). Other potential reasons for the differences seen are whether personal transportation is included and the estimated environmental impacts of storage. It can be noted that the magnitude of the emissions more than doubled when energy use for 'building infrastructure' and library administration activities related to the journals were added in the study by Gard and Keoleian (2003). Those authors had a scenario adding personal transportation to and from the library which added more than 80 times the primary energy use resulting from the other activities of the system assessed, with the assumption of 10 readers per article. However, as it was not clear how to estimate the relevant amount of greenhouse gas emissions corresponding to the transportation primary energy use as assessed by Gard and Keoleian (2003), this scenario was not included in Table 5. Nors et al. (2009) emphasise the importance of the disposal phase when calculating carbon footprints and their study illustrates the different outcomes depending on the modelling of methane emissions from landfilling of paper products.

**Table 5.** Greenhouse gas emissions related to the weight of the printed products assessed in different studies under some different assumptions

| **Product** | **Reference** | **Emissions** (kg $CO_2$eq/ kg printed product) | **Life cycle phases considered** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Paper | Print | Distr | Pers trspt | Shop /Lib(1) | Waste mgmt |
| Scholarly books, Norway (2) | Enroth 2009 | **0.5** | | Low energy | | | | |
| Scholarly books, Norway (2) | Enroth 2009 | **0.7** | | High energy | | | | |
| Daily newspaper, Finland | Nors et al. 2009 | **0.8** | | | | | | |
| Daily newspaper, Finland | Nors et al. 2009 | **0.9** | | | | | | |
| Weekly magazine, Finland | Nors et al. 2009 | **1** | | | | | | |
| Weekly magazine, Finland | Nors et al. 2009 | **1** | | | | | | |
| Printed comm., Denmark | Larsen et al. 2009 | **1** | | | | | | |
| Daily newspaper, Sweden | Paper II | **1.5** | | | | | | |
| Daily newspaper, U.S. | Toffel and Horvath 2004 | **2** | 100% recycl | | | | | |
| Literary hardback, Sweden | Paper III | **2** | | | | 2 km/ book | | |
| Daily newspaper, Europe | Paper II | **2** | | | | | | |
| Journal article (Scholarly), U.S (3) | Gard and Keoleian 2003 | **3** | | | | | | |
| Daily newspaper, U.S. | Toffel and Horvath 2004 | **3** | 50% recycl | | | | | |
| Daily newspaper, Japan(4) | Yagita et al. 2003 | **4** | | | | | | |
| Literary hardback, Sweden | Paper III | **4** | | | | 10km/ book | | |
| Scholarly books, U.S. | Kozak 2003 | **6** | | | | | | |
| Journal article (scholarly), U.S.(3) | Gard and Keoleian 2003 | **9.5** | | | | | | |

(1) Greenhouse gas emissions related to bookshop and library.
(2) Only carbon dioxide emissions.
(3) Calculations made for this table, based on results presented as primary energy by Gard and Keoleian. The factor 0.3 was used to calculate primary energy to grid energy (reversing the calculation performed in Gard and Keoleian 2003), and the factor 0.6 kg $CO_2$eq./kWh was used for all energy. The weight of the printed product was calculated for this table based on my own assumption of 80 g/m² paper weight.
(4) The weight of the printed product was calculated for this table based on my own assumption of page size (40x28 cm) and paper weight (45 g/m²).

Based on the above-mentioned differences in scope of the studies listed in Table 5, the differences in greenhouse gas emissions per kg printed media seem reasonable. Potential differences in other impact categories could be due to similar reasons but also, perhaps to a larger degree, on different data availability e.g. which emissions that are accounted for.

Papers II, and IV studied electronic media accessed and read from an energy-efficient device and it is clear that the manufacturing and for some impact categories also the waste management of the device mainly influenced the environmental impacts; waste management having the potential to reduce environmental impact through recycling. Energy efficiency and usability need to be balanced. A very energy-efficient device still needs to provide enough usability to result in low environmental impacts per unit of benefit. The total use of a device will also be related to its life time.

Concerning the comparison of printed and electronic media, the results of the screening LCAs performed and presented in Papers II-IV indicate that in some cases printed media may be preferable and in some cases electronic. Assumptions regarding users' practices are crucial for the outcome. The study on newspapers (Paper II) indicates that there is potential for the e-reading device studied to decrease the environmental impacts of newspapers. The study was based on a newspaper with 40 pages and 2.4 readers per copy. If there were more pages and/or fewer readers, the newspaper read from the e-reading device in the study would have been more clearly preferable. However, there are limitations to the study and there are large uncertainties regarding the production and disposal data for the e-reading device, as well as the assumptions regarding personal activities such as how much the device is used and for how long. When e-books were studied (IV), improved data on device production and disposal were used and the resulting impacts of production of the e-reading device was in this study higher than in the newspaper study. The potential greenhouse gas emissions were double that related to production of the e-reading device in the newspaper study. For most other impact categories the difference was larger, with the values in the newspaper study being lower. However, the data used in the book study are also uncertain, as they are based on connecting components in the dismantled device to the available data on electronic components in Ecoinvent 2.0 and no data were available for the e-ink screen or for assembling the e-reading device. Inclusion of these factors would increase the impacts, but the extent of the increase could not be estimated. Production of the e-ink screen may be an energy-intensive process, which could be significant for the resulting environmental impacts. Also, disposal data are still uncertain. The use of the e-reading device is another crucial factor. In the newspaper study the assumptions were a one year life of the e-reading device and that it was used for 30 minutes every day to read the newspaper and for an additional 30 minutes to read something else. The book study assumed a two year life time and that the device was used for the sole purpose of reading books. In the base scenario the user was assumed to read a total of 48 books on the e-reading device. The assumptions made in the two studies illustrate differences in total hours of use for an e-reading device. In the newspaper study the device is used for 365 hours in total and in the books study, with a rough assumption of reading of roughly 20 pages per hour the device is used for 870 hours. The total use of the e-reading devices is clearly related to practices which will vary from person to person, and will thus lead to different environmental impacts per function or benefit provided and different environmental preferences for printed or electronic media.

Regarding the difference in the outcomes of the newspaper and book studies, where the first indicates a potential benefit from an environmental perspective for the e-reader version of the newspaper whereas the other clearly results in a draw, this difference can at least partly be attributed to the difference in paper utilisation. For a newspaper, more paper is used than is generally read, whereas all pages of a book are generally read. Substituting electronic time for reading on paper which is all read or partly read could be a relevant difference.

Weber et al. (2009) performed a study very similar to the book study presented in Papers III and IV, but considering different forms of delivering music. Their study showed environmental benefits of digital delivery. A major difference when assessing electronic and recorded music delivery, compared with electronic and printed media, is that it can be assumed that the music delivered requires similar amounts of energy in the use phase, as electronic devices are needed for listening to the disc as well.

In the case of invoices, the results of the study performed (Paper V) were clearer, but only cumulative energy demand and greenhouse gas emissions were covered. The results indicate that a transition from paper invoices to electronic invoices would be beneficial regarding energy demand and greenhouse gas emissions. In cases where paper copies are not requested, the transition seems to be a natural step, but if users see a need for paper copies then the electronic invoice may be printed in any case and the potential environmental benefit will be significantly decreased. Schmidt and Hedal Klöverpris (2009) performed a similar study on the consequences of changing from sending documents by conventional mail to electronic distribution in Denmark. Their results indicated environmental benefits from such a change in terms of climate change potential, acidification potential, nitrification potential, photochemical ozone creation potential and total energy consumption (Schmidt and Hedal Klöverpris 2009).

The resulting influence of the energy used for distribution of electronic content on the total environmental impact differs between different studies. In Papers II-V the energy required for internet distribution was estimated based on different references and assumptions. The internet distribution did not result in major environmental impacts as compared to the other activities in the studied systems. However, in Paper II the sensitivity analysis in which a high energy demand per MB of data transmitted was tested indicated that this could influence the results. In Paper II the amount of data sent electronically was high in relation to the corresponding amount of printed media per reader (140 MB/kg printed media and reader) compared with Paper III and IV (2.5 MB/kg printed media). The assumption on average use of servers is important, as the electricity use related to the server is a large part of the total figure for internet electricity use (Taylor and Koomey 2008); the reference used in Papers II-IV. In both these papers specific energy use of servers were used in the base scenarios. In the consequential LCA on invoices, the main potential negative impacts of a transition were due to the electricity use by servers.

Limitations of the LCA studies (Papers II-V) include the lack of 'good' data for some activities (for example for internet use, bookshops, e-ink screen production, disposal of electronic waste), as well as the uncertainty in some assumptions made (life time and use of the studied products, how people travel, etc.). Impacts related to land use and water use were not covered.

The study of invoices (Paper V) was limited to assess cumulative energy demand and greenhouse gas emissions. Paper V had a limited scope and did not include advertisements, which are often sent with the paper invoices to customers, or other means of paying invoices than via the internet. Furthermore, in a consequential assessment marginal data should be used, but this was not always possible and current average figures were frequently used as approximation. This was judged sufficient for our screening study, which mainly covered the more direct long term consequences of a transition, while the structural and behavioural consequences and the potential impacts of these were not addressed. It could be suggested that by making electronic invoices the standard, people without computers would buy one and some people would become more comfortable with using the internet, etc. Such changes in practices, and impacts of these, could lead to substantial consequences of different kinds which were not addressed in the study. In addition, the study assumed that if the paper invoices were eliminated, the paper used for these and for their envelopes would not be produced, thus avoiding the production of pulp and paper. As biomass and land area are limited resources exposed to global competition (Sokka and Soimakallio 2009), this assumption is a simplification. A reduced demand for office paper would probably lower the price of office paper and/or pulp, which would probably have consequences for production and consumption (see Finnveden et al. 2009 for a discussion and further references on consequential LCA and negative feedback mechanisms). In a more extensive study these consequences would be interesting to elaborate upon. Limitations of the LCA studies are further elaborated upon in the different sections below.

LCAs of products provide information on a micro scale. In Paper VI the aim was to complement this with some information regarding the direct environmental impacts of the ICT sector and the entertainment and media (E&M) sector globally. The macro scale is essential to capture any increase in total consumption and the risk of e.g. non-substitution in practice. In Paper VI greenhouse gas emissions and operational electricity use were assessed as a start, but other impacts need to be assessed as well. The scale of the sector contributions indicates that the ICT sector and the E&M sector are part of the reason for global greenhouse gas emissions, neither major nor insignificant. The current development in the sectors could be important, as it could lead to an increase in the direct environmental impacts, but potentially contribute to decreased indirect impacts. Macro scale studies could report on the impacts of development and be used prospectively. There were limitations to the study in Paper VI, since as global figures on devices in use or subscribers were not always available, data were scaled up to reflect operational electricity and greenhouse gas emissions globally and the results of earlier studies were adjusted to correspond to 2007 values. The data available mainly concerned industrial countries. Greenhouse gas emissions from land use related to forestry were not included, nor carbon storage in printed products. There are still major uncertainties regarding how to include biogenic carbon and carbon sequestration in assessments (Kujanpää et al. 2009). The disposal phase was not covered in Paper VI. Despite these shortcomings, the quantitative results gave an indication of the order of magnitude, roughly 1.4% and 1.7%, respectively, of global greenhouse gas emissions in 2007.

### Impacts of practices

The resulting environmental impacts of printed and electronic media are largely dependent on the users' practices (as shown in Papers II-V). These practices will affect the direct and indirect environmental impacts of the systems studied. In the longer term, behavioural and structural changes (Berkhout and Hertin 2004) can have significant effects as well. If for example a change to electronic invoices has an impact on the general practices as mentioned above this could lead to other environmental impacts than expected. Different consequences could be anticipated e.g. spending more time on the internet could imply less time for other activities, increase demand for more advanced electronic devices, provide a sense of increased inclusion, etc. On a societal level these potential consequences could lead to considerable, positive and negative environmental and social impacts. Including such potential impacts in consequential assessments would make the assessments more complex, but at least in some cases also more relevant. With consequential LCA, it is suggested that all activities affected by the choice or change studied be included in the assessment of potential impacts (Ekvall and Weidema 2004). For new technologies and solutions this could be a way to emphasise the potential for future benefits and to discover potential future drawbacks by widening the system boundaries. Sandén and Karlström (2007, p. 1479) emphasise the need to include "effects due to learning and structural change" when emerging technologies are studied. For public authorities making strategic decisions, this could be relevant when assessing for example new ICT solutions or support for sustainable practices to try to cover the potential for major changes in general practices and structural changes.

When comparing printed and electronic media, a requirement for a potential decrease in overall impact (direct and indirect) is that one product would in practice replace the other, or in a different way alter activities in a sustainable direction. Without that, the different alternative products and their respective environmental impacts would just be additive. Users' practices are difficult to assume and assess, but need to be handled as the final impact will often depend on them. Currently this potential for differences in personal activities can be handled in environmental assessment in sensitivity analyses or scenarios. Studies of everyday practices could provide useful input to LCAs. One way to make use of knowledge on practices in environmental assessment can be to illustrate the potential resulting environmental impacts of different practices, i.e. using explorative scenarios where different practices are assumed (Höjer et al. 2008; Börjeson et al. 2006).

Even though the devices and communication networks are getting more energy efficient, this development would need to be combined with sufficiency, lower consumer demands (Tukker et al. 2010). There is a risk of a rebound effect in that if transmission and hardware becomes more efficient and cheaper, then more devices may be bought, used briefly and scrapped (Plepys 2002). However, the industry should still aim for efficient use of resources, cleaner processes and products and facilitation of recycling after disposal. As end-consumer activities will have a major influence on the overall outcome regarding environmental impacts of media and communication products (Plepys 2002; Papers II-V), authorities and industry groups also have a responsibility to facilitate sustainable practices through supporting and providing incentives that make it easier for people, businesses and organisations to change practices and norms, enabling sustainable development. As Tukker et. al. (2010, p. 21) states "Consumption choices are based not only on individual choices but also on existing and available infrastructure and on established social norms". More information on potential effects, including rebound effects, and their causes could assist policy-makers in their complex tasks (Plepys 2002). As concluded by Tukker et al. (2010) there is a need for research and proactive solutions enabling the realization of sustainable practices. Further, Hilty et al. (2006, p. 1625) call for "a set of specific ICT-related policies to unfold the potential of ICT to support sustainable development and to inhibit ICT's negative environmental impacts at the same time." In order to elaborate on such policies, sustainability assessments need to be performed to indicate potential impacts, including direct and indirect behavioural and structural impacts and describe robust pathways. Even though the assessments will not provide the answers, they can provide possibilities for increased learning. However, as Gasparatos (2008, p. 287) notes, "planning for and assessing the progress towards sustainability inevitably becomes a complicated task".

## System boundaries and functional unit

When assessing the environmental impacts of media and communication products, the definitions of system boundaries and functional unit are crucial (Hischier and Reichart 2003; Zurkirch and Reichart 2000), as for most end-consumer products. In a stand-alone study of a single product the total environmental impacts will to some degree depend on whether activities such as personal transportation for obtaining the product and storage in the shop and in the home are included with the studied system. In studies by Gard and Keoleian (2003), Kozak (2003) and Paper III, personal transportation was a significant contributor to the potential environmental impacts of the printed media studied. In Paper III the bookshop energy use was included, although the data were based on a single shop and thus only give a uncertain indication. The proportion of the environmental impacts originating from the bookshop was approximately as large as that from distribution and storage before delivery with slight variations between impact categories (see Figure 5). The storage of books in private homes was not included within the system boundaries in Paper III. A rough estimation of the energy use for storing the printed book studied in a bookshelf at home indicated that this could account for a slightly lower energy use (80%) than that per book related to the bookshop as modelled in Paper III. Storing printed media for several years could also have implications for the environmental impacts through carbon storage in the paper. This was not included in the studies presented here but could be interesting to study further, especially drawing on higher level changes in practice and structural changes, as mentioned above.

Even though the results of most environmental assessments of printed media show that the production of pulp and paper is a main contributor to the environmental impacts (Enroth 2006), the widening of system boundaries to include personal transportation and storage puts these production processes in perspective. As the work underlying this thesis shows, a high amount of end-consumer transport (10 km/book in Paper III) related to the printed media, in this case a defined novel, could outweigh the environmental impacts of producing the printed media for most impact categories (Borggren and Moberg 2009, Appendix 2). Transport and housing are two main reasons for consumption-related environmental impacts (Tukker et al. 2010). Media products are related to these through e.g. personal transportation for buying or picking up printed media and the storage of printed media in shops, homes and offices. In a wider perspective, the material goods that we acquire and keep will demand space and in the longer term possibly increase or decrease demand for space and transportation. This wider perspective with structural and behavioural impacts arising in addition to the direct and indirect impacts which are typically assessed in current studies could considerably change the resulting potential environmental impacts of products and the consequences of introducing or choosing products.

In comparative studies the discussion on system boundaries is relevant as well, but for these the definition of the functional unit is also a major challenge. To make a fair comparison of one media product with another, the function or benefit provided and to which all environmental impacts are related must be reasonable for both. The importance of definition of the functional unit for comparative studies is emphasised in LCA methodology (Baumann and Tillman 2004). In theory the function provided by two products may be defined in the same way, but in practice, as the products are by definition not the same, they will often provide somewhat different functions. If the difference is apparent and tangible, this can be solved using the methodological suggestions on how to handle multi-output allocation problems provided in LCA literature (e.g. Ekvall and Finnveden 2001). However, in practice some functions are more qualitative and/or individual, and not easily handled. In the case of media products this can be illustrated by the difference in the benefit of reading the newspaper on paper, on the office PC or in the mobile; a Sunday breakfast reading of the daily newspaper; checking the latest news on the internet edition before going to lunch, even taking a look at a video clip from a football game; or getting an update through short news messages on the mobile phone on the bus to a meeting. All these may be provided by the same newspaper company, and may all be covered by the functional unit used in Paper II 'the consumption of newspaper during one year by one unique reader'.

Similarly, the choice between a literary hardback, paperback or e-book will concern preferences not covered in a functional unit defined as 'reading a pre-defined novel'. However, in the case of books, the difference can be said to be related mainly to issues such as image and cost, but the content that is digested is the same. For newspapers and magazines where the whole content is often not read the function or benefit provided may not be equal to the whole content. Moberg et al. (2007) studied a newspaper read on paper, on the internet and on an e-reading device. In this case the internet edition was assumed to be read for 10 minutes and 30 minutes per day. The 30 minutes were used to make the function more comparable to the traditional reading of printed newspapers (30 minutes per day on average according to TU (2006) and the 10 minutes per day were more in line with actual practice (Holsanova and Holmqvist 2004), but assumedly provided a different function. The results differed considerably, illustrating the importance of the functional unit and its interpretation. Different functions of a newspaper could be regarded as e.g. amount of knowledge gained or degree of amusement, but these can be hard to quantify.

The need to consider the differences in function should not be neglected when interpreting and using the results. To handle the multi-functionality of media and communication products, Hischier and Reichart (2003) suggest that several approaches are used, exemplified in a case study of news related to 'reading or watching an average news item', 'reading or watching the daily news' and 'average daily media consumption'. The advantage of this, according to Hischier and Reichart (2003), would be that recommendations leading in the wrong direction can be avoided. Still, the different functional units suggested by Hischier and Reichart do not really illustrate the potential differences in benefit or function provided; they rather answer different questions.

### Data inventory, assumptions and allocation

Gathering information and data for the screening LCAs in Papers II-V illustrated the ever present need for more and better data. For printed media there are general pulp and paper production data available, for example in the Ecoinvent 2.0 database (Hischier 2007). These data are based on information which is about 10 years old and even though the pulp and paper industry is bound to change slowly as investments in new technology and machines are expensive and long term, it is likely that the best practice, and perhaps even the general average of today, will provide better environmental performance. Comprehensive datasets for resource use and emissions from average printing processes are not easily available. In these cases, if new data need to be collected but the study has limitations which do not allow extensive time for gathering new data, this may lead to the use of old datasets or datasets mainly covering energy and major material use, as well as emissions that are regularly measured by the companies. Larsen et al. (2009) point out the need for a more comprehensive inventory of toxicological substances. Biogenic $CO_2$ was not accounted for, but the uptake was assumed to be equal to the emissions, within the studied system. When studying systems where biogenic material is a major component, e.g. paper, the uptake and emissions of carbon dioxide should be handled more specifically. However, due to lack of specific data this was not possible in the current study.

With Ecoinvent 2.0 (Frischknecht et al. 2007a) the availability of electronic data improved substantially. Earlier studies suffered from a lack of transparent data of good quality for electronic products (Reichart and Hischier 2003). The problem is inherent as new ICT products are released at a high speed. New innovative products using new technology, here exemplified by e-ink displays, may be hard to assess as information about the production and materials used may be hard to get. This can lead to underestimation of the environmental impacts of new products compared with old. Plepys (2004) comment on the problem of lack of data, and note that this is especially the case for electronic products because of the rapid innovations and complexity of the products. Further, Plepys (2004, p.54) describe the problem of using general material data when high grade material is actually used in the production processes, demanding higher purity which is considered connected to higher energy use.

The uncertainties arising as a consequence of the inherent need to make assumptions are also important. In prospective studies as well as studies based on general data, there is seldom appropriate information available. For prospective studies, the system to be modelled needs to be assumed. If the product studied is new, the experience of e.g. practices related to the product and the life time of the product are limited. When a general product is studied rather than a specific brand with defined suppliers, general data are often not available and company-specific data may then be used as estimation and general practice needs to be assumed. Assumptions are often tested in sensitivity analyses. In Papers II, III and IV, it is clear that assumptions regarding total use (number of users, lifetime, additional use) and personal transportation are of crucial importance for the results.

So far the media content production has often not been covered within most environmental assessments (e.g. Enroth 2009; Larsen et al. 2009: Kozak 2003), or it has been based on rather uncertain and incomplete data (Papers II, III and IV). For the mass media it can be assumed that as content is produced for many consumers, the environmental impacts per functional unit are small. The basis of this assumption may change as the actors involved in media production increase and broaden. If more content is produced for fewer consumers, the relative environmental impact of content production and storage may increase.

There has also been a major change in the distribution of media and the environmental data available on internet distribution are still associated with considerable uncertainties. It is not possible to describe in any detail the actual distribution via the internet, as the route taken differs from one time to another. Attempts made to estimate energy use for internet distribution have assessed the total energy use of a system and divided it by estimations on the total amount of data transmitted in the system. The latter is also associated with uncertainty. The decision to allocate energy use based on the amount of data transmitted (MB) is not the only answer to the allocation problem, as it can be argued that the system is provided because there is a demand and customers generally pay for access and not per MB of data transmitted. Thus the energy use could also be allocated equally between all customers (users). There is also the speed and quality perspective, sending a certain amount of data at high speed or at lower speed and with different demands for quality. In the physical distribution system, e.g. the road system, transport work is generally measured as tonne-kilometres and environmental data are provided for different sizes of vehicles and with different assumptions on load factors. In a similar way, internet distribution could be differentiated regarding whether the distribution demands an individual line, as in some cases for video on demand, or whether it is just distributed through ordinary internet channels with the occasional loss of quality, e.g. through Youtube. However considering the weight and distance (e.g. in tonne kilometres) is not a solution, as the distance each MB is transported is generally not known. The transmission on submarine cable systems has, in an LCA, been measured as Gigabit kilometres (Gbkm), as in such systems the distance is known (Donovan

2009). The figures on energy use per amount of data transmitted also change from one year to another. This is due to the capacity of the existing networks not being fully used and to more data being transported every year while the energy use is not increasing at the same pace. Weber et al. (2009, p. 11-12) update their figure on internet energy use by assuming a 50% per year increase in internet data flows and a 14% per year increase in internet electricity use.

Allocation of manufacturing and operational environmental impacts of end-consumer devices is not straight-forward either. In practice, use time is often applied for allocation and the use time of one specific activity is related to the daily average use time and the life time of the device. However, a user may download a film (activity A) while chatting with a friend (activity B) and listening to the radio (activity C), in all cases using the PC. Then the functional time is tripled, which is not considered when allocation is based on running time.

### Impact assessment

Focusing on climate change, energy and additional energy-related emissions may lead to sub-optimisation. For example, toxicity is an important issue which is often not handled as there are, or have been, large data gaps and uncertainties both in inventory data and impact assessment methods (Finnveden et al. 2009). When toxicological impacts are included in environmental studies the results should be interpreted carefully. In the European scenario in Paper II, the main reasons for the resulting potential toxicological impacts were emissions to air and water from electricity production. This may be due to high electricity use in the mechanical pulping for newsprint production, but may also be due to lack of data regarding toxicological emissions from other processes (Larsen et al. 2009). In addition, insufficient data on toxicological emissions from distribution was at least part of the reason for distribution not being a significant part of the total weighted environmental impact using Ecotax02 in Paper II. When assessing environmental impacts of printed and electronic media, toxicological impacts are most probably an important issue e.g. related to solvents used for printing and cleaning of print presses, as well as ink pigment production (Larsen et al. 2009) and different substances and chemicals used in the production of electronic goods (Plepys 2002) and e-waste handling (Leung et al. 2008; Nnorom and Osibanjo 2009).

A main drawback of Papers II - IV, where a number of impact categories are covered, is that land use is not. Land use may be important for both printed and electronic media, e.g. for forestry and mining respectively. Work is underway to develop methodology for handling impacts of land use within LCA, but according to Finnveden et al. (2009) there is so far no agreement on how to handle the land use issues and the use of the methods in practice is limited. Water use is another issue which was not covered, and that could be relevant at least for the printed media as pulp and paper industry use considerable amounts of water.

Weighting, an optional part of an LCA, was implemented in Paper II. The use of different weighting methods illustrates the inherent uncertainty related to weighting as it is based on value choices. The difference in the overall weighted results using the min or max version of Ecotax02 was 100-fold for the newspaper read on an e-reading device. The weighted results using Eco-indicator 99 were dominated by fossil fuel resources and respiratory impacts on human health, whereas the Ecotax02 total impact was dominated by toxicological impacts.

## 5.2 *Methods for environmental and sustainability assessment*

Characterising and discussing methods in an overview such as that in Paper I can facilitate the further development of methods. As suggested in Paper I, there may be similarities concerning methodological choices where solutions and discussions within one field (one method) may be relevant for others. The example highlighted concerns that of attributional or consequential studies, which is much discussed and under development in the field of LCA (Finnveden et al. 2009), and seem to be relevant for other methods as well, e.g. methods focusing on environmental impacts of regions and nations or of companies and organisations. Correspondingly, the discussion on decision support, learning and the usability of detailed analyses in the field of environmental assessment in planning and policy-making (Nykvist and Nilsson 2009; Owens et al. 2004) could also be relevant for e.g. product- and sector-related methods perhaps partly dependent on the intended target group of the assessment.

There is a need for a wide range of tools for sustainability assessment (Ness et al. 2007; Paper I). When aiming for sustainable development, it is not only the environmental impacts that should be considered. In order to justify strategies and policies or production and use of certain products, social impacts also need to be covered. In Figure 13, based on Figure 2 and with inspiration from Table 1 in the report edited by Benoît and Mazijn (2009), it can be noted that if S-LCA was not being developed, there would be a gap for the object product regarding social impacts. S-LCA is now under development and Paper VII aims to facilitate discussion and further development.

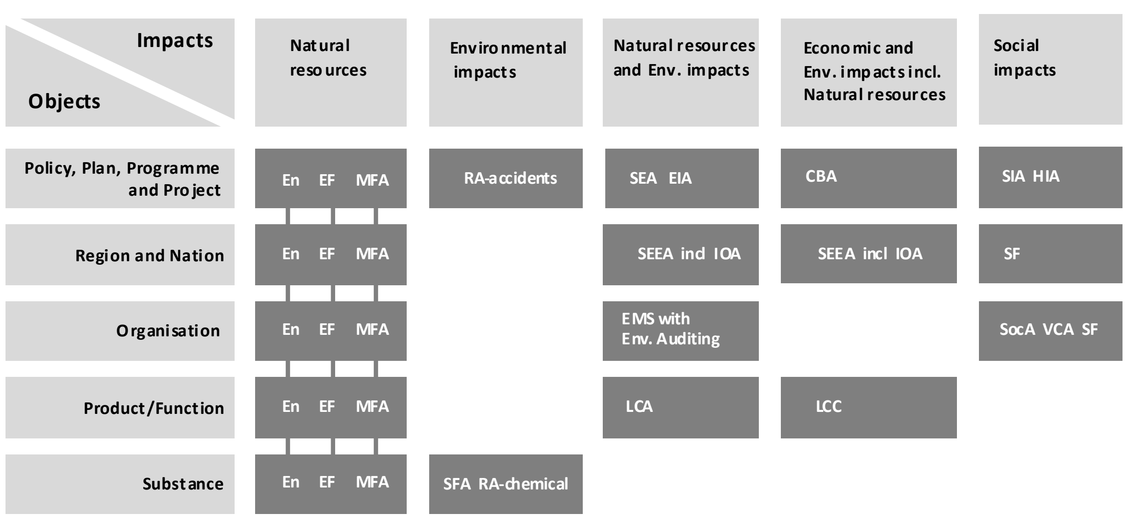


**Figure 13** Tools shown in relation to their focus, i.e. the object to which the impacts are related and the impacts regarded (based on Figure 1 in Paper I and inspired by Table 1 in Benoît and Mazijn (2009)). The coverge of tools is not exhaustive. Abbreviations are as listed in Table 3 and SIA: Social Impact Assessment; HIA: Health Impact Assessment; SF: Social Footprint; SocA: Social Accountability; and VCA: Value Chain Assessment.

Theoretical methodological development is starting to be complemented by practice. However, at this stage the practical application of S-LCA is still mainly within the academic field (e.g. Blom and Solmar 2009; Ciroth and Franze 2009). Jørgensen et al. (2009) interviewed employees in CSR departments in a number of Danish companies and concluded that the usability of S-LCA was not obvious to the interviewees and that the life cycle perspective was considered demanding. Not surprisingly, product comparisons were stated to be of interest if the advantages of the company's own product could be shown, but the usability of S-LCA for internal management was regarded as limited (Jørgensen et al. 2009). The life cycle perspective is demanding and for social assessment where databases are not readily available, the scepticism is understandable. However, Baumann (2000) studying the early practice of LCA in two Swedish companies emphasise the importance of the presence of key people driving the introduction and practice of LCA, 'LCA entrepreneurs', and of the adoption of LCA activities elsewhere as well to justify own adoption. This pattern could prove to be similar for S-LCA.
By performing an S-LCA or the first part, the hotspot assessment where potential high risks for negative social impacts are identified, an indication can be given on where social improvement and company efforts are most needed. The workers at the beginning of the supply chain (farthest away from the end-product) are generally the most disadvantaged (ILO 2007) but many companies practise their social responsibility activities mainly in the first, and sometimes second, tier of suppliers (Jørgensen et al. 2009; Moberg et al. 2009) The Danish study mentioned above (Jørgensen et al. 2009) reported that at least one interviewee foresaw that business partners will demand that the company producing a product for the market be responsible for the conduct of the companies throughout the supply chain. Still, there are considerable needs for further development of the methodology for S-LCA to facilitate industry practice (Benoît and Mazijn 2009; Blom and Solmar 2009). Some of these development needs are listed in 5.3. Other users of S-LCA could include NGOs and authorities of different kind, with perhaps different ambitions and objectives.

There are many challenges and development needs to handle regarding S-LCA. One difference to LCA is that more inventory data will not be directly related to the production process as such but rather be a consequence of context, e.g. management practices (Parent et al. 2010). In these cases it is suggested that an activity variable is used to relate inventory data from different life cycle phases to each other; activity variables are suggested to be working hours or monetary value added (Parent et al. 2010; Paper VII). However, Clift and Wright (2000) illustrate that environmental impacts are not corresponding to the economic value and in the cases they study the environmental impacts are high at the beginning of the supply chain where the economic value is low and the opposite is true closer to the end-consumer product. As stated above, workers at the beginning of the supply chain often have worse working conditions (ILO 2007), and thus the conclusions of Clift and Wright (2000) may well be relevant for social impacts as well. The relation between working hours and social impacts may be a more relevant activity variable, but this is still to be studied.

Owens et al. (2004) discuss the benefits of combining more technical and deliberative assessment approaches. In the guidelines for S-LCA edited by Benoît and Mazijn (2009) the participation of stakeholders in the process is emphasised.

In the studies presented in Papers II-V, stakeholders from companies representing the products assessed were involved and data were collected from companies in the supply chain. Although not studied specifically, my impression is that this contributed to learning for the companies and the individuals taking part. However, the actual effect of this potential learning would be difficult to assess. Heiskanen (2002, p. 434) states that "the central role of LCA-based tools and models is not in solving problems, but in *constructing problems in a distinctive way* and making people aware of them, and at least in principle responsible and capable of solving them".

Consequential assessment (Papers I and V) is a relevant approach in many cases for studies on new media and communication solutions. As Plepys (2002, p. 521) suggests, information on effects and causes are relevant in order to support decision-making where environmental consideration and economic growth are balanced. Attributional and consequential studies may lead to different, complementary information when the system boundaries are widened to include the potential consequences of resource competition (Sokka and Soimakallio 2009; Ekvall and Andrae 2006). As ICT hardware includes many rare substances with considerable resource demand for acquisition (Plepys 2002), increased (or decreased) production is likely to affect many other activities. In Paper V consequential assessment was used, but not to its full extent, and the results of the study were seen as harder to communicate and understand than the attributional studies performed. This can be another reason for using attributional and consequential assessments in parallel, as the attributional results will be more straight-forward and at the same time more will be learned about the actual differences in results between the two approaches. The consequential LCA in Paper V did not differ much to an attributional LCA, as the effects of e.g. decreased demand for office paper in Paper V were not elaborated upon.

Wrisberg et al. (2002) and Paper I identify a lack of tools for environmental assessment in relation to strategic planning in companies and organisations. It could be suggested that consequential LCA be used, perhaps in combination with other tools, depending on the object related to the strategic planning. Further, tools for environmental assessment in relation to policies, plans and programmes in large companies and organisations could be developed using experiences from strategic environmental assessments.

Sustainability assessment related to media and communication was examined in this thesis. Papers II-V cover environmental assessments (screening LCAs) of media products; the intention of these studies was to provide new knowledge about environmental performance and data gaps. Considering the usability of the results for media companies, it could be argued that learning about its impacts is always good for a company, especially when reporting on that of others (as many media companies do). However, the potential actions taken based on the new knowledge gained through comprehensive but less specific studies such as those in this thesis are more difficult to foresee. These studies provide rough results indicating a direction and illustrating the key factors on which the results depend. A thought is that this kind of general information would rather be useful on a more strategic (and public) level, as discussed above, aiming to support decisions which will facilitate sustainable practices and structural changes; identifying possible paths in the direction of sustainable development as well as those perhaps leading in the opposite direction. In order to support companies and organisations to address more advanced levels of environmental (or sustainability) improvements in strategic planning and investments, transparent drivers are needed (Wrisberg et al. 2002). In addition, strategic choices for media companies and ICT software industry could lead to considerable consequences more directly related to the hardware products. These processes and impacts are generally not covered by the providers of virtual products or services which do not sell the hardware themselves (this is discussed briefly in Moberg et al. 2009).

## 5.3 Future research needs

While this thesis and other recent publications provide more knowledge in the field of media and communication from a sustainable development perspective, there are still many future research needs, some of which are mentioned here.

Regarding the different processes forming part of media product life cycles, an area where more knowledge is needed in particular is that of electronic distribution. The changing practice of distribution, from physical to down-loading to streaming, the expansion of communication networks globally and the progress on more energy efficient solutions need to be assessed. Methodological issues in relation to electronic distribution, i.e. allocation, also need further study. The resource use, emissions and following environmental impacts associated with production of printed and electronic media are increasingly documented. However, more, and updated, information is needed; and in particular studies reflecting the toxicological impacts as well as impacts related to land use would give more comprehensive knowledge. For both printed and electronic media, observational studies of everyday activities and future studies reflecting potential changes in practices and structural changes could form relevant input for future LCAs. The disposal of electronic waste is an area where future studies on environmental impacts are of great interest, both on product and macro levels. Substance flow analyses would be of interest here in order to map where waste ends up and how it is handled, but more detailed environmental and social assessments of the actual disposal activities are also necessary.

The impact assessment methods for LCA are under development. In terms of media and communication products, impact assessment methods and experiences of using new methods for assessing toxicological impacts, land use and water use would be useful in order to broaden the knowledge base and decrease uncertainties. Climate change is an impact category receiving a lot of attention at the moment, so the problems regarding how to handle biogenic carbon in relation to land use and carbon storage are increasingly being discussed. More research and assessment experiences are needed in this field too.

Studies on a macro level, considering different environmental impacts as well as social impacts, would provide important information on the direction of development, adding to the product and company level information.

The usability of a method for S-LCA needs to be further evaluated (Jørgensen et al. 2009) and the method needs to be applied in practice in order to facilitate further development and improvement. Benoît and Mazijn (2009) provide a list of suggestions for further research and development for S-LCA. These include the need for case studies; development of databases, software tools and models for presentation of results; further development of consequential S-LCA; documentary experience on system boundary practices in S-LCA; development of methodological sheets describing the suggested data collection related to each sub-category; and development of impact assessment methods. The need for development of impact assessment methods are also emphasised by Jørgensen et al. (2010) and Parent et al. (2010).

The field of media and communication could pose a challenge for the application of S-LCA, with complex supply chains including high risk activities both within the supply chain and within disposal. The aim of performing these early S-LCAs would be to learn more about the potential 'total' social impacts, to provide possibilities for improvement and to facilitate the development of S-LCA methodology. Social benefits from media and communication solutions include providing more easy access to e.g. education, medical services and information on human rights. On the other hand it can be argued that e.g. integrity and security are put at risk. Access and inclusion may be directed towards the already privileged rather than those needing it the most. Relevant social aspects, using a life cycle perspective, can also be identified in raw material acquisition, production and waste management, and this is studied by e.g. Manhart and Griesshammer (2006) and Manhart (2007). At the moment there are no comprehensive studies of potential social impacts of specific ICT products. In a pre-study, Moberg et al. (2008) considered the use of S-LCA for ICT products, i.e. the possibilities and limitations of using a life cycle perspective regarding social impacts of products. That study indicated that applying a life cycle perspective when considering social impacts of ICT products could facilitate the inclusion of processes and stakeholders in the beginning of the life cycle, where impacts may be considerable and negative. In addition, the methodological development for handling user benefits within the assessment could be addressed by applying the method to a service which clearly provides possibilities of major societal benefits, e.g. e-health and e-education.

Environmental and social consequences of changes in practices and of structural changes should be addressed on both a product and a macro level in future studies in order to capture different level effects. As Berkhout and Hertin (2004) suggest, the direct and indirect impacts most frequently assessed to date should be combined with assessment of structural and behavioural impacts, which in the end could be crucial. Even though the methodological discussions regarding consequential LCA have been many (e.g. Sandén and Karlström 2007; Ekvall and Andrea 2006; Ekvall and Weidema 2004) and consequential LCAs have been performed, this is still a field where more experience is needed. As assumptions on the actual consequences of a decrease or increase in e.g. the use of a certain resource gives rise to uncertainty and the inclusion of 'all' consequences would lead to a very large system under study scoping as well as the interpretation, communication and use of results of consequential assessments are relevant topics for future research including experiences of studies performed.

In cases where the users' practices may significantly influence the overall impact related to a choice or a product, sustainable practice could be encouraged or facilitated by companies as well as authorities of different kinds. The usability of tools for environmental and sustainability assessment using attributional and consequential approaches for the purpose of strategic learning and decision-making facilitating sustainable practices would be a relevant area of further research. Relevant methodological choices and potential useful combinations of different tools would be interesting to consider.

The effects of sustainability assessment results on actions by stakeholders of different kinds would be an interesting and challenging field of study for media and communication. This could, for example, be covered in the evaluation of research findings presented by the Centre for Sustainable Communications; its mission being "to enable innovative media and communication services for sustainable practices" (CESC 2009).

# 6 Conclusions

In this thesis, potential environmental impacts related to media and communication are assessed using LCA and sector analysis. These are only two of a range of available methods for environmental and sustainability assessment. One conclusion of this thesis is that there is a need for several different methods. The object of study (e.g. product, project, plan, policy, organisation, etc.) and the types of impacts which are of interest (environmental, natural resources, economical, social, etc.) will determine the most appropriate method for a specific situation. There is potential for interaction between actors from different methodological fields and for learning from on-going discussions and development, e.g. regarding consequential assessments.

The ICT sector and the entertainment and media (E&M) sector, like all other sectors, give rise to environmental impacts. It is estimated that the contribution to the global greenhouse gas emissions were of the same order for the ICT sector and E&M sector respectively in 2007, roughly 1-2% each. Further macro studies need to be made in order not to miss that perspective.

In terms of printed and electronic media products, no general conclusions can be drawn regarding the preference from an environmental perspective. Both printed and electronic media give rise to environmental impacts of different kinds. A potential for e-reading devices to decrease the total environmental impacts of newspaper reading is illustrated in the screening LCA of newspapers. On the other hand, the environmental impacts of the book studied are shown to depend largely on users' practices and there is no clear-cut answer on whether the printed or electronic version is preferable. The consequential screening LCA of a change to electronic invoices indicate that cumulative energy demand and greenhouse gas emissions could be considerably decreased if printed invoices are replaced with electronic. All the studies have limitations due to lack of data, uncertainties in the data used and methods used for assessment of toxicological impacts. Land use and water use impacts are not assessed.

Using a life cycle perspective, the following key factors which could influence results are identified for environmental assessments and comparisons of printed and electronic media products:

- Total use of electronic devices

  As there are environmental impacts related to producing electronic devices as well as to their disposal, a high total use of each device produced justifies it to a larger extent from an environmental perspective. With a longer lifetime and through frequent use, the environmental impacts per benefit or functional unit can be decreased.

- Total use of printed media

  Printed media production gives rise to environmental impacts; by sharing printed media products and increasing the number of readers per copy, the environmental impacts per benefit or functional unit can be decreased.

- Amount and type of paper

The amount and type of paper used for a specific product is highly connected to the resulting environmental impacts. Fewer pages and lower paper weight can for example decrease the environmental impacts.

- Energy use of electronic devices

Electronic media may give rise to considerable environmental impacts in the use phase. The energy use of the electronic devices related to the electronic media depends on the use time and on the power draw of the device.

- Potential printing of electronic media

If products which are electronically distributed are printed, the environmental impacts of producing the paper and of printing are added to that of the electronic device used. This increases the environmental impacts related to the electronic media. The magnitude will depend e.g. on the amount of pages printed, the printer used and the potential effect on the use of the electronic device.

- Electricity mix

For processes which have a high electricity demand the electricity mix used will influence the resulting environmental impacts. Thus the geographical location of pulp and paper industries and other electricity-demanding industrial processes can be crucial. If the electronic devices used by the end-consumer have a high energy demand, the electricity mix may also be a critical factor for the resulting environmental impacts.

- System boundaries

When considering the environmental impacts of a product, sector, plan or other object, the definition of the system boundaries is crucial. In the case of printed media, for example, the choice of including personal transportation and storage in shops and homes can influence the final results.

There are uncertainties related to the studies performed and to environmental and sustainability assessments in general. Substantial data gaps were identified for production of the e-ink screen and disposal of electronic devices such as the e-reading devices studied here. In addition the environmental impacts related to the electronic distribution needs further research and methodological guidelines, as the data and the allocation to different uses are still associated with considerable uncertainty. Furthermore, some impact categories are less well covered. There are data gaps for toxicological emissions and the impact assessment methods used add to the uncertainty of the results, as all potential impacts of emissions inventoried are not covered or not even known. The potential impacts related to land use are not covered in the studies performed, nor in most previous studies. Land use is a relevant impact category for both printed and electronic media, mainly regarding forestry and mining processes. Water use was not considered. Regarding the emissions of greenhouse gases, the potential of carbon storage in printed media could also be considered for products with a long life, such as books.

There are also uncertainties associated with the assumptions made. Sensitivity analyses are used to illustrate these and can facilitate an interpretation with greater awareness on complexity and uncertainty. As there may be difficulties in formulating functional units that accurately describe the function or benefit provided by some different media products, the differences need to be considered in interpretation or in the use of results. Despite uncertainties and difficulties, learning is provided through performance of assessments and communication of results; both on the potential impacts and on the uncertainties and lack of knowledge.

The potential social impacts of printed and electronic media have so far not been assessed using a life cycle perspective. Guidelines for S-LCA, as suggested by the UNEP-SETAC Life Cycle Initiative Working Group for integration of social aspects into LCA, are presented here. These are intended to provide guidance for goal and scope, inventory, impact assessment and interpretation stages of an S-LCA and to form a basis on which software and databases can be developed. Another important role of the guidelines is to facilitate discussions, criticism and proposals for improvement and development of the methodology suggested.

The screening LCAs performed indicated that users' practices and everyday activities could substantially influence the resulting environmental impacts. Here, the scope was limited to direct and to some extent indirect environmental impacts. Including the environmental impacts of more long-term changes in practices and potential structural changes, as well as potential social impacts, could provide important additional insights and increase the possibility of facilitating sustainable practices related to media and communication.

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