Environmental impact of printed and electronic teaching aids, a screening study focusing on fossil carbon dioxide emissions

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Abstract: This study was initiated in order to clarify the environmental impact of different kinds of teaching aids easily available today. The aim of the study is to give a screening comparison of the environmental impact when it comes to the global warming potential of printed versus electronic teaching aids. A life cycle perspective is used in the study which means that the different specific life cycle steps of the media products are analysed. In the study, the environmental impact is limited to the impact category global warming. The study focuses on the emissions of fossil carbon dioxide which is the only climate gas included in the analysis.

The study shows that the impact on global warming of a web based electronic teaching aid is approximately 10 times higher than the environmental impact of a printed textbook, if a low energy computer equipment scenario is used. If a high energy computer equipment scenario is used, the impact is nearly 30 times higher for the web based electronic teaching aid compared with the impact of the printed textbook. A reason for this is that a textbook can be used for a long time by many users.

Keywords: Environmental impact, Printed textbooks, Electronic teaching aids, Media products

1. Introduction

This study was initiated in order to clarify the environmental impact of different kinds of teaching aids easily available today. The original study was financed by NHO Grafisk in Norway.

The aim of the study is to give a screening comparison of the environmental impact when it comes to the global warming potential of printed versus electronic teaching aids. For the electronic teaching aids, the study is focusing on electronic solutions that are available in practice today for teaching compulsory-school pupils, i.e. solutions using computer equipment for the use phase.

The number of published studies comparing the environmental impact of printed and electronic media products is quite low. Some of the more recent studies are focusing on media products with relatively short life time such as newspapers (Moberg et al 2007) and invoices (Moberg et al 2008) or automatically generated documents, e.g. monthly bank account statements (Schmidt and Kløverpris 2009). This study compares the environmental impact of a media/information product with a long life time and many users.

2. Methods

A life cycle perspective is used in the study which means that the different specific life cycle steps of the media products are analysed. In Figure 1 and Figure 2 the life cycle steps of the respective media product are illustrated together with the system boundaries of the study. For the printed textbook the following steps are included; pulp and paper production, transportation of paper, prepress, printing, distribution of the books, use during studies and waste management of the books. For the web based electronic teaching aid the steps included are formatting the teaching material, use of internet infrastructure, production of computer equipment for users, distribution of computer equipment, use of electronics during studies and waste management of electronics. Editorial work is not included in the study, however, this work is assumed to be comparable for the two types of products. Details about the life cycle steps and the assumptions made are described in Table 1 and Table 2.

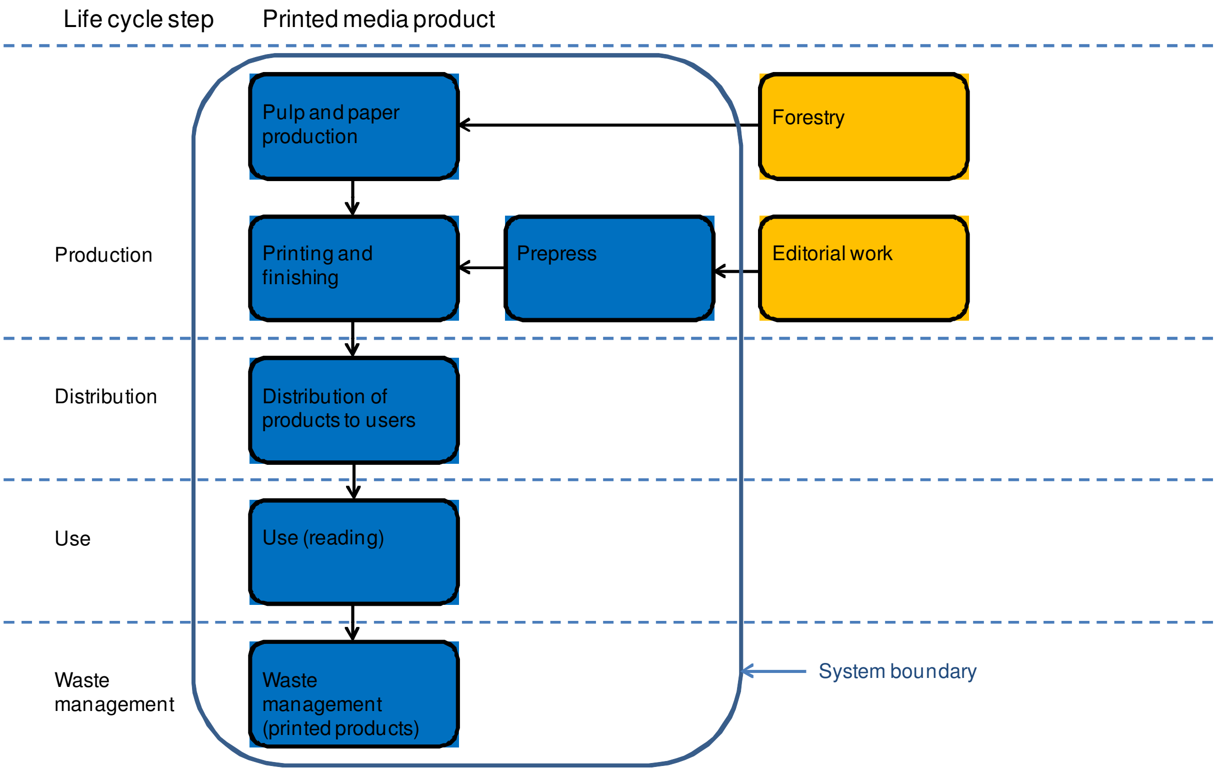

Figure 1 The life cycle steps of printed products and the system boundary for the studied printed textbook.

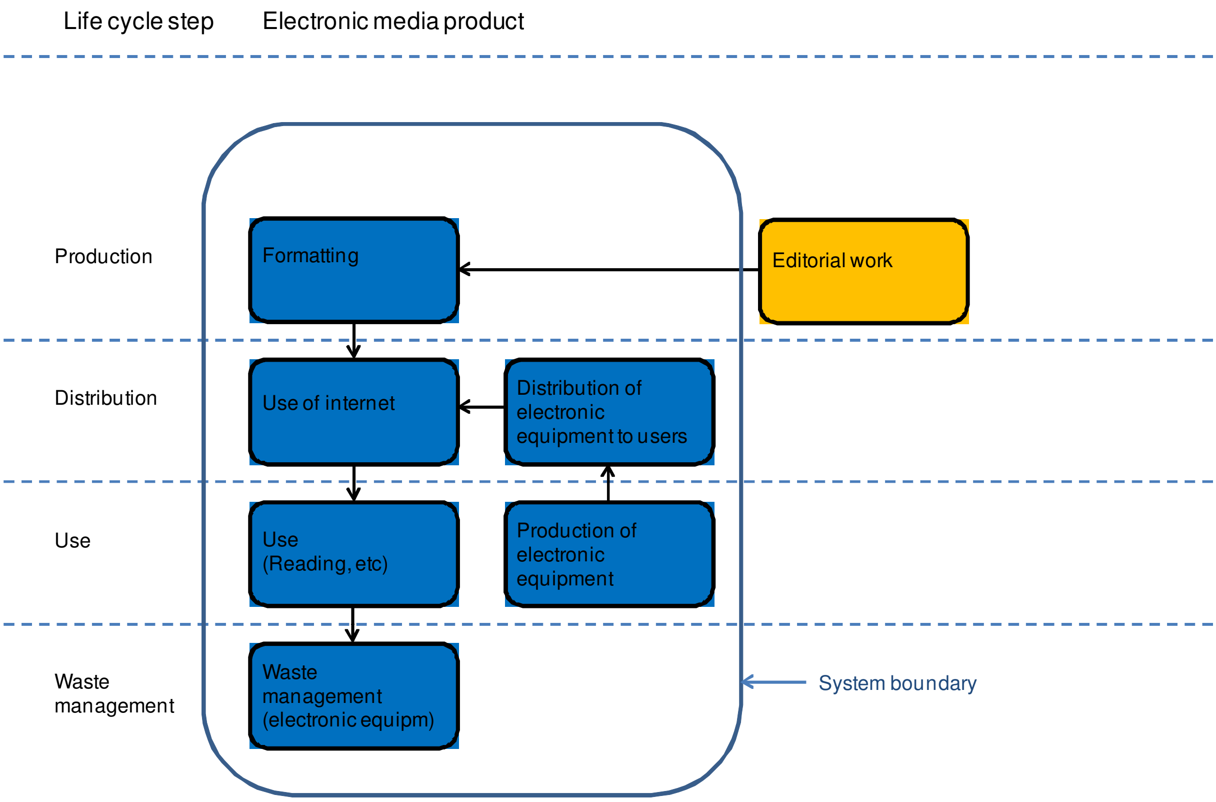

Figure 2 The life cycle steps of electronic media products and the system boundary for the studied electronic teaching aid.

In the study, the environmental impact is limited to the impact category global warming. The study then focuses on the emissions of fossil carbon dioxide which is the only climate gas included in the analysis. This means that mainly the use of energy and transportation in the different product life cycles are taken into consideration in the study. For some processes, data on fossil carbon dioxide equivalents is used for the calculations due to availability of data.

The functional unit of the study is "Use of teaching aid during five years for 5,000 pupils per year (i.e. 25,000 pupil years). Each year the pupils use the teaching aid 2 hours per week for 40 weeks. The pupils reside in six different cities in Norway".

The studied printed product weighs 0.8 kg/book which corresponds a total weight of 4.8 tonnes of paper including 17% paper waste at the production. The total weight of the final product thus is 4.0 tonnes. A life time of 5 years is assumed for the textbooks. For the electronic teaching aid, the share of the total impact from the needed computer equipment for users is calculated to be 3.7%, based on a life time of 5 years and a total use of approximately 10,900 active hours during this life time. For both types of media products, low as well as high energy scenarios were studied. For the printed product this means that two different levels of energy use for the printing process were studied. For the electronic product the low energy scenario included laptops for the users and the high energy scenario included desktops and LCD screens for the users.

Table 1 Details about the life cycle steps of the studied printed text book and assumptions made.

Process	Description
Pulp and paper production	Direct emissions of fossil carbon dioxide from the production of pulp and paper and indirect emissions as a consequence of bought electricity (Swedish average). Data for a specific paper produced in Sweden was used (Grycksbo Paper, 2008).
Transportation of paper	Emissions of fossil carbon dioxide from the transportation by truck of paper from the paper mill to an assumed printing company in Oslo. Emission data for a truck with draw bar trailer, long distance, was taken from Baumann and Tillman (2004). The distance was estimated to 400 km.
Printing and finishing	<u>Energy</u> Two different scenarios for energy use at the printing company were used. In both cases the data include all type of energy used at the printing companies, i.e. not only electricity but also energy used for heating, etc. The low energy scenario with a use of 610 kWh/tonne product represents fairly large offset printing companies (Enroth 2006). The high energy scenario with a use of 1590 kWh/tonne product represents rather small offset printing companies (Enroth et al 2003). For the calculation of emissions of fossil carbon dioxide, Nordel[1] was assumed for the printing process. <u>Printing plate</u> Data for use of plate in offset printing is found in Larsen (2004) where the figure 4.16 m^2/tonne printed product is reported as an average. With an assumed thickness of 0.3 mm, this results in a value of 3.37 kg/tonne offset product. Based on figures given by EAA (2008) for emissions of CO_2-equivalents from European production of primary aluminium, sheets and recycled aluminium, the emissions when producing the printing plate were estimated. Since 100% of the printing plates are recycled the calculation is based on 95% recycled and 5% primary aluminum in order to compensate for the EAA reported average loss of aluminum when recycling. <u>Printing ink</u> The use of ink for offset printing is reported in Larsen (2004) as 5.8 kg/tonne printed product. Data on fossil CO_2 emissions from the production of printing ink was calculated to 1180 kg/tonne printing ink, based on inventory data for mineral oil based black ink in Strömberg (1998).
Distribution of the books	The emissions arising from the distribution by truck of the books from the assumed printing company in Oslo to schools in six different cities in Norway (Oslo, Kristiansand, Stavanger, Bergen, Trondheim and Tromsø) were estimated. Emission data for a truck with draw bar trailer, long distance, was taken from Baumann and Tillman (2004). The transport work was calculated to 1600 tonne*km.
Use	No emissions from the use of text books.
Waste management	For the waste management of paper 80% fiber recovery and 20% incineration with energy recovery were assumed based on the situation for newsprint in Sweden (Moberg et al 2007). This however does not fully represent the situation for fine paper. The impact of handling waste paper was estimated based on an emission of 0.06 kg CO_2-equivalents/kg paper calculated from data given in Moberg et al (2007).

[1] Nordel includes electricity production in Denmark, Finland, Iceland, Norway and Sweden. (Moberg et al 2007)

Table 2 Details about the life cycle steps of the studied electronic teaching aid and assumptions made.

Process	Description
Formatting	The time for formatting the editorial material for the electronic web based teaching aid was approximated to 50 hours. This only represents the assumed extra time compared with the printed textbook when a print original is produced based on the editorial material. A desktop computer and a screen were assumed for this process. The use of energy for the process was calculated based on the effect of 78 W for a desktop and 31 W for a LCD-screen during active use (Jönbrink and Zackrisson 2007). For the calculation of emissions of fossil carbon dioxide, Nordel was assumed for the formatting process. The use of internet infrastructure for uploading the material is not taken into account in this process.
Use of internet	The energy need for the use of internet infrastructure is based on the estimated size of the downloaded material, in this case 1500 MB, and approximations of the energy required for using the internet backbone. The internet backbone was described by Taylor and Koomey (2008) as servers, data storage, hubs, routers, LAN[2] switches and WAN[3] switches. Data for the energy intensity of using the internet backbone, 3 Wh/MB, is given in Moberg et al (2008), p 34, for the use of fixed networks and transport networks. This figure was extrapolated in order to approximately describe the situation 2007. In addition, the use of access technologies such as modem and DSLAM[4] is accounted for. In this case the use of energy was calculated based on the effect of 9 W for modem and 5 W for DSLAM. It is assumed that only ten different schools are downloading the teaching aid material from internet once a year during the period of five years which is studied.
Distribution of electronic equipment	The emissions arising from the distribution of the electronic equipment to the users in schools in the six different cities in Norway from the production in China were estimated. 3.7% of the environmental impact from the transportation was allocated to the functional unit of the study. Emission data for large ships >8,000 dwtonne and trucks with draw bar trailer, long distance, were taken from Baumann and Tillman (2004). Data on weights of the computer equipment were found in Jönbrink and Zackrisson (2007).
Use	For the functional unit, the time for using the teaching aids was estimated to 2,000,000 hours (2 hours x 40 weeks x 5 years x 5,000 pupils). Two different scenarios for use of the electronic teaching aid were studied. The use of energy was calculated based on the effect during active use; 32 W for a laptop, 78 W for a desktop and 31 W for a LCD-screen (Jönbrink and Zackrisson 2007). For the calculation of emissions of fossil carbon dioxide, Nordel was assumed for the use phase.
Production of computer	3.7% of the environmental impact from the production of electronic equipment was allocated to the functional unit of the study. For production of a laptop the emission of 81 kg CO_2-equivalents was used for the calculation, for production of a desktop the emission of 138 kg CO_2-equivalents was used based on data in Jönbrink and Zackrisson (2007).
Production of screen	3.7% of the environmental impact from the production of electronic equipment was allocated to the functional unit of the study. For production of a LCD-screen the emission of 55 kg CO_2-equivalents was used based on data in Jönbrink and Zackrisson (2007).
Waste management of electronics	For the waste management of electronics, 95% material and energy recovery and 5% landfill were assumed based on information in Jönbrink and Zackrisson (2007). The impact of waste handling of electronics was estimated based on the following reported data; -1 kg CO_2-equivalents for a desktop or a laptop and 4 kg CO_2-equivalents for a LCD-screen.

[2] LAN, Local Area Network.
[3] WAN, Wide Area Network.
[4] DSLAM, Digital Subscriber Line Access Multiplexer. For consumers, there is one DSLAM per subscriber. In the case of business, internet connection is less energy demanding per computer (Moberg et al 2008). Here, one DSLAM per school is assumed.

3. Results

The study describes the significant life cycle steps of each product type; see the illustrations in Figure 3 and Figure 4. The results show that the pulp and paper production as well as the printing process contribute significantly to the total impact on global warming of printed textbooks. In addition, it is indicated that the waste management step contributes in a considerable manner. The advantages of material recovery of fibres are not obvious when studying impact on global warming since energy requiring processes and lots of transportation are often used. For the web based electronic teaching aid, the production of computer equipment for the users and the use phase contribute in a significant way to the total impact on global warming of this type of product.

A relatively small contribution to global warming is seen from transportation activities for both types of products in the study.

The results of the calculations in the study are summarised in Table 3 for the printed textbook scenarios and in Table 4 for the web based electronic teaching aid scenarios.

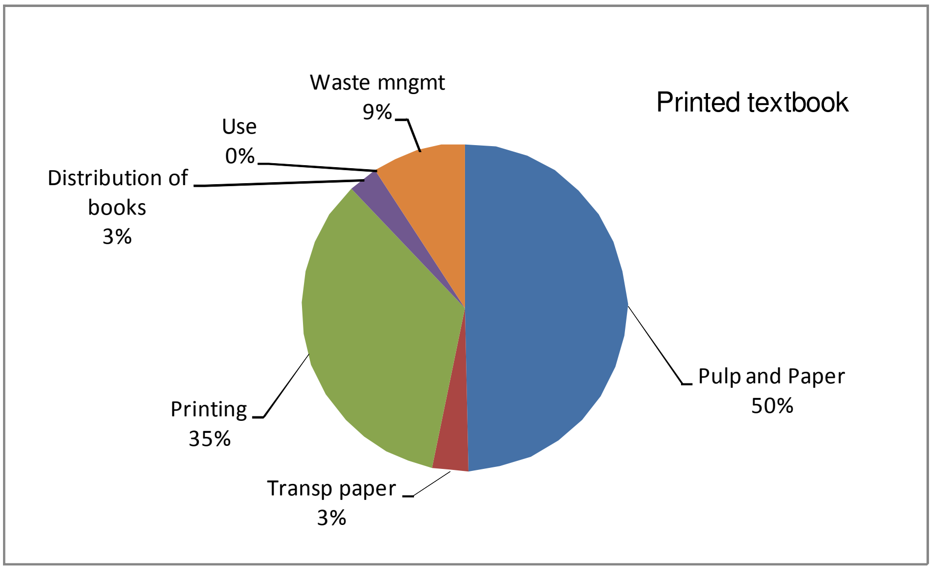

Figure 3 The contribution from the different life cycle steps of the studied printed textbook (high energy printing scenario) when it comes to fossil carbon dioxide emissions.

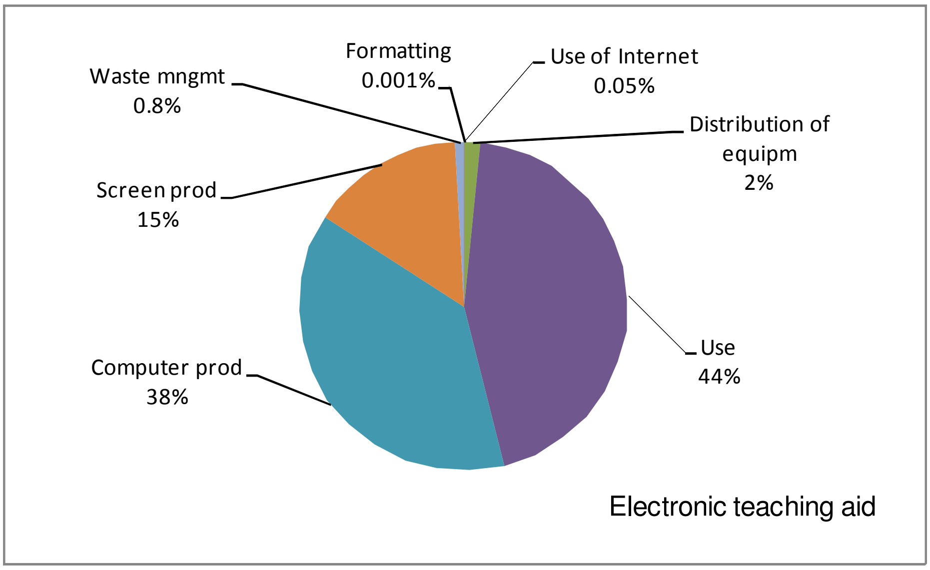

Figure 4 The contribution from the different life cycle steps of the studied web based electronic teaching aid (high energy scenario with desktops & screens) when it comes to fossil carbon dioxide emissions.

Table 3 Emissions of fossil carbon dioxide (in kg) from the studied printed textbook scenarios. The contributions from the different processes as well as the total amount are shown.

	Pulp and Paper, Direct emissions	Pulp and Paper, Bought electricity	Transp, Paper	Printing, Energy	Printing, Plate	Printing, Ink	Distrib, Books	Use	Waste mngmt	Total
Printed textbook (low energy printing)	1170	129	91	334	13	27	77	0	240	2080
Printed textbook (high energy printing)	1170	129	91	871	13	27	77	0	240	2620

Table 4 Emissions of fossil carbon dioxide (in kg) from the studied web based electronic teaching aid scenarios. The contributions from the different processes as well as the total amount are shown.

	Formatting	Use of internet, Backbone	Use of internet, Access Techn	Distrib, Equipm	Use	Computer prod	Screen prod	Waste mngmt	Total
Web based electronic teaching aid (laptops)	0.75	31	0.38	169	8770	14980	0	-185	23800
Web based electronic teaching aid (desktops & screens)	0.75	31	0.38	1070	29870	25530	10180	555	67200

The study shows that, with the given prerequisites, the impact on global warming of a web based electronic teaching aid is approximately 10 times higher than the environmental impact of a printed textbook, if a low energy computer equipment scenario (with lap tops) is used. If a high energy computer equipment scenario is used (with desktops and LCD screens), the impact is nearly 30 times higher for the web based electronic teaching aid compared with the impact of the printed textbook.

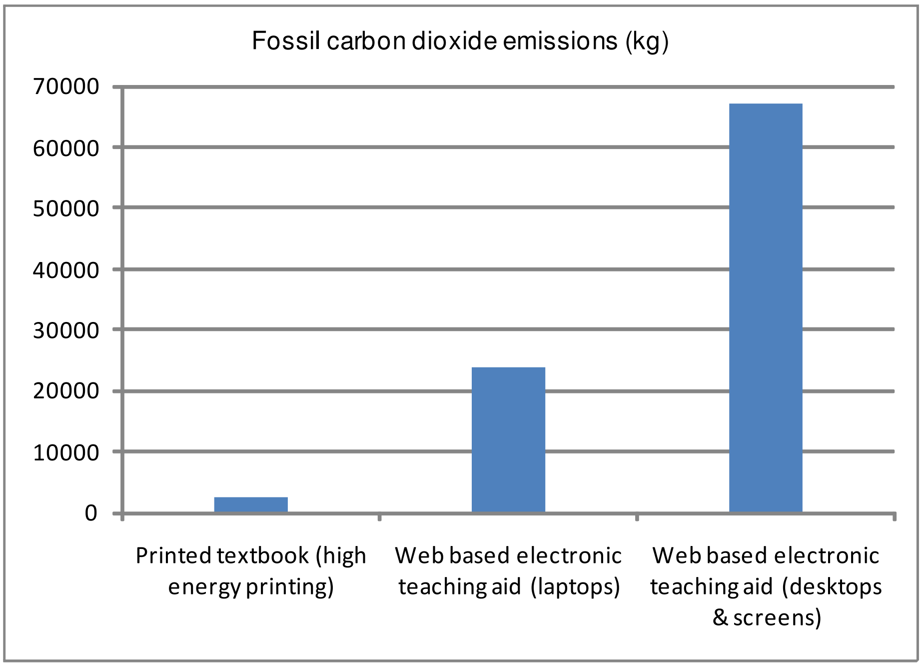

Figure 5 Total fossil carbon dioxide emissions (in kg) for the main alternatives of teaching aids studied.

4. Discussion

In comparing studies like this it is always important to take the function of the products, in this case different types of teaching aids, into consideration. With different character of the products it can be difficult to find comparable functions. This study does not illustrate how the different teaching aids influence the study results of the pupils. It can be claimed that printed and electronic teaching aids have different strengths and therefore somewhat different use and target groups.

The study shows possible improvements within the different products systems. For the printed product it is important to choose environmentally adapted papers and to optimise the use of energy in the printing process. For the electronic information product, the study shows that the production of electronics and the use phase are comparatively energy intense. To develop and choose energy efficient equipment are therefore of great importance. In this case, so called e-book reader devices which need substantially lower energy during use, will therefore be of great interest in the future. Very promising results for e-book reader devices are for example described by Kozak (2003) and Moberg et al (2007). Notable for all energy intense activities is that the mix of energy sources when producing electricity has a great influence on the global warming potential.

A limitation of the study is that it focuses on only one impact category, global warming. The reason for this is the large general interest in this environmental task and a possibility to delimit the screening study. Besides, global warming has earlier shown to be a significant aspect of media products and energy intense products. However, other environmental impacts have to be analysed as well, where toxicity is especially important to mention.

The biogenic carbon dioxide is defined as zero in this study, which means that no specific attention has been made to carbon sequestration in forests or carbon stored in forest products. With a life cycle perspective of products, these aspects are assumed to be of limited importance for this study.

The environmental effects of the use of internet infrastructure are not yet very much studied and data are scarce. There is a need for more studies in this field, especially since the development of techniques is intense. In this study energy intensity data from Moberg et al (2008) is used. These data can be compared with data given by Taylor and Koomey (2008) which is higher and data given by Schmidt and Kløverpris (2009) which is somewhat lower. There are still large uncertainties about the energy use of internet infrastructure and other networks as well as how to allocate the energy use between different services such as data, television and voice calling. Nevertheless, it is interesting to start estimating the environmental effects of information and communication technologies (ICT).

In this study, the use of internet is not so large since it is assumed that only ten different schools are downloading the teaching aid material from internet once a year during the period of five years which is studied. The picture will be different if every user has to download the material themselves.

5. Conclusions

The study shows that the impact on global warming of a web based electronic teaching aid is approximately 10 times higher than the environmental impact of a printed textbook, if a low energy computer equipment scenario is used. If a high energy computer equipment scenario is used, the impact is nearly 30 times higher for the web based electronic teaching aid compared with the impact of the printed textbook.

A reason for this is that a textbook is used for a long time by many users. This makes this type of printed product relatively energy effective and therefore it has a fairly low impact on global warming.

6. Acknowledgements

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