Environmental Impact Assessment Review 30 (2010) 177–191

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Printed and tablet e-paper newspaper from an environmental perspective — A screening life cycle assessment

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ARTICLE INFO

Article history:
Received 18 December 2008
Received in revised form 2 July 2009
Accepted 2 July 2009
Available online 26 August 2009

Keywords:
Life cycle assessment
Newspaper
E-paper
Multichannel
Reading tablet
Electronic media

ABSTRACT

Viable alternatives to conventional newspapers, such as electronic papers, e-papers or e-readers, are intended to have many of the qualities of paper, such as reading using reflective light, high resolution, 180° viewing angle. It has been suggested that the environmental impact of e-paper can be lower than for printed and internet-based newspapers. However, in order to find the facts of the matter, a thorough life cycle perspective covering raw material acquisition, production, use and disposal should preferably be used to study the environmental performance of the different products. A screening life cycle assessment was performed to describe the potential environmental impacts of two product systems; printed on paper and tablet e-paper newspapers. Results show that the most significant phase of the life cycle for both product systems was the production of substrate or platform. Accordingly, key aspects that may affect the resulting environmental performance of newspaper product systems were for the printed newspaper number of readers per copy and number of pages per issue and for the tablet e-paper newspaper lifetime and multi-use of the device. The printed newspaper in general had a higher energy use, higher emissions of gases contributing to climate change and several other impact categories than the tablet e-paper newspaper. It was concluded that tablet e-paper has the potential to decrease the environmental impact of newspaper consumption. However, further studies regarding the environmental impact of production and waste management of electronic devices and internet use, as well as more comprehensive assessment of toxicological impacts are needed. As the data on the electronic devices becomes more comprehensive this may prove to be a major limitation of electronic newspaper systems. Developers are suggested to strive towards minimisation of toxic and rare substances in production.

1. Introduction

New products and services are constantly developed. In the media sector, new channels for better providing content are tried, both with current readers but also with new target groups in mind. Sometimes there is a genuine need, sometimes it is part of the on-going competition for users, consumers and advertisers. Content can today be accessed via television, computer, printed media, mobile phone and in some cases via electronic paper devices. Financial issues are at the front of the competition — who will get the most out of the market? The consumers and their preferences and choices are investigated and acted on. The pros and cons of the different media are considered. During the last decade or so, device manufacturers have sought to provide a reading experience more similar to that of reading printed material, a development leading to a number of electronically distributed electronic paper devices or e-papers. For the end-user, viable alternatives to conventional newspapers have been available for roughly three years. Flemish daily De Tijd was the first occurrence of an e-newspaper, using the iRex iLiad device in February 2006 (http://www.tijd.be) and the first consumer product was the Sony PRS-500, launched in September 2006. The devices are often referred to as electronic papers, e-papers or e-readers. These products are intended to share many of the qualities of paper, such as reading using reflective light, high resolution, 180° viewing angle and high contrast. These properties, along with notably low-power consumption, distinguish

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0195-9255/$ – see front matter
doi:10.1016/j.eiar.2009.07.001

the e-paper displays from other devices which rely on traditional display technologies, carrying LCD, OLED, CRT or plasma screen components (see e.g. Senarclens de Grancy, 2008). Apart from the display itself, the e-paper device consists mostly of standard components, such as plastic housing, low-power one-chip microprocessor, rechargeable battery, controller boards and implements for navigation; e.g. buttons, jog wheels, and joysticks.

The tablet e-paper newspaper seems favourable also from an environmental point of view. If it is used instead of a printed newspaper, the paper material (substrate), offset printing, mail room operations, physical distribution of the printed newspaper, etc. can be avoided altogether. The e-paper device has substantially lower energy use during down-loading and reading compared with using a computer for reading newspapers on the internet. Thus, it has been suggested that the environmental impact can be lower than for printed and internet-based newspapers. However, Berkhout and Hertin (2004) discussing environmental impacts of information and communication technologies (ICTs) come to the conclusion that generally the use of these technologies lead to both positive and negative environmental impacts. A life cycle perspective should be used to study the environmental performance of the products. In this way, shifts of environmental impacts from one part of the life cycle to another can be identified, as well as possible trade-offs between different environmental impacts.

Several studies have been made of the environmental impact of printed media and paper (e.g. Axel Springer Verlag AG, Stora & Canfor, 1998; Axelsson and Dalhielm, 1997; Johansson, 2002; Larsen et al., 2006). Internet-based newspaper reading or reading from PDAs (personal digital assistants) have been compared to reading of printed newspapers in previous studies (Hischier and Reichart, 2001; Toffel and Horvath, 2004; Yagita et al., 2003). In addition, other kinds of information in printed or electronic form have been compared from an environmental perspective. Gard and Keoleian (2003) studied digital and printed journal articles and Kozak (2003) printed scholarly books and e-book reading. Many of the studies comparing electronic reading with reading printed matter have focused on energy or climate change (e.g. Gard and Keoleian, 2003; Kamburow, 2004; Yagita et al., 2003). The results indicate that the reading time for internet-based newspapers is crucial (Hischier and Reichart, 2001; Yagita et al., 2003). The number of unique readers has been shown to influence the environmental performance (Gard and Keoleian, 2003). Studies on e-paper include a German study focusing on the cumulative energy use for the three product systems printed, online and e-paper newspaper using a life cycle perspective (Kamburow, 2004). A Canadian life cycle assessment (LCA) study covering printed newspaper and e-paper newspaper was presented by Trudel at a life cycle management conference in 2007, but the study has not been published so far (Trudel, 2007). The field of study is thus still rather new, especially concerning the use of e-paper devices, and more research is needed to describe the environmental consequences of new ways of distributing and obtaining news or other information.

2. Method

2.1. Aim and scope

The aim of the current paper is to describe the potential environmental impacts of the two product systems printed newspaper and tablet e-paper newspaper and analyse the environmental aspects of e-paper compared to printed newspapers. The paper is a further elaboration of a technical report (Moberg et al., 2007a) which was also presented at the 34th Iarigai conference on Advances in Printing and Media Technology (Moberg et al., 2007b).

A screening life cycle assessment was performed. A full LCA can be time consuming and resource extensive. Instead of starting with a full LCA, an alternative approach can be to perform a so called screening LCA to identify the most important aspects of the studied system. If requested, more detailed studies can then be directed to these important aspects (Lindfors et al., 1995). A screening LCA is usually performed using readily accessible data. Since the aim is to identify the most important processes, data quality is of less importance than in a full LCA. However, it is important to include all processes and materials that can be of major importance, if some processes or materials are known to be of minor importance, they can be excluded.

Information from Sundsvalls Tidning (ST) was used partly as inspiration, as this Swedish newspaper has been produced and distributed as a printed newspaper, a tablet e-paper newspaper as well as an internet-based newspaper. ST has performed a full-scale test with an iRex iLiad e-paper device, and was thus able to provide important input. Part of the newspaper data defining the two product systems studied was obtained from ST, for example edition and number of readers, whereas other data were from other sources, for example distribution of printed newspapers and number of pages. Data from ST were obtained through personal communication with Svenåke Boström at ST (2006).

The study performed was comparative and attributional rather than consequential, studying the environmental impacts of the respective system as they are rather than the consequences of a choice between them (Rebitzer et al., 2004). In line with the methodology for attributional studies average data, and not marginal, were used.

The scope of the study was firstly to study a newspaper from a European perspective, with European electricity mix and waste flows, etc. In addition, a Swedish scenario was tested where the electricity mix, waste management and distribution of printed newspaper were altered.

The functional unit of the study was ‘the consumption of a newspaper during one year by one unique reader’. The two product systems were studied separately and no combinations were made within the scope of this study (e.g. reading of a tablet e-paper newspaper combined with a printed version).

Several different environmental impact categories were assessed; resources used (non-renewable, renewable and total), acidification, climate change, eutrophication, photochemical oxidant (photo-oxidant) formation, ozone depletion and toxicity based on Guinée (2002) and Finnveden and Östlund (1997). The greenhouse gas emissions of the climate change impact category were assessed without including biogenic carbon dioxide uptake or emissions, assuming this to be adding up to zero with a life cycle perspective.

In addition to the results for each impact category, two different kinds of weighting methods were used; Ecotax 02 (Finnveden et al., 2006) and Eco-indicator 99 (Goedkoop and Spriensma, 2000). Ecotax 02 is a monetary method where the weighting is based on environmental taxes and fees in Sweden. The unit is SEK, the Swedish currency. The Ecotax method has two alternative weighting factors, minimum (min) and maximum (max), representing the span of taxes and fees on various substances within the same impact category. Eco-indicator 99 is a method where three damage categories are weighted: ecosystem quality, human health and resources. To deal with the fact that damage modelling and weighting implies value choices and that there will always be different points of view influencing these, the Eco-indicator 99 have developed three different perspectives of the methodology, using the archetypes hierarchist, individualist and egalitarian as described in Cultural Theory. In our study we used the default recommended version with a hierarchist perspective.

2.2. Studied systems

In the screening LCA performed, the studied systems included activities from the cradle to the grave. For the printed newspaper this meant that forestry, pulp and paper production, editorial work, prepress, printing and distribution of the newspaper were covered, including the production of supply material (Fig. 1). The waste management of the waste newspaper was also covered. For the tablet e-paper newspaper the production of the tablet e-paper device, editorial work, distribution

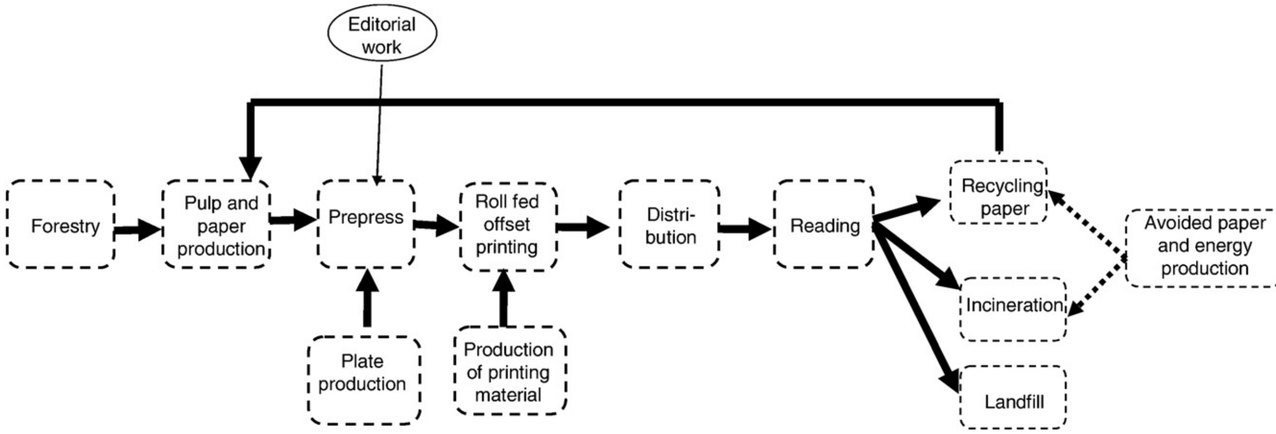

Fig. 1. Simplified flow chart of the printed newspaper life cycle.

via internet (assumed direct transmission to the e-paper), use phase (reading on screen) and waste management of waste tablet e-paper device were within the system boundaries (Fig. 2). Transportation in different stages of the life cycles was also included.

Most of the data used were from the database Ecoinvent 1.2 as provided in GaBi 4.112 (PE International software tool). Some of the inventory data for printing were derived from earlier studies at STFI-Packforsk (e.g. Axelsson and Dalhielm, 1997; Strömberg, 1998). The tablet e-paper device was modelled (screening) by LBP (Lehrstuhl für Bauphysik) at Stuttgart University, mainly based on data from the GaBi 4.112 database. Data are valid for roughly 2002, with some datasets older and some more recent. For a full list of references, see Moberg et al. (2007a).

The results presented in this paper are describing newspaper consumption in a European and a Swedish scenario, respectively. This means that the newspaper company and the reader were assumed to either be European and European energy mixes and waste management practices were used or, in the other scenario, data used were more reflecting Swedish conditions specifically using a Nordic energy mix and Swedish waste management practices. In addition, assumptions on distribution of printed newspaper differed between the scenarios where the European scenario was modelled with a more urban distribution (less transport per newspaper). The electronic equipment was assumed to be produced in China and transported to Europe by ship and truck.

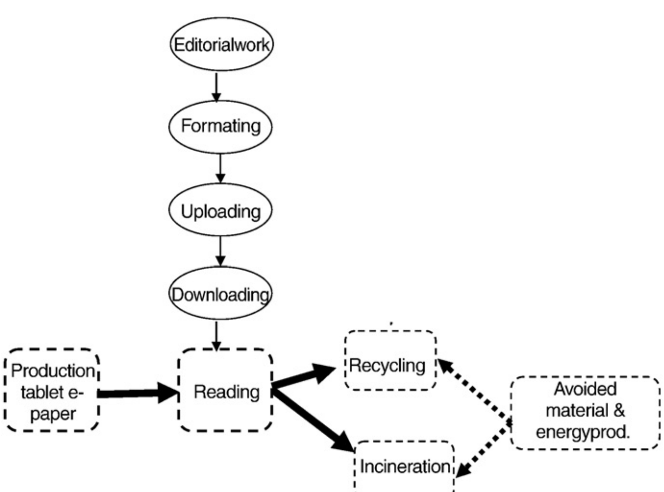

Fig. 2. Simplified flow chart of the tablet e-paper newspaper life cycle.

3. Inventory

3.1. Content production

The basis of a newspaper is the content. The inventory data available for content production covered energy use for editorial work only (electricity and heat): 6480 MJ/edition, and were taken from another, smaller newspaper (15,000 copies and 28 pages) (Lindblad, 2001). Data are fairly complete but some aspects are missing on e.g. journalists' fieldwork. Content production (editorial work) was allocated equally between each unique reader, independent of the newspaper version. The total number of unique readers of the newspaper was assumed to be 86,000/day (printed, internet-based and tablet e-paper newspaper readers).

3.2. Printed newspaper

The printed newspaper studied is described in Table 1. The printed newspaper was assumed to have 40 pages in tabloid format and 32,000 copies printed per day, quite typical for an average provincial newspaper in the Nordic region. Each copy of the newspaper is in average read by 2.4 readers. The paper used was assumed to be European average 45 g/m^2 mechanical pulp and DIP (de-inked pulp)-containing newsprint and the data used for pulp- and paper production represent data for an average integrated mill in the year 2000 (Ecoinvent 1.2). Data on printing and prepress were mainly from STFI-Packforsk sources (see Moberg et al. 2007a). Data from an internal STFI-Packforsk database gave an estimation of fuel consumption for urban distribution of 0.0043 l fuel/newspaper used in the European scenario and for rural distribution 0.015 l fuel/newspaper used in the Swedish scenario. The waste management of the waste newspaper was in the European scenario modelled as 60% to material recycling, 30% to landfill and 10% to incineration with energy recovery (CEPI, 2006) and in the Swedish scenario 80% to material recycling and 20% to incineration with energy recovery (FTI, 2007).

3.3. Tablet e-paper newspaper

Tablet e-paper newspaper is a product still under development. Data for this product system was therefore relatively hard to access within the scope of the study and assumptions and estimations had to be made to a larger extent. The tablet e-paper newspaper studied is described in Table 1. The data on readers per day was an approximation of a probable scenario in five years, based on discussion with Svenåke Boström at ST. Technical data regarding the e-paper device relate to the iRex iLiad tablet e-paper device as used by Sundsvalls

Table 1
Description of the newspaper product systems studied.

Parameter	Printed newspaper	Tablet e-paper newspaper
Edition	32,000 copies/day, 6 days/week	7 days/week
Size	40 pages, tabloid format ($40 \times 28\,cm^2$)	5 MB/day (2.5 MB two times per day)
Number of readers	76,000 unique readers/day (2.4 readers per copy)	2000 unique readers/day
Paper	45 g/m^2 DIP-containing newsprint	
Up-loading speed (server)		3 MB/s (24Mbits/s), (0.0025 MB/day and reader)
Internet		Modem 9 W Core network 3 Wh/MB
E-paper power (down-loading)		0.75 W
Down-loading speed		0.25 MB/s (2 Mbits/s)
Power (reading)		Tablet e-paper 0.001 W
Reading time	30 min/day (not considered in the study)	30 min/day (50% of total use)
Use for other purposes		30 min/day
Life time of electronic product		1 year

Tidning in their test. General information regarding their device was provided by iRex Technologies (Leurs, personal communication 2006 and 2007). For the production of the tablet e-paper, information on the composition was used, and for the PWBs the component mix was taken from the electronic component configuration of a personal computer motherboard. There was no data on the production of the Eink e-paper available.

The e-paper newspaper is sent, from a server to the readers. The e-paper edition is published directly to the unit using wireless LAN, not routed via a PC or laptop. Technically, in the case of Sundsvalls Tidning the document is published by Sundsvalls Tidning to Irex on-line service in Belgium using FTP (file transfer protocol). When the user presses the "update" button on the Illiad unit, it invokes the on-board FTP client which connects to a server address which is hardcoded into the software. Typically, the iLiad is during installation configured with the user's WLAN settings, hence sharing the data channel (broadband or cable connection) as regular PCs in the home or office. In Moberg et al. (2007a) operation of the internet infrastructure was not included. In this paper an estimation is added, accounting for operation of modem (9 W), as well as energy use for core network (based on Taylor and Koomey, 2008).

The energy use of the modem allocated to the tablet e-paper newspaper is calculated as the energy used for down-loading, but also as a share of the stand-by energy use, assuming that the modem is not turned off when not in use. We have used Swedish figures on total internet use to indicate the total non-use time of the modem. According to Findahl (2007, p 35), the average internet user uses the internet 9.3 h/week (i.e. 80 min/day). In Sweden the average household is 2 persons (SCB, 2008). As the tablet e-paper newspaper needs internet 20 s/day 0.2% of the stand-by energy use was allocated to the tablet e-paper newspaper. The energy use for transmission of data is based on estimates made by Taylor and Koomey (2008), reflecting internet use in the U.S. during 2006. Taylor and Koomey suggest a span of 9–16 kWh/GB information sent, excluding end-use equipment (e.g. modem and PC or tablet e-paper device). This figure includes servers and data storage. In the present study energy use of servers at the newspaper company and iRex are covered to some extent already. 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). As the energy use at the newspaper company is an aggregated and uncertain figure for editorial work from 2001 and energy use of servers at iRex uncertain, the inclusion of energy use for servers was made in a sensitivity analysis (using 16 Wh/MB). In the specific case of Sundsvalls Tidning the e-paper newspaper is sent twice a day to the reader (2.5 MB each sending), this amount is used in the study.

The reading time, 30 min/day, was an assumption based on the reading time for printed newspaper (TU, 2006). A rough estimation of the time for other use of the tablet e-paper was 30 min/day. This other use could include reading e-books, e-documents, e-journals, etc. The use time is uncertain, since the tablet e-paper is not yet frequently used and information on user behaviour is not readily available. The assumption of product lifetime of one year is conservative, and is mainly based on the rapid development of this new product, resulting in an actual lifetime that is shorter than the technical lifetime. In addition, the assumption was made in order to avoid underestimation of the impacts of the e-paper device in relation to its use time. It can be assumed that the actual lifetime will increase as the e-paper device matures. A two year life time was tested in a sensitivity analysis. After disposal, 70% of the material is assumed to be recycled and 30% incinerated with energy recovery. This may be an overestimation of recycling and an underestimation of landfill. No readily available data on recycling of electronics was available at the time of the study and data on the recycling process is missing. The incineration is modelled as incineration of plastics from consumer electronics (using data from Ecoinvent 1.2).

4. Results and discussion

4.1. Comparison of printed and tablet e-paper newspaper

In Figs. 3 and 4 a comparison is made between the two media. In the comparison the printed newspaper is compared to the tablet e-paper newspaper with a life time of one year and with lower internet energy use, as described above. All results of the comparison are shown as relative values. The printed newspaper in the European scenario is set to 1 and the others are illustrated in relation to this. The actual values for each impact category can be found, for the tablet e-paper newspaper in Figs. 5–20 and for the printed newspaper in Moberg et al. (2007a).

In the European scenario the printed newspaper gave rise to a higher potential impact in all impact categories studied (Fig. 3). In the Swedish scenario the printed newspaper gave rise to a higher potential impact in all impact categories studied but one, the marine aquatic ecotoxicity (Fig. 3). The potential impact of the tablet e-paper newspaper was less than half of the printed version for total energy use, eutrophication, photochemical ozone creation and for aquatic and terrestric ecotoxicity in both the European and Swedish scenario.

The total weighted results, using Ecotax02 min, Ecotax02 max and Eco-indicator 99 (Fig. 4), in the European scenario indicated that the tablet e-paper newspaper would be environmentally preferable to the printed newspaper. In the Swedish scenario, the Ecotax02 min and Eco-indicator 99 weightings resulted in the preference of tablet e-paper newspaper while the Ecotax02 max weighting showed that the printed newspaper was preferable. The printed newspaper weighted result was, with Ecotax02 max, about 90% of the tablet e-paper newspaper result.

It can be questioned whether it is relevant to compare different media and if they really provide the same function and benefit (e.g. Holmqvist et al., 2003; Holsanova and Holmqvist, 2004). The issue of utility and function is in many cases not exactly the same as products and services are developed or provided in different ways (Hischier and Reichart, 2003). Anyway, the comparison is made to give an estimate of the relation between the environmental performances of the different versions of a newspaper.

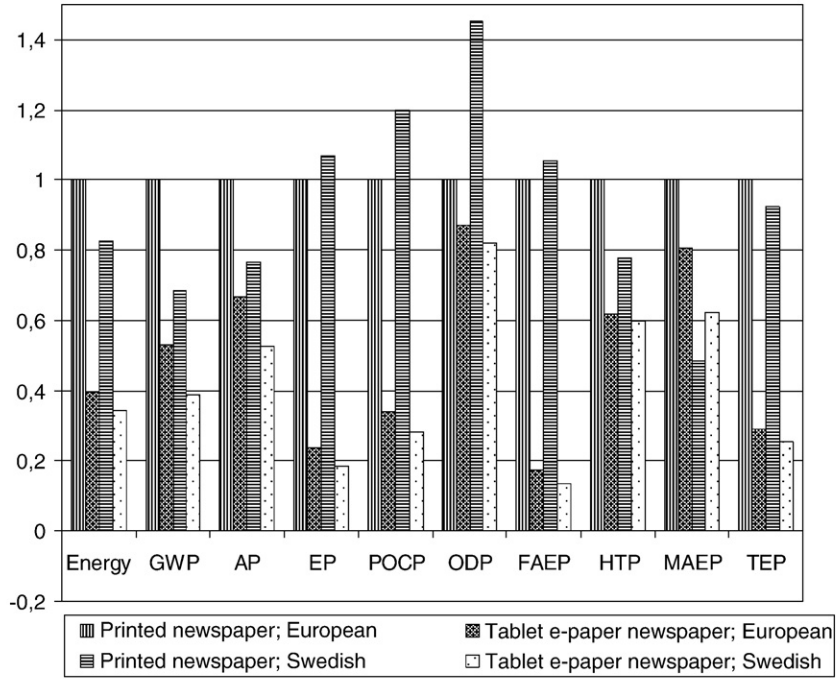

Fig. 3. Comparison of the two different media: printed newspaper and tablet e-paper newspaper in a European and Swedish scenario respectively. The environmental impact of the printed newspaper in the European scenario is set to 1 and the other product systems' environmental impacts are illustrated in relation to that. The impact categories are abbreviated; Energy: Cumulative energy demand; GWP: Global warming 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; TEP: Terrestric ecotoxicity potential.

4.2. Printed newspaper

The newsprint paper caused the main environmental impact of the printed newspaper in most impact categories, as illustrated for global warming potential in Fig. 5. In the European scenario the newsprint production is roughly 45% of the global warming potential. The paper, in the Swedish scenario, contributes to 40% of the total impact and distribution 30%. This is in line with previous studies, e.g. Enroth (2006) states that the use of paper (forestry, pulp and paper production) generally gives rise to 30–70% of the total

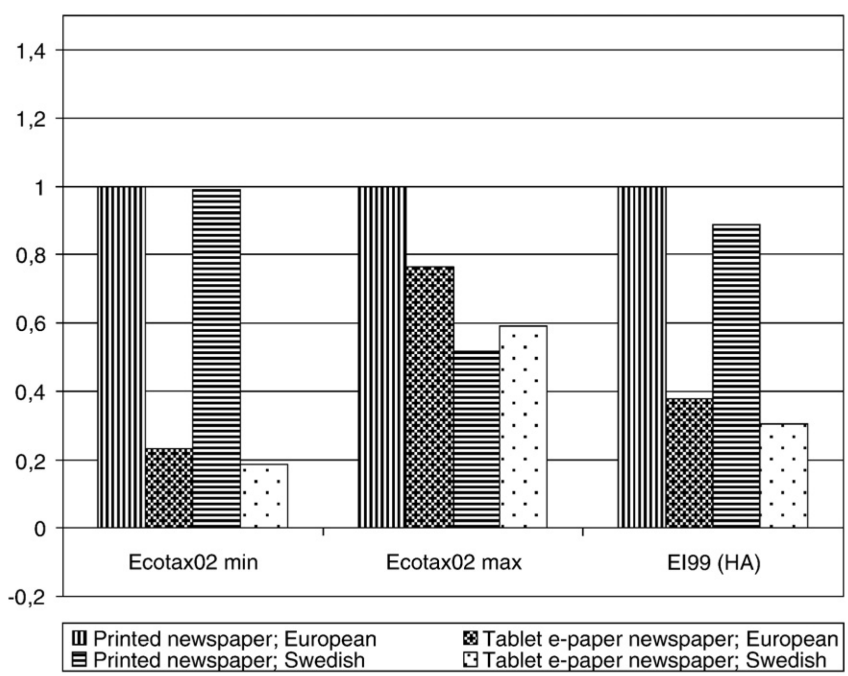

Fig. 4. Comparison of the two different media: printed newspaper and tablet e-paper newspaper in a European and Swedish scenario respectively. The environmental impact of the printed newspaper in the European scenario is set to 1 and the other product systems' environmental impacts are illustrated in relation to that. The results are weighted using Ecotax02 min and max version and Eco-inidcator 99 (HA).

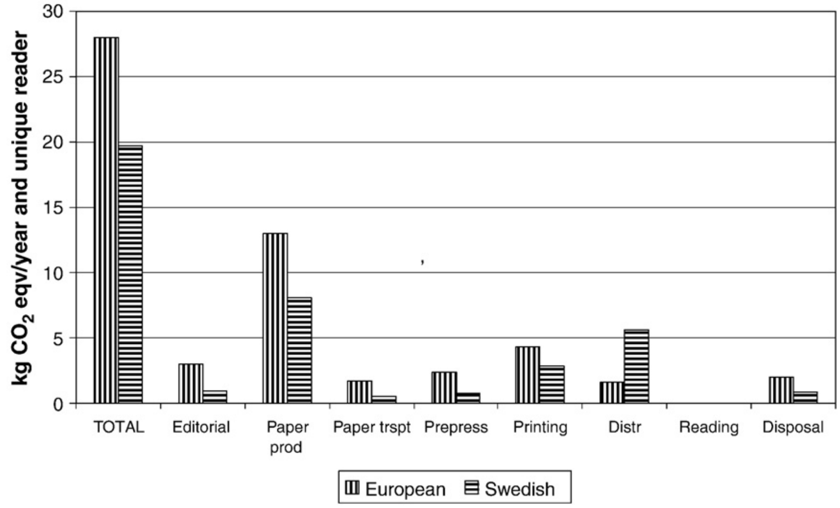

Fig. 5. The printed newspaper global warming potential in a European and Swedish scenario respectively.

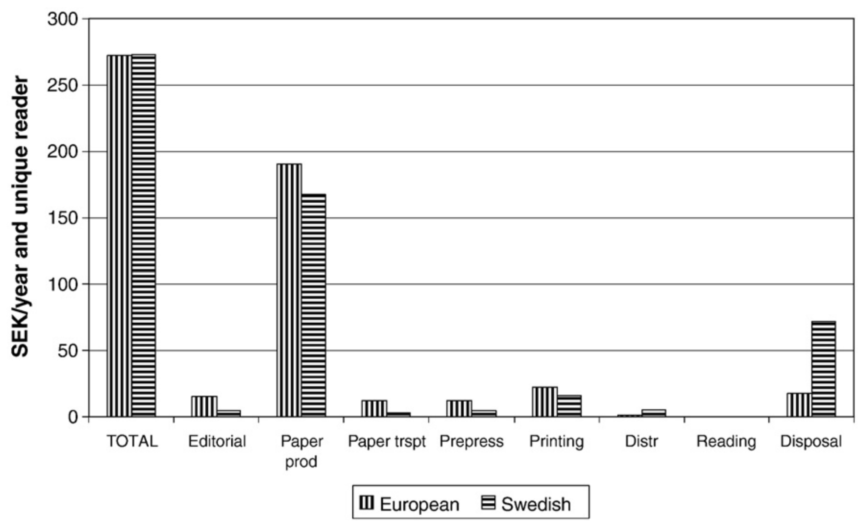

Fig. 6. The printed newspaper weighted values using the Ecotax02 min version weighting method in a European and Swedish scenario respectively.

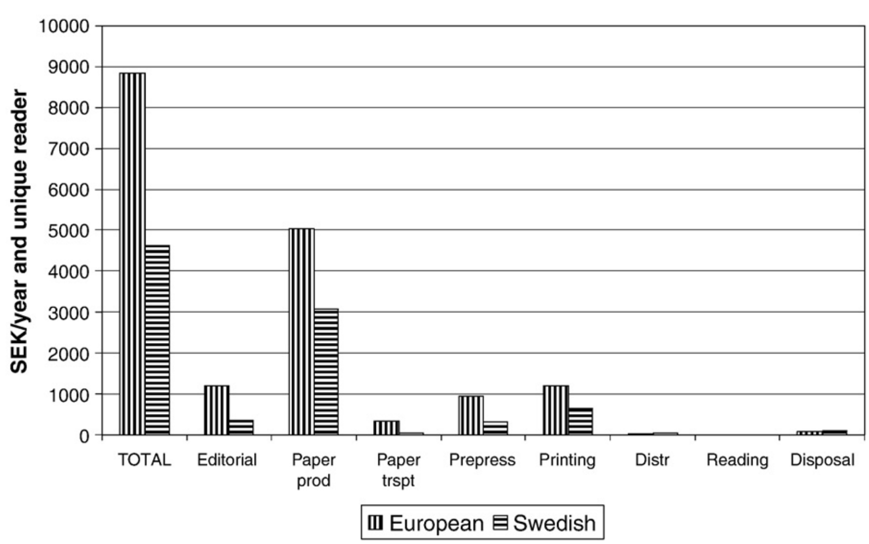

Fig. 7. The printed newspaper weighted values using the Ecotax02 max version weighting method in a European and Swedish scenario respectively.

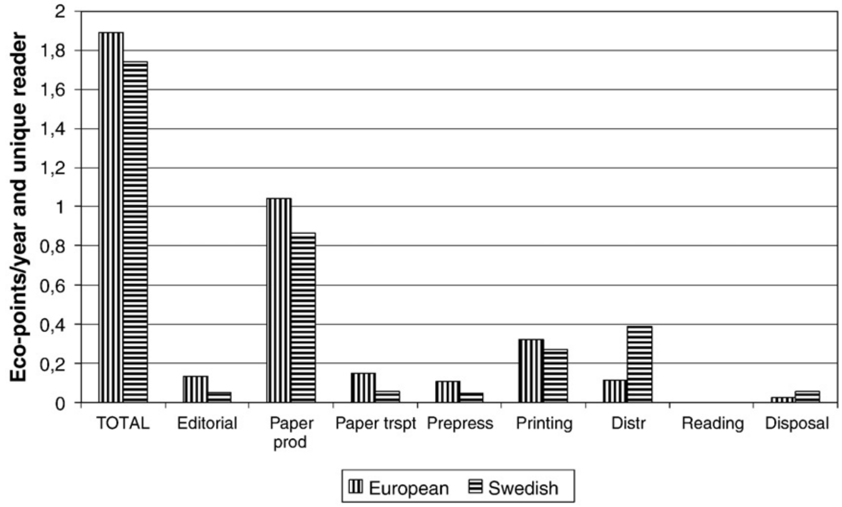

Fig. 8. The printed newspaper weighted values using the Eco-indicator 99 (HA) weighting method in a European and Swedish scenario respectively.

environmental impact of printed paper products. The magnitude of the impact from paper production varies between the impact categories (see Moberg et al., 2007a). In most cases, printing gave rise to the second largest impact in the European scenario, but several other activities gave rise to comparable impacts in several impact categories. In the Swedish scenario, distribution was a significant activity as well (e.g. Fig. 5).

It can be noted that the main reasons for toxicological impacts in the European scenario are due to emissions to air and water from electricity production. This can partly be explained by the high electricity use in mechanical pulping for newsprint production, but may also be a result of lack of data regarding emissions of toxicological substances in other processes and non-comprehensive characterisation methods. Larsen et al. (2006) in their LCA of sheet fed offset printing showed that printing had a large share of the total environmental impact, higher than paper. They explain their results, which differ from many previous studies, with a higher coverage of toxicological substances emitted from the printing process. The same detailed coverage had however not been made for the pulp- and paper production, etc. Larsen et al. (2006), in any case, show that more comprehensive inventories may lead to higher resulting environmental impact, especially for toxicological impacts.

Weighting the different environmental impacts into single values the results also show that the production of the paper gave rise to the main potential impacts (Figs. 6–8). Using the Ecotax 02 min method (Fig. 6), printing was the second most important activity in the European scenario and in the Swedish scenario the waste treatment. Distribution was not significant when Ecotax 02 methods were used (Figs. 6 and 7), at least partly due to toxic emissions missing to a large extent for the distribution inventory data. With the weighting method Eco-indicator 99, printing was second to paper in the European scenario and distribution in the Swedish (Fig. 8). One reason to the difference between the Eco-indicator 99 and Ecotax 02 weighted results in the case of distribution was that the Eco-indicator 99 weighted resource use relatively higher than toxicological issues compared to Ecotax 02.

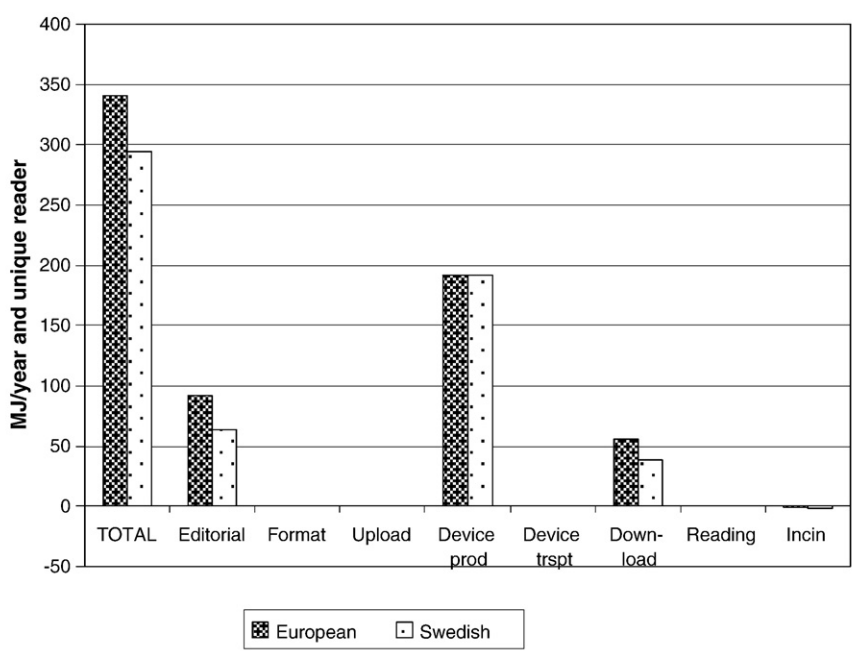

Fig. 9. The tablet e-paper newspaper total energy use (cumulative energy demand) in a European and Swedish scenario respectively.

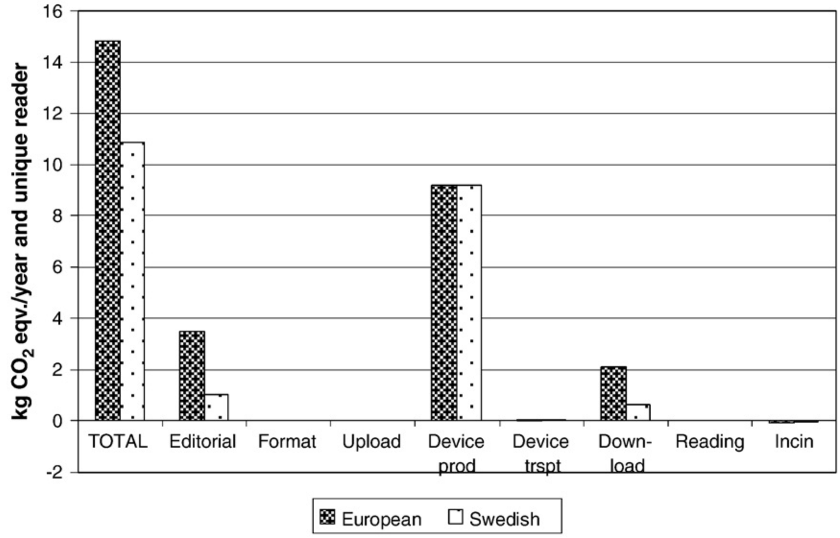

Fig. 10. The tablet e-paper newspaper global warming potential in a European and Swedish scenario respectively.

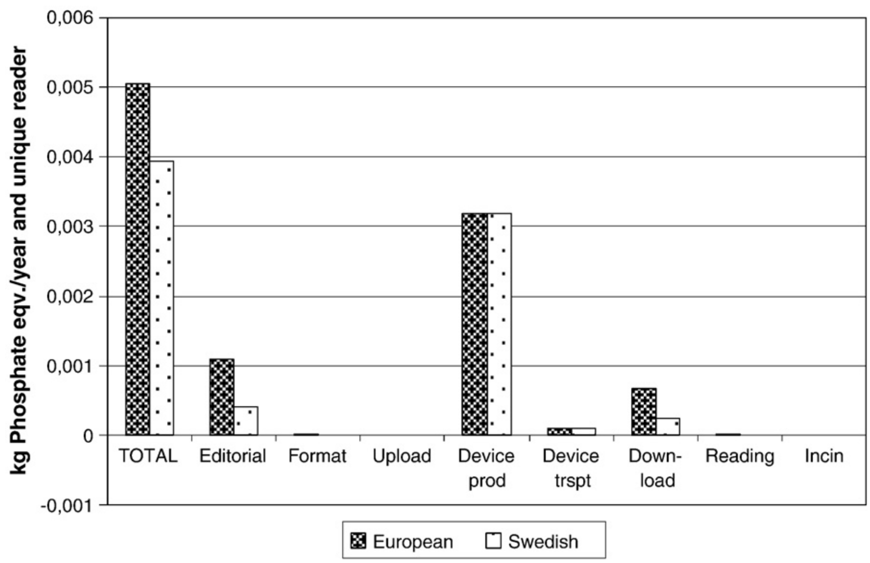

Fig. 11. The tablet e-paper newspaper eutrophication potential in a European and Swedish scenario respectively.

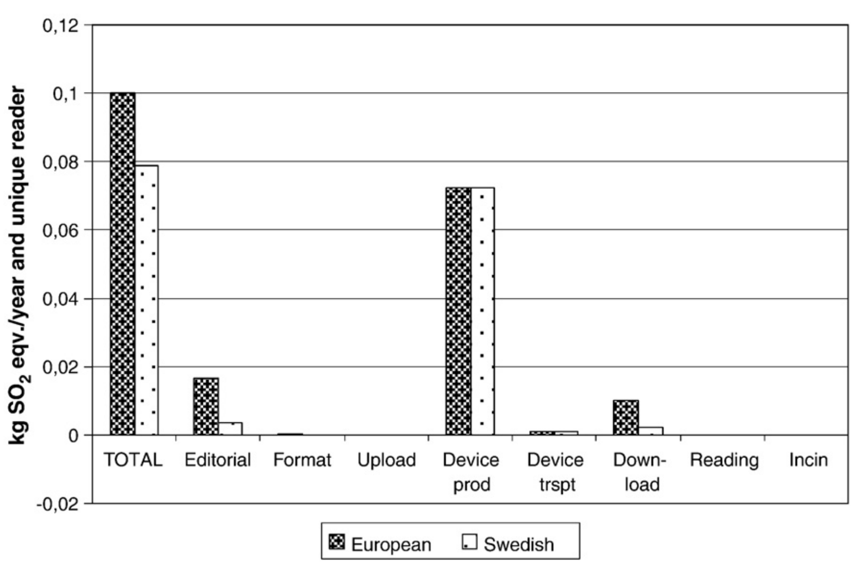

Fig. 12. The tablet e-paper newspaper acidification potential in a European and Swedish scenario respectively.

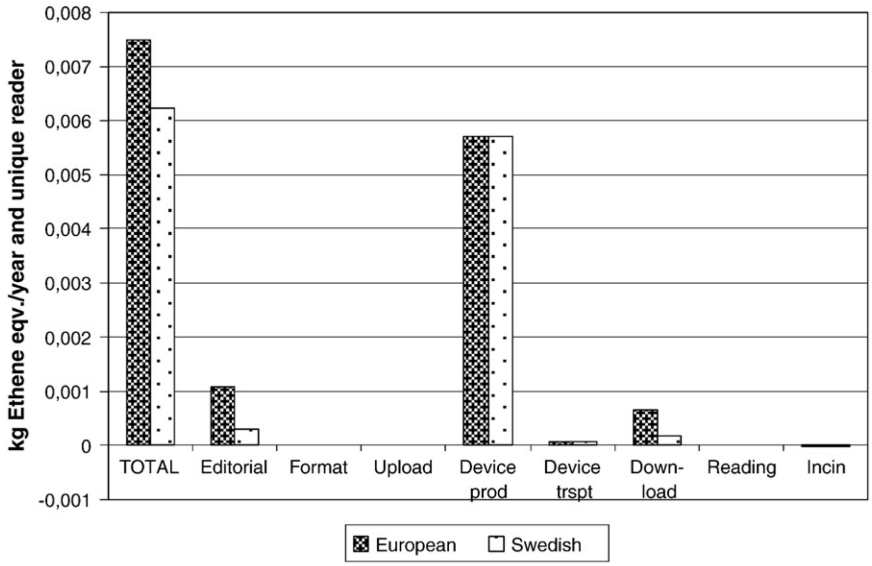

Fig. 13. The tablet e-paper newspaper photochemical ozone creation potential in a European and Swedish scenario respectively.

4.3. Tablet e-paper newspaper

4.3.1. Different impact categories and weighted results

For all impact categories, the production of the tablet e-paper device made up the largest part of the tablet e-paper newspaper life cycle (Figs. 9–18). For human toxicity potential, however, the waste treatment (incineration of plastics) was at the same level of impact in the Swedish scenario (Fig. 16). Even though the data on editorial work were limited the environmental impact of this activity is significant, especially in the European case (e.g. Fig. 10). The size of the potential impact caused by editorial work and down-loading are varying depending on the scenario, European or Swedish, as the impact is due to electricity use. In the Swedish the electricity mix is in general giving less potential environmental impact. The low energy use of the device makes the use phase (reading) less important than for example if using a computer and the significance of the editorial work in the tablet e-paper newspaper life cycle will be mainly dependent on the magnitude of environmental impact from production and waste management of the tablet e-paper device, as discussed below.

When weighting the results using Ecotax 02, min and max version, and Eco-indicator 99 the results were similar for Ecotax 02 max and Eco-indicator 99. In these weightings the tablet e-paper production made up the major part of the total weighted results and the rest was the editorial work, and to a smaller extent the down-loading (Figs. 20 and 21). In the Swedish case the dominance of the production was substantial. However, when the Ecotax 02 min weighting method was used in the European case editorial work, tablet e-paper device production and incineration gave rise to similar potential impact and the potential impact of down-loading was also significant (Fig. 19). In the Swedish case with the Ecotax02 min weighting incineration of waste plastic parts, e-paper production, editorial work and down-loading were giving rise to the total potential impact, in that order. This difference as well as the considerable difference in total weighted values using the Ecotax min or max versions (60 and 7000 SEK/unique

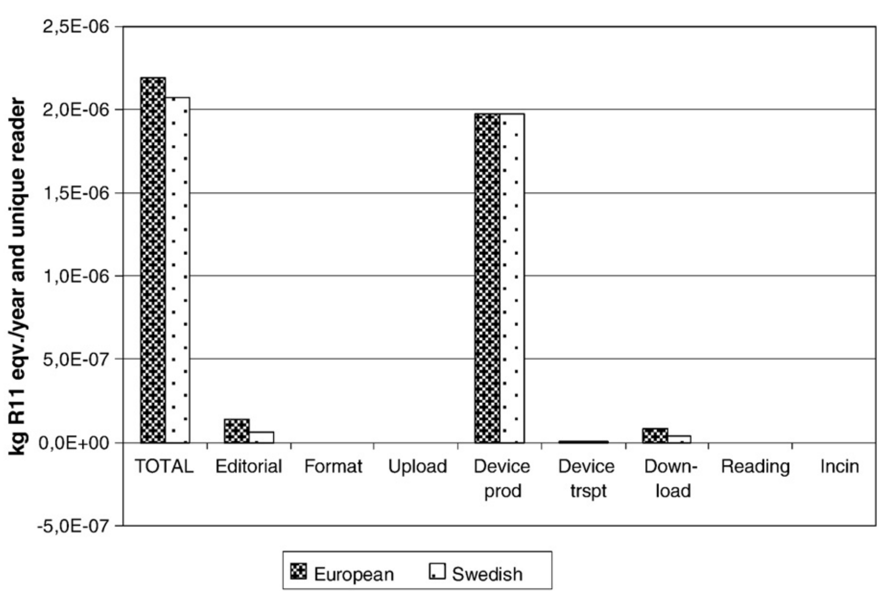

Fig. 14. The tablet e-paper newspaper ozone depletion potential in a European and Swedish scenario respectively.

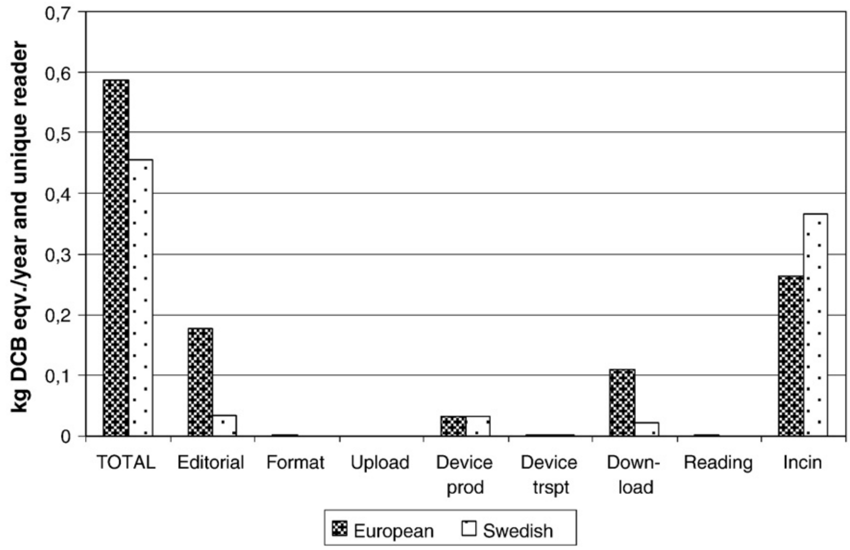

Fig. 15. The tablet e-paper newspaper freshwater aquatic ecotoxicity potential in a European and Swedish scenario respectively.

reader and year respectively) indicates the inherent uncertainty of weighting.

4.3.2. Life time and internet energy use — sensitivity analyses

To consider the effect of a couple of uncertain assumptions the lifetime and the internet energy use were varied, as illustrated in Figs. 22 and 23. A two year lifetime was tested as well as the higher end figure of internet electricity use (16 Wh/MB) which includes a considerable energy use for servers and data storage and is probably a major overestimation of energy use of this particular internet activity. As the e-paper production was a main part of the potential impact of all impact categories, the doubling of the life time results in a considerable decrease in potential impact. This decrease could also have been achieved through doubling the total use, assuming that the e-paper device was used for 2 h/day in total, whereof 30 min for newspaper reading. On the other hand a lower use rate, e.g. only using the tablet e-paper device when travelling, would lead to higher impact per time of use. The lifetime of two years as suggested in the sensitivity analysis is in line with the life time suggested by Behrendt (2004, as cited in Senarclens deGrancy (2008) for e-paper displays. Even though the data on the tablet e-paper production and waste management is uncertain it is clear that it is of major importance. As a consequence the life time and total use of the device is important as it decides the size of the potential impact allocated to each unit of use or service provided. In Figs. 21 and 22 the decrease in potential impact if a 2 year life time is assumed as illustrated for the European and Swedish scenario respectively.

With a considerably higher energy intensity of the internet the total impact of the tablet e-paper newspaper was significantly increased (Figs. 22 and 23). If such high energy intensity would be confirmed, the size of the electronic newspaper sent to the reader would be a crucial issue. As the tablet e-paper is sent directly from a newspaper company to a reader, in this case via one external server, there is limited use of servers. This would imply a larger probability for lower energy intensity of internet use. In the case of web-based newspapers a wider range of external servers may be connected to the site, e.g. web-TV and advertisement. In this case a higher energy use per MB may be more likely. The estimations made by Taylor and Koomey (2008) reflect 2006 conditions and as the amount of data has increased more rapidly than the energy use of the internet system, the

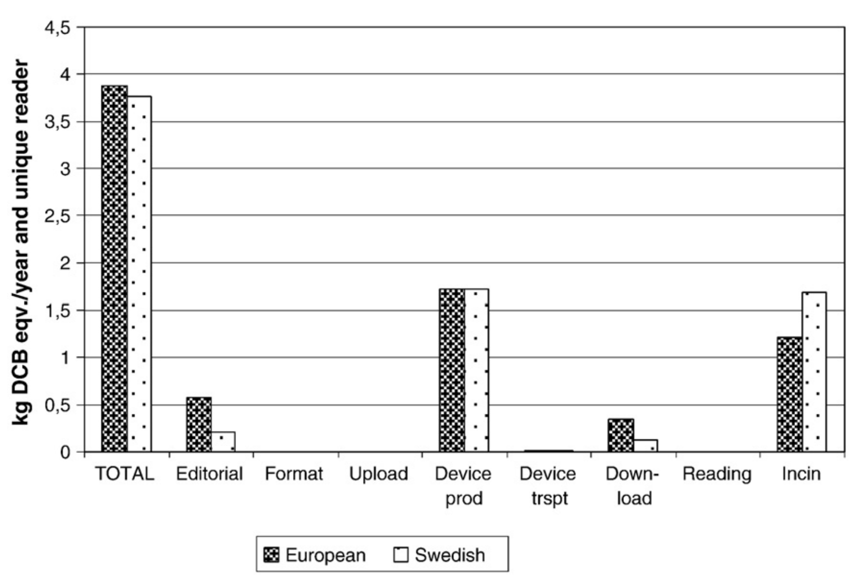

Fig. 16. The tablet e-paper newspaper human toxicity potential in a European and Swedish scenario respectively.

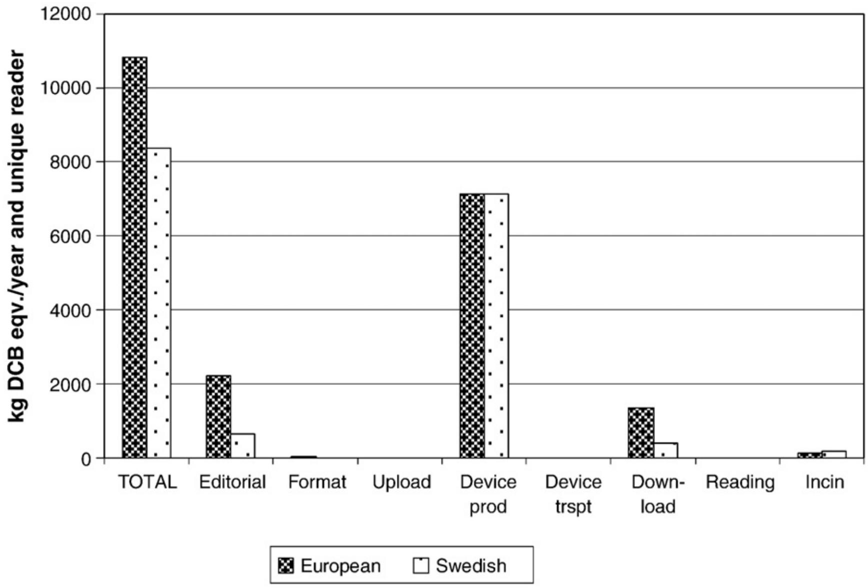

Fig. 17. The tablet e-paper newspaper marine aquatic ecotoxicity potential in a European and Swedish scenario respectively.

energy intensity will be lower for coming years (Malmodin, Ericsson Research, personal communication).

4.4. Comparison with previous studies

Most of the previous studies comparing printed and electronic newspapers have looked at web-based newspapers read from a computer screen (e.g Hischier and Reichart, 2001; Yagita et al., 2003). Hischier and Reichart (2001) in their comparison between printed newspaper, television and internet showed that using the internet for around 25 min or watching television for roughly 1.5 h gave an environmental impact of similar magnitude to that of a printed newspaper. Their results were presented as weighted values, using Eco-indicator 99. Yagita et al. (2003) compared printed and internet-based newspapers regarding CO_2 emissions, excluding waste treatment. With their assumptions the internet-based newspaper gave rise to lower CO_2 emissions than the printed version as long as the PC was not used for more than 1.4 h and 1.1 h/day for notebook and desktop respectively. Yagita et al. (2003) compared the printed newspaper copy with the internet-based newspaper and did not consider the possibility of more than one reader per copy. In Moberg et al. (2007a) the internet-based newspaper read for 30 min on a desktop computer was shown to have a similar environmental performance per unique reader as a 40 page printed newspaper.

Differences between internet-based news read on a computer screen and tablet e-paper newspapers relevant here include the power draw during use of the devices and the possibility to use the device for multiple purposes. An interesting device to study further would be the mobile phone. In a comparison by Kamburow (2004) the e-paper newspaper resulted in a larger cumulative energy use compared with printed and internet-based newspapers. The energy figure was roughly 5 and 25 times higher for the e-paper newspaper when the electronic news was distributed via the internet and UMTS (Universal Mobile Telecommunications System) respectively. Kamburow used a figure for primary energy for data transmission via the internet from Reichart and Hischier (2001), who in turn made own

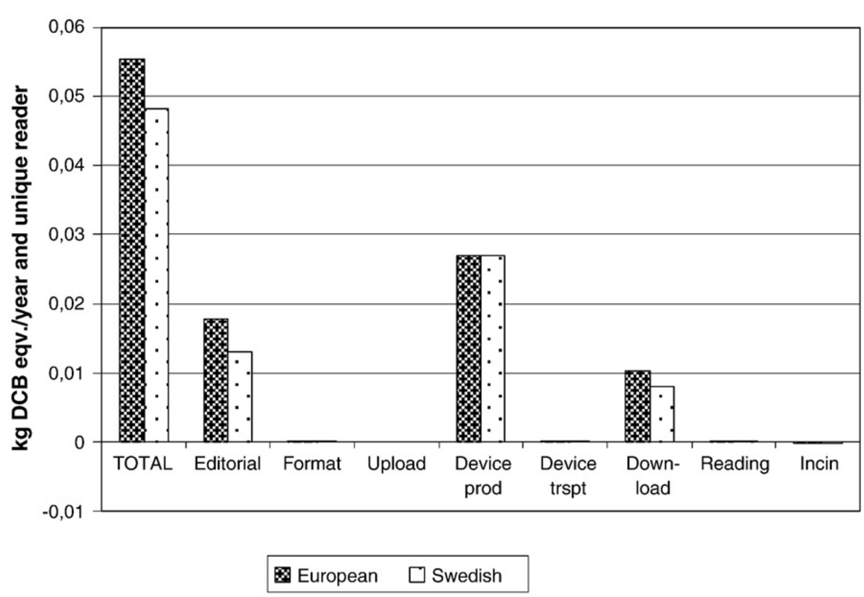

Fig. 18. The tablet e-paper newspaper terrestric ecotoxicity potential in a European and Swedish scenario respectively.

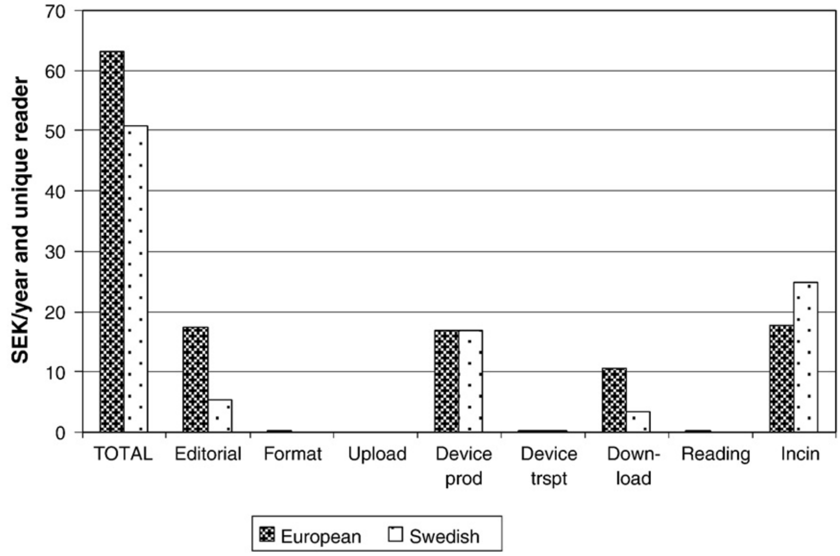

Fig. 19. The tablet e-paper newspaper weighted results using the Ecotax02 min version weighting method in a European and Swedish scenario respectively.

calculations partly based on information from the Swiss science network SWITCH (Reichart and Hischier, 2001). The figure, 1.1 MJ primary energy/MB, can be roughly estimated as an electricity use of 100 Wh/MB assuming a factor of 3 for primary energy. This can then be compared to the 9–16 Wh/MB suggested by Taylor and Koomey (2008), which explains part of the difference. Both Kamburow (2004) and Taylor and Koomey (2008) emphasise the roughness of their internet energy figures and the large uncertainties. Further, Kamburow performs sensitivity analyses showing that the distribution channel is important for the final results. Indicating that DAB (Digital Audio Broadcasting) and DVB-T (Digital Video Broadcasting Terrestrial) could be preferable to internet and UMTS. This illustrates clearly that there is a need for further research in this area.

4.5. Limitations and need for further research

In our study, screening data were used in some cases and some data were missing. The main inventory data lacking for tablet e-paper newspaper were material recycling of parts of the waste electronic devices, production of e-ink screen and construction of internet infrastructure. The component mix of the PWBs (printed wiring boards) was taken from the electronic component configuration of a personal computer motherboard. For material recycling the effect of the missing data is difficult to predict, but the potential impact would probably be a little lower, since virgin production of materials would be avoided. At the same time use of energy and chemicals as well as emissions of the recycling process would be added. Regarding the assumption on electronic components for the tablet e-paper, the effect on the results is hard to anticipate. Further and more detailed studies are needed. For the printed newspaper, data on the production of certain supply chemicals were missing. These missing data may have resulted in underestimation of the potential environmental impact.

It should be noted that the uncertainties are large for the toxicological impact categories. There are knowledge gaps, making it difficult to characterise toxicological impacts, and there are data gaps concerning toxicological emissions in the data inventories. It is still important to include toxicological impacts, but to be aware of the uncertainties. The importance of toxicological impacts from electronic

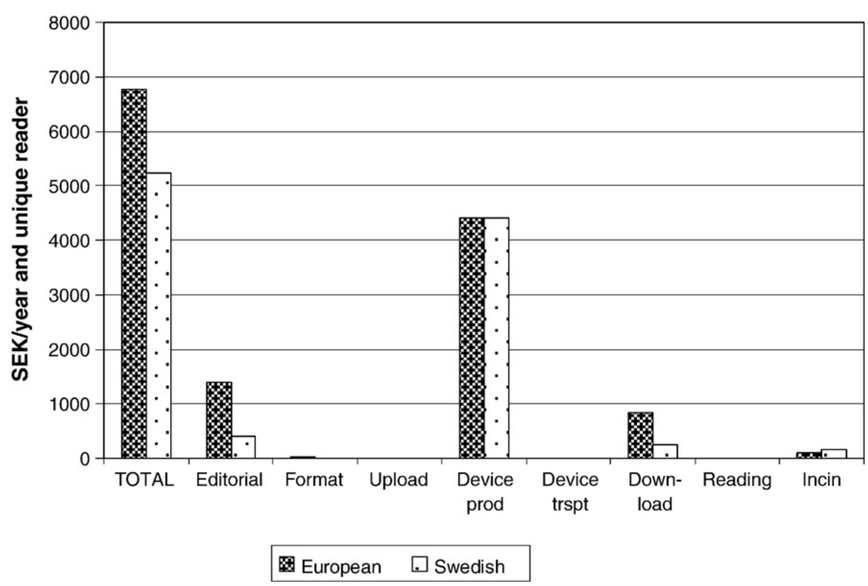

Fig. 20. The tablet e-paper newspaper weighted results using the Ecotax02 max version weighting method in a European and Swedish scenario respectively.

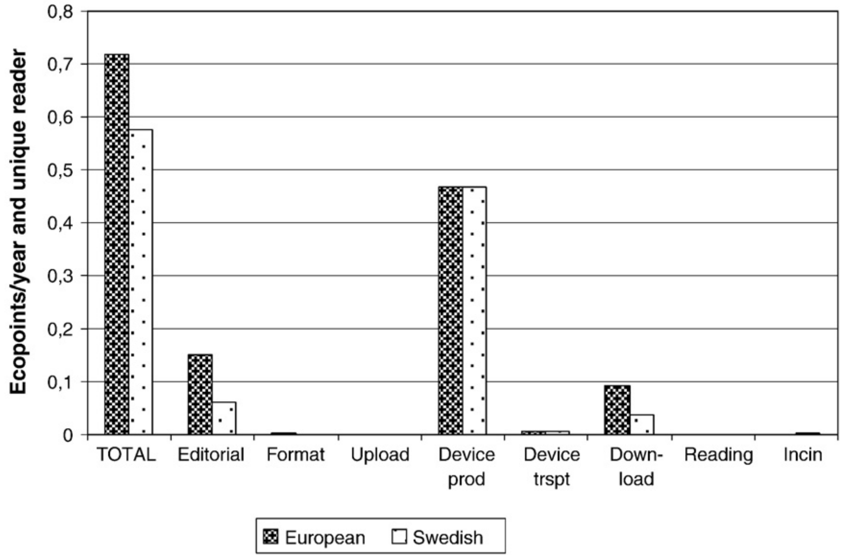

Fig. 21. The tablet e-paper newspaper weighted results using the Eco-indicator 99 (HA) weighting method in a European and Swedish scenario respectively.

equipment is illustrated by the results for the tablet e-paper where toxicological impacts from production of the device is the most important environmental aspect according to the Ecotax 02 max weighting method. Weighted results are inherently uncertain. Using different weighting methods within the same study illustrates this uncertainty and emphasises the need to interpret the results and consider underlying assumptions and data. The total weighted results of the two product systems consisted mainly of toxicological impacts when Ecotax 02 was used, but when Eco-indicator 99 was used the main impact category was resources (fossil fuels) and human health (respiratory). Different categories of toxicological impacts were significant with the different versions of Ecotax 02 (min and max) and the total weighted values differed considerably. This illustrates both the inherent uncertainty of weighting and the uncertainty regarding toxicological impacts.

The importance of behavioural aspects are illustrated in this study, e.g. in the importance of the total use time and life time of the e-reader and the number of readers for the printed newspaper. The actual environmental impact will also be determined by the use of the consumers and whether a tablet e-paper will replace the printed newspaper or if they will be combined and both are used. This would need to be further studied.

There are still few studies on the environmental impact of internet use. With large amounts of data sent to an efficient and frequently used device, this may be relevant to consider as discussed above. Other types of distribution systems would also be interesting to study further, e.g. mobile communication networks.

5. Conclusions

The results presented here show that the most significant phase of the life cycle for both product systems was the production of substrate or platform (the paper and the tablet e-paper device respectively). Accordingly, key aspects that may affect the resulting environmental performance of newspaper product systems were for the printed newspaper number of readers per copy and number of pages per issue and for the tablet e-paper newspaper lifetime and multi-use of the device. Another key aspect when comparing printed and electronic

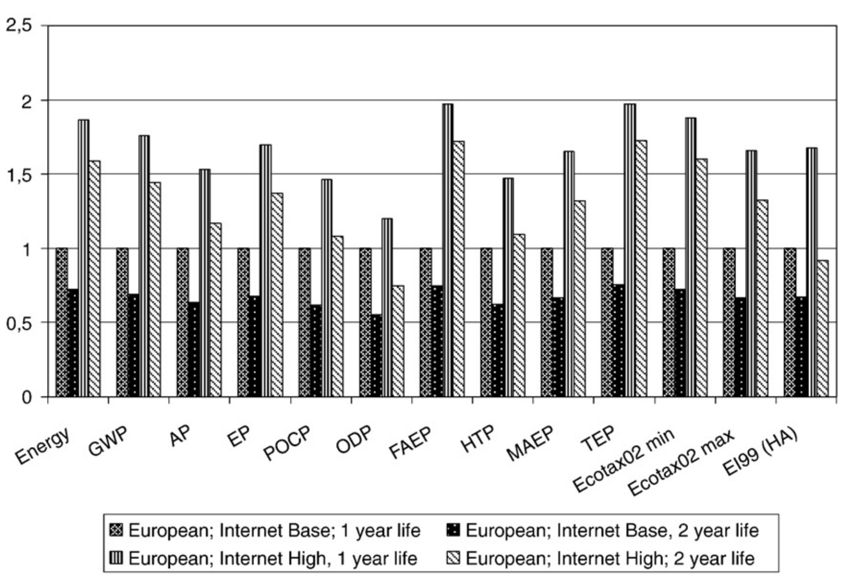

Fig. 22. Sensitivity analysis concerning the life time of the tablet e-paper device and the energy intensity of the internet. The effect of the changed assumptions in the European scenario is illustrated in relation to the environmental impacts of the base scenario, which are set to 1. The impact categories are abbreviated; see Fig. 3.

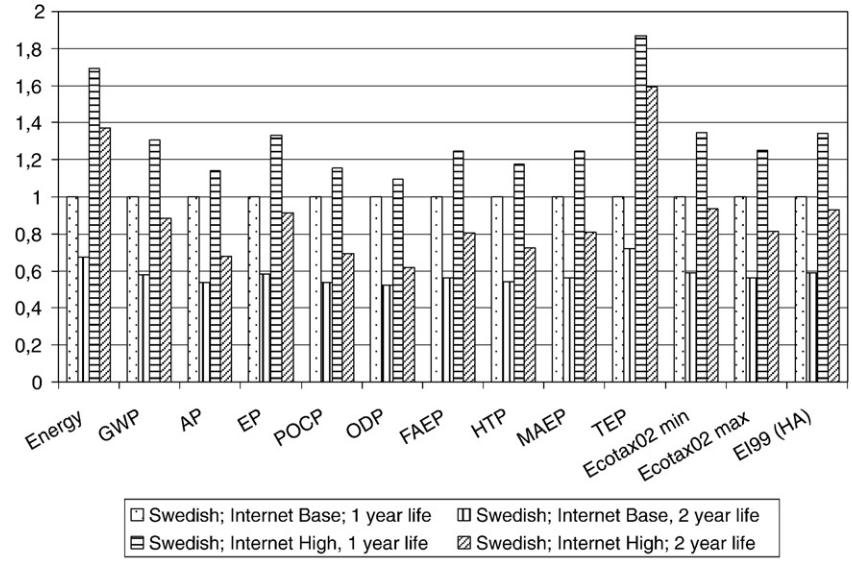

Fig. 23. Sensitivity analysis concerning the life time of the tablet e-paper device and the energy intensity of the internet. The effect of the changed assumptions in the Swedish scenario is illustrated in relation to the environmental impacts of the base scenario, which are set to 1. The impact categories are abbreviated; see Fig. 3.

media in general is the energy use of the device for reading electronic versions. In the case of the tablet e-paper, however, the low energy requirement during use is a key feature. Compared to an internet-based newspaper the tablet e-paper has the advantage of a very low energy use during reading. On the other hand the internet-based newspaper read on a computer, has the advantage of using a device which has a longer life time and is used for many purposes. The printed newspaper has the lowest environmental impact in the use phase. The production of the paper, the printing and the distribution in contrast gives rise to major environmental impact. The sources and amounts of energy used for the pulp- and papermaking processes are important for the overall environmental performance of the printed newspaper. Generally, the sources of electricity used can influence the results as the potential impacts vary as illustrated by the European and Swedish scenarios.

Even though newspaper consumption is a fairly small part of the global environmental impacts so are many other sectors and industries and still there is a need for a common achievement with contributions in different fields in order to enable the path towards sustainable development. It can be noted that Malmodin (2008) in a global assessment estimates that the entertainment and media sector (mainly TV and paper media) gives rise to 800 Mton CO_2 emissions/year, of which 30% is paper and printing. In the same paper, the ICT sector is stated to give rise to 500 Mton CO_2 emissions/year globally.

The results of this paper indicate that there is a potential for tablet e-paper to decrease the environmental impact of newspapers. Not all impact categories were however equally well covered in the study. In general, LCA covers energy-related resources and emissions better than process-specific and material-specific impacts. In particular, the results for the toxicological impact categories should be interpreted with special care. It may be particularly important for producers and users of the tablet e-paper to check the chemicals used in the product in order to avoid backlashes. Emissions of toxicological concern are often overlooked in LCAs (Finnveden, 2000). As the data on the electronic devices becomes more comprehensive this may prove to be a major limitation of electronic newspaper systems. Developers are suggested to strive towards minimisation of toxic and rare substances in production. In addition, waste management issues should be handled in the development of the product. It should be considered that the product should not end up as hazardous waste after fulfilling its purpose since this will lead not only to environmental impact, but also to more costly waste management.

From a user perspective the environmental impact of the tablet e-paper device is depending on the actual total use and life time, which may to some extent be decided by the user, as well as whether it will replace some other media or just add to others, increasing total impact.

Acknowledgements

The study which this paper is based on was performed as a co-operation between STFI-Packforsk and the Royal Institute of Technology (KTH), Division of Environmental Strategies Research and Department of Media Technology and Graphic Art. In addition, the study was a forerunner (a pilot project) in the Centre for Sustainable Communications, a Vinnova Centre of Excellence at KTH and this screening study will form the basis for continuing work within this field. STFI-Packforsk, the Swedish Newspaper Publishers' Association (TU) and Vinnova funded this study. The authors would like to thank the reference group including Birgit Backlund, STFI-Packforsk and Svenåke Boström, Sundsvalls Tidning. iRex Technologies, through Philip Leurs, are acknowledged for helpfully providing information about the iLiad e-paper device. Constructive and valuable comments from reviewers are appreciated.

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