KTH Centre for Sustainable Communications

Title:
Effects of a total change from paper invoicing to electronic invoicing in Sweden.

A screening life cycle assessment focusing on greenhouse gas emissions and cumulative energy demand.

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Preface

This study was carried out at the Department of Environmental Strategies Research at KTH, the Royal Institute of Technology. In addition, it has been performed within the Centre for Sustainable Communications.

The study was funded by Itella Information AB, a Finnish goods and information logistics company operating in several northern European countries. However, the study and the results are the responsibility of the authors, who also decided on publication of the results.

The authors are grateful for help with data collection and for reflections and discussions at meetings with staff at Itella Information, especially Susie Eliasson, Anders Falk, Lars G Mattsson, Gunnar Rogeman and Tobias Wikström. Many other people were helpful when asked for data and information and they are listed in the reference list under personal communications. Their help is gratefully acknowledged.

Summary

Electronic invoicing is a current alternative to traditional invoices distributed on paper. There are reasons to believe that electronic invoicing is environmentally preferable to traditional invoicing, as the production of paper and envelopes, the printing process and the physical distribution can be avoided. However, there are additional needs for servers, etc. when electronic invoices are used. To assess the environmental performance of a product or a service or to compare two alternative ways of providing a service, a life cycle perspective should preferably be used.

The study presented here is a screening life cycle assessment (LCA) aimed at assessing the consequences of a complete transition from all paper invoicing to all electronic invoicing in Sweden. Readily accessible data were used and the focus was on cumulative energy demand and emissions of greenhouse gases. The main purpose of the study was to increase our knowledge about the advantages and disadvantages of such a transition. An additional aim was to identify areas with a lack of data and major uncertainties.

In an LCA, environmental impacts are related to the function provided by the product or service studied. The function provided by invoices is to distribute information about payment obligations from supplier to customer. This may be business-to business (B-to-B) or business-to-consumer (B-to-C).

The functional unit used in this study illustrates the total amount of invoices in Sweden during one year (I. Boström, personal communication), and is described as:

'The distribution of 1.4 billion invoices, whereof 70% B-to-C and 30% B-to-B.'

In the study we looked at two extreme cases, all invoices distributed on paper and all invoices distributed electronically, and assessed the consequences of changing from all paper to all electronic invoices. In this kind of consequential analysis, only processes affected by the change should be included. Processes that are the same independent of invoice medium were therefore not covered here. The consequences over a longer time perspective were considered, meaning that potential new investment in equipment or technology could be included.

Two base scenarios that differed only concerning the electricity mix were studied. One scenario had lower emissions of greenhouse gases (CO_2cap) and the other higher use of fossil fuels (High gas price). Assumptions made for the base scenarios were tested through sensitivity analyses.

The paper invoice life cycle assessed in this study started with forestry, production of pulp and paper and production of envelopes, followed by printing and placing in envelopes. The distribution is performed by mail, which includes central sorting and distribution by different modes of transport. When the invoice has reached its destination the handling differs depending on whether it has reached a business (B) or an end-consumer (C). After payment, paper invoices to businesses have to be physically

stored in an archive for ten years. Eventually the waste invoices are passed through material recycling and incineration. All envelopes are incinerated.

In the base scenarios the paper invoice consists of two A4-pages printed on one side. In a sensitivity analysis a reduced size of one A4-page per invoice was tested.

Electronic invoicing, as modelled in this study, started with the business system of the company sending out the invoice information. Processes within the business system that are the same as for the paper invoice were not considered. In the case of B-to-B, information from the business system is sent to software, which converts the information into a suitable format. The information is sent from the software to the business system of the company or organisation to which the invoice is addressed. The business systems of the two companies communicate with the bank for the payment operation, but this process is the same as in the case of paper invoices and was therefore not included in the system studied. Finally the invoice is stored electronically. For B-to-C, the information from the business system of the company sending out the invoice is sent to the software and to an 'e-archive' – a database from which the information is downloaded when someone requests it via the internet. The customer receives a notice about the invoice on the internet bank website and can download it from the e-archive through internet access and make the payment.

In the study, all payment transactions were assumed to be made via the internet. This was a simplification based on the assumption that other options for payment that are currently used for paper invoices have similar or higher energy use and greenhouse gas emissions than internet payment. These options require paper production and distribution of transaction forms or travel for payment at the bank.

The assumption in the base scenarios was that the electronic invoices were not printed at home or at the company. The effect of printing the electronic invoices was tested in a sensitivity analysis.

Other assumptions tested in sensitivity analyses included transport distance, use of laptop instead of desktop computer, sending paper invoices B-to-B with first class mail, longer computer time for handling B-to-B electronic invoices and longer time for internet use handling B-to-C paper invoices.

The study examined the consequences of changing 1 400 000 000 invoices from distribution on paper to electronic distribution. The resulting figures describe the possible impacts of a change. A negative value describes a benefit, e.g. energy use avoided as there is no need for paper production.

The results of the study show that changing from paper invoices to electronic invoices was beneficial. If all invoices in Sweden were to be changed from paper to electronic, a total energy saving of around 1 400 TJ-equivalents/year and reductions of greenhouse gas emissions corresponding to 39 000 to 41 000 ton CO_2-equivalents/year would be made, depending on the electricity mix used.

Sensitivity analyses assuming longer transport distances and sending invoices by first class mail revealed slightly greater benefits from a change. When electronic invoicing was assumed to give rise to increased use of computers for B-to-B invoice handling compared with handling paper invoices, there was a slight decrease in the advantage of changing to electronic invoicing. This highlights the fact that the system for handling electronic invoices needs to be fairly efficient to gain the full benefit concerning greenhouse gas emissions. For paper invoices, increasing the internet time needed (B-to-C) for transferring information manually to the bank website gave a slightly larger benefit for electronic invoicing, particularly when the time difference exceeded one minute per invoice and when the electricity mix was mainly of fossil origin.

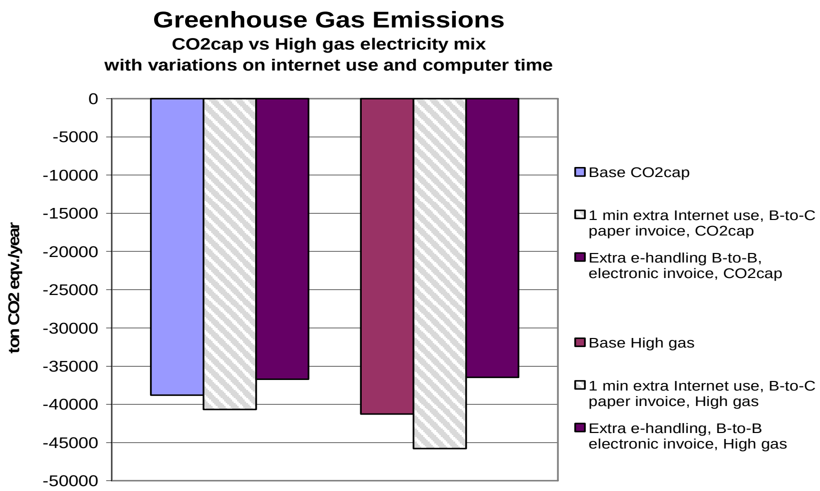


Figure 1 Sensitivity analyses considering variations in user handling of invoices. The base scenario is compared with a case where B-to-C paper invoicing leads to one minute extra internet use per B-to-C paper invoice compared with electronic invoices, and with a case where B-to-B electronic invoicing leads to five minutes extra computer use per electronic B-to-B invoice compared with paper invoices. Analyses were made for both the CO_2cap and High gas price electricity mixes.

A larger decrease in benefit compared with the base scenarios was seen when the amount of paper used was tested in sensitivity analyses. When the paper invoices were assumed to only consist of one A4 page instead of two, the benefit of changing to electronic invoices decreased considerably (Figure 2). When the electronic invoices were printed, using a laser jet printer, the benefit of changing to electronic invoices also decreased. The fact that there still was a benefit when electronic invoices were printed on a laser jet printer compared with sending invoices on paper by post was mainly due to the need for envelopes and the mail distribution.

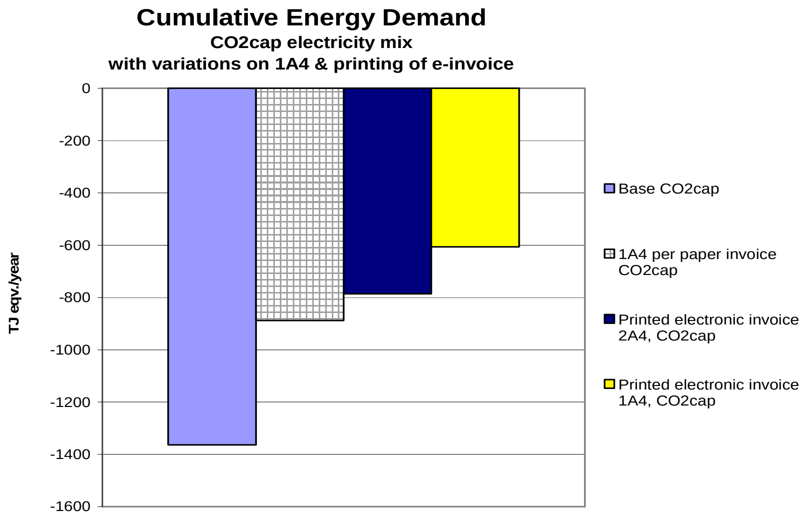


Figure 2 Sensitivity analyses considering variations in paper use and printing. The base scenario is compared with a case where the paper invoice consists of one A4 sheet, a second case where electronic invoices are printed on two A4 sheets, and a third case where paper invoices consist of one A4 sheet and electronic invoices are printed on one A4 sheet. All systems used the CO_2cap electricity mix.

For the paper invoices, the production of the paper (including forestry and pulp production) was the main reason for the cumulative energy demand and the greenhouse gas emissions. Other activities making major contributions were the distribution, archive storage of the B-to-B invoices, digital printing and placing in envelopes. The waste management (paper recycling and incineration) led to a benefit for the paper invoices concerning cumulative energy demand, as other production of heat, electricity and newsprint paper could be avoided. For greenhouse gas emissions, waste management was beneficial when the High gas price electricity mix was used (and avoided). With the CO_2cap electricity mix the emissions from recycling were higher than the emissions avoided.

For the electronic invoices, the main impact of the system studied concerned the energy use by servers.

It should be noted that the full product systems were not covered in this study since only the consequences of a change were studied, and thus activities not affected by that change were not covered.

The study concluded that there are benefits in terms of cumulative energy demand and emissions of greenhouse gases in changing from paper invoicing to electronic invoicing. The magnitude of the benefit depends partly on the nature of the existing paper invoice system, but the magnitude can also be influenced by the design and use of the electronic invoicing system. Avoiding printing electronic invoices and designing easy and efficient systems for handling electronic invoices are key issues.

Sammanfattning

Elektroniska fakturor är numera ett alternativ till traditionella pappersfakturor. Med elektroniska fakturor kan pappersproduktion för fakturor och kuvert, tryckning och fysisk distribution undvikas. I och med detta finns det anledning att tro att elektroniska fakturor är att föredra ur miljösynpunkt. Vissa processer och aktiviteter tillkommer också vid en övergång till elektronisk fakturering, t ex användning av servrar för konvertering och förvaring av fakturor elektroniskt. Vid bedömning av miljöpåverkan från en produkt eller tjänst eller för att jämföra olika varianter av samma produkt eller tjänst bör ett livscykelperspektiv användas.

Den studie som presenteras i denna rapport är en förenklad livscykelanalys (LCA) med syftet att studera konsekvenser av en övergång från pappersfakturor till elektroniska fakturor i Sverige. Lättillgängliga data har använts och studien har avgränsats till primärenergianvändning (cumulative energy demand) och utsläpp av växthusgaser. Fördelar och nackdelar, med avseende på primärenergianvändning och utsläpp av växthusgaser, har identifierats, liksom dataluckor och osäkerheter gällande miljöbedömning av de studerade produktsystemen.

I en livscykelanalys relateras miljöpåverkan till den funktion eller nytta som den studerade produkten eller tjänsten ger. Fakturor informerar om betalningsåtaganden. Fakturor skickas mellan företag (B-to-B) eller från företag till slutkonsument (B-to-C). Den så kallade funktionella enheten i studien illustrerar den totala mängden fakturor i Sverige under ett år (Boström, personlig kommunikation) och beskrivs på följande sätt:

"Distribution av 1,4 miljarder fakturor, varav 70% till slutkonsument och 30% till företag"

En förändring från extremfallet där alla fakturor är pappersfakturor till extremfallet där alla fakturor är i elektroniskt format har studerats. En konsekvensanalys har utförts, detta innebär att enbart sådant som berörs av förändringen inkluderas i studien. Processer som är desamma oberoende av fakturaformatet har inte hanterats, t ex den elektroniska hanteringen av fakturor i företags ekonomisystem. Konsekvenser har studerats med ett långt tidsperspektiv, vilket innebär att det finns möjlighet till nya investeringar som en konsekvens av förändringen.

Två basscenarion har studerats. Dessa skiljer sig åt enbart gällande vilken el-mix som använts. I det ena fallet har en el-mix med låga emissioner av växthusgaser används (CO_scap) och i det andra en mix med mer fossila energikällor (High gas price). Olika antaganden som gjorts i basscenariona testas i så kallade känslighetsanalyser för att se om antagandena påverkar resultaten.

Pappersfakturans livscykel, i denna studie, startar med skogsbruk, massa- och papperstillverkning. Sedan trycks fakturan, kuvert tillverkas, fakturan stoppas i kuvert och sänds med post till mottagare. När fakturan nått mottagaren skiljer sig hanteringen åt beroende av om mottagaren är ett företag eller en slutkonsument. Efter att fakturan betalats måste pappersfakturan arkiveras av företag i tio år. Efter arkivering, och i slutkonsumentfallet efter betalning, blir fakturorna pappersavfall som hanteras genom materialåtervinning och till viss del förbränning. Alla kuvert går till förbränning.

I basscenariot består pappersfakturan av två A4-papper enkelsidigt tryckta. I en känslighetsanalys har antagandet om pappersfakturor bestående av ett A4-ark enkelsidigt tryckt testats.

Elektroniska fakturor startar i denna studie sin livscykel i det avsändande företagets affärssystem. Processer i affärssystemet som är desamma för pappersfakturan ingår inte. Fakturor som skickas till andra företag konverteras med hjälp av en mjukvara till ett önskat format. Fakturainformationen skickas till det mottagande företaget. Företagens affärssystem kommunicerar med banken på samma sätt oberoende av i vilket format fakturan nått företaget. Fakturan arkiveras elektroniskt i tio år. Elektroniska fakturor som skickas till slutkonsument går också via mjukvaran för konvertering. Den sänds också till ett så kallat e-arkiv, en databas från vilken informationen kan laddas ner via Internet. Mottagaren av den elektroniska fakturan blir informerad via internetbanken och kan ladda ner informationen från e-arkivet och göra sin betalning.

I studien antas alla betalningstransaktioner göras via Internet. Detta är en förenkling med antagandet om att andra betalningssätt som används för pappersfaktura idag medför samma eller högre primärenergianvändning och utsläpp av växthusgaser (t ex genom pappersproduktion och distribution av bankgiroblanketter samt resor vid manuell betalning).

I basscenariot antas att inga elektroniska fakturor skrivs ut av företag eller slutkonsument. I en känslighetsanalys testas detta antagande.

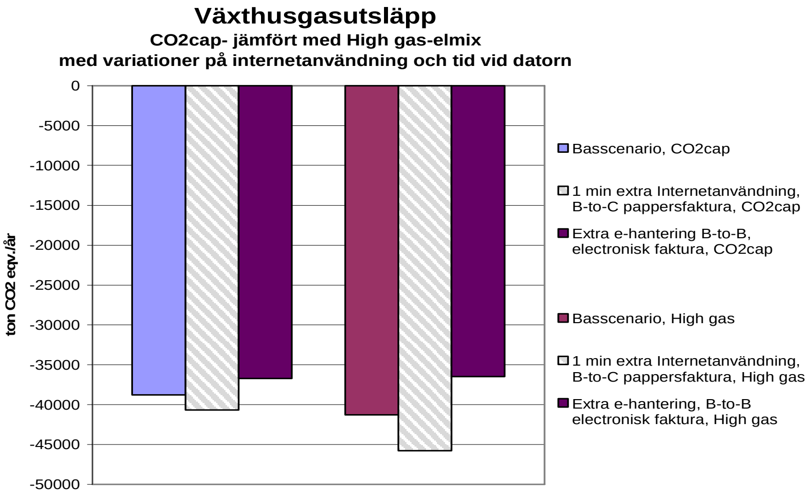
Känslighetsanalys används också för transportavstånd, typ av dator (stationär eller bärbar), ekonomi- eller första klass brev för företagsfakturor, ökad datoranvändning vid hantering av elektroniska fakturor på företag samt ökad Internetanvändning vid hantering av pappersfakturor för slutkonsument.

Konsekvenser av att gå från 1,4 miljarder pappersfakturor till lika många elektroniska har studerats för primärenergianvändning och utsläpp av växthusgaser. Resultaten presenterar möjliga konsekvenser av förändringen. Negativa värden påvisar vinster med förändringen, t ex energianvändning som kan undvikas om papper inte behöver produceras.

Resultaten visar att det är fördelaktigt att övergå till elektroniska fakturor när det gäller primärenergianvändning och utsläpp av växthusgaser. Om alla fakturor i Sverige omvandlades skulle primärenergianvändning minska med ca 1 400 TJ-eqv. /år och utsläpp av växthusgaser skulle kunna minska med mellan 39 000 och 41 000 ton CO_2-ekvivlanter per år, beroende av vilken el-mix som påverkas.

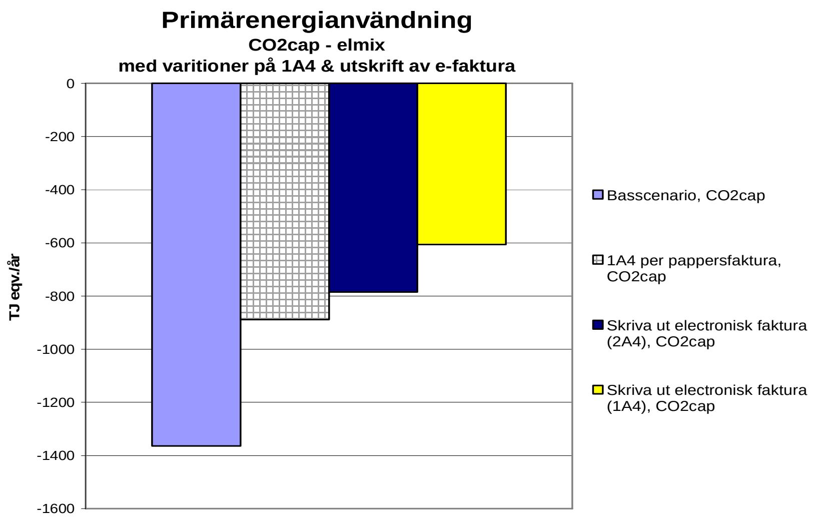
Känslighetsanalyserna visar att längre transportavstånd och att skicka fakturor med första klass brev ger en något större fördel som följd av förändringen. Om de elektroniska fakturorna ger upphov till en ökad användning av datorer, jämfört med hantering av pappersfakturor, minskar fördelen med en förändring något. Detta visar på behovet av effektiva system för hanteringen. Om pappersfakturor hos slutkonsument, å andra sidan, innebär att Internet måste användas betydligt längre, i och med att all information måste föras in manuellt, ökar fördelen av att övergå till elektroniska fakturor (Figur 3).

Dessa effekter på resultaten visar på att fördelen kan vara något större eller något mindre.



Figur 3 Känslighetsanalys gällande mottagarens hantering av fakturan. Basscenarion i jämförelse med ett fall där pappersfakturor till slutkonsument kräver en minuts extra Internetanvändning jämfört med elektroniska fakturor och ett annat fall där elektroniska fakturor till företag ger upphov till fem minuters extra datoranvändning jämfört med hantering av pappersfakturor.

En större påverkan på resultatet medför den känslighetsanalys som testar effekten av att pappersfakturorna skulle bestå av enbart en A4-sida. Även den känslighetsanalys som antar att elektroniska fakturor skrivs ut på laserskrivare medför betydande minskning av fördelarna med att övergå till elektroniska fakturor (Figur 4). Fortfarande är det dock en fördel, vilket främst beror på att pappersfakturan kräver kuvert och fysisk distribution.



Figur 4. Känslighetsanalys gällande pappersanvändning och utskrift av elektroniska fakturor. Basscenarion i jämförelse med ett fall där pappersfakturor består av en A4, ett andra fall där elektroniska fakturor skrivs ut på laserskrivare (två A4), samt ett tredje fall där pappersfakturor består av en A4 och elektroniska fakturor skrivs ut (en A4). El-mixen CO_2cap används.

När det gäller pappersfakturan står pappersproduktionen (skogsbruk, massa- och pappersproduktion) för den enskilt största delen av primärenergianvändningen sam utsläppen av växthusgaser. Andra aktiviteter med betydande påverkan är distribution, arkivering av förestagsfakturor samt digitaltryck och kuvertering. Avfallshanteringen (pappersåtervinning och förbränning) är fördelaktig för pappersfakturan när det gäller primärenergianvändningen eftersom papper, el och värme produceras och därmed slipper man producera dessa på annat sätt.

När det gäller elektroniska fakturor står energianvändningen för servrar för den största delen av påverkan

Det bör noteras att den totala påverkan från respektive faktura med ett livscykelperspektiv inte studerats, utan enbart de delar som påverkas av en förändring från pappersfaktura till elektronisk faktura.

En av studiens slutsatser är att det är fördelaktigt, med avseende på primärenergianvändning och utsläpp av växthusgaser att övergå från pappersfakturor till elektroniska fakturor. Hur stor fördelen är beror delvis på de pappersfakturor som byts ut, men även på hur systemet för elektroniska fakturor utformas. Att undvika att skriva ut elektroniska fakturor samt att införa enkla och effektiva system för hantering av elektroniska fakturor är ett par nyckelfaktorer.

Table of contents

1. Introduction

1.1 Background

New solutions based on information and communication technology (ICT) have been proposed as a way towards sustainable development, through e.g. more efficient use of resources and decreased environmental impact. ICT solutions may allow reductions in travel and transport and de-materialisation through the provision of virtual goods and services. Studies on paper products and their possible conversion to virtual products show that there is in general an environmental benefit in using the virtual products or services (see for example Gard and Keoleian, 2003; Kozak, 2003; Toffel and Horvath, 2004; Moberg et al., 2007).

Electronic invoicing is a current alternative to traditional invoices distributed on paper. Most companies have computerised business systems today and handle most of their information and data electronically in any case. Since July 2008, Swedish state authorities are expected to handle invoices (in- and out-going) electronically, according to SFS 2000:606. In a pilot study on electronic invoicing and state authorities (ESV, 2005), one of the outcomes was that provided that all Swedish authorities introduced electronic invoicing in 2008, about €400 million would be saved during 2006-2012. Thus, according to ESV (2005), there is an economic incentive in changing from paper invoices to electronic invoices.

In addition, many consumers are starting to handle their banking using the computer. In Sweden, 78% of people using internet pay their bills via the internet (Findahl, 2007, p. 42) and 71% of the population above 18 years use the internet. Roughly 50% of the total population now pay their bills on the internet.

In practice, invoice handling and banking activities are moving towards more virtualisation, and it may be the case that the previous obvious solution to distributing information about economic transactions – on paper through the post – is becoming a less convenient way in many perspectives.

In addition, there are reasons to believe that electronic invoicing is environmentally preferable to traditional invoicing, as the production of paper and envelopes, the printing process and the physical distribution can be avoided. However, there is a lack of studies in which the advantages and disadvantages of electronic invoicing are considered and quantified. One exception is a German study (Quack and Möller, 2005) on telephone bills from Die T-Com (former Deutsche Telekom AG). That study came to the conclusion that electronic invoices are preferable from an environmental point of view as long as not too many print-outs are made of the electronic invoices.

To assess the environmental performance of a product or a service or to compare two alternative ways of providing a service, a life cycle perspective should preferably be used. With this approach possible 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.

1.2 Aim of the study

The present study used a screening life cycle assessment (LCA) as described below to assess the consequences of a transition to electronic invoicing in Sweden. The main aim of the study was to increase current knowledge about the advantages and disadvantages of a possible transition. A secondary aim was to identify areas with a lack of data and major uncertainties.

The target group for this report is broad and covers companies, organisations and the public, as well as researchers in the field of environmental assessment and media and communication.

2. Method

2.1 Life cycle assessment

Life Cycle Assessment (LCA) is a method to assess the potential environmental impacts and resources used throughout a product's life from raw material acquisition through production, use and disposal. The term 'product' can include also services. An ISO standard has been developed for LCA providing a framework, terminology and some methodological choices (ISO, 2006a and b). An LCA is divided into four phases (Figure 5): Goal and Scope Definition, Inventory Analysis, Life Cycle Impact Assessment (LCIA), and Interpretation. The result of the Inventory analysis is a compilation of the inputs (resources) and the outputs (emissions) from the product over its life-cycle in relation to the so-called 'functional unit'. The latter is a description of the functions that the product (or service) provides. All results in an LCA are related to this functional unit. In comparative studies the functional unit needs to be the same for the alternatives compared and the definition of the functional unit is essential so that the alternatives are compared on a fair basis.

The LCIA phase is divided into several elements, some of which are regarded as optional (ISO, 2006a). The first elements of the LCIA (Classification and Characterisation) are based on more or less traditional natural science and aim to describe the contribution from the system studied to a number of environmental impact categories such as resource depletion, human health impacts and ecological consequences. One of the optional elements of LCIA is called weighting and includes a valuation of different impact categories against each other. In the present study the focus is on two impact categories, as explained later.

There are two different types of LCA, accounting or attributional LCA and consequential or effect-orientated LCA (see e.g. Baumann and Tillman, 2004). In attributional LCA a system is described as it is. 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 accounting type of LCA uses data for the processes involved. This means that different types of average data should be used, for example for the energy system. In consequential LCAs, which reflect the changes, data reflecting processes affected by these changes should be used. This normally means some form of marginal data. In the present study a consequential LCA was performed, as the aim was to study the consequences of a change.

When considering marginal data, these may be considered in different time perspectives. For example, a distinction can be made between a short time perspective in which no new investments are made, and a longer time perspective in which new capacity may be installed. In this study, we considered a longer time perspective allowing new capacity to be installed, e.g. electronic equipment or new power plants for generation of electricity.

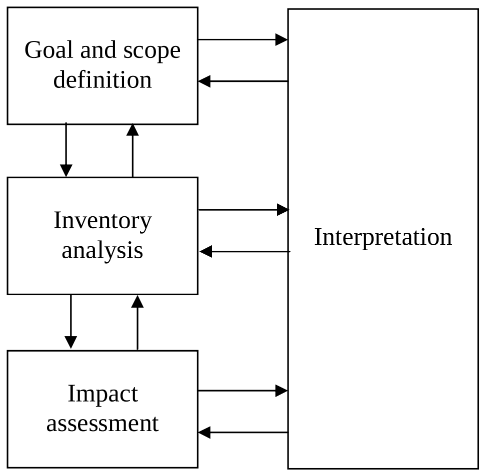


Figure 5. The four phases of a Life Cycle Assessment (ISO, 2006a).

2.2 When processes serve different purposes

Life Cycle Assessment is one example of an environmental systems analysis tool (Finnveden and Moberg, 2005). As in all types of systems analysis, the question of system boundaries is essential. There are three major types of system boundaries that are essential (Guinée, 2002):

1) Between the technical system and the environment
2) Between significant and insignificant processes
3) Between the technical system under study and other technical systems.

In relation to the first system boundary, it can be noted that an LCA should cover the entire life-cycle. Thus the inputs should ideally be traced back to raw materials as found in nature. For example, crude oil can be an input, but not diesel oil since the latter is not found in nature, but is instead produced within the technical system. In parallel, the outputs should ideally be emissions to nature.

The second system boundary is further discussed in section 2.3.

The third system boundary is relevant when a process is shared between several product systems and it is not clear to which product the environmental impacts should be allocated.

One example of an allocation problem relates to waste treatment and recycling. Consider a printed invoice. In the waste management phase it can for example be incinerated with energy recovery. In this case, the waste treatment serves two purposes: dealing with a waste problem and producing a new product: heat and/or electricity. In an LCA on paper invoices, the incineration plant can thus be considered part of the invoice lifecycle or part of the lifecycle of heat and electricity, or part of both.

There are two ways of handling this type of allocation problem that differ in principle. One is to allocate (partition) the environmental impacts between the two products (invoice and energy). This can be done on the basis of several principles, e.g. physical causation or economic value. The other approach to solving the allocation problem is to avoid it by expanding the system boundaries and including both products in the system model. In this approach the emissions from the incineration are included in the product system, but an alternative competing source of energy is also included in the system model. It is then assumed that the energy from the invoice incineration can replace energy from the competing source, which is thus avoided. The environmental impacts from the competing energy source are then subtracted from the environmental impacts from incineration of the waste paper. In this way the invoice system is credited for producing heat and/or electricity. If the paper is recycled instead of being incinerated, the recycled material can replace paper from other sources. In the same way as for incineration, the invoice system can then be credited for avoiding the production of paper from other sources.

Recycling of materials can occur in two different ways: closed-loop and open-loop. In closed-loop recycling, the material is used to produce the same type of product again. An example can be glass which is used to produce glass. In closed-loop recycling, the modelling of the whole loop can be made within the product system studied and no allocation problems will occur. In open-loop recycling, the material is used to produce another type of product. One example is waste fine paper which is recycled into newsprint.

System expansion is recommended in the ISO standard (ISO, 2006b). It is also specifically recommended for consequential assessments by for example Tillman (2000) and Ekvall and Weidema (2004).

2.3 Screening LCA - general

A full LCA can be time- and resource-consuming. Instead of starting with a full LCA, an alternative approach can be to perform a screening LCA with the aim of identifying the most important aspects of the system under study. If wanted, 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. It is important to include all processes and materials that can be of major importance, but if some processes or materials are known to be of minor importance, they can be excluded.

3. Scope of the study

3.1 Functional unit

The function provided by invoices is to distribute information about payment obligations from supplier to customer. This may be business-to business (B-to-B) or business-to-consumer (B-to-C).

The functional unit used in this study illustrates the total amount of invoices in Sweden during a year, and is described as:

'The distribution of 1.4 billion invoices, whereof 70% B-to-C and 30% B-to-B.'

The figure of 1.4 billion invoices per year and the relative distribution of B-to-C and B-to-B invoices were obtained through personal communication with Ingrid Boström at Intrum Justitia (personal communication, 2008), which carried out an internal study that produced these figures referring to the period 2003-2004.

In the current study we looked at the two extreme cases, all invoices distributed on paper and all invoices distributed electronically, and focused on the consequences of changing from all paper to all electronic invoices.

3.2 System boundaries

The two systems studied describe traditional paper invoicing and electronic invoicing. The aim of the study was to consider the consequences of changing from paper invoices to electronic. It was the possible consequences of the change that were studied and not the total impacts of the paper or electronic invoicing. The flowcharts in Figure 6 and Figure 7 illustrate the processes covered in the study. Processes that remain unaffected by the change were excluded, some of these are shown outside the system boundaries in the flowcharts, e.g. the bank invoice handling. The internet use is within the boundaries, but only the difference in internet use resulting from a change is accounted for here.

In line with the consequential assessment, system expansion was used. Thus electricity and heat produced in waste incineration were assumed to replace electricity and heat from other sources (see below). Recycled paper was assumed to replace paper produced from other sources.

As discussed in section 2.1, 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 possibility for new investments was included. With a short-term perspective, the consequences are limited by investments already made. For example the marginal electricity data only reflects already installed capacity and an increase in use of computers will not lead to the production of new computers in the short term, but the computers already available will be used more. With a long-term perspective, the possibility for new investments can be used to illustrate other consequences, e.g. an increased use of computers can be assumed to lead to more computers being produced. As far as possible, consequences were assessed using marginal data.

This study dealt with invoices in Sweden. Some of the processes part of the life cycle of invoices occur outside Sweden, e.g. production of computers to be used for invoice handling.

The study was simplified in some dimensions. Readily available data were generally used for the processes in the systems studied and the impacts assessed were energy use and emissions of greenhouse gases. Other impacts are only briefly discussed. The current situation was assessed, and the most recent inventory data possible were used. However, some data were older, e.g. data for pulp and paper production were from 2000-2002. There are ongoing improvements in creating more energy-efficient processes, both in the pulp and paper industries and in the ICT sector, and thus the results may look different, or be of a different magnitude, in coming years.

3.3 Data sources

The LCA software tool SimaPro 7.1.8 was used for this study (PRé Consultants, 2008). As far as possible, data obtained in the Ecoinvent 2.0 database (Frischknecht et al., 2007) as provided in SimaPro were used. Reference to data sources are given in the descriptions below and in the data sheets in Appendix 1.

Information and data were in some cases obtained from Itella Information or other 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 study when ideal data were not readily available.

As the study covered invoicing in Sweden, it was not possible to use specific data for transport distances; computer types used; invoice handling time at companies; etc. and generic data were often not available. The starting point of the study was two base scenarios which were the same except for the marginal electricity mix used. Some assumptions and estimates were made and some of these were then varied in sensitivity analyses to see whether different assumptions changed the final results (see 4.2.31).

3.4 Impacts considered

The study did not cover all environmental impacts but was limited to cumulative energy use and emissions of greenhouse gases. These impacts were assessed using the impact assessment methods 'cumulative energy demand' and 'greenhouse gas emissions' as implemented in the SimaPro software.

To assess the cumulative energy demand a method provided with Ecoinvent 2.0 (Frischknecht et al., 2007) was used. The method assesses the total energy used in the system studied based on figures for the intrinsic values of the energy carriers. These values describe the amount of energy withdrawn from nature (primary energy). The method displays the energy use in different subcategories (fossil, nuclear, primary forest, biomass, wind, solar, geothermal and water). All subcategories are reported in MJ-equivalents and we chose to present our results as aggregated values in the main report, but all resulting values as presented in SimaPro can be found in Appendix 3.

Greenhouse gas emissions were 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-eqv.) of the system studied. We used the 100-year perspective. 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. Carbon emitted from biogenic sources in another form, e.g. methane, was accounted for. When studying systems where biogenic material is a major component, e.g. paper, the uptake and emissions of carbon dioxide should preferably be handled more specifically. However, due to lack of specific data this was not possible in the current study.

In future studies, other environmental impacts should also be considered to avoid shifting from one kind of environmental impact to another.

4. Inventory

4.1 Process flowcharts – an overview

4.1.1. Printed paper invoicing

Printed paper invoicing includes several processes. The product system studied here is shown in Figure 6. Upstream of the actual distribution of invoices, the system covers forestry, production of pulp and paper, production of envelopes, printing processes and production of materials needed for printing. In addition, the business systems and the flow of information providing the content of the invoices are also illustrated in Figure 6 but these processes are outside the system boundaries of the study, since they are the same independent of whether the invoices are distributed on paper or electronically.

Following the printing and enveloping of the paper invoices they are distributed by post, which includes central sorting and distribution by train, truck and/or car (Posten Meddelande AB, 2007a) and also by aeroplane if the invoice is sent by first class mail (Posten Meddelande AB, 2007b). According to Per Liljedahl from the Swedish messaging and logistics operator Posten, most invoices are sent by economy class mail rather than first class (personal communication, 2008). In the base scenarios, economy class letters were assumed for all invoices. When the invoice has reached its destination the handling differs depending on whether it has reached a business (B) or an end-consumer (C). The handling in practice also differs between consumers and between businesses. For practical reasons, in this study the invoice handling by consumers and businesses was modelled as a single type, an assumed average handling for consumers and for businesses.

In the case of B-to-B, the activity following the distribution of the paper invoice is called data capture and starts with the opening of the envelope and, when needed, preparation of the documents. The invoice information then needs to be transferred into the company or organisation business system, which is done manually or by scanning the document. All invoices were assumed to be electronically handled in the end. When scanning is performed this activity is followed by interpretation by software and by manual verification, before the information is transferred into the business system. In the study, a rough assumption was made that 50% of the B-to-B paper invoices were scanned and verified. The other 50% were assumed to be manually entered into the system. The computer time for manually entering the invoice information was roughly assumed to be the same as the possible extra time of computer use for handling electronic invoices (e.g. authorisation).

The business systems of the two companies communicate with the bank for the payment operation. All communications with the bank and handling within the bank are the same regardless of whether the original invoice was sent physically or electronically (T. Mylly, Nordea, personal communication).

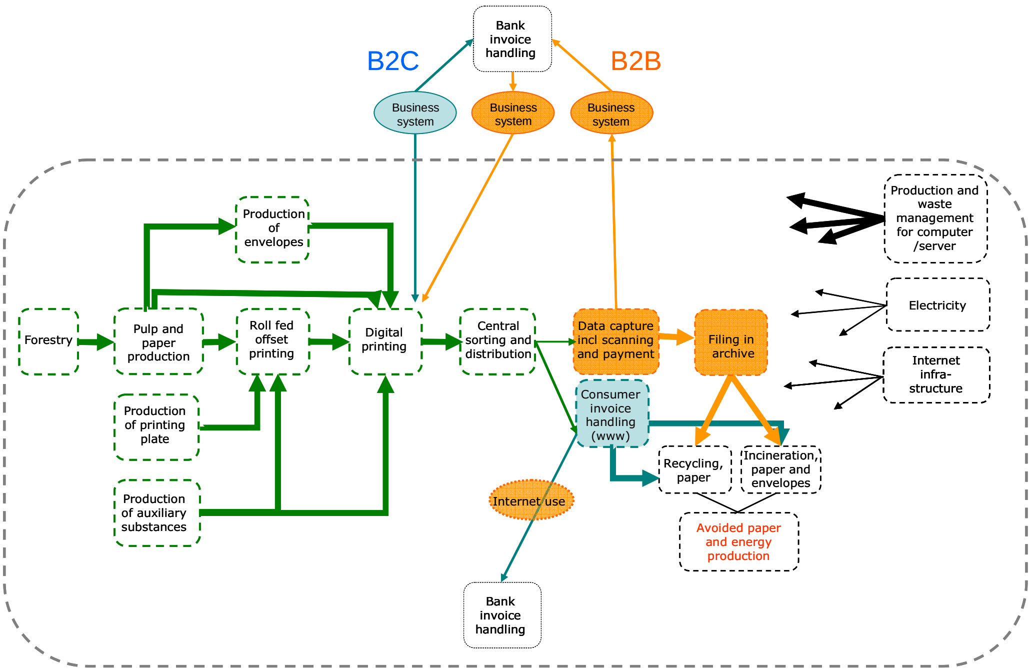


Figure 6. Flowchart of the printed paper invoice product system. Processes inside the dashed line were dealt with in the study. Bold arrows indicate physical transportation. Blue colour illustrates activities specific for B-to-C and orange colour activities specific for B-to-B.

Paper invoices are then physically filed in an archive. After the invoice has been in the archive for 10 years, as required in the law on bookkeeping (SFS 1999:1078), it is disposed of. The waste management of office paper was assumed to be incineration (34%) and material recycling (66%) based on figures for Sweden 2006 (Naturvårdsverket, 2008). The waste envelopes were assumed to be incinerated.

For B-to-C invoices the consumer was assumed to handle the invoices electronically, so that the handling includes the use of a computer and connection to the internet. This is today in practice only true for roughly 50% of the Swedish population (Findahl, 2007). Alternative ways of handling paper invoices include the sending of signed paper forms to the bank. This action includes paper, envelopes and distribution by post. Another option would be to go to the bank and make a payment manually. This action includes travel by some mode and a paper form. The environmental impacts of these actions were not considered in this study. The energy use and greenhouse gas emissions of the latter alternatives is probably greater, or at least not less than, use of the internet for the handling of invoices. In addition, the trend is towards increased use of the internet (Findahl, 2007).

The processes at the bank are the same as for electronic invoicing. However the internet use by the consumer may differ, and thus the latter was included within the system boundaries of this study. After making the payment the invoice is disposed of (possibly after some storage, which was not considered here). The waste management was assumed to be the same as for B-to-B above, as the figures on recycling and incineration refer to Swedish office paper overall.

The additional benefits produced when the waste paper and envelopes were treated (paper produced from recycled paper and electricity and heat recovered from waste incineration) were dealt with through system expansion (as described in section 2.2). Thus the environmental impact of producing newsprint and of producing electricity and heat from other energy sources was assumed to be avoided, and credited to the system studied as subtracted impacts.

4.1.2. Electronic invoicing

A description of the electronic invoicing product system, as modelled in this study, is presented below. The description is based on communications with staff at Itella Information, mainly Tobias Wikström. Some of the data used are specific for this company, e.g. data on servers, but were considered to be relevant as approximations for this study. The product system is illustrated in Figure 7. With electronic invoicing the information is sent and received in electronic form. No printing on paper is assumed in the base scenario.

In the case of B-to-B, information from the business system is sent to software, which converts the information into a suitable format. For B-to-B every step is critical concerning time, which means that the information sent is streamlined and there are no images sent. The electronic invoice is sent via the internet to the receiving business. The receiver makes the monetary transaction electronically in the same way as with a paper invoice (the latter information might be scanned or manually transformed to electronic format). The communication between the sender of the invoice and the bank is also the same as for a paper invoice and was not considered here.

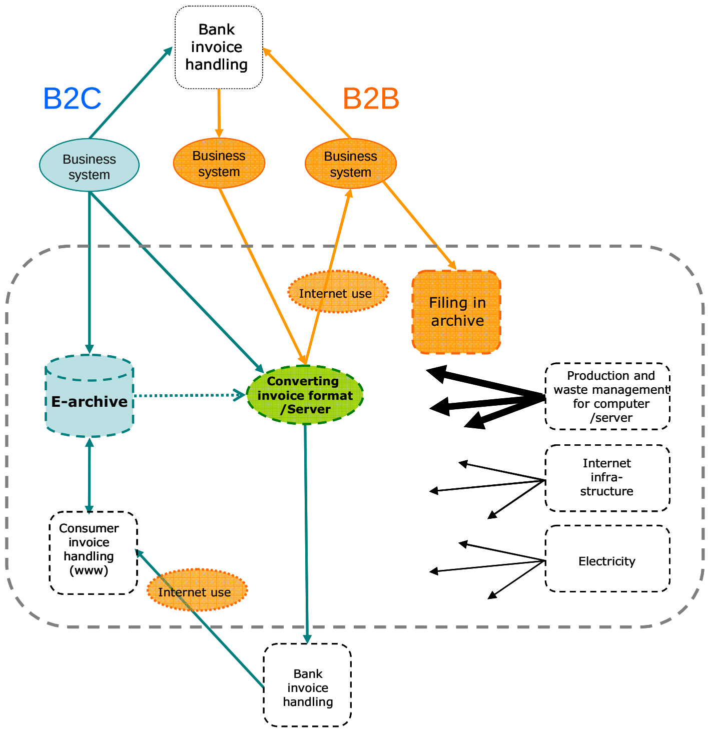


Figure 7. Flowchart of the electronic invoice product system. Processes inside the dashed line were dealt with in the study. Bold arrows indicate physical transportation. Blue colour illustrates activities specific for B-to-C and orange colour activities specific for B-to-B.

For B-to-B it was assumed that some businesses have business systems or workflow systems that handle the electronic invoice information automatically, while others have not. In the latter case manual handling of the electronic invoice is needed. In the base scenarios we assumed that the time using the computer for handling electronic and paper invoices at receiving businesses was similar, except for the computer use for verifying scanned paper invoices. This was based on assumptions on extra computer use needed for electronic invoices for e.g. authorisation etc. of electronic invoices and for manual handling in some businesses, as well as assumptions on extra computer use needed for manual handling of 50% of B-to-B paper invoices. (The other 50% of paper invoices were assumed to be scanned). Finally the invoice is stored electronically.

For B-to-C**,** the information from the business system of the company sending out the invoice is sent to the software converting the invoices to the right format and to a so-called e-archive; a database from which the information is downloaded when someone requests it via the internet. The information sent to and from the e-archive includes images and metadata (the B-to-C invoicing is not time-critical and therefore images can be included). From the e-archive a confirmation is sent to the software stating that the image and information are now available for the customer. Invoice information and reference information concerning where to find the image are sent from the software to the bank. A notice about the electronic invoice is displayed on the internet bank website of the customer. The customer can then access the invoice information from the e-archive server via the internet. The payment is made via the internet, in the same way as with a paper invoice (with a paper invoice the information is entered manually). For B-to-C, the assumption was that all payments are made via the internet. As the electronic invoice information is already available at the internet bank, there is no need to manually enter information (such as the OCR-number, account, etc.), thus the assumption was that the computer use time and the internet use time were lower for a B-to-C electronic invoice than a paper invoice. Another possibility is to send the B-to-C electronic invoice via e-mail and then the customer needs to manually transfer the information to the internet bank. This was not covered in the current study.

The assumption in the base scenarios was that the electronic invoices were not printed at home or in the office. The effect of printing the electronic invoices was tested in a sensitivity analysis.

4.2 Data inventory

4.2.1 General

In this section the data inventoried and used to model the systems are described process by process. All data that are new and have not previously been published elsewhere are presented in Appendix 1. LCA is an iterative process and thus in some cases rough data were used and if the process proved not to be significant for the results of the study, these rough data were then not further elaborated. On the other hand, if the process seemed important, more effort was made to obtain better data within the limits of the study.

4.2.2 The invoice

According to Susie Eliasson at Itella Information (personal communication, 2008), the average invoice corresponds to two A4-pages, most often printed on one side. A comparable average invoice distributed electronically is approximately 3.5 kB in size according to Eliasson. In the study base scenarios, these average values were used for all invoices. In a sensitivity analysis the possibility of a one A4-page paper invoice was tested.

4.2.3 Forestry

Data for forestry are from the Ecoinvent 2.0 database (Werner et al., 2007). In the modelling for the current study data for pulp and paper production were used, as described below, and data on forestry were pre-selected in these processes.

4.2.4 Pulp and paper production

The printed paper invoice was assumed to be printed on 80g/m^2 fine paper (wood-free uncoated), which is normal office paper. The data used reflect average European values with 50% production at integrated paper mills and 50% production at non-integrated paper mills (Hischier, 2007a).

The same type of paper, wood-free uncoated, but a little thicker (90 g/m^2) was assumed to be used for producing the envelopes. This is based on the type of paper used by Bong Ljungdahl Sverige AB, a major Swedish envelope producer (Magnus Olofsson, personal communication).

Hischier (2007a, p 129) used the average transport distances as follows; wood transport 100 km (whereof 80 km by lorry and 20 km by train), other input materials 600 km by train and 100 km by lorry, and residues 20 km by lorry. This transportation was not varied in the sensitivity analysis on transportation distance since it was not one of our assumptions but rather an average value.

The pulp and paper-making processes in some cases produce by-products, e.g. tall oil and turpentine, but no allocation of environmental impacts to these by-products was made in this study. Furthermore, no system expansion was made to consider the benefits of these by-products.

The datasets from Ecoinvent (Hischier, 2007a) were modified to enable the change of electricity mix used according to the definition of the current study. This modification was made for the paper-making process itself, the sulphate pulp production, the kaolin production, the industrial residue wood and the wood chips.

4.2.5 Envelope production

Data on envelope production were obtained from Bong Ljungdahl Sverige AB (Magnus Olofsson and Thomas Thomasson, personal communications). Data represent standard envelopes of the size C5 (162x229 mm), white paper, 90 g/m^2 with a polystyrene window.

Table 1. Input data for the production of envelopes

	Amount
Paper	7.98 g/envelope
Polystyrene	0.23 g/envelope
Glues of different kind	0.17 g/envelope
Ink for inside	0.24 g/envelope
Energy	0.0034 Wh/envelope

Data for the production of glues and ink were not available and thus the environmental impact of producing these was not included.

Due to losses in the production processes of approximately 8%, the resulting envelope weighs 8 grams. The paper lost was assumed to all be recycled and the polystyrene lost to be incinerated. These waste management processes are described below.

For this process the electricity mix used was varied in the two base scenarios. Transport of paper to the envelope production site was assumed to be 100 km (900 km tested in a sensitivity analysis). The transport was assumed to be by truck (16-32 tonnes) using data from Ecoinvent 2.0 (Spielmann et al., 2007).

4.2.6 Offset printing

Offset printing is used for pre-printing of company-specific details, such as address, logo etc., and was assumed to be in colour on one side of each A4-sheet. The assumptions on pre-printing were based on information from Susie Eliasson and Gunnar Rogeman at Itella Information. More than two-thirds of the invoices printed at Itella Information are pre-printed, 70% of the pre-print being printed with web offset and 30% with sheet-fed offset, 80% of the pre-printed papers being printed on one side only and all the pre-printed paper being printed in colour (G. Rogeman, personal communication).

In the study the assumption was 67% pre-printing, which may be a slight underestimation as more than two-thirds of the invoices at Itella Information are pre-printed. The data used were for sheet-fed offset (Larsen et al., 2006) since we could not easily obtain data for web offset. All pre-printed papers were assumed to be printed on one side only.

Generally, web offset is slightly less energy-demanding than sheet-fed. The data used included an energy use of 0.88 MWh/tonne product for printing. Enroth (2006, p 75 and 77) presents average values for web offset in the range 0.7-0.8 MWh/tonne product for coldset offset newspaper printing and 0.6 MWh/tonne product for heatset offset printing. Environmental impact per printed copy from offset printing depends not only on whether a web or sheet-fed offset technique is used, but also on for example the number of copies printed and the ink cover.

Considering the above, the data used in this study were an overestimation of the environmental impact of the offset pre-printing of invoices, but were used as a first estimation. If this process is shown to contribute significantly to the overall results more relevant data should be sought. The data are based on Larsen et al. (2006) and are presented in data sheets in Appendix 1.

We assumed that film was not used for printing, since it is not common today. We also excluded data on finishing, since this is not relevant for invoices. For the district heating used at the printing plant, the data on heat production described below were used.

For this process the electricity mix used was varied in the two base scenarios. Transport of paper to the printing site was assumed to be 100 km (900 km tested in a sensitivity analysis). The transport was assumed to be by truck (16-32 tonnes) using data from Ecoinvent 2.0 (Spielmann et al., 2007).

4.2.7 Production of material for offset printing

The data used for offset printing included the material composition of plates, printing ink, fountain solution and the cleaning of the presses. Where possible, available data in the Ecoinvent 2.0 database were used for supply materials (Althaus et al., 2007), although production of all substances and material was not included (see Appendix 1).

The aluminium for the printing plate was assumed to be from a mix of primary and secondary aluminium and the plates were assumed to be recycled, replacing primary aluminium.

4.2.8 Digital printing

Digital printing was assumed to be used for the actual printing of invoice information. The information on digital printing also included the process of putting the invoices into envelopes, since the data were not separable. Information was obtained from Gunnar Rogeman at Itella Information (personal communication, 2008).

An average for energy use at the printing offices in Stockholm and Malmö was used in this study (5 Wh/page printed, 11 Wh/average paper invoice). The paper wasted during the printing process was set at 2.1% of the total (based on 2006 figures). The use of toner (black) was set at approximately 25 g/1000 pages. The energy figures included all electricity used in the facilities, not only that used for the printers. Emissions from the printers were not included.

For this process the electricity mix used was varied in the two base scenarios. Transport of paper to the printing site was assumed to be 50 km (100 km tested in a sensitivity analysis) from the offset printing site (67% of the paper) and 100 km each (900 km tested in a sensitivity analysis) from the paper mill (33% of the paper) and the envelope production site. The transport was assumed to be made by truck (16-32 tonnes) using data from Ecoinvent 2.0 (Spielmann et al., 2007).

4.2.9 Toner production

According to information obtained by Gunnar Rogeman at Itella Information from their supplier of printing material, the company print approximately 40 000 pages per kg of toner. This can be compared with the average figure used in an LCA of toner (Ahmadi et al., 2003) which was approximately 22 000 copies per kg of toner. This difference can be explained through printing of invoices having lower toner coverage than average printing.

Data for toner production were taken from Ecoinvent 2.0 (Hischier et al., 2007) and represent the production of black toner powder (5% carbon black, 18% magnetite, 70% binder resin and additives).

4.2.10 Central sorting and distribution

The invoice in its envelope was assumed to be handled by the Swedish messaging and logistics operator Posten. Data from the environmental product declaration (EPD) published by Posten for economy class letters and first class letters were used. Underlying data used were provided by Charlotta Szczepanowski at Posten AB (personal communication, 2008).

Economy class means that the letter sent is distributed to the receiver on the third day. The data cover the distribution of the letter from posting the letter via sorting and transportation to distribution at the receiver's address. Transportation is by electric train, truck and/or car (Posten Meddelande AB, 2007a).

First class letters are distributed on the next day and the distribution is made in a similar way to economy class, but to some extent aeroplane freight is also used (Posten Meddelande AB, 2007b).

The data used in this study are shown in Table 2 and the data sheet is shown in Appendix 1.

Table 2 Data used for central sorting and distribution of mail, based on Posten Meddelande AB (2007a and b) and personal communication with C. Szczepanowski at Posten AB (2008)

	Economy class	First class
Electricity	0.3 Wh/g letter	0.3 Wh/g letter
Petrol	0.025 g petrol/g letter	0.025 g petrol/g letter
Diesel	0.032 g diesel/g letter	0.030 g diesel/g letter
Aeroplane fuel (Kerosene)	-	0.075 g kerosene/g letter

All paper invoices were assumed to be sent by economy class letter. In a sensitivity analysis B-to-B invoices were assumed to be sent by first class. The electricity mix used was varied in the two base scenarios.

4.2.11 Servers

The two central environments used for producing the electronic invoices are the software for converting invoice format and the e-archive. The e-archive is where the electronic invoice information and image are stored and from where the consumer obtains their information when connecting via the internet. An estimate on energy use for these two environments was given by Tobias Wikström at Itella Information (personal communication, 2008). The estimate was based on the effect (in kW) of the six servers used, which was recalculated to annual energy use. The equipment used for converting format gives rise to substantially higher energy use than the e-archive, according to Tobias Wikström. The total energy use for the servers is roughly 78 000 kWh/year. Today these servers facilitate the production of roughly 3 million electronic invoices per year. However, these servers handle not only electronic invoices, but also several other kinds of electronic documents. Tobias Wikström estimates that the electronic invoices are approximately 5-10% of the total volume handled by the servers. In the current study we used the latter figure, giving higher energy use per invoice, so as not to underestimate the energy use for electronic invoices. This assumption would have been varied if it had had a significant influence of the results of the study.

The figure on energy use did not include cooling and auxiliary equipment. According to Koomey (2007) based on figures from Greenberg et al. (2006, as cited in Koomey 2007, p5.) a factor of 2 can be used to include cooling and auxiliary equipment. We used this factor, giving 2.6 to 5.2 Wh per invoice with the span above. In the study the higher figure was used.

Six servers are used at Itella Information and the lifetime of the servers was roughly assumed to be 3 years. This means that one year's use of the servers corresponds to the production and waste management of two servers (one-third of the six servers used). Here we used production and waste management data for two stationary computers as an approximation for one server. This was a rough estimation based on communications with Andrzej Gutowski at KTH (personal communication, 2008). This approximation was thought to be preferable to omitting the server production and waste management due to lack of specific data.

For this process the electricity mix used by the servers was varied in the two base scenarios

4.2.12 Electronic distribution

The electronic invoices are sent via the internet to the receiving business in the case of B-to-B invoices. This means that the assumed average of 3.5 kB is sent for every B-to-B invoice in the studied system. The modelling and assessment of internet use is described below. The communication between the business and the bank is made electronically in both systems, and there is no difference between paper invoices and electronic invoices (T. Mylly, personal communication, 2008).

In the case of B-to-C invoices, the communication between the business and the bank is made electronically in both systems, and there is no difference between paper invoices and electronic invoices (T. Mylly, personal communication, 2008). The bank sends the consumer a notice on the personal internet banking website, but the possible environmental impact of this notice was assumed to be insignificant and was not included. The consumer electronic invoice handling, when the invoice is actually accessed via the internet, is described below.

4.2.13 Data capture

Data capture is the handling of the invoice information as it reaches the receiver in the case of B-to-B invoices. The main difference between data capture for printed paper invoices and electronic invoices lies in getting information that is on paper into the company's business system. This can be done manually or by scanning. The process of data capture for paper invoices includes 1) opening the envelope, 2) preparing the documents, 3) possibly scanning and if scanning is used followed by 4) interpretation of the invoice, and 5) verification (personal communication with Susie Eliasson, Itella Information, 2008). Thereafter the invoice information can be transferred to the business system and the original paper invoices needs to be stored in archives for 10 years (see below).

We did not have a figure on how many of the paper invoices are actually scanned and transferred in that way into the business system. We made a rough estimation of 50% of all B-to-B invoices, to illustrate possible impacts of scanning.

The assumption is that if the invoices are not scanned they are manually entered into the business system and that the time using the computer for this purpose is the same as for manually transferring the information of electronic invoices into the business system. Thus this activity was not included in the study.

The environmental impact of data capture includes the energy use for scanning and verification and the use of computers for verification, including production and waste management of the computer. The production and waste management of the scanning equipment was not included due to lack of data and the assumption that the impacts are limited. Information from Itella Information (G. Rogeman, personal communication 2008) was used to estimate the impact of data capture. At Itella Information eleven scanning machines are used for about six hours per day. The scanning machines have 170W efficiency (nine of them) or 260W efficiency (two of them) and 60 000 documents (A4 papers) are scanned per day. Only one page per invoice is scanned, and thus 60 000 invoices per day are scanned. This gives an energy use of 0.27 Wh/invoice. The verification is performed by 85 persons working at their PC for six hours per day, 210 days per year. Assuming 110W, and accounting for sleep- and off-modes on an office computer (IVF 2007, p 193), for a desktop computer with LCD screen this gives an energy use of 1.0 Wh/invoice.

The scanned invoices may also be electronically stored (archived) in parallel with the legally required physical storage of the original paper invoice. In this study we assumed that the scanned invoice was not stored in an electronic archive and that the information was just transferred into the company business system.

For this process the electricity mix used was varied in the two base scenarios. A sensitivity analysis tested the possible effect of using laptop computers without additional screens instead of desktop computers with screens, as in the base scenarios. When a laptop without additional screen is used the energy use is lower, 0.32 Wh/invoice (IVF 2007, p 193), compared with the above figure for desktop computers.

4.2.14 Consumer invoice handling

For B-to-C, when the consumer receives the traditional paper invoice, there is extra manual handling compared with receiving an electronic invoice that is not printed. There is the extra handling of opening the envelope and taking care of the invoice after payment, either to waste management directly or via some kind of storage. Secondly there is the extra computer time needed for payment. In this study only the difference regarding internet use was considered. The assumption was that all consumers pay their invoices electronically. The average energy use and greenhouse gas emissions resulting from paying at the bank or through sending payment forms were not thought to be substantially lower than that from paying via the internet, but more probably higher.

Manually transferring the data from the paper invoice to the bank website requires more time than when the electronic information is already there as in the case of the electronic invoices in this study. A rough estimation is that the extra internet use is 10 seconds per invoice. In a sensitivity analysis, 1 minute extra internet use was tested. The energy use of internet infrastructure is described below.

For this process the electricity mix used was varied in the two base scenarios. The use of laptops without additional screens instead of desktop computers with screens was tested in a sensitivity analysis. With an 110W (IVF 2007, p 193) desktop computer with LCD screen, the energy use is 0.18 Wh/invoice, accounting for sleep- and off-modes. With a 32 W (IVF 2007, p 193) laptop the energy use is 0.06 Wh/invoice.

4.2.15 Extra computer time for handling B-to-B electronic invoices

For B-to-B, it was assumed there is no difference in computer time needed for handling the electronic invoice compared with the paper invoice. However, the possible effects of extra time using the computer was tested in a sensitivity analysis, by assuming that the handling of the electronic invoice could take 5 minutes extra compared with the paper invoice. This extra time would be used for e.g. authorisation of electronic invoices and other electronic handling, which is performed non-electronically in the case of paper invoices.

This sensitivity analysis was made with the two different electricity mixes. Only a desktop computer with LCD screen was tested, not a laptop, as the idea was to test the effect of this possibility in a kind of worst case version.

4.2.16 Bank invoice handling

At the bank today, all invoices are already handled electronically. Even when the invoice is printed and sent to a business or consumer the bank still gets the invoice electronically (T. Mylly, personal communication, 2008). Thus, there would be no significant difference for the bank invoice handling if paper invoices were electronically distributed instead. The bank invoice handling was therefore omitted from the systems studied.

4.2.17 Electricity production

The electricity used for different purposes in this study was accounted for as marginal electricity, since the study was a consequential assessment, focusing on consequences of a possible change in behaviour. The marginal electricity was assumed to be a mix for the Nordic electricity market over a longer time period. Two different electricity mixes were tried in different scenarios, as suggested by Finnveden (2008). The composition of the mixes is shown in Table 3 and is based on Mattsson et al. (2003). 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. The scenario 'CO_2cap' 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.

Table 3. Percentage composition of electricity mixes used (from Mattsson et al., 2003)

%	**CO_2 cap**	**High gas price**
Wind	21.79	11.32
Nuclear	23.09	0
Biomass CHP	35.72	00.53
Coal CHP	00.77	59.99
Oil	-01.41	03.03
Natural gas	19.95	25.33
Hydro power	00.10	-00.21

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 some cases where this was possible, and where major amounts of electricity were used

For the production of computers (as described below) we did not alter the electricity data since the marginal mixes described above are for northern European conditions and the production of the electronic devices and components are mainly in Asia. We assumed that the marginal electricity there is probably highly based on fossil fuels, which is in line with the electricity used in the datasets.

The processes where we did change the electricity were (see Appendix 1 for more detailed information):

- Production of fine paper (for invoices and envelopes)
- Recycling of paper
- Production of newsprint (the avoided paper production)
- Use of printer for printing electronic invoices

Based on Dones et al (2007, p.168) electricity distribution losses from plant to grid were accounted for as 8.8%.

4.2.18 Internet use

Environmental impacts of internet use are not easy to assess and deciding on the share of the environmental impact of a certain operation is difficult. A lot of equipment is used for a wide range of different operations and it is not clear-cut how the energy use and other impacts should be divided between these operations or benefits that the internet provides. Based on discussions with Jens Malmodin at Ericsson and Dag Lundén at TeliaSonera (personal communication, 2008) an estimation of energy use related to internet use was made in the ways described below. It should be noted that the data on internet use are uncertain, especially regarding allocation.

In the current study internet use was affected by the studied change to electronic invoices in two cases. Consequently, internet use was included when used by businesses sending out invoices (in B-to-B) and when used by consumers handling their invoices (in B-to-C). All other internet use was the same regardless of whether the invoice was distributed on paper or electronically. Different kinds of information were available for the two processes and thus internet use was handled in different ways, as described below.

- impacts per MB, here used for B-to-B

For internet use related to the size of data sent, the figures used were based on an assessment of the ICT sector globally (Malmodin et al., in preparation) and personal communication with Jens Malmodin (2008). In this assessment, fixed network operation is estimated to use about 100 TWh/year globally. These networks are used for fixed telephony, internet use, etc. The figure is based on an operator survey made by Ericsson covering 26% of global subscribers, which was scaled up. This figure is quite rough. The fixed network figure covers network electricity use as well as energy used for operator activities (offices, etc.). The network system starts 'after the modem'.

In addition to the fixed networks there is also a need for transport networks. Malmodin used figures from Roth et al. (2002) and modified them to represent 2005 figures, giving a figure of 16 TWh/year globally.

The total energy use is split based on the size of information handled (in MB) globally. The estimated size of communications transported by bit-traffic in access networks during 2005 globally was 20 million Terabytes, of which 40% was non-mobile telephony (Malmodin, based on Ericsson, 2007). We combined the figure for fixed networks and the figure for transport networks and subsequently divided the energy use for these two services by 20 million Terabytes to get a rough estimate of energy use per MB (0.006 Wh/kB). Using this figure, the energy use per average invoice sent on the internet is 0.02 Wh. This figure could be roughly halved if extrapolated to 2007 (J. Malmodin, personal communication, 2008), since the transported bit-traffic has increased and the energy use has not increased at the same magnitude. However, we used the 0.02 Wh/invoice as a first estimate, keeping in mind the potential.

For servers, data from Itella Information were used (as presented above). These servers are used for providing access to invoices via the internet but also for other purposes, such as converting file format. Limiting the use of servers to these may lead to an exclusion of some other servers or data networks that may be used for internet operation. According to the assessment by Malmodin et al. (in preparation) the servers and data networks globally use 166 TWh/year, which would give 0.03 Wh/invoice. This is substantially lower than the energy use for the servers in the current study (5.2 Wh/invoice) and thus the possible underestimation is insignificant at least in relation to the Malmodin figures. The production and waste management of the internet infrastructure were not included in the study due to lack of data. This was to some extent included when considering internet use based on use duration as presented below. For internet use based on MB, the allocation could not be made based on the information available.

The figures for internet use per MB were used for modelling business use of the internet, for the electronic distribution of invoices to other businesses. For this activity we had the size of the information sent (3.5 kB/invoice), but not the time of internet use.

For this process the electricity mix used was varied in the two base scenarios.

- impacts per hour of use

Another way of handling impacts of internet use is to consider the effect (in W) in the different parts of the internet system and to calculate the energy use based on duration of use.

The data used here were mainly based on discussions with Dag Lundén at TeliaSonera (personal communication, 2008) and with Jens Malmodin at Ericsson (personal communication, 2008).

According to Dag Lundén, the major energy-demanding parts of using the fixed network are closest to the user, e.g. the use of modem and the so-called DSLAM (Digital Subscriber Line Access Multiplexer) for connecting to the internet.

To model the impact of the internet per hour of use, data on energy use for modem and DSLAM, but also for the internet operator and the transport and transmission of data were included. In addition, information concerning the production of cables and the emissions of CO_2-equivalents from construction work for putting cables into the ground was included. In the same way as for internet use per MB, the servers used were those described above for converting invoice formats and providing invoices for access via the internet.

Cables and construction

The data available for construction work (including design, construction and dismantling) were obtained from Dag Lundén at TeliaSonera and were based on a study made by Tingstorp (1998). The CO_2-equivalents are from cradle to grave and were included in the current study as an aggregated value, which according to Dag Lundén is mainly emissions from diesel and petrol use.

Production of copper cable was partly included. Data on average cable from TeliaSonera give 367 kg copper and 31 kg aluminium per km cable. The energy use for production of copper cable (EUALEW) is 587 kWh/km (Dag Lundén, citing Möller, 1996). No data were readily available for the production of optic fibre cable.

The length of the TeliaSonera copper and optic fibre cables was used to calculate the total emissions for construction work and cable production. Impacts were allocated amongst the TeliaSonera subscribers. For copper cable a range of 700 000-1 100 000 was given by Dag Lundén and we used 900 000 km as an average. For fibre optic cable 62 535 km were included. There are 5 400 000 network subscribers, whereof 4 400 000 are fixed voice subscribers and 1 000 000 broadband subscribers, according to TeliaSonera operational data from 2007. The lifetime of the cables buried in the ground was assumed to be 35 years (based on an estimation made by Dag Lundén). The impact of construction work was divided equally between the broadband and fixed voice subscribers. Using these figures, emissions of 2.9 kg of CO_2-eqv. were obtained for each subscriber and year for construction work. The values used are overestimations since today, construction work involves the possibility of adding more fibre cables without re-digging. The number of subscribers may also be higher, as business subscribers were possibly lacking, according to Dag Lundén. Thus, there is potential to decrease the figure on emissions from construction work per subscriber by roughly a factor of four.

Modem

The modem was assumed to be 9W. Since the internet per hour of use was only used for consumers in this study, a modem was assumed to be used in all cases. The modem was assumed to not be turned off when not in use. If the modem were to be turned off when not in use, the total energy use of the internet system would be lowered substantially, as the modem is a major contributor

DSLAM

The DSLAM for Internet access was assumed to be 5W. For consumers, there is one DSLAM per subscriber. In the case of businesses, internet connection is less energy-demanding per computer, but as this was not relevant here it was not further elaborated upon.

Operation

For the internet operator and transport and transmission, 1W and 3W were assumed respectively. These figures are estimations illustrating energy use per subscriber (J. Malmodin, personal communication, 2008). In the current study, the server or data centre energy use were not included in the internet use, since they were accounted for in other processes (servers as described above). The use of computers for internet access was handled separately (see Computers below).

The figures given in Watts above were decided upon in discussion with J. Malmodin (personal communication, 2008) and were comparable with figures per subscriber for ADSL-access from TeliaSonera (Isaksson, 1999, as cited and modified by Dag Lundén).

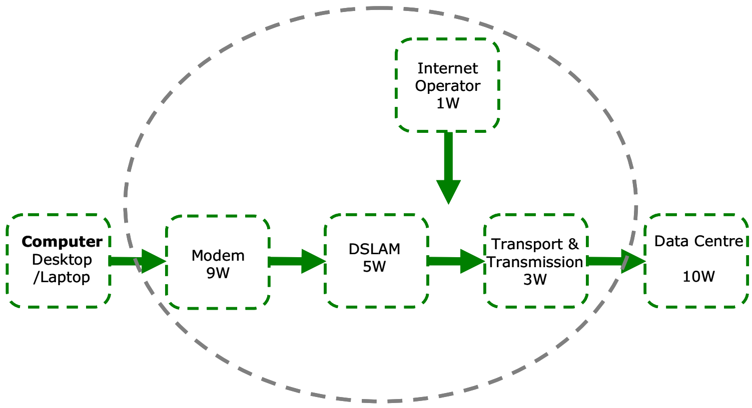


Figure 8. Illustration of the parts included in estimation of energy use for consumer use of the internet, based on duration of use. Figures are based on personal communications with Jens Malmodin at Ericsson Research (2008).

Internet use

To account for the energy used by the internet infrastructure when not in use, a relevant share of the non-active use time was allocated based on duration of use. In this study, as mentioned above, we assumed that all invoices were paid via the internet. This is a simplification and an overestimation of the internet use for invoice handling. However, in line with this assumption we assumed that all consumers use the internet for an average of 80 minutes per day, which is the average internet use in Sweden (Findahl, 2007). An internet subscription is probably more often per household than per user and therefore we estimated 160 minutes per day and household as there are on average 2 individuals per household (SCB, 2008). This means that for 89% of the time the internet is not used by a subscriber/household. The energy use during the non-active time was allocated to the active use, based on duration of active use.

The production and waste management of the internet infrastructure were not included in the study due to lack of data, except for the copper cables described above.

In the current study, the figures for internet use were based on the time used for consumer handling of B-to-C paper invoices. For this activity we assumed an extra internet use of 10 seconds per paper B-to-C invoice (giving 0.45 Wh/paper invoice for internet use and 0.35 Wh/paper invoice for desktop computer use). The amount of extra time needed is a rough assumption which is probably very individual, depending both on how paper invoices to be paid via the internet are handled but also how electronic invoices are handled on the internet, since it is the difference in duration of use that should be considered.

For this process the electricity mix used was varied in the two base scenarios. The use of laptop without additional screen instead of desktop computer with screen was tested in a sensitivity analysis.

4.2.19 Computer/server production

In the base scenarios, the use of a desktop computer with a TFT-LCD screen, keyboard and mouse was assumed. Data were taken from the Ecoinvent database (Lehmann and Hischier, 2007) and describe a common desktop computer during the time period 2002-2004 (Pentium 4, processor speed 2000 MHz, 40 GB RAM HDD, 512 MB working memory). The screen data describe a 17-inch screen produced in Japan representing production in the late 1990s. Data are presented as global average data.

In a sensitivity analysis, the use of a laptop computer without additional screen was tested. Data were taken from the Ecoinvent database (Lehmann and Hischier, 2007) and describe a usual laptop computer for the time period 2002-2004 (Pentium 3, processor speed 600 MHz, 10 GB RAM, 128 MB working memory, 12.1 inch screen).

The datasets describing the different modules and components making up the PC, screen and laptop are based on different data sources as described in Hischier et al. (2007).

The same data were used for the production of one server as for the production of two desktop computers (assumption based on personal communication, A. Gutowski, 2008).

4.2.20 Transportation of computers and related equipment

The transportation of computers, screens, etc. was assumed to be by boat (transoceanic freight ship) from China to Europe and further to the users in Sweden by truck (16-32 tonnes). The distance was estimated at 15 000 km by boat and 500 km by truck. This distance was not changed in the sensitivity analysis concerning transport distances.

Data on truck and freight ship transportation were taken from the Ecoinvent database (Spielmann et al., 2007).

4.2.21 Computer use

The use of computers is mentioned for each process where there is a difference in computer use between paper and electronic invoices.

For the electricity use of computers, figures from IVF (2007, p. 193) were used. These are average figures for idle-, sleep- and off-modes for computers on the market in 2005. The idle modes are 78.2 W for a desktop computer and 31.4 W for a LCD screen, while for a laptop in the idle mode the figure is 32 W. To account also for the time in sleep- and off-mode, we used computer use patterns for office and home equipment respectively (IVF, 2007 p. 101). All energy use in sleep- and off-mode was allocated to the active use time.

For this process the electricity mix used was varied in the two base scenarios.

4.2.22 Computer/server waste management

Ecoinvent 2.0 was also used for the data on waste management of electronic equipment. These data are based on experiences and data for Swiss conditions, but also on literature sources for WEEE-treatment (waste electrical and electronic equipment treatment) activities (Hischier, 2007b).

The treatment includes dismantling of the devices and treatment of the fractions so that hazardous components are taken care of and other important components are refined and recycled. In the dataset used for desktop, LCD screen and laptop, both manual and mechanical dismantling are used. For keyboard and mouse device, only mechanical dismantling is used.

4.2.23 Use of printer

In the base scenarios it was assumed that no electronic invoices were printed out on paper. This was assumed for both B-to-B and B-to-C. However, the possible effect of all invoices being printed was tested in sensitivity analyses, both for two A4 and for one A4.

The printer used in the sensitivity analyses was assumed to be a laser jet printer for black and white printing during 2002-2006, for home use or for smaller offices. Data were taken from the Ecoinvent database (Lehmann, 2007) and include the production, energy consumption for the different modes in the use-face, rail and road transport from factory to user, toner usage and benzene emissions. The life span was assumed to be 4 years (Lehmann, 2007).

According to Lehmann (2007), the electricity use in active mode is 300W on average and assumed printing capacity is 13 pages per minute. The energy consumption for printing one A4 is 0.384 Wh and the energy consumption for using a desktop computer while printing was set at 0.113 Wh for B-to-C and 0.0456 Wh for B-to-B.

In the case of printing, a rough estimation of transport was made assuming 2 km per 500 A4 sheets. This is a high figure and was used to test whether this transport made a difference. Transport was assumed to be by car (private car, 5% ethanol) and transport data were taken from the Ecoinvent database (Spielmann et al., 2007). The transportation of paper from the paper plant to the shop was assumed to be 100 km by truck (data from the Ecoinvent database, as described in Spielmann et al., 2007).

The waste management procedure was assumed to be similar to the computer/server treatment. First the printer was dismantled and then the important or hazardous components were treated further and recycled when possible. Plastics and toner were incinerated (Hischier, 2007b).

In the sensitivity analyses concerning printing of electronic invoices, the electricity mix was varied.

4.2.24 Archiving

Original invoices received in B-to-B communication have to be stored for 10 years before they can be disposed of (SFS 1999:1078). For B-to-C invoices no storage was considered in the study.

- Paper

In the case of paper invoices the storage is physical and thus there is a need for heating and to some extent lighting for storage areas. In some cases there may also be a need for regulating humidity or cooling, but this was not included in this study due to lack of data.

Data for archiving paper invoices were based on specific information from KTH - Royal Institute of Technology (T. Mullo, personal communication, 2008). According to Tomas Mullo, 18 514 invoices per m^2 are stored in the archive used at KTH. Data for heating office space were used for estimating the energy use for the archive; 118 kWh per m^2 and year based on figures from 2006 (SCB, 2007). Using this figure, the energy use for heating is 6.4 Wh per invoice and year. Heating was assumed to be district heating produced from natural gas and biomass, as described below for heat avoided.

According to Tomas Mullo (personal communication, 2008) there is room for another 385 invoices per m^2. In the study we assumed that the archive was not fully utilised, which is the case in practice.

No transportation was assumed for filing the B-to-B paper invoices into the archive.

- Electronic

In the case of electronic invoices the storage was assumed to be electronic, on a server. Information on the energy use for server archives was provided by Bo Westin at KTH - Royal Institute of Technology (personal communication, 2008). The data used were based on the approximate maximum effect of a server, 345 W in this case, and the archiving capacity, 1.6 Tb in this case. Only 60% of the server capacity was utilised in practice according to Bo Westin. Using these figures, the energy consumption for one invoice (3.5 kB) is approximately 0.11 Wh for 10 years of storage.

For this process the electricity mix used was varied in the two base scenarios.

4.2.25 Recycling of waste paper

The waste paper for recycling in the study referred to the paper invoices, 66% of which were assumed to be recycled into new paper. This was the recycling rate of office paper in Sweden in 2006 (Naturvårdsverket, 2008). The rest were assumed to be incinerated with energy recovery (see below). As there are no data available, to our knowledge, on the marginal waste management option for waste paper, the current average was used as an approximation.

For paper recycling, data from Ecoinvent 2.0 as described in Hischier (2007a) were used. The data used are on recycling with de-inking, representing European conditions in 2000. The sorting and storage of the waste paper at the plant were included in this process. The dataset was altered regarding the electricity mixes used in the study. This modification was made for the recycling process itself, the kaolin production and the sorting of collected paper.

The paper produced from the recycled fibres was assumed to replace newsprint paper produced from virgin fibres (see section 4.2.27).

For this process the electricity mix used was varied in the two base scenarios. The transportation of waste paper to the recycling site was assumed to be 100 km (900 km was assumed in the sensitivity analysis concerning longer transportation distances). The transport was assumed to be by truck (16-32 tonnes) using data from Spielmann et al. (2007).

4.2.26 Incineration of waste paper and envelopes

The fraction of the paper invoices that was not recycled, 34%, was assumed to be incinerated with energy recovery. All the envelopes were assumed to be handled in this way. An envelope consists of 95% paper, 3% polystyrene (for the window) and 2% glue. There were no readily available data on incineration of the glue, and this was not included in the waste management modelling in the study.

For the paper invoices and the paper part of the envelopes, data on paper disposal to municipal incineration were used as provided in Ecoinvent 2.0 (Doka, 2007). The polystyrene windows of the envelopes were handled through the use of data for disposal of polystyrene to municipal incineration (Doka, 2007). These data correspond to average Swiss technology for municipal solid waste incineration (MSWI) in 2000.

All resources used and emissions produced in the datasets (Doka, 2007) are related to the disposal function of incineration of waste with energy recovery and the energy production has 'zero burden'. To handle the benefits of heat and electricity being produced while disposing of the waste in this study, we included the amount of energy produced. The electrical and thermal efficiency of the plant was modified to better illustrate Swedish conditions. An efficiency of 0.91 for CHP (combined heat and power) plants fuelled by household waste was used (Uppenberg et al., 2001). Figures on electricity and heat produced from Swedish waste incineration plants in 2007 were used to get an estimate of the respective proportions of electricity and heat produced (Avfall Sverige, 2008). The net energy produced from waste paper was set at 1.38 MJ electric energy and 11.45 MJ thermal energy per kg waste paper, while for polystyrene (PS) incineration the corresponding figures were 3.78 MJ electric energy and 31.36 MJ thermal energy per kg PS. The same amount of heat and electricity was then accounted for as avoided electricity and heat production (so-called system expansion).

For this process the electricity mix avoided was varied in the two base scenarios. The transport distance of waste paper to the incineration site was assumed to be 50 km (100 km was tested in the sensitivity analysis regarding longer transportation distances). The transport was assumed to be by truck (16-32 tonnes) using data from Spielmann et al. (2007).

4.2.27 Avoided paper production

When waste paper is recycled into new paper the studied system of paper invoices (and the system of printed electronic invoices) provides an additional function/benefit. Besides the distribution of information regarding payment, new paper is produced at the end of the invoice life cycle. To make the paper invoicing and electronic invoicing systems comparable regarding the functions provided, the paper invoicing system was expanded (as was the printed electronic invoices system) to include avoided paper production. This avoided paper production was assumed to be newsprint with no de-inked pulp, which means newsprint made solely from virgin fibres. Ecoinvent data, as described in Hischier (2007a), were used. These data represent European paper production in 2000. The dataset was altered for the electricity mixes used in this study. This modification was made for the paper-making process itself, the sulphate pulp production, the kaolin production, the industrial residue wood and the wood chips.

For this process the electricity mix avoided was varied in the two base scenarios.

4.2.28 Avoided electricity and heat production

The electricity avoided as electricity is produced through waste incineration was assumed to be marginal electricity and thus the same mixes as described above under electricity production were used.

The heat production avoided was assumed to be marginal heat production. Based on Sahlin et al. (2004) we used a mix of heat produced from biomass (76%) and natural gas (24%). Sahlin et al. (2004) in their study focused on changes in district heat production when more waste was incinerated with energy recovery. They investigated this through modelling and through questionnaires to district heating companies. We used combined results, assuming only biomass and fossil fuel (the two main alternatives) and assuming the fossil fuel to be natural gas. The avoided heat production could also have been assumed to be from incineration of other waste. Municipal solid waste as a fuel can roughly be approximated to a mixture of biofuels and fossil fuels. Thus the mix of biomass and natural gas used can also be seen as an approximation of other waste as a marginal heat source.

Ecoinvent data for heat production from wood chips (Bauer, 2007) and natural gas (Heck, 2007) at combined heat and power plants were used.

4.2.29 Data quality and uncertainty

Readily available data were used in the study. To a large extent the database Ecoinvent 2.0 was used (Frischknecht et al., 2007). The impact categories studied were cumulative energy demand and greenhouse gas emissions. These impact categories can in general be said to be relatively well covered in the data inventories. In the impact assessment step the substances (resources and emissions) not covered by the impact assessment methods used seemed to be irrelevant for the impact categories in question. Thus, as far as coverage of the impact assessment methods used is concerned, the quality was good.

The Ecoinvent database is one of the more comprehensive and newly updated LCA databases that are available, and for a general study looking at data on the national level the data provided seem sufficient. Unfortunately, some inventory data are only for Swiss conditions and in these cases the data may be considered of lower quality for the purpose. This can also be the case when Swedish conditions differ considerably from the European average.

For offset printing, the available data from Larsen et al. (2006) were used for all the offset printing, even though they refer to sheet-fed offset printing and the actual case is a mix of sheet-fed and web-fed offset printing. As described earlier, this led to a probable overestimation of the offset printing impact. Company-specific data were used in many cases where new data were gathered for the study, as general national data were not available. In a consequential analysis the ideal data are those that are suggested to be marginal; however the actual marginal data are in many cases not known or suggested. In these cases, current average figures were used as an approximation as good as any other. For this kind of screening study this was judged to be sufficient.

Marginal data were used for electricity and heat production. For these processes there are several studies available discussing and suggesting marginal data. In addition, as regards energy use, experience has shown that different choices of energy sources may have a significant impact on the results in many cases.

To reduce uncertainty in the results of the study, sensitivity analyses were carried out as described below.

4.2.30 Missing data and limitations

Some data were not easily available and could not be obtained within the framework of the current study. Production and waste management data for scanning equipment, modem and most other internet infrastructure were lacking.

The data on internet use are a rough estimate. The data on construction work for burying cables only include the aggregated emitted CO_2-equivalents. Inventory data and experience of assessing the environmental impacts of internet use relating to some benefit provided (e.g. hours of use, or MB transferred) are limited. Within the framework of this study, it was not possible to go deeper into this issue. The data used were uncertain and the allocation of energy used for internet infrastructure construction and use should be further studied. However, the use of the internet for invoice handling was only to some extent affected by the change from paper invoices to electronic, as paper invoices were also assumed to be paid via the internet. The extra time needed for handling paper invoices on the internet was assumed to be rather low.

In addition the handling of invoices by businesses and end-consumers are based on assumptions.

4.2.31 Base scenarios and sensitivity analyses

In order to assess the importance of different assumptions, several different scenarios were modelled as sensitivity analyses. To start with, two base scenarios were defined, with the only difference that different electricity mixes were used (Table 4). The importance of different assumptions as described in Table 4 was then tested through a series of sensitivity analyses.

Table 4. Description of the base scenarios and variations made in sensitivity analyses

	Base scenarios	**Variation**
Electricity mix	CO_2cap and High gas price respectively	
Number of pages (paper invoice)	2 A4 (printed on one side)	1 A4 (printed on one side)
Size of electronic invoice	3.5 kB	
Offset printing	67% of invoices pre-printed with offset	
Distribution	Economy class mail	B-to-B invoices sent by first class mail
Computer type	Desktop and LCD screen	Laptop without additional screen
Consumer invoice handling	10 seconds extra time used on the internet per B-to-C paper invoice	1 minute extra time used on the internet per B-to-C paper invoice
Data capture	50% of B-to-B paper invoices scanned and verified	
Extra time for electronic handling of electronic invoice	-	5 minutes extra computer time needed to handle electronic B-to-B invoices.
Electronic invoice handling	No electronic invoices printed by user	All electronic invoices printed by user
Transportation	Short distances	Long distances

5. Results

5.1 General

In the study, the consequences of changing 1 400 000 000 invoices (the number of invoices in Sweden each year) from distribution on paper to electronic distribution were examined. The resulting figures describe the possible impacts of this change. Negative values describe a benefit, e.g. energy use avoided as there is no need for paper production.

Section 5.2 describes the consequences of this change for the base scenarios and for the sensitivity analyses made. Section 5.3 describes the paper invoice and electronic invoice systems, as modelled in the study, in a more disaggregated way, considering the parts of the respective system that contributed most to the cumulative energy demand and emissions of greenhouse gases. In the discussion in chapter 6, the resulting figures on emissions of greenhouse gases are related to other relevant activities to illustrate their magnitude.

5.2 Consequences of a change from paper to electronic invoices

5.2.1 Cumulative energy demand

Regarding cumulative energy demand, the change from paper invoices to electronic invoices is beneficial. If all invoices in Sweden were to be changed, a total energy saving of around 1 400 TJ-eqv./year would be made in the base scenarios (Figure 9). The difference depending on the electricity mix used for the base scenario is insignificant. The main reason for the difference is less energy use, as paper is avoided.

Below, the results of sensitivity analyses are presented using the CO_2cap electricity mix only, since the results were more or less the same irrelevant of electricity mix used for the cumulative energy demand. All results are presented in Appendix 3.

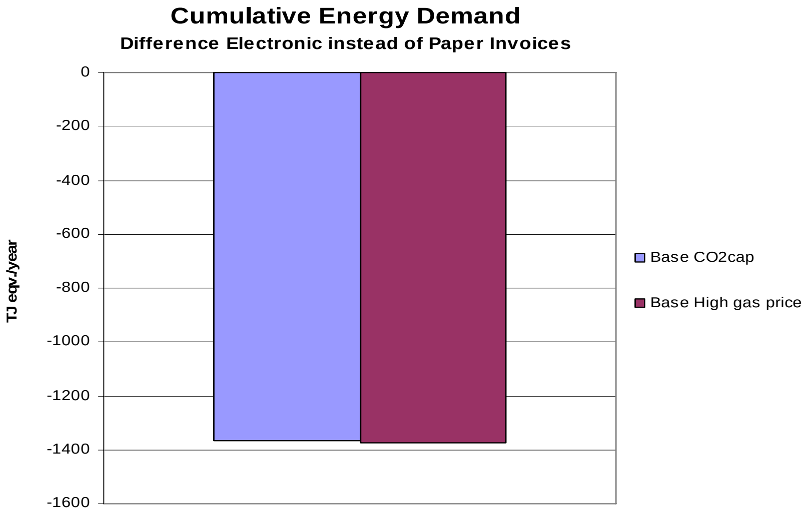


Figure 9. Potential consequences in terms of cumulative energy demand if all invoices in Sweden were changed from paper to electronic. Base scenario, with two different electricity mixes.

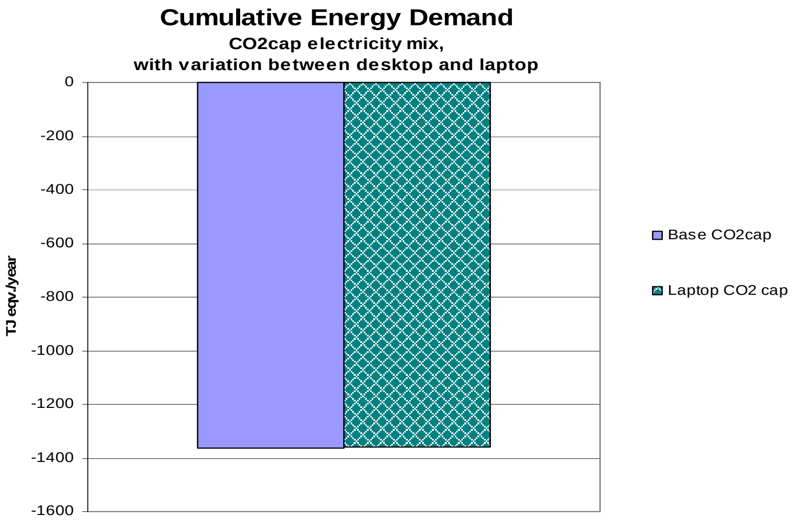


Figure 10. Sensitivity analysis considering type of computer used, showing the resulting difference in terms of cumulative energy demand. In the base scenario a desktop computer with screen is used and in the other case this is changed to a laptop computer without additional screen.

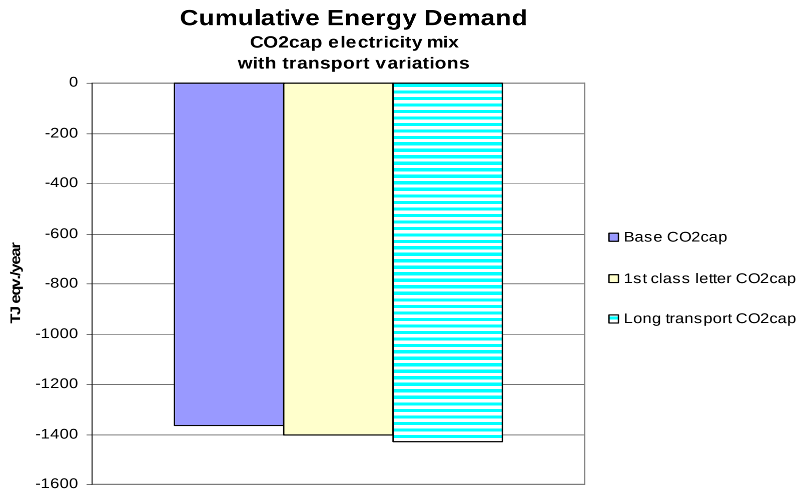


Figure 11. Sensitivity analysis considering variations in transportation. The base scenario is compared with a case where B-to-B invoices are sent by first class mail and another case where transportation distances are assumed to be longer. All systems using the CO_2cap electricity mix

Only a small change in the resulting cumulative energy demand occurred when the assumption on computer type used was altered from desktop to laptop (Figure 10). Increasing transport distances and sending B-to-B invoices by first class mail led to slightly different energy savings going from paper invoices to electronic (Figure 11). When the B-to-B invoices were assumed to be sent by first class mail, the total energy saving of a change to electronic invoices increased by 40 TJ-eqv./year. Assuming longer transport distances increased the total energy saving of the change to electronic invoicing by 65 TJ-eqv./year.

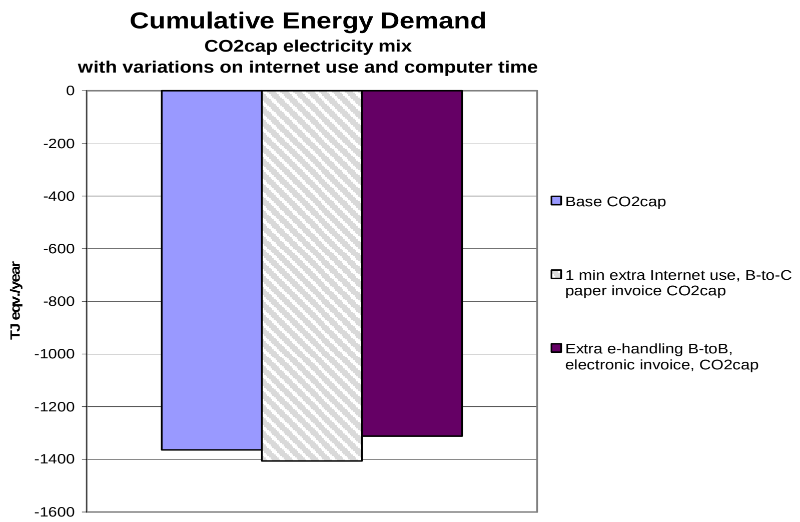


Figure 12. Sensitivity analysis considering variations in user handling of invoices. The base scenario is compared with a case where B-to-C paper invoices leads to one minute extra use of the internet per B-to-C paper invoice compared with electronic invoices, and another case where B-to-B electronic invoices leads to five minutes extra computer use per B-to-B electronic invoice compared with paper invoices. All systems using the CO_2cap electricity mix

When information from B-to-C paper invoices is entered manually on the internet bank website more time is needed compared with receiving information there electronically via electronic invoices. In a sensitivity analysis the extra time needed was increased to one minute per invoice (compared with 10 seconds in the base scenario) to consider the importance of this parameter. The benefit of changing from paper to electronic invoices with this longer internet use increased by 40 TJ-eqv./year (Figure 12). On the other hand, if the change to electronic invoices were to lead to more time (an extra five minutes in this case) using the computer for administration of B-to-B invoices, 50 TJ-eqv./year less would be saved through a change to electronic invoices (Figure 12).

However, the key issue here is the amount of paper that is avoided (Figure 13). If the paper invoice consisted of one A4-sheet instead of two, the cumulative energy demand which could be saved by a change to electronic invoices would decrease to roughly 890 TJ-eqv./year. Similarly, if the electronic invoice system also included paper use through electronic invoices being printed on a laser jet printer after being distributed, the gain would decrease to 790 TJ eqv./year. However, there is still a benefit since the paper invoice needs an envelope, physical distribution, etc.

If the change were from paper invoices consisting of one A4 page each to electronic invoices being printed on a laser jet printer (one A4), the cumulative energy demand would result in a benefit of only 610 TJ-eqv./year.

Overall, the base scenarios and the sensitivity analyses show that there is a potential for energy savings in changing from paper invoices to electronic invoices. The figures obtained were similar for the sensitivity analyses using the High gas price electricity mix (see Appendix 3).

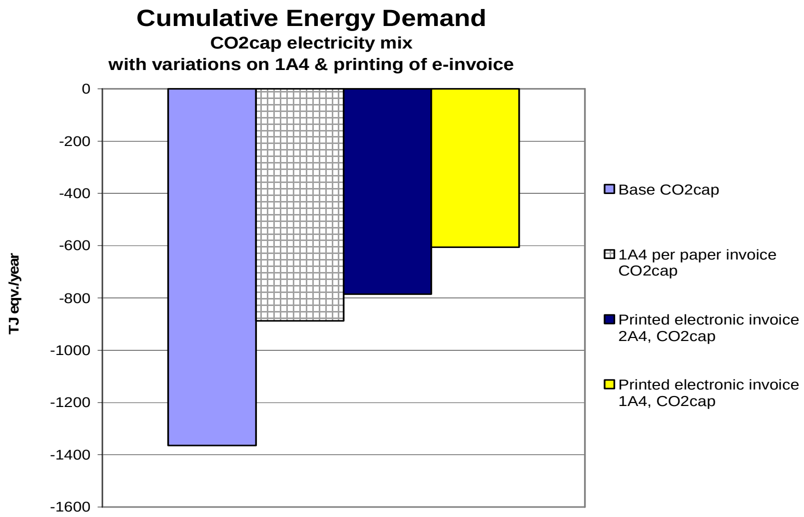


Figure 13. Sensitivity analysis considering variations in paper use and printing. The base scenario is compared to a case where paper invoices consist of one A4 sheet, a second case where electronic invoices are printed on two A4 sheets and a third case where paper invoices consist of one A4 sheet and electronic invoices are printed on one A4 sheet. All systems using the CO_2cap electricity mix.

5.2.2 Greenhouse gas emissions

In the base scenarios, the change from paper invoices to electronic invoices led to reductions in greenhouse gas emissions corresponding to 39 000 to 41 000 ton CO_2-equivalents/year depending on the electricity mix used (Figure 14).

In the base scenario with the CO_2cap electricity mix, the emissions arising from the electronic invoice system were small compared with the paper invoice system. As the main impact from the electronic invoice system came from use of electricity (as is further described below), the greenhouse gas emissions from the electronic invoice system increased substantially when the electricity mix was changed to the more CO_2-intensive High gas price electricity mix. However, as the emissions of the paper invoice system increased as well, the total benefit of altering to electronic invoices was even higher with the High gas price electricity mix.

The results of sensitivity analyses are presented below.

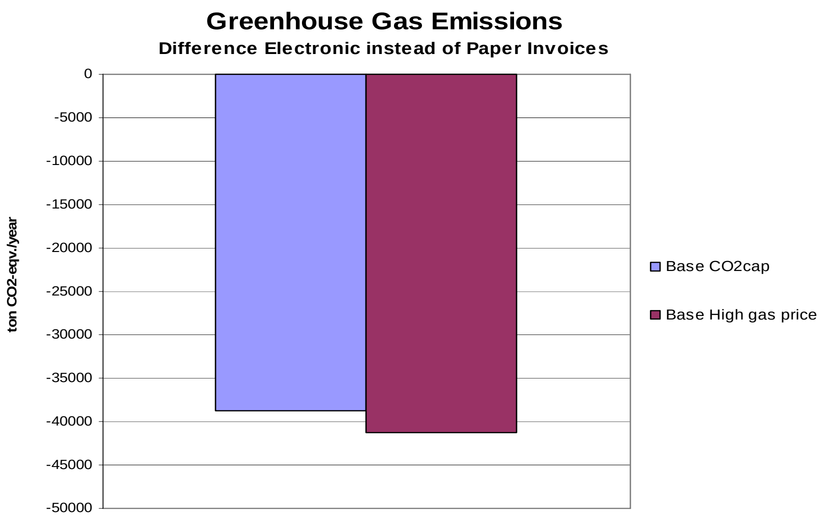


Figure 14. Potential consequence in terms of greenhouse gas emissions if all invoices in Sweden were changed from paper to electronic. Base scenario, with two difference electricity mixes.

In the systems studied, the use of computers was not a key issue, and thus the difference from using a more energy-efficient laptop compared with a desktop PC had no significant effect on the overall results (Figure 15).

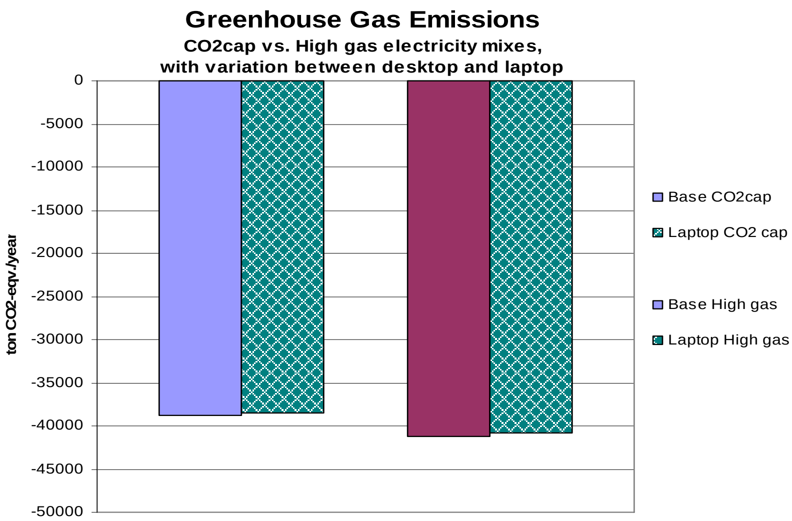


Figure 15. Sensitivity analysis considering type of computer used, showing the resulting difference in terms of greenhouse gas emissions. In the base scenario a desktop computer with screen is used and in the other case this is changed to a laptop computer without additional screen.

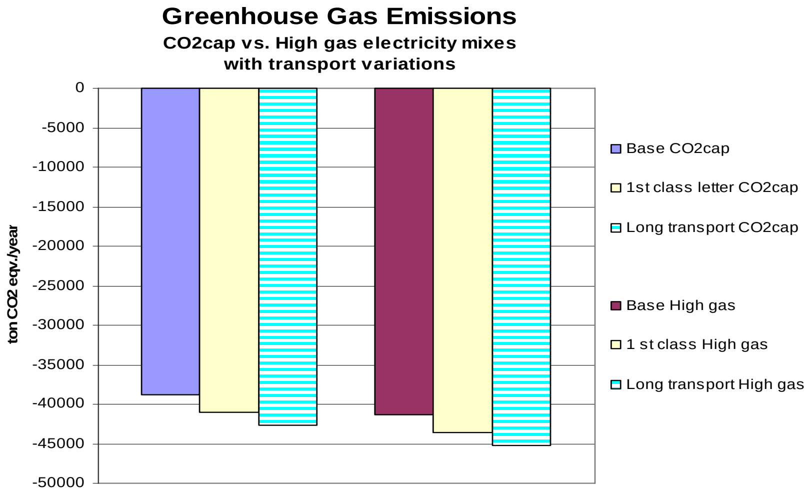


Figure 16. Sensitivity analysis considering variations in transportation. The base scenario is compared with a case where B-to-B invoices are sent by first class mail and another case where transportation distances are assumed to be longer.

If B-to-B invoices were to be sent by first class mail, the greenhouse gas emissions that could be saved through converting to electronic invoices would increase by 2 300 ton CO_2-eqv./year. In addition, if transportation distances were longer, e.g. for paper transport, the savings could be increased by an additional 3 900 ton CO_2-eqv./year (Figure 16).

In the base scenarios it was assumed that there was no difference in the handling of an electronic or paper B-to-B invoice at the business or organisation receiving the invoice. If the handling of B-to-B electronic invoices were to require more use of computers, the benefit of electronic invoices would decrease slightly (Figure 17). Here the assumption of five minutes extra time per electronic B-to-B invoice was tested in a sensitivity analysis and this led to a decrease in savings potential compared with the base scenarios corresponding to 2 100 ton CO_2-eqv./year using the CO_2cap electricity mix and 4 800 ton CO_2-eqv./year using the High gas price electricity mix.

If the B-to-C paper invoices were to lead to a substantially longer time using the internet for manually entering data, the benefit of changing to electronic invoices would increase by 1 900 or 4 500 CO_2-eqv./year depending on electricity mix (Figure 17). The results show that if the difference in duration of use is high, this process could affect the level of benefit obtained.

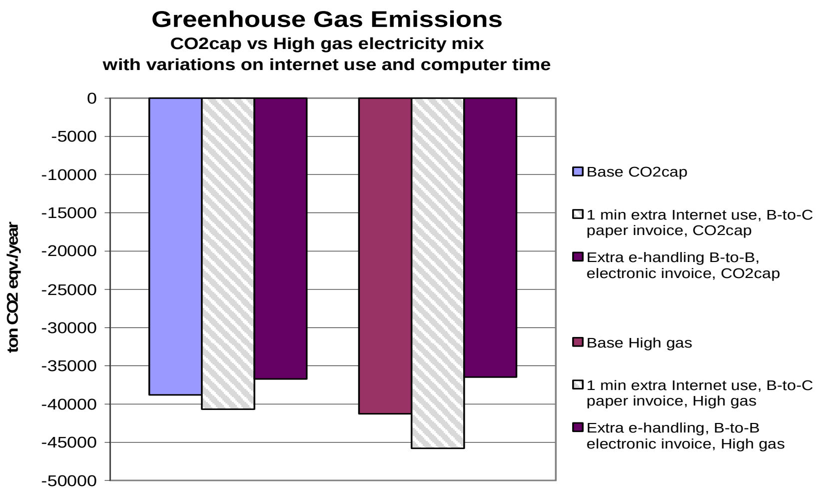


Figure 17. Sensitivity analysis considering variations in user handling of invoices. The base scenario is compared with a case where B-to-C paper invoices lead to one minute extra use of Internet per B-to-C paper invoice compared with electronic invoices, and another case where B-to-B electronic invoices lead to five minutes extra computer use per electronic B-to-B invoice compared with paper invoices. All systems using the CO_2cap electricity mix

A large decrease in benefit, compared with the base scenarios, could be seen when the amount of paper used was changed in sensitivity analyses (Figure 18). When the paper invoices were assumed to only consist of one A4 sheet instead of two, the benefit of changing to electronic invoices decreased by 12 000 ton CO_2-eqv./year or 17 000 ton CO_2-eqv./year depending on whether the CO_2cap electricity mix or the High gas price electricity mix was used. When the electronic invoices were assumed to be printed using a laser jet printer, the benefit of changing to electronic invoices decreased by 22 000 ton CO_2-eqv./year or 12 000 ton CO_2-eqv./year depending on whether the CO_2cap electricity mix or the High gas price electricity mix was used. In the former, the benefit almost halved when the electronic invoices were printed. The fact that there was still a benefit when two A4 pages were printed on a laser jet printer compared with sending two A4 pages on paper was mainly due to the need for an envelope and the distribution.

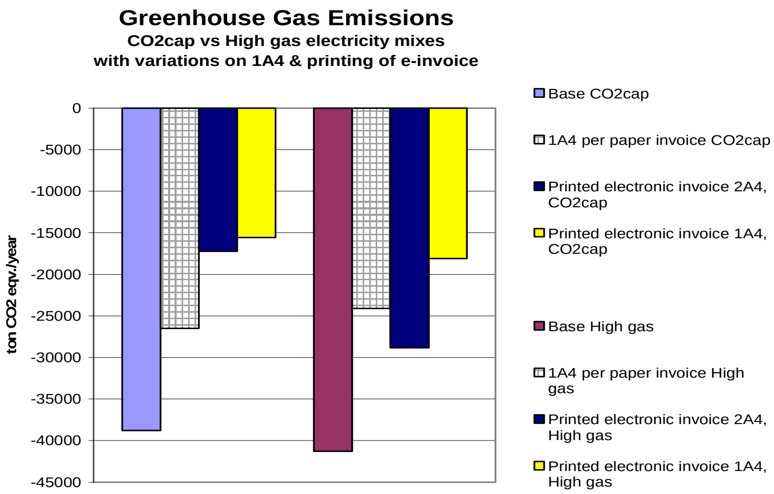


Figure 18. Sensitivity analysis considering variations in paper use and printing. The base scenario is compared with a case where paper invoices consist of one A4 sheet, a second case where electronic invoices are printed on two A4 sheets and a third case where paper invoices consist of one A4 sheet and electronic invoices are printed on one A4 sheet.

The overall result throughout all variations was that there was a benefit in terms of emissions of greenhouse gases in changing from paper invoices to electronic invoices. Of the different alternatives tested here, the least benefit was gained when the paper invoice was only one A4 sheet and when the corresponding electronic invoice was printed with a laser jet printer after being distributed. In this case 16 000 – 18 000 tons of CO_2-eqv. per year would be avoided through changing 1 400 000 000 invoices from paper to electronic.

5.2.3 Other environmental impacts

The focus of the current study was limited to energy use and greenhouse gas emissions. However, results concerning other impact categories of the CML characterisation method (abiotic depletion, acidification, eutrophication, ozone layer depletion, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity and photochemical oxidation) can be calculated. Since the focus here was on energy and greenhouse gases, limited efforts were made to check the data quality or relevance of these other impact categories. The results should therefore be interpreted with caution. Bearing that in mind, there seems to be a general benefit from changing to electronic invoices for other impact categories too. However, this should be studied in more detail to get reliable results.

5.3 Flows in the two systems

5.3.1 General

The two systems studied were modelled separately, including only processes where a change from paper to electronic invoices would make a difference, and then the difference between the two systems was studied. The electronic invoice and paper invoice systems as modelled in the study are shown below. However it should be noted that it is not the total environmental impact of the systems that is presented, as this was not the aim of the study.

Figure 19, Figure 21, Figure 25 and Figure 27 show the results in flow charts as presented in the software used (SimaPro 7.1.8). The box at the top illustrates the full life cycle, and thus 100% of the studied impact. The boxes below contribute in a cumulative manner. The thickness of the arrows indicates the magnitude of the impact from the process and its pre-processes. Red arrows illustrate disadvantages and green benefits. All processes are not illustrated, but only those contributing the most to the impact shown, since there would not be room for all processes part of the studied life cycle of the invoices. The figures at the top of each box are not always easy to follow but make sense in the modelling of the system. The percentage given in the lower left-hand corner probably gives better information to the reader.

5.3.2 Cumulative energy demand

As can be seen in Figure 19 and Figure 20, for the electronic invoice system the major energy use was for the use of servers (for converting file formats, providing access to the invoices and storing them). The figures show the base scenario with CO_2cap electricity mix. For the base scenario with the High gas price electricity mix the flows looked the same, but the main energy use came from coal and not from nuclear and wood as in the base scenario with CO_2cap electricity mix (see Appendix 2).

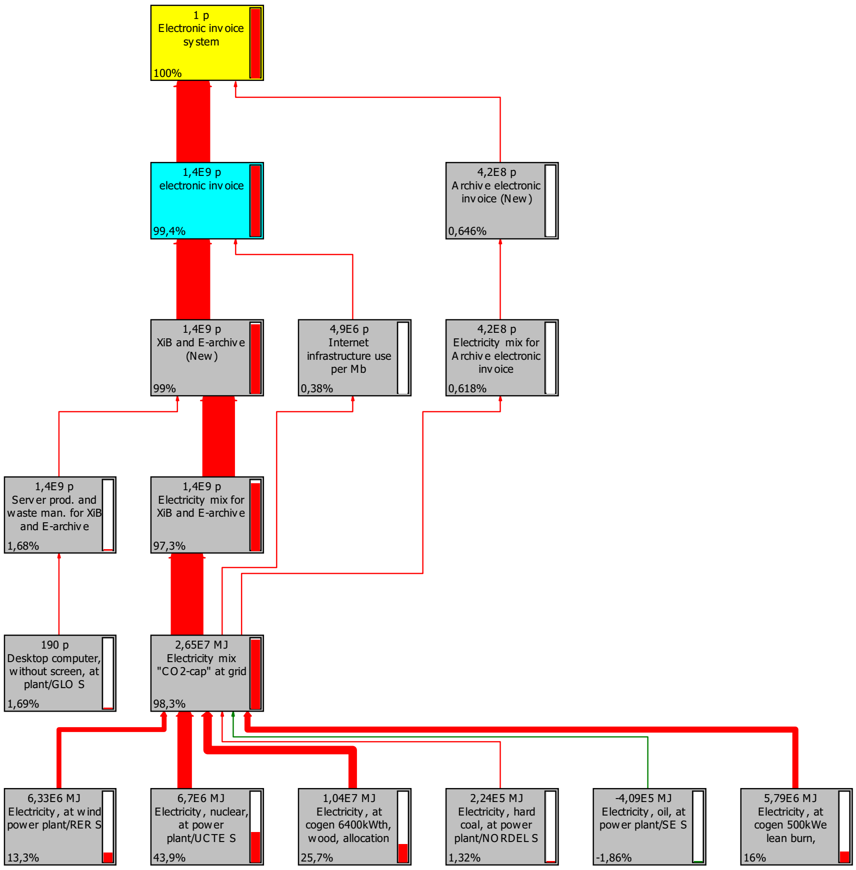


Figure 19. Network showing the cumulative energy demand for the electronic invoice system in the base scenario with CO_2cap electricity mix. Processes shown contributed more than 0.3% to the total energy demand. XiB and E-archive are the environments used for converting invoice format and storing electronic invoices for access via the internet. The data used for these are described under Servers in the data inventory.

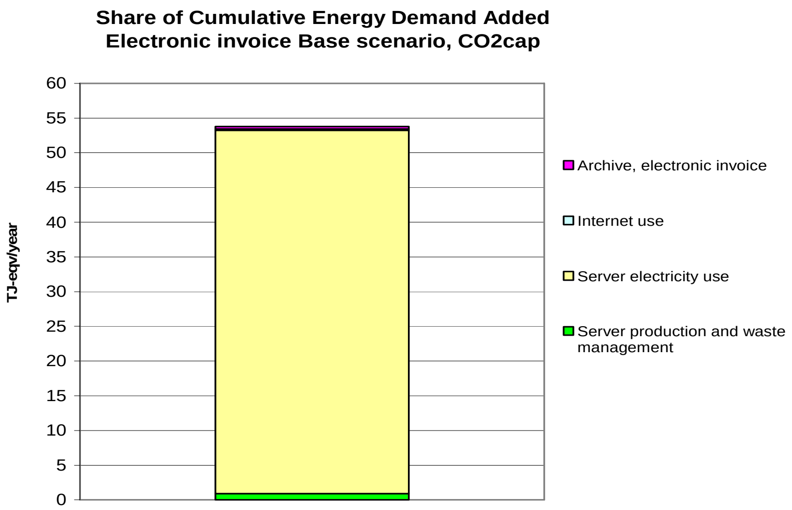


Figure 20. Cumulative energy demand in the electronic invoice system modelled in the study. Different processes of the life cycle contributed to the cumulative energy demand. Note that the scales are different for the different figures regarding cumulative energy demand.

In the paper invoice system (Figure 21), the paper was the main contributor to the cumulative energy use, partly as the wood biomass counts as renewable energy and partly as the pulp and paper-making processes are energy-demanding. The cumulative energy demand is presented in more disaggregated form in Appendix 3. The green arrows in the waste scenario processes (Figure 21) indicate that avoiding production of heat, electricity and newsprint saves energy, even though paper recycling requires energy as well. The flows were similar in the base scenario with the High gas price electricity mix (see Appendix 2).

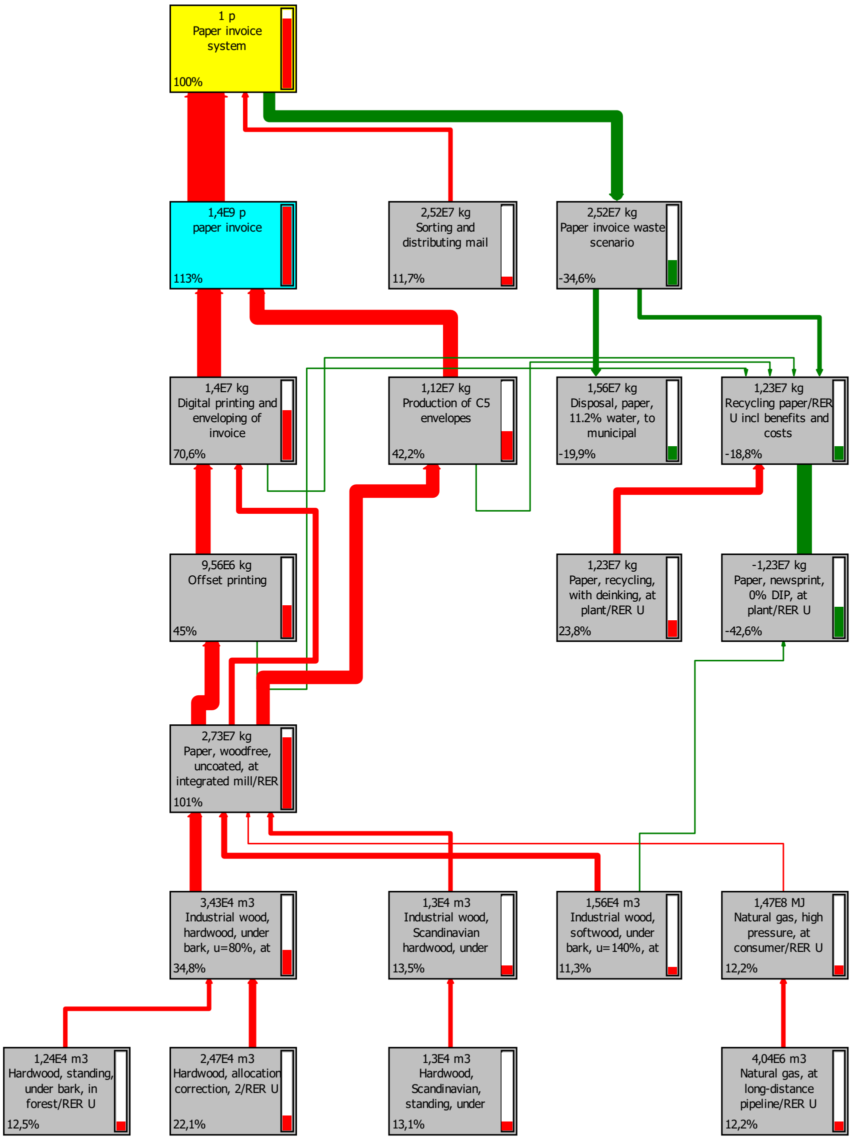


Figure 21. Network showing the cumulative energy demand for the paper invoice system in the base scenario with CO_2cap electricity mix. Processes shown contributed more than 0.3% to the total cumulative energy demand.

Figure 22 shows that the other parts of the life cycle with high energy demand were distribution, storing the paper invoices in archives and the digital printing and placing in envelopes.

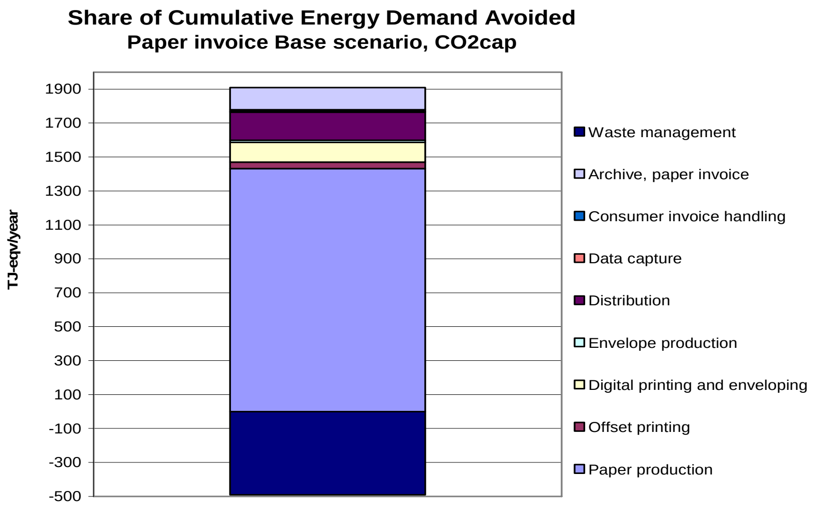


Figure 22. Cumulative energy demand in the paper invoice system modelled in the study. Different processes of the life cycle contributed to the cumulative energy demand. Note that there are positive and negative values, where the negative values indicate a benefit (avoided energy demand). Note that the scales are different for the different figures regarding cumulative energy demand.

Considering the invoice systems modelled in the sensitivity analyses, in some cases there was a significant difference in the distribution of the total impact within the invoice life cycles compared with the base scenarios. Figure 23 shows the paper invoice system with one minute extra internet time per invoice. Here, the distribution was more or less the same as in the base scenario (Figure 22), but the internet use occupied a larger share of the total. Figure 24 shows the electronic invoice with laser jet printing of two A4 pages. Here it can be seen that the cumulative energy demand for the paper was the largest part of the total value. The waste management of the paper compensated for part of this energy demand through avoided production of electricity, heat and newsprint paper.

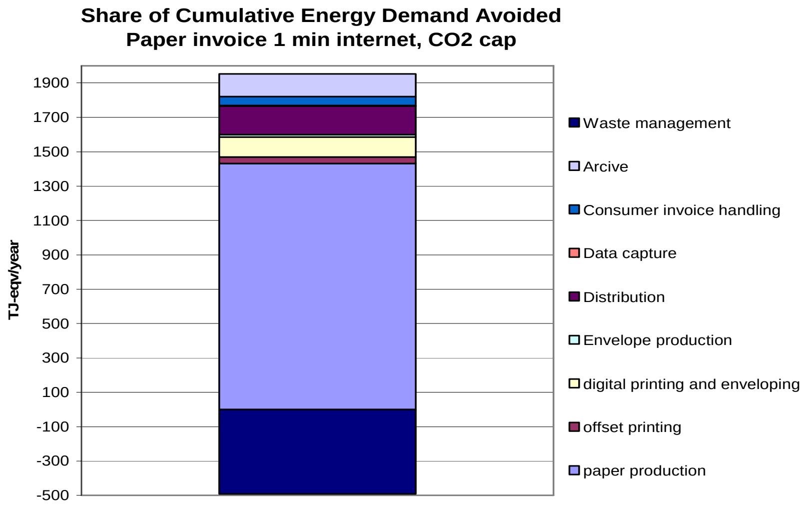


Figure 23. Cumulative energy demand in the paper invoice system modelled with the assumption that one minute extra time of internet use was needed per paper invoice compared with an electronic invoice. Different processes of the life cycle contributed to the cumulative energy demand. Note that there are positive and negative values, where the negative values indicate a benefit (avoided energy demand). The scales are different for the different figures regarding cumulative energy demand.

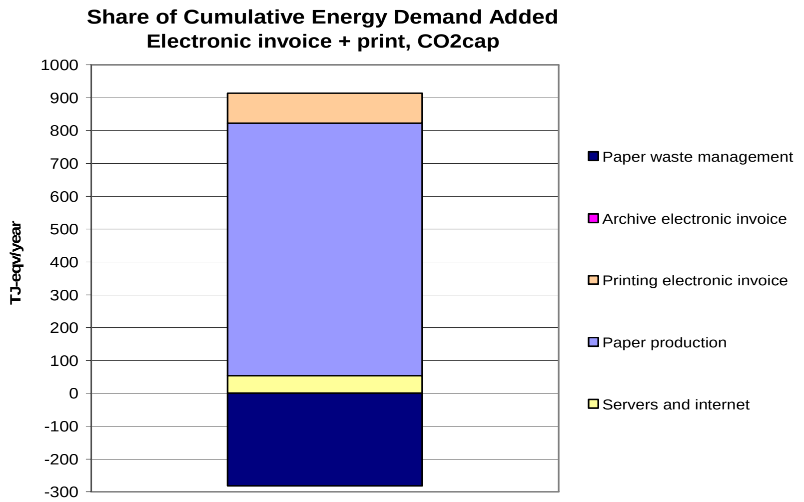


Figure 24. Cumulative energy demand in the electronic invoice system modelled with the assumption of printing two A4 pages on a laser jet printer. Different processes of the life cycle contributed to the cumulative energy demand. Note that there are positive and negative values, where the negative values indicate a benefit (avoided energy demand). The scales are different for the different figures regarding cumulative energy demand.

5.3.3 Greenhouse gas emissions

Similarly to the cumulative energy demand, for the electronic invoice system the main contribution to the greenhouse gas emissions came from the use of the servers. In the base scenario with CO_2cap electricity mix (Figure 25 and Figure 26) the greenhouse gas emissions mainly arose from electricity generated from natural gas. In the base scenario with High gas price electricity mix, on the other hand, the emissions were from electricity from coal (Appendix 2). The differences in magnitude of greenhouse gas emissions are shown in Figure 26.

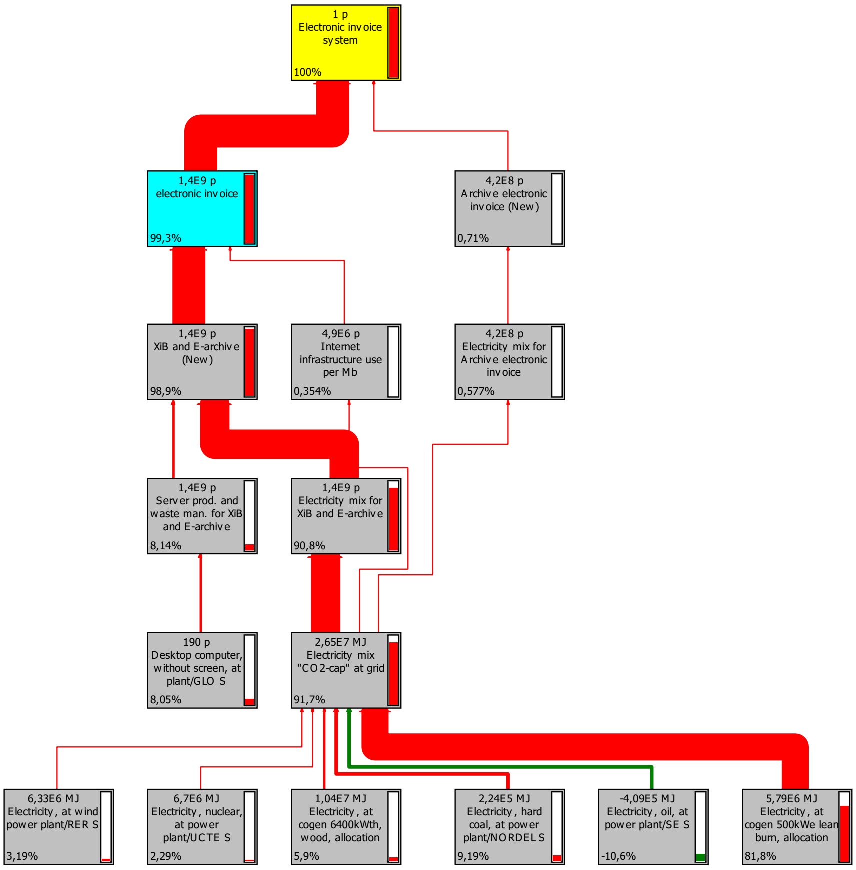


Figure 25. Network showing the greenhouse gas emissions for the electronic invoice system in the base scenario with CO_2cap electricity mix. Processes shown contributed more than 0.05% to the total emissions (CO_2eqv.). XiB and E-archive are the environments used for converting invoice format and storing electronic invoices for access via the internet. The data used for these are described under Servers in the data inventory.

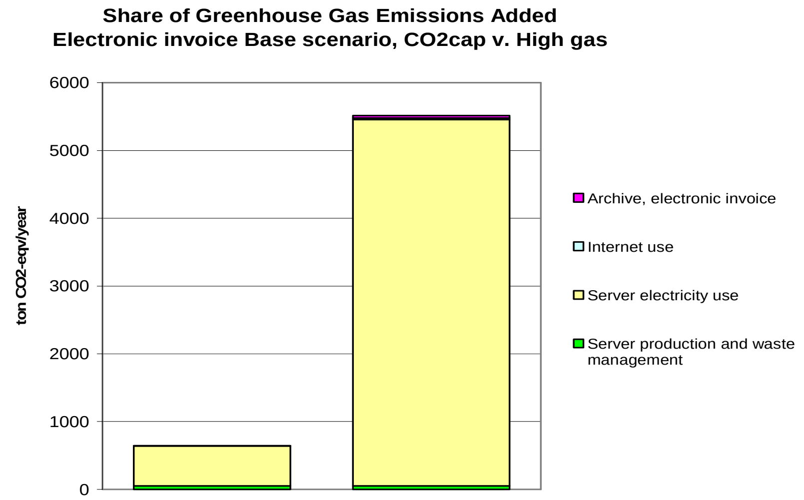


Figure 26. Greenhouse gas emissions in the electronic invoice system modelled in the study. Different processes of the life cycle contributed to the cumulative energy demand. The left column illustrates the base scenario with CO_2cap electricity mix and the right the base scenario with High gas price electricity mix. The scales are different for the different figures regarding cumulative energy demand.

In the paper invoice system the paper again had a major impact. In the base scenario with CO_2cap electricity mix (Figure 27 and Figure 28), even the waste scenario contributed to the greenhouse gas emissions as the recycling of paper used natural gas in the process and the avoided production of newsprint used electricity with low levels of greenhouse gas emissions (CO_2cap electricity mix) and thus less greenhouse gas emissions were avoided.

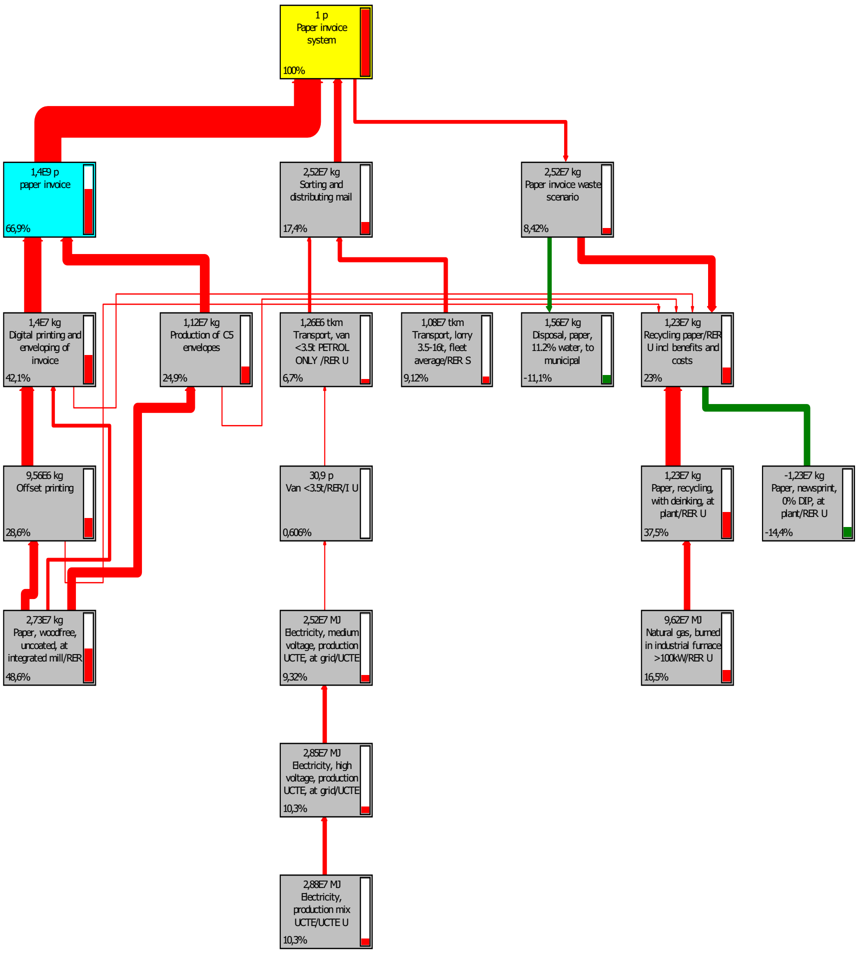


Figure 27. Network showing the greenhouse gas emissions for the paper invoice system in the base scenario with CO_2cap electricity mix. Processes shown contributed more than 5% to the total emissions (CO_2eqv.).

With another electricity mix, the base scenario with High gas price electricity mix, the paper still made the largest single contribution (Figure 28). With this electricity mix the waste management led to avoided greenhouse gas emissions, as the avoided newsprint production led to avoidance of higher amounts of greenhouse gas emissions. In the base scenarios, independent of electricity mix used, the distribution was a major source of greenhouse gas emissions, while with the High gas price electricity mix digital printing and enveloping had a larger share of the impact.

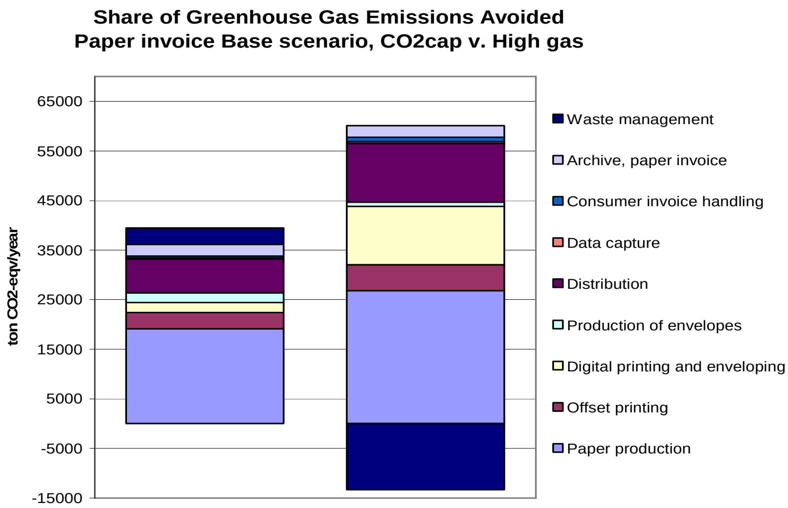


Figure 28. Greenhouse gas emissions in the paper invoice system modelled in the study. Different processes of the life cycle contributed to the emissions. The left column illustrates the base scenario with CO_2cap electricity mix and the right the base scenario with High gas price electricity mix. Note that there are positive and negative values, where the negative values indicate a benefit (avoided energy demand). The scales are different for the different figures regarding greenhouse gas emissions.

Considering the invoice systems modelled in the sensitivity analyses, in some cases there was a significant difference in the distribution of the contribution to respective impact within the invoice life cycles compared with the base scenarios. Figure 29 shows the paper invoice system with one minute extra internet time per invoice. Here, the distribution was similar to that in the respective base scenario (Figure 28), but the internet use had a larger share of the total. With the High gas price electricity mix in particular, the greenhouse gas emissions related to internet use were significant. However, as pointed out in the section on inventory, the internet inventory data and allocation were uncertain, giving a probable overestimation of emissions per year for the handling of invoices.

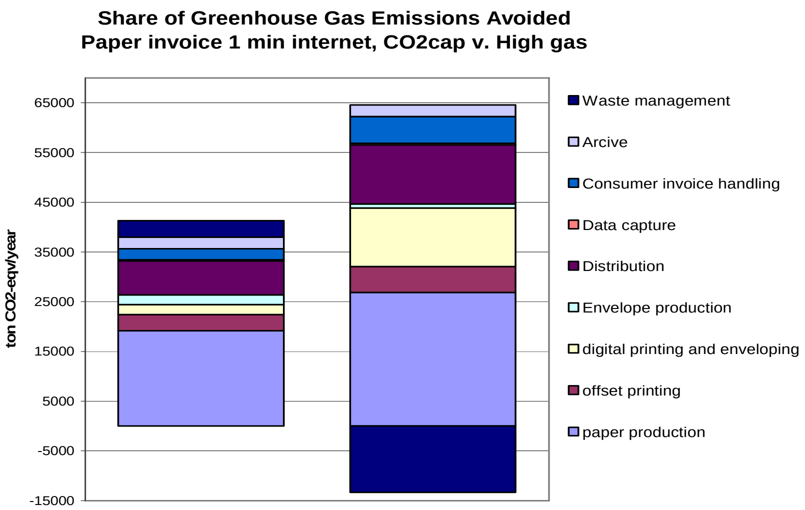


Figure 29. Greenhouse gas (GHG) emissions in the paper invoice system modelled with the assumption that one minute extra internet use is needed per paper invoice compared with an electronic invoice. Different processes of the life cycle contributed to the emissions. The left column illustrates the base scenario with CO_2cap electricity mix and the right that with High gas price electricity mix. Note that there are positive and negative values, where the negative values indicate a benefit (avoided energy demand). The scales are different for the different figures regarding GHG emissions.

Figure 30 shows the electronic invoice system with laser jet printing of two A4 pages. Here it can be seen that the greenhouse gas emissions for the paper comprised the largest part of the total value. The waste management of the paper compensated for part of the greenhouse gas emissions of the paper production through avoided production of electricity, heat and newsprint paper in the base scenario with High gas price electricity mix. The use of the printer, including the use of a computer while printing, was also responsible for a major part of the total emissions. The reason for this was mainly toner production, but also the transportation of the paper from the store to the user (business and consumer). For the latter the assumption was on the high side, as noted in the inventory section, and this result should be considered with this in mind. Toner use of course depends on the toner coverage needed for printing each invoice. In the base scenario with the High gas price electricity mix, the energy use for servers was also responsible for a major part of the total emissions.

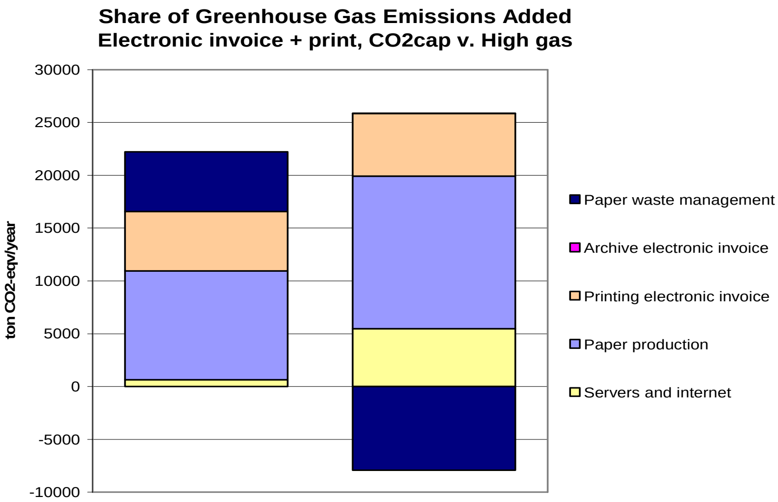


Figure 30. Greenhouse gas (GHG) emissions in the electronic invoice system modelled with the printing of two A4 pages on a laser jet printer. Different processes of the life cycle contributed to the emissions. The left column illustrates the base scenario with CO_2cap electricity mix and the right that with High gas price electricity mix. The "Servers and internet" has been aggregated into one process; the Servers are the absolute major part of this aggregated process impact. Note that there are positive and negative values, where the negative values indicate a benefit (avoided energy demand). The scales are different for the figures regarding GHG emissions.

6. Discussion and conclusions

6.1 How great is the benefit?

The results from this study show that there are benefits concerning energy use and greenhouse gas emissions in changing from paper invoicing to electronic invoicing. Looking from a Swedish perspective, comparing all invoices on paper to all invoices electronically distributed, there is a potential saving of 1 400 TJ/year and 41 000 tonnes CO_2-eqv./year. However, if the paper invoices are sent using only one A4 sheet and the electronic invoice is printed out on paper (one A4 per electronic invoice), the savings are only about 610 - 620 TJ/year and about 16 000 – 18 000 tonnes CO_2-eqv/year (depending on the electricity mix used). The latter describes the sensitivity analysis resulting in the least advantage from changing from paper to electronic invoices.

To illustrate the savings of greenhouse gases we compared our results to figures from everyday life. The categories we chose to use were driving a private car, intercontinental flight and 60W light bulbs.

Private car

The 41 000 tonnes CO_2-eqv/ year that could be avoided through a change are equivalent to driving about 225 000 tkm/year by private car. Or put in a different way, 240 000 round trips from Stockholm to Gothenburg. However, if the reduction were only about 16 000 tonnes CO_2-eqv./ year as in the least beneficial case tested here, the driving distance would decrease to 86 000 tkm/year or 90 500 round trips from Stockholm to Gothenburg. The distances are illustrated in Figure 31.

The car used was assumed to be a private car that runs on petrol with 5% ethanol. The data for the car were taken from the Ecoinvent database (Spielmann et al., 2007) and include the whole transport life cycle (operation of private car, ethanol 5%; maintenance of private car; disposal of private car; road operation; road maintenance, road disposal). According to Spielmann et al. (2007) the data for vehicle operation and road infrastructure reflect the Swiss conditions.

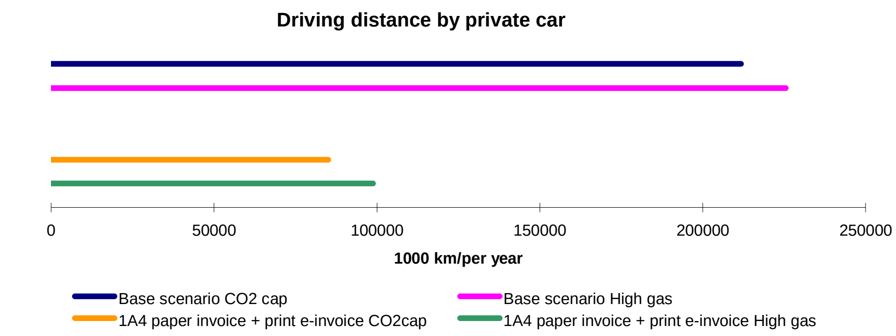


Figure 31. The greenhouse gas emissions that could be saved by a change from electronic invoices to paper invoices in relation to emissions from driving a private car.

Intercontinental passenger aircraft

The 41 000 tonnes CO_2 eqv./year that could be avoided through a change are equivalent to about 23 000 round trips from Stockholm to Bangkok, or 8 700 round trips from Stockholm to Bangkok with the lower figure of 16 000 tonnes CO_2 eqv./year. The comparison is illustrated in Figure 32.

The aircraft used in this comparison was a passenger aircraft for intercontinental flight. Data from Switzerland were used as an average for Europe and were taken from the Ecoinvent database (Spielmann et al., 2007). These data include operation of aircraft; production of aircraft, construction and land use of airport; maintenance and disposal of airport. The aircraft can transport 320 passengers with an average weight of 100 kg/person.

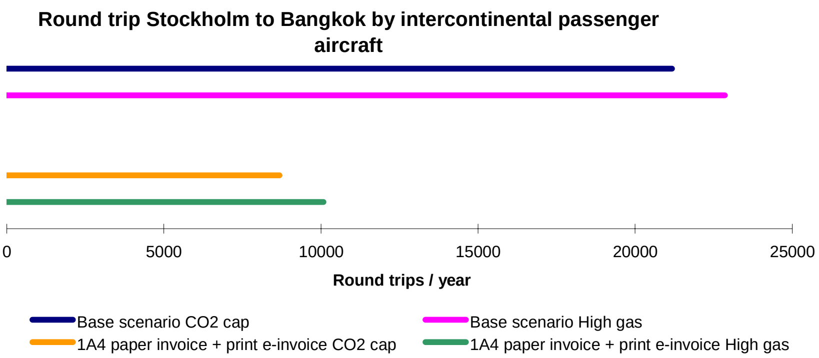


Figure 32. The greenhouse gas emissions that could be saved by a change from electronic invoices to paper invoices in relation to emissions from travelling by aeroplane. Number of round trips possible for one person Stockholm - Bangkok.

Light bulb, 60W

Assuming the CO_2cap electricity mix, the 39 000 tonnes CO_2-eqv./year that could be avoided through a change are equivalent to about 7 850 000 light bulbs burning the usual 1 000 hours (41 days) or one light bulb burning for 900 000 years (if that were possible). The lower saving of 16 000 tonnes CO_2-eqv./year is equal to about 3 150 000 light bulbs burning for 1 000 hours each or one light bulb burning for 360 000 years.

The light bulb used for this comparison was a conventional 60W light bulb. The data were taken from the ETH-ESU 96 database (Frischknecht et al., 1996) and are based on a light bulb made of glass, filled with nitrogen and argon under low pressure, with a tungsten wire that causes it to glow. A normal light bulb burns for about 1 000 hours (41 days) (Frischknecht et al., 1996).

Climate goal

The Swedish climate goal for 2008-2012 states that greenhouse gas emissions should decrease by 4% compared with the 1990 level, which was 72 043 000 tonnes CO_2-eqv. In 2006 the emissions were about 65 749 000 tonnes (Naturvårdsverket, 2007 p. 13). A decrease of 8.7% has thus been achieved already. The challenge is the further decreases needed. A change from all paper invoices to all electronic invoices leading to a decrease of 41 000 tonnes CO_2-eqv/year would give another 0.06% decrease.

The comparisons above indicate that the change from paper invoices to electronic invoices is not the solution to climate change, but is one of hopefully many small steps. As other studies have shown that there is an additional economic incentive, this step should not be the most difficult to take (see ESV, 2005). The present study considered electronic invoices, but there are other documents that could also be altered to electronic form, making the potential for decreased energy use and greenhouse gas emissions potentially larger.

6.2 Electronic invoices

The studied system of electronic invoices, defined by processes that would be affected by a change from paper invoices to electronic invoices, was not straight-forward to define. Many processes that handle electronic documents at the same time handle several other kinds of documents and data. Allocation is therefore not always easy. In addition, many servers and networks are not used at full capacity, but there is potential for increasing the use without increasing energy use. The figures on the electronic invoicing system can become more reliable and there is a need for more studies on how to assess the environmental impact of digital information flows. Other ways of providing electronic invoices could also be studied, e.g. B-to-C invoices via e-mail.

In the current study readily available data has been used. It should be considered that businesses handling their own electronic invoices and smaller companies providing these services may be less energy-efficient than the larger logistics business Itella Information, the source of some of the information on electronic invoices.

The results show that the main energy demand and greenhouse gas emissions of the electronic invoice system as modelled here arose from energy use of the servers where the electronic invoices were converted, stored and accessed, as long as the electronic invoice was not printed. In the study we used the higher end figure for this energy use. Better use of the full capacity of servers would lead to less energy use per MB handled and stored. With the lower end figure, the impact related to the energy use of the servers would be halved. Ongoing development is attempting to make servers and data centres more energy-efficient. The factor of 2 that we used for cooling and auxiliary equipment of server rooms (doubling the server energy use) may soon be lowered.

As part of the electronic invoice product system were not covered here, i.e. the parts that will not be affected by a change from paper to electronic invoices, the total energy demand and greenhouse gases was not assessed.

If the electronic invoices are printed, the cumulative energy demand and emissions of greenhouse gases are substantially increased. The paper used is the main reason, but also the toner used for printing and the transportation of paper from the shop. Regarding the latter, a high estimate on transport work for printer paper was used to study the possible impact. This sensitivity analysis was almost like a worst case scenario, assuming that all receivers of an invoice printed it and that they all transported the printer paper inefficiently. The contribution of transportation in this case should be carefully interpreted.

For the electronic invoices the electricity mix was of great importance for the resulting greenhouse gas emissions, since the major proportion of the total result was caused by electricity use.

In the end, it seems that the key issue for electronic invoices is whether they will remain in electronic form or be printed once or even several times. Another possible risk that could lead to higher energy use is if the handling of the invoices were to lead to a substantially increased use of computers and the internet. The test here with five minutes extra computer time per B-to-B electronic invoice led to a small but detectable change, even though only the business invoices (30% of the total amount of invoices) was considered. The receiver of the invoice will have an influence on the final performance of the electronic invoices concerning energy use and greenhouse gas emissions through printing habits and efficiency in invoice handling.

6.3 Paper invoices

For the paper invoice system it is the paper that is the key issue. As the amount of paper within the studied system is lowered, the cumulative energy demand and the greenhouse gas emissions also decrease. If there is not a change to electronic invoices, the use of paper for paper invoices should be minimised, avoiding photo-copying and invoices of several pages in order to lower energy demand and greenhouse gas emissions. Waste management of the waste paper leads to lower energy demand, as production of heat, electricity and newsprint paper can be avoided. Regarding greenhouse gas emissions, waste management is beneficial, decreasing emissions, when the High gas price electricity mix is used (and avoided). However, when the CO_2cap electricity mix is used (and avoided) the emissions from the waste management are larger than those avoided, leading to a contribution to greenhouse gas emissions.

The other processes of the paper invoice system modelled that contribute to a larger extent to the cumulative energy demand are distribution, archiving, digital printing and enveloping. For greenhouse gas emissions the main contributing processes (in addition to paper and waste management as already discussed) are distribution, offset printing, archiving, digital printing and enveloping and envelope production with the CO_2cap electricity mix. With the High gas electricity mix, the main processes are distribution, digital printing and enveloping and offset printing.

The sensitivity analysis on longer internet use for the paper invoice compared with the electronic invoice showed that internet use may have an impact, but the data used for this were uncertain and were considered overestimations. The environmental impact of internet use and its allocation between user and uses need to be further studied. As economic transactions are increasingly being handled electronically, the paper invoice has a disadvantage as its information needs to be transformed to electronic form.

For the senders of paper invoices, the physical mailing of the invoice may have an additional function; providing the receiver with additional information. In the current study we did not consider the commercial and other information delivered together with the paper invoices. It is not clear what the consequences of turning from paper to electronic invoices would be on this extra information. The question of whether it would still be sent on paper or whether it would become electronic as well, or not be sent at all, would need to be further assessed.

6.4 Consequences of a change

The consequences of a change from all paper invoices to all electronic invoices in Sweden were studied concerning cumulative energy demand and emissions of greenhouse gases. The consequences with a longer time perspective were considered, meaning that there was potential for new investments.

The results of the study show that there is a benefit to be gained from the change, at least concerning energy use and greenhouse gas emissions. Sensitivity analyses showed differences in the magnitude of the benefit, but all results showed some benefit. There is possibly potential for larger benefits than those presented in the results provided best possible practice is used for electronic invoicing.

Paper use was the main issue concerning consequences of a change from electronic to paper invoices in the perspective of cumulative energy demand and greenhouse gas emissions.

The time using the internet is relevant but the difference in time needs to be considerable to make the effect significant, especially since the data on internet use in the study were most probably overestimations, as described in the section on data inventory.

The possible extra computer time needed for handling electronic invoices can decrease the benefit. This is interesting since it highlights the fact that the system for handling electronic invoices needs to be fairly efficient to enable the full benefit to be gained concerning greenhouse gas emissions. However, it should be kept in mind that additional impacts from handling of paper invoices were not considered, e.g. distribution of paper invoices for authorisation.

For simplicity, the assumption was made that all consumers and businesses handle their invoices electronically. This means that all paper invoices were assumed to be paid via the internet too. This is not the case today, as roughly 50% of the population is said to use the internet to pay their invoices (Findahl, 2007). No estimations on energy use or greenhouse gas emissions from alternative ways of handling payment were made in this study. These estimations, had they been made, would have included paper and envelopes for sending payment instructions, as well as physical distribution or travel by different modes to visit the bank office for manual payment. These activities would most probably have led to energy use and greenhouse gas emissions of the same magnitude as paying via the internet, or higher. One way of paying that would probably be more beneficial than the electronic invoices is autogiro, but this alternative is probably relevant only for a limited number of invoices. Had only a proportion of the paper invoices been assumed to be paid via the internet, the change to electronic invoices could have led to an increase in internet use, but at the same time the paper invoices would have had other processes within the system leading to energy use and greenhouse gases expected to be similar to or higher than those of the internet use. The results of this study were thus presumably not affected by the assumption that all receivers of invoices handle their invoices electronically.

In the study, the B-to-B electronic invoices were assumed to be sent via the internet to the receiver, while the B-to-C electronic invoices were assumed to be noted on each consumer's internet bank website and then accessed from the e-archive server via the internet. Other possible ways of electronic distribution and access were not studied. If the electronic invoice is not printed, however, the benefit of the change seems to be a robust result.

The assessment considered two product systems that are already in a process of change. As business and financial systems are mainly computerised today, it seems convenient to have information distributed in this format too. Paper invoices seem to provide an extra step, as the information needs to be translated to electronic form in any case. However, if the users see a need for a paper invoice, they may print the electronic invoice anyway. The study shows that this would lead to a considerable decrease in the potential benefit of electronic invoices.

Reminders on non-paid invoices were not covered in this study but would lead to a larger amount of invoices in total, increasing the possible benefit of a change. The magnitude of the benefit depends on the assumptions made in the same way as for the other invoices (e.g. printing of electronic invoices). A change could also lead to a possible effect on the need for reminders. Would electronic invoices lead to more reminders, or less? In addition, possible photocopies of paper invoices were not considered. When authorising a paper invoice a copy may be made for the files, in the same way as an electronic invoice may be printed.

In other studies comparing a paper medium with an electronic medium, the general result is that the electronic medium is preferable (e.g. Gard and Keoleian, 2003; Yagita et al., 2003; Moberg et al., 2007). It should be noted that many of the comparisons focus on energy use or greenhouse gas emissions. Cases where a paper medium can be favourable are when there are many readers per copy of the printed document, or when a lot of energy is used in the use phase of the electronic medium, e.g. a non-energy efficient device and relatively long reading time. In a German study by Quack and Möller (2005) electronic invoices were in general shown to be preferable to paper invoices from an environmental perspective, one key issue being the possible print-out.

6.5 Future studies

Through this screening LCA we identified several areas for further research, some of which are discussed below.

In the current study only cumulative energy demand and greenhouse gas emissions were considered. Other environmental aspects should be included as well to get a more comprehensive environmental result.

The electronic invoice system could be studied in more detail, looking at smaller companies using electronic invoices and comparing their handling of electronic invoices with the data from the larger information logistics business used in the current study. In addition, different behaviour and context of receivers could be studied. Going into detail, best practices and worst practices could be identified. Other possible ways of distributing electronic invoices could be studied. The assessment of the total environmental impact of electronic and paper invoices could be interesting as well, not only considering the consequences of a change.

More studies on user behaviour could give additional information regarding the potential of electronic invoices and other electronic documents.

The study could be expanded to cover for example the use of the biomass that was previously used for paper production. The consequences of a change could then include the production of energy from biomass avoiding other energy production or other possible use of the biomass or the land area used for forestry.

Further studies on the environmental impacts of internet use would be interesting. As mentioned above, the data used here were to some extent estimates and the allocation in particular should be further considered.

6.6 Conclusions

There is a benefit regarding cumulative energy demand and emissions of greenhouse gases when a change is made from paper invoicing to electronic invoicing. The magnitude of the benefit depends partly on the nature of the paper invoice system currently used, but the magnitude may also be influenced by how the electronic invoice system is designed and used. Avoiding printing electronic invoices is a key issue. Making authorisation systems, payment procedures etc. easier to manage and use would be advantageous concerning energy use and greenhouse gas emissions.

The results show that the benefit concerning cumulative energy demand and greenhouse gas emissions of changing from paper invoices to electronic invoices was affected only a little or not at all by:

- Desktop or laptop computer being used
- Electricity mix used (regarding cumulative energy demand)

Some assumptions had a small impact:

- Electricity mix used (regarding greenhouse gas emissions)
- Extra time using computers or internet, if kept within reasonable limits
- Transport distances
- Type of mail distribution (economy class or first class)

Finally, some assumptions significantly affected the overall benefit of a change:

- Use of two or one A4-sheets for the paper invoices
- The possible printing of the electronic invoices

However, in all cases assessed here there was a benefit in terms of cumulative energy demand and emissions of greenhouse gases in going from paper invoices to electronic invoices.

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