Life Cycle Assessment of Toner Cartridge HP C4127X

Environmental impact from a toner cartridge according to different recycling alternatives

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Abstract

The project is a comparative life cycle assessment of HP's toner cartridge C4127X, used in a laser printer. Two different alternatives after the use have been studied. One according to HP's present recycling programme and one where the cartridge is restored at Tepro Rebuild Products AB. The aim of the study is to conclude which of the two alternatives that have the greatest environmental load and how great the load is for each alternative.

The functional unit in the study is "30 000 copies, 5 % average coverage". The delimitations taken into account are that the laser printer, apart from the toner cartridge, is excluded. Paper and electricity consumed during the use of the toner cartridge are analysed, though. In the alternative with restoring, the toner cartridge has not been followed after the last restoring, actually it is then shipped to Holland for further usage.

Two scenarios have been studied for each alternative. The main scenario, where the load for manufacturing of paper and belonging activities have been included, and the alternative scenario, where the load of the different paper activities are not included.

The result of each alternative's environmental load, presented in four data categories, one characterisation method and three weighting methods, indicates that the alternative with restoring are better for both scenarios. It also shows that the activities with the greatest impact on the environment are the ones associated with paper. The alternative with restoring are, from an environmental point of view with the above mentioned methods, barely two times better than the alternative with HP's recycling programme, for the scenario without paper.

When, besides paper, the electricity, that is consumed, using the toner cartridge, is excluded the result is that the re-use alternative is full measured two times better than the other alternative is.

Since paper manufacturing and electricity consumption at use are not directly corresponding with the toner cartridge, its manufacturing, restoring and after life treatment, this result (full measured two times) can be seen as the most significant when comparing the two alternatives. Though, paper and electricity are needed to fulfil the functional unit.

The greatest source of error would be the lack of data of component manufacturing and assemblage of the cartridge.

The conclusion is that it is motivated to re-use of toner cartridges. An important aspect though, is that the environmental load of the toner cartridge from a comprehensive view, also including paper, electricity and printer, plays a minor part of the total load.

Acknowledgements

This project has been carried out as a final exam work of ten Swedish university points at the University of Kalmar at the request of Bläck & Write. It has been done during the second half of the autumn term 2001.

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1 Introduction

1.1 Background

In 1995 Bläck & Write had a Life Cycle Assessment of ink cartridges [19] carried out. The result was that ink cartridges that were re-used four times were about two times better than original cartridges regarding environmental impact according to the weighting methods “EPS”, “Ecoscarcity” and “Environmental Theme ET”. They would now like to follow up with a LCA of toner cartridges.

Tepro Rebuild Products AB restores toner cartridges which, among others, are sold by Bläck & Write. To confirm that re-used toner cartridges have less environmental load than original cartridges, a life cycle assessment was inquired from University of Kalmar. This commission was accepted as a final exam work, which is a part of the education in environmental engineering.

The life cycle assessment is intended for marketing and to give information where efforts should be made to improve the product from an environmental point of view.

1.2 Aim

The aim of the study is in the first place, with life cycle assessment methodology, to show which of the two alternatives, HP toner cartridge in HP’s recycling programme and HP toner cartridge which is sent to Tepro Rebuild Products AB after use, that causes the greatest environmental load.

Second to investigate the size of the environmental impact for the two alternatives, on the basis of certain categories and impact assessments.

1.3 Delimitations

The delimitations presented here are such that are not directly connected to the methodology of the life cycle assessment; those are presented in chapter 3.

The scope of the study is ten Swedish university points (ten weeks studies) and it has been carried out during the second half of the autumn term 2001.

The main delimitation of the study is that we have focused on HP’s toner cartridge C4127X. Within the scope of this we have studied the two recycling alternatives provided by HP and Tepro. For each alternative two scenarios have been investigated, one including paper consumption and the other excluding paper consumption connected with the use of the toner cartridge. For the scenario excluding paper consumption sensitivity analyses have been carried out, one where the electricity consumption have been excluded and one where the energy consumption associated with the production of steel have been higher than in the rest of the study.

1.4 Methodology

To begin with information were gathered. That included information about life cycle assessments as well as the processes at HP and Tepro and the life cycle of the toner cartridge, besides that LCI-data (Life Cycle Inventory) about material and processes associated to the toner cartridge.

The information from Tepro and knowledge about their processes were gathered during a visit at Tepro in Malung (Sweden). The rest of the information have been gathered mainly by e-mail and phone calls. At an early stage literature studies were pursued, foremost on the Internet but printed literature were also studied. Valuable information has also been received from our supervisor. To find suggestions about the disposition and procedure of our work other life cycle assessments have been studied. Information about HP’s recycling programme was received while information about their manufacturing and assemblage is confidential. Therefore data about this were not handed over to us.

To find out which materials the toner cartridge consists of, and the amount of each material, the cartridge was dismantled and the different parts weighed. The types of material were established of our own or when needed by the help of experts. See paragraph 2.1.

In order to carry out the study two flowcharts were made, one for each alternative. The flowcharts are the same until the user-phase with the exceptions of some amounts in the different flows. After that, one chart continues with HP’s recycling programme and the other with Tepro’s after-use alternative. The flowcharts have then been built in LCAiT [8]; a computer-based program especially developed for life cycle assessments by CIT Ekologik at Chalmers. Data for the processes have then been inserted when received.

2 Technical description of toner cartridge C4127X

The LCA were carried out on HP's toner cartridge C4127X, since that holds a prominent position on the market, regarding sales.

2.1 The life cycle of toner cartridge C4127X

HP is a worldwide company that sells a variety of electronic products, computer products and supplies, among those toner cartridges for laser printers. HP have a recycling programme where you can send used toner cartridges. The recycling takes place in France and the recycling extent worldwide is 20 %. The received toner cartridges are recycled to 95 %, based on weight [10].

The business concept of Tepro Rebuild Products AB is to receive, primarily, toner cartridges, which are restored and provided with new toner. After that the cartridges can be used again and should then have the same quality as new ones according to Tepro's concept. The toner cartridges are restored two times at Tepro. When they are received a third time they are shipped to Holland, since Tepro can not guarantee the quality after the cartridges have been used that many times with the present restoration. When a toner cartridge is received at Tepro, it is dismantled, left over toner is removed, certain parts are exchanged, new toner is filled and the cartridge is tested before it is packed and ready for delivery. The first time the toner cartridge is received the drum and its belonging cogwheels are exchanged, a plastic rail is replaced with a metal rail, a wiper blade is exchanged and a seal is placed to keep toner from running out. The second time the toner cartridge is received, which is seen by the marking at the toner cartridge, the same operations as the first time takes place, except that the drum and its cogwheels are not exchanged (it is also a metal rail and not a plastic rail that is exchanged this time).

2.2 Description of the function of toner cartridge C4127X

The toner cartridge is an essential part of the laser printer and adds to that prints can be made. HP's C4127X weighs a little less than a kilo without toner and about 1,450 kilos with toner.

The toner cartridge works the following way, the drum, which has a light sensitive coating, is charged with a positive electrostatic tension. The laser in the printer lights the drum where it is supposed to be white (no text or picture etc.). Since the charge at the drum is lost where it is lighted a picture (of what you wish to print) of positive charges will stay on the drum. Toner, which have a negative charge, are pulled forward with a roller and are dragged onto the drum where there are positive charges. Below the paper, which is being transported, there is a positively charged source that is greater than the drum's. Toner is pulled to the stronger charge and onto the paper. Pressure and heat makes toner (which is a powder consisting of among other things plastic) melt and stick to the pores of the paper. The print is ready.

The material structure in the toner cartridge, including packing, is shown in table 1 and 2. Note that toner is not included in the tables. The figures in table 1 are valid for one original toner cartridge. The figures in table 2 are valid for a toner cartridge that has been restored twice at Tepro; accordingly; new parts are included.

Table 1. Material structure, HP original toner cartridge

Material	Weight (g)
Aluminium	76,68
Copper	0,55
Steel	387,76
Polystyrene	449,69
Nylon	27,73
PVC	6,28
Polyurethane	19,94
Corrugated board	482,93
Paper	24,47
LDPE	26,44

Table 2. Material structure, Tepro toner cartridge

Material	Weight (g)
Aluminium	124,15
Copper	0,55
Steel	577,38
Polystyrene	449,69
Nylon	44,69
PVC	18,84
Polyurethane	21,63
Corrugated board	693,18
LDPE	30,76

3 LCA-specific data, toner cartridge C4127X

3.1 Functional unit – FU

FU is the unit that the LCA-study is based on and the unit to which everything is related. It is also the functional unit that makes it possible to compare different systems to each other.

The functional unit has been defined as; "30 000 copies, 5 % average coverage". That corresponds to one re-used toner cartridge restored two times, and three original toner cartridges. Five-percent average coverage is a "normal" printout and the standard used by the line of business [13].

3.2 System boundaries

3.2.1 Natural systems

The involved materials have been followed from cradle to grave where possible. Though, lack of time and information has caused that everything has not been followed through the entire life cycle. Materials put in landfill has not been followed further but has been regarded as in its grave. This may not be entirely true but it is an assumption that has been made to make the study easier to complete.

3.2.2 Time

Data in the LCA are taken from studies made between 1995 and 2001. For what time the study is valid is entirely dependent on what happens in this field of activities of HP and Tepro. If HP's share of recycled toner cartridges is increased their impact of each printout will obviously change. Likewise if Tepro were to change the number of restorations they make for each toner cartridge.

3.2.3 Geographical boundaries

The following assumptions have been in the study: manufacturing/assemblage in Japan, spare parts manufacturing in Holland, use and restoration in Sweden and HP's recycling in France.

3.2.4 Technical system

Capitals in form of tools, machines, buildings and travels needed and their life cycles are not included, it is just the environmental impact and the activities directly applicable to the toner cartridge that are included. The laser printer in which the toner cartridge is placed has for example not been included or investigated with LCA-methodology.

When the toner cartridge in the re-use alternative leaves restoration/refilling3, the study is delimited toward further use since information about what happens with the toner cartridge is unsatisfactory.

3.2.5 Environmental Impact Assessment

For the environmental impact assessment we have chosen to show the data categories CO_2, NO_x, energy consumption and generation of waste, the characterisation method “Global Warming (100 years)”, which is focused on the greenhouse effect, and the weighting methods “EPS 2000”, Eco Sweden 98” and “Tellus”.

3.3 Characterisation and weighting

Characterisation means that the gathered LCI-data are multiplied with a specific characterisation factor, which is valid for the effect on the environment you wish to investigate. By multiplying the contribution of the different emissions with the characterisation factor, you get a gathered value of how much these emissions contributes to a certain environmental impact category, for instance, acidification, eutrophication or greenhouse effect.

In the study the characterisation method “Global Warming (100 years)” has been used. Within this method, which shows the systems contribution to the green house effect, all contributing emissions are converted to CO_2–equivalents. The index of CO_2 is 1 and for example the index of CH_4 is 21 which means that the amount of CH_4 is multiplied by 21 to be equivalent with CO_2.

The characterisation is based on scientific connections, contrary of the weighting methods. Instead it is weighting objectives of different kinds that is the basis of the weighting and the environmental impact assessment. Examples of weighting objectives are humans’ willingness of payment, political objectives and critical limits of load in the nature. Hence different methods values different emissions in different ways. A certain emission can be very significant in one method but hardly noticeable in another one.

In order to get the weighting as objective as possible three different methods are used in the study. The chosen ones are “EPS 2000”, “Eco Sweden 98” and “Tellus”.

“EPS” is an abbreviation for “Environmental Priority Strategies in product design”, it is based on willingness of payment to avoid damages, by use of resources and emissions, of five safe guard objects. The five objects are biodiversity, human health, biological production, consumption of natural resources and aesthetic values. The total environmental impact is summed up to a load number measured in ELU, Environmental Load Unit.

“Eco Sweden 98” values ecoscarcity, that is the relationship between the actual flow of resources and a critical flow based on laws and regulations. The result is presented in Ecopoints.

“Tellus” is based on the control cost for the society of a number of pollutants. From that prices are established when some criteria air pollutants is let out. The result is presented in dollars.

4 Inventory

4.1 Flowchart

The life cycles of the two alternatives are visually described below by two flowcharts. Figure 1 and 2 presents simplified flowcharts for the life cycles of the toner cartridges. Each arrow represents a transport.

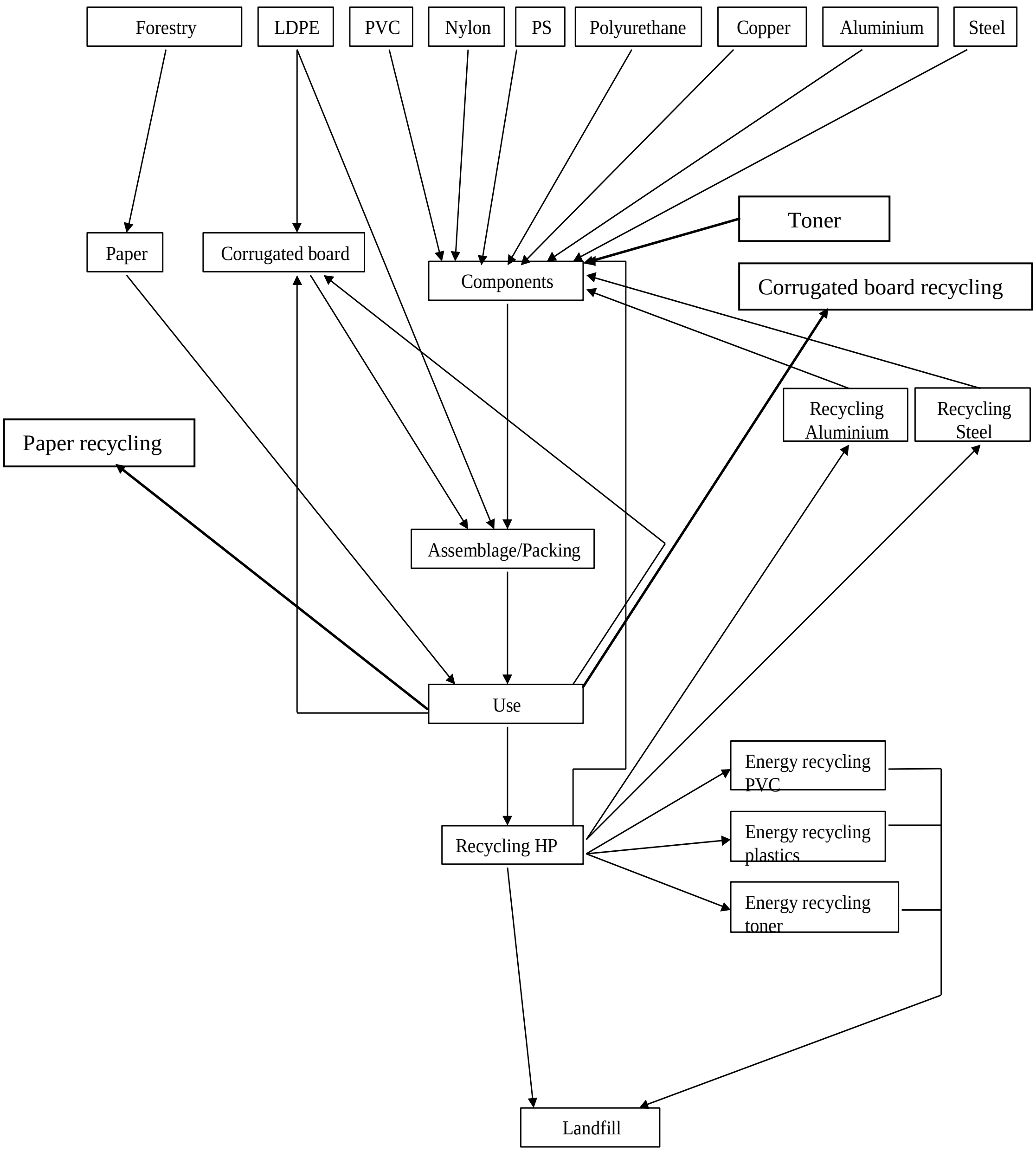

Figure 1. The life cycle of an original toner cartridge

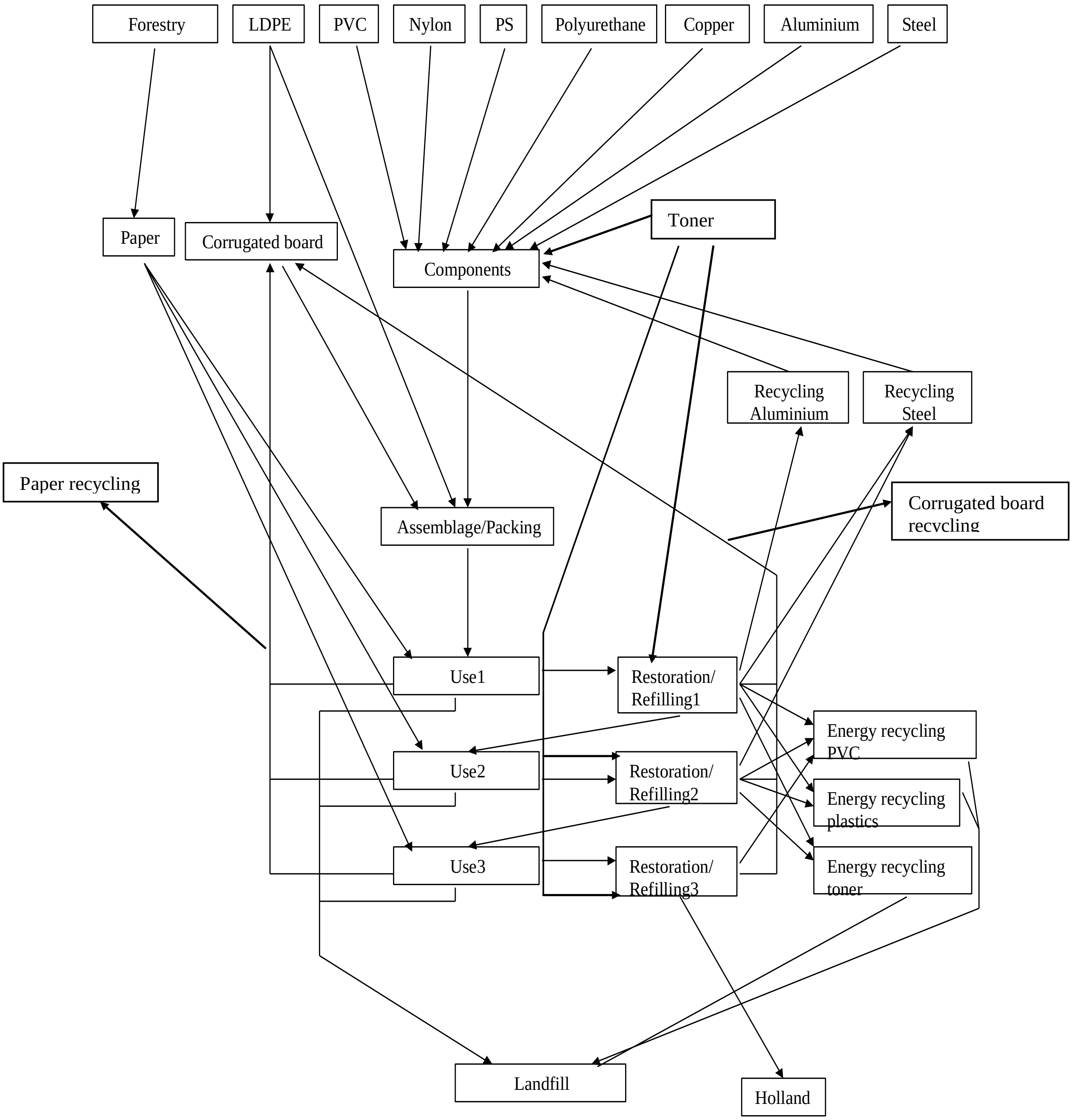

Figure 2. The life cycle of a re-used toner cartridge

4.2 Description of activities

The following paragraphs present the different activities in the two alternatives life cycles, assumptions and where data has not been available.

In some cases slight changes have been made, in order to increase the coherence in the study and between different activities. These changes are presented under each activity.

Where energy sources have been presented in weight, they have been transformed to energy content. This have been the case in the activities; forestry, aluminium production, aluminium recycling, steel recycling, copper production, diesel production, heavy fuel oil production and electricity production. Used heating values and transformation values are presented in appendix 6.

Where water has been presented in m^3 (paper production, corrugated board production, steel production) it has been transformed to kg. The used reference is; 1 m^3 = 1000 kg.

The values of electricity consumption in the activities, toner production, component manufacturing, assemblage/packing and recycling HP have been estimated, with some origin in the electricity consumption of restoration/refilling.

Activities that only appear in one of the alternatives are followed by either (O) original or (R) restored, re-used.

4.2.1 Paper

4.2.1.1 Forestry

The activity brings primary products to the paper production. The energy consumption is according to SkogForsk [15] 200 MJ for 1 m^3sub (solid under bark). In the study other input material is included and the number 200 MJ is exceeded. The inflows [15] are valid for the north of Sweden while outflows [16] are an average for Sweden. In the transport between forestry and paper production the weight of 1 m^3sub has been assumed to be 1000 kg [2].

4.2.1.2 Paper production

The data [5] is for production of fine paper. Input material is provided by forestry.

Changes compared to the source; “P total” has been changed to “P” and “surface water” to “water”.

4.2.1.3 Paper recycling

Since there is more outflow of paper from the different use-activities than there is inflow of waste paper in the activity corrugated board production this activity has been created. Thus the activity is just there as a place to put the remaining paper, in LCAiT. The activity has no other purpose, it does not generate any product, waste or emissions.

4.2.1.4 Corrugated board production

The corrugated board is the one needed to manufacture the packages in which the different products are delivered, partly HP's original toner cartridge, and partly the restored toner cartridges from Tepro. The data used [4] starts after the delivery of input material (recycled paper) and ends with the finished product.

Changes compared to the source; "paper, board, recycled" has been changed to "paper and board".

4.2.1.5 Corrugated board recycling

This activity is similar to the paper recycling and has only been created since there is more corrugated board leaving the different activities for restoration/refilling than there is inflow of waste corrugated board in the corrugated board production. The activity has, similar to paper recycling, no other purpose and does not generate any product, waste or emissions.

4.2.2 Plastics

All data for the different plastics have been taken from APME [3]. When an emission has been specified as <0.01 mg or an energy source as <0.01 MJ by APME, it have not been included in our study because of the very small impact it would have on the result.

The different kinds of water (river water, seawater, municipal water, etc.) specified for the plastics have in the study been gathered as an inflow called "water".

For the different kinds of energy each kind has been accounted for, contrary to the summarised values that are also provided by APME. The tables with the weight of the energy sources are not included, included are just the tables with energy contents. The data stretches from the cradle to a product ready for delivery.

4.2.2.1 Plastic production, Low Density Poly Ethylene, LDPE

LDPE is used to pack the toner cartridges in both HP's and Tepro's packages. That the bags around the toner cartridges consist of LDPE is an assumption based on the fact that LDPE [12] is used in the package of an entire laser printer. Besides LDPE is a common material for plastic bags in general.

Changes compared to the source; "other metals" has been changed to "metals".

4.2.2.2 Plastic production, Nylon

Since the material used for the cogwheels has not been specified the assumption has been made that it is nylon, which is a common material for that kinds of product.

Changes compared to the source; "other metals" has been changed to "metals".

4.2.2.3 Plastic production, Polystyrene, PS

PS is the plastic that the case of the toner cartridge consists of.

4.2.2.4 Plastic production, Polyurethane

The plastic produced in this activity is used for a wiper blade that is put inside the drum and never is replaced. Experts in the field of plastic [7] claimed that it was TPE. In a magazine there was a company which sold wiper blades made of urethane. Since there is urethane based TPE the wiper blade was assumed to consist of this.

In the absence of data for urethane based TPE it was approximated to polyurethane, which is available at APME.

Changes compared to the source; “gas” has been changed to “natural gas”, “phosphate as P2O5” has been changed to “P2O5”.

4.2.2.5 Plastic production, PVC

The wiper blade that is replaced during the restoration is assumed to consist of PVC [7] and it is being produced in this activity.

Changes compared to the source; “gas” has been changed to “natural gas”, “phosphate as P2O5” has been changed to “P2O5” and “unspecified metals” has been changed to “metals”.

4.2.3 Metals

For activities where the source is Sunér [18], data for substances of the same kind and sort has been added together, for example substances in “emissions to air” and “emissions to air from electricity production”. The part “Final energy carriers”, with energy contents, has not been included. Instead, the part in Sunér’s report with weights of energy sources has been transformed to energy contents. Used heating values are presented in appendix 6.

All data for metals includes environmental impact from mining of raw material to metals ready for delivery.

4.2.3.1 Steel production, low and high energy, virgin material

There are a variety of steel products produced in a variety of ways. Two activities have been included in the study; one that corresponds to the lowest energy consumption per produced kilogram of steel in the source [20], and one that corresponds to the highest energy consumption. This has been done to rule out any possibility that the result should be depending on the way the steel is produced. However, this is not likely considering the small amount of steel that the toner cartridge consists of.

The data [20] in the activities corresponds to an average for a certain way of producing steel from steelworks worldwide.

Changes compared to the source; “waste” has been changed to “unspecified” in the category “non-elementary waste”.

4.2.3.2 Steel production, recycled

The activity is scrap based. The steel that is replaced at the restoration is brought here.

Changes compared to the source [18]; “waste” has been changed to “unspecified” in the category “non-elementary waste”, “slag” has been changed to “slags and ashes” and “tot-P” has been changed to “P”.

4.2.3.3 Aluminium production, virgin material

There are two kinds of cylindrical shaped rollers in the toner cartridge, consisting of some sort of light metal. In lack of information, the assumption has been made that the rollers consist of aluminium. In the activity the aluminium is entirely produced of bauxite.

Changes compared to the source [18]; “waste” has been changed to “unspecified” in the category “non-elementary waste” and “tot-P” has been changed to “P”.

4.2.3.4 Aluminium production, recycled

The activity is scrap based. The aluminium that is replaced at the restoration is brought here.

Changes compared to the source; “waste” has been changed to “unspecified” in the category “non-elementary waste”. Electricity is in the source [18] specified in MJ, contrary to the rest of the report. Because of this the assumption has been made that it is a misprint and the data has been treated as if it were specified in gram (as in the rest of the report).

4.2.3.5 Copper production

When copper is produced you also get some by-products that have an economical value and are being taken care of. Examples of such by-products are gold, silver and selenium. In Suner’s report [18] there are two different ways to allocate the environmental impact. One where the entire impact is allocated to the copper, and another, economic allocation where the impact is divided among the produced products that have an economical value. The latter allocation is the chosen one since this has been regarded as fairer and giving a clearer picture of reality. In the source there is one kg copper leaving the activity while the input of copper is less than one kg. Because of this 400 g copper have been added, divided in “Cu” and “Cu scrap”.

Changes compared to the source; “waste” has been changed to “unspecified” in the category “non-elementary waste” and “Rich Cu scrap” and “Other Cu scrap” have been changed to “Cu scrap”.

4.2.4 Toner production

Toner consist of half Styrene Acrylate Copolymer, half iron oxide.

The electrical consumption has been estimated to 5 kWh / kg toner.

4.2.5 Component manufacturing

The inflow of material in the activity is as much as the weight of the product that leaves the activity plus 10 %. If a screw of steel is manufactured there is 110 gram of steel entering the activity. This is an estimation of the loss, when raw material is refined into products.

Outflow is completed components. For the sake of simplicity completed components are shipped to “assemblage/packing” as well as “restoration/refilling” from the same activity. For each toner cartridge in the re-use alternative the outflow of components are 968,6 g to assemblage/packing, 168,5 g to restoration/refilling1 and 104,1 to restoration/refilling2. In the other alternative the outflow is 968,6 g to assemblage/packing.

The electrical consumption has been estimated to 30 kWh / toner cartridge.

4.2.6 Assemblage/packing

Inflows to the activity are completed components and a HP-package. The components are put together, packed and shipped to the user. The activity takes place in Japan.

The electrical consumption has been estimated to 10 kWh / toner cartridge.

4.2.7 Use

4.2.7.1 Use

The HP original cartridge is used in the activity. For each use paper, toner and energy is consumed. According to HP’s product information [13] you get around 10 000 prints per toner cartridge. Based on this the paper consumption is 46,7 kg, see appendix 3, and the energy consumption has been calculated to 63 kWh, see appendix 4, for each used toner cartridge. Toner leaves on the printed papers and as rest in the toner cartridge. The paper is assumed to reach the paper recycling, sooner or later.

4.2.7.2 Use2 (R)

In this activity the toner cartridge is used again after being restored at Tepro. The same assumptions as above go for consumption and waste. (The toner cartridges still give about 10 000 prints [1]).

4.2.7.3 Use3 (R)

Here the restored toner cartridge is used for the last time. Same assumptions about consumption and waste as above.

4.2.8 Restoration/refilling

4.2.8.1 Restoration/refilling1 (R)

A used HP toner cartridge is input. LDPE, corrugated board, toner, aluminium, nylon, steel and PVC leave as waste. LDPE and corrugated board come from the package, aluminium and nylon from the drum, steel and PVC from the wiper blade and toner, as rest, from the used toner cartridge [1].

Outflow is also a packed toner cartridge after restoration at Tepro that goes to use2. All waste of the same kind has been added to simplify the handling of data in the study. This has been done in all the restoration/refilling activities. The electricity consumption is 2,02 kWh per toner cartridge, see appendix 1.

4.2.8.2 Restoration/refilling2 (R)

Inflow is a used toner cartridge that already has been restored at Tepro once. LDPE, corrugated board, toner, steel and rubber leave as waste. Tepro uses a long-life drum that is placed in the toner cartridge at restoration/refilling1 [1]. Because of this the drum can be used again and there is no waste in form of aluminium and nylon (which the drum is made of). Outflow is also a packed toner cartridge after restoration at Tepro that goes to use3. The electricity consumption is as in restoration/refilling1.

4.2.8.3 Restoration/refilling3 (R)

Inflow is a used toner cartridge that has been restored at Tepro two times before. The toner cartridge leaves, without modification, and is shipped to Holland for further usage [1]. LDPE and corrugated board leave in form of waste.

4.2.9 Energy recovery

Three things go to energy recovery, mixed plastics, PVC and toner. The recovered energy is specified as an open outflow, and is assumed to reduce the energy production at some other, undefined, place.

In the used report [17] to get emissions and energies, there are a variety of different allocations. The chosen allocations are presented in appendix 5. The remaining ash is placed at a landfill.

4.2.9.1 Energy recovery, mixed plastics

From the restored cartridge, the energy in the LDPE-bags and the nylon cogwheels are recovered here. These parts have been treated in the section called “mixed plastics” in Sundqvist’s report [17].

In the alternative with HP’s recycling programme LDPE, PS, polyurethane and nylon are input and treated as mixed plastics.

4.2.9.2 Energy recovery, PVC

Treated here is the PVC used for the wiper blade, against the drum.

4.2.9.3 Energy recovery, toner

Information about the energy content in toner has not been located. Since toner consist of about 50 % plastics (styrene acrylate copolymer) and about 50 % iron oxide it is treated as “mixed plastics” and “metals” [17] and half the value for the emissions for each category have been used.

4.2.10 Landfill

The ash from the energy recovery and the toner that is separated when the recycled paper from the use is turned to corrugated board are placed at landfill, (in LCAiT the mentioned toner have been placed at landfill right after the use, though). Environmental impact originating from the landfill has not been included.

4.2.11 Recycling HP (O)

20 % [10] of all sold HP-toner cartridges in the world are sent here. Information about the processes are inadequate, but the toner cartridges are assumed to be dismantled to its parts, at the recycling factory in Grenoble, France, after which the different materials are sent to different places for recycling.

The electricity consumption has been estimated to 2 kWh / toner cartridge.

4.2.12 Diesel production

The activity delivers diesel to all truck transports. “Emissions to water” in the source [8] has been placed under “non-elementary water emissions”.

4.2.13 Heavy fuel oil production

The activity delivers oil to the two freighters that leaves Japan for Sweden. “Emissions to water” in the source [8] has been placed under “non-elementary water emissions”.

4.2.14 Electricity production

The activity delivers electricity to those activities that are in need of it and have not already got environmental impact from electricity consumption in their data. “Emissions to water” in the source [8] has been placed under “non-elementary water emissions”. In the source waste has been called “other” this has been changed to “unspecified”.

4.2.15 Transports

All transports present in the two alternatives are presented below. Assumptions have been made regarding distance, way of transport and to a certain degree also regarding geographical location. Transports that only appear in one of the alternatives are followed by either (O) original or (R) restored, re-used in the column specific transport.

Table 3. Transports during the life cycle of the toner cartridges. (O = original, R = restored, re-used)

From activity	To activity	Distance (km)	Way of transport	Specific transport
Forestry	Paper production	500	Heavy truck	
LDPE-production	Assemblage/packing	200	Heavy truck	
LDPE-production	Restoration/refilling	350	Heavy truck	R
PVC-production	Component manufacturing	200	Heavy truck	
Polyurethane-production	Component manufacturing	200	Heavy truck	
Nylon production	Component manufacturing	200	Heavy truck	
PS-production	Component manufacturing	200	Heavy truck	
Aluminium production	Component manufacturing	200	Heavy truck	
Steel production	Component manufacturing	200	Heavy truck	
Copper production	Component manufacturing	200	Heavy truck	
Paper production	Assemblage/packing	350	Heavy truck	
Assemblage/packing	Use	30 000	Freighter	
Paper production	Use	350	Heavy truck	
Corrugated board production	Assemblage/packing	350	Heavy truck	
Component manufacturing	Assemblage/packing	200	Heavy truck	
Toner production	Assemblage/packing	200	Heavy truck	
Use	Recycling HP	2000	Heavy truck	O
Use	Landfill	10	Heavy truck	
Use	Corrugated board production	350	Heavy truck	
Recycling HP	Al-recycling	100	Heavy truck	O
Recycling HP	Steel-recycling	100	Heavy truck	O
Recycling HP	Corrugated board production	350	Heavy truck	O
Recycling HP	Landfill	10	Heavy truck	O
Recycling HP	Energy recovery mixed plastics	100	Heavy truck	O
Recycling HP	Energy recovery PVC	100	Heavy truck	O

Recycling HP	Energy recovery toner	100	Heavy truck	O
Recycling HP (Cu)	Component manufacturing	500	Heavy truck	O
Energy recovery	Landfill	10	Heavy truck	
Al-recycling	Component manufacturing	500	Heavy truck	
Steel-recycling	Component manufacturing	500	Heavy truck	
Restoration/refilling	Corrugated board production	350	Heavy truck	R
Toner production	Restoration/refilling	30 000	Freighter	R
Corrugated board production	Restoration/refilling	350	Heavy truck	R
Component manufacturing	Restoration/refilling	2000	Heavy truck	R
Use	Restoration/refilling	350	Heavy truck	R
Restoration/refilling	Use	350	Heavy truck	R
Restoration/refilling	Energy recovery mixed plastics	100	Heavy truck	R
Restoration/refilling	Energy recovery PVC	100	Heavy truck	R
Restoration/refilling	Energy recovery toner	450	Heavy truck	R
Restoration/refilling	Holland	2000	Heavy truck	R
Restoration/refilling	Al-recycling	100	Heavy truck	R
Restoration/refilling	Steel-recycling	100	Heavy truck	R

5 Results

This section presents the two alternatives environmental impact based on data categories and environmental impact assessments. Two scenarios have been evaluated; the main scenario, with paper, which includes all activities, and an alternative scenario, without paper, where activities connected to the paper production have been excluded. Though, the functional unit is actually not fulfilled without paper.

5.1 Data for Life Cycle Inventory

The inventory results for the four data categories, CO2- and NOx-emissions to air, energy consumption and generation of waste, are presented here. The results have been divided between the different alternatives and scenarios.

5.1.1 Main scenario, with paper

The scenario includes all activities, thus also activities connected to the consumption of paper at use. Emissions to air of CO2 and NOx, total consumption of energy and the generated amount of waste for the two alternatives are presented below. This is shown in table 4 and figure 3-6, there is also a percentage distribution of the emissions of CO2 and NOx for the different alternatives in tables 5 and 6.

All results are related to the functional unit “30 000 copies, 5 % average coverage” which correspond to three original toner cartridges or one toner cartridge re-used and restored two times.

The tables and charts show that the original alternative is 10-20 % higher than the re-use alternative. The main reasons for the difference is the consumption of electricity at the manufacturing of the toner cartridge and the production of PS, where 3 times as much material is needed for the original alternative. There is also a significant difference in the freight of toner cartridges between Japan and Sweden, for the emissions of NOx this is the determining factor. The freight takes place three times in the original alternative compared to one time in the re-use alternative. That the difference is not greater depends mainly on the fact that the paper consumption at use is the same in both alternatives, and that activities connected to this gives the greatest environmental impact in both alternatives.

”Freighter 1” and ”freighter 2” are the freights of toner cartridges respectively toner, with freighter between Japan and Sweden. ”Heavy truck 41” is the transport between forestry and paper production, ”heavy truck 26” is the transport between paper production and use while ”heavy truck 33” is the transport (of paper) between use and paper recycling as well as corrugated board production.

Table 4. The environmental impact of the two alternatives, four data categories, main scenario, with paper

Data category	Original	Re-used	Difference in percents, original/re-used (%)
CO_2 (kg)	87	77	13
NO_x (kg)	0,62	0,55	13
Energy (MJ)	3060	2540	20
Waste (kg)	35,1	30,3	16

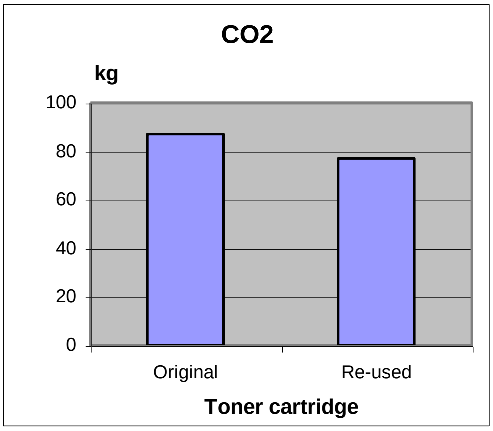

Figure 3. Emissions, CO_2, main scenario, with paper

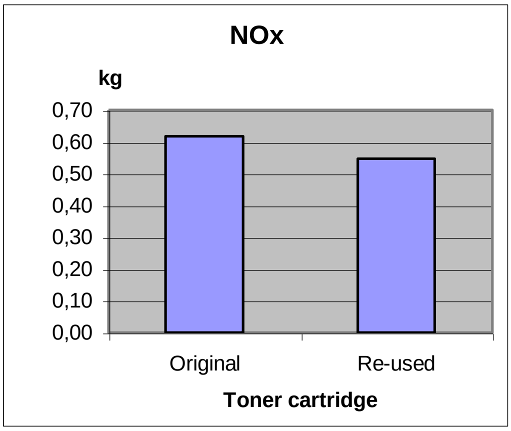

Figure 4. Emissions, NO_x, main scenario, with paper

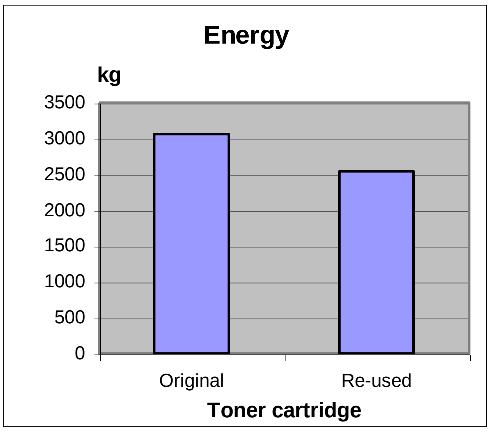

Figure 5. Total energy consumption main scenario, with paper

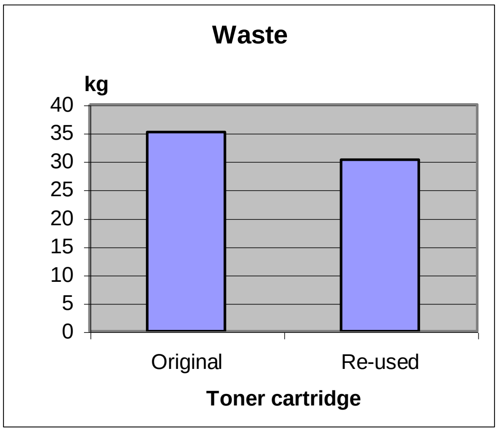

Figure 6. Total amount of waste main scenario, with paper

Table 5. Percentage distribution of CO2-emissions, main scenario, with paper

Activity	CO2-emissions for original toner cartridge (kg)	Contribution in percent of CO2-emissions for original toner cartridge (%)	CO2-emissions for re-used toner cartridge (kg)	Contribution in percent of CO2-emissions for re-used toner cartridge (%)
Paper prod.	39,2	45,06	39,2	50,91
Electricity prod.	14,3	16,44	10,8	14,03
Heavy truck 41	9,79	11,25	9,79	12,71
Forestry	5,19	5,97	5,19	6,74
Heavy truck 33	2,26	2,60	2,26	2,94
Heavy truck 26	2,26	2,60	2,26	2,94
Diesel prod.	2,01	2,31	2,03	2,64
PS-production	3,86	4,44	1,29	1,68
Freighter1	3,69	4,24	1,23	1,60
Al-production	1,02	1,17	0,45	0,58
Rest	3,4	3,91	2,5	3,25
Total	87	100	77	100

Table 6. Percentage distribution of NOx-emissions, main scenario, with paper

Activity	NOx-emissions for original toner cartridge (g)	Contribution in percent of NOx-emissions for original toner cartridge (%)	NOx-emissions for re-used toner cartridge (g)	Contribution in percent of NOx-emissions for re-used toner cartridge (%)
Paper prod.	237	38,47	237	43,41
Heavy truck 41	111	18,02	111	20,33
Forestry	55,3	8,98	55,3	10,13
Freighter1	94,9	15,41	31,6	5,79
Heavy truck 26	25,6	4,16	25,6	4,69
Heavy truck 33	25,6	4,16	25,6	4,69
Electricity prod.	22,5	3,65	17,0	3,11
Freighter2	-	-	14,6	2,67
Diesel prod.	12,5	2,03	12,7	2,33
PS-production	16,3	2,65	5,44	1,00
Rest	15,3	2,48	10,2	1,87
Total	616	100	546	100

5.1.2 Alternative scenario, without paper

The scenario does not include activities connected to the paper consumption at use. Emissions to air of CO2 and NOx, total consumption of energy and the generated amount of waste for the two alternatives are presented below. This is shown in table 7 and figure 7-10, there is also a percentage distribution of the emissions of CO2 and NOx for the different alternatives in tables 8 and 9.

All results are related to the functional unit "30 000 copies, 5 % average coverage" which correspond to three original toner cartridges or one toner cartridge re-used and restored two times.

The tables and charts show that the original alternative is up to 90 % higher than the re-use alternative. The main reasons for the difference is the consumption of electricity at the manufacturing of the toner cartridge and the production of PS, where 3 times as much material is needed for the original alternative. There is also a significant difference in the freight of toner cartridges between Japan and Sweden, for the emissions of NOx this is the determining factor. The freight takes place three times in the original alternative compared to one time in the re-use alternative.

"Freighter 1" and "freighter 2" are the freights of toner cartridges respectively toner, with freighter between Japan and Sweden.

Table 7. The environmental impact of the two alternatives, four data categories, alternative scenario, without paper

Data category	Original	Re-used	Difference in percents, original/re-used (%)
CO2 (kg)	26,3	16,3	61
NOx (g)	149	79,3	88
Energy (MJ)	1790	1270	41
Waste (kg)	18,5	13,7	35

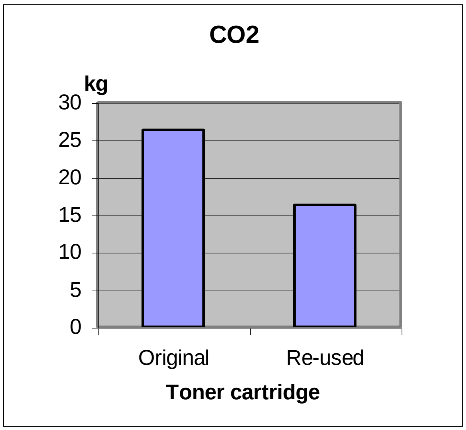

Figure 7. Emissions, CO2, alternative scenario, without paper

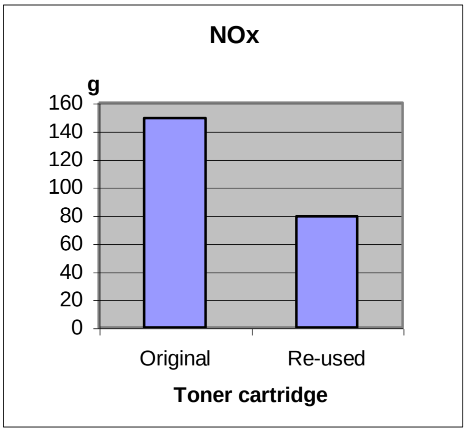

Figure 8. Emissions, NOx, alternative scenario, without paper

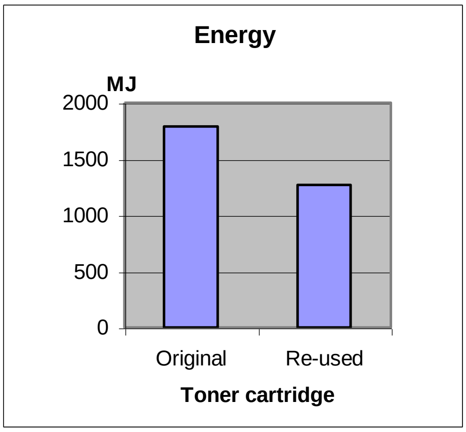

Figure 9. Total energy consumption alternative scenario, without paper

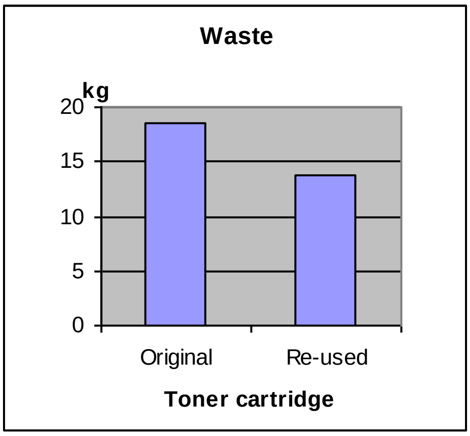

Figure 10. Total amount of waste, alternative scenario, without paper

Table 8. Percentage distribution of CO2-emissions, alternative scenario, without paper

Activity	CO2-emissions for original toner cartridge (kg)	Contribution in percent of CO2-emissions for original toner cartridge (%)	CO2-emissions for re-used toner cartridge (kg)	Contribution in percent of CO2-emissions for re-used toner cartridge (%)
Electricity prod.	14,3	54,37	10,8	66,26
PS-production	3,86	14,68	1,29	7,91
Freighter1	3,69	14,03	1,23	7,55
Al-production	1,02	3,88	0,45	2,76
Rest	3,43	13,04	2,53	15,52
Total	26,3	100	16,3	100

Table 9. Percentage distribution of NOx-emissions, alternative scenario, without paper

Activity	NOx-emissions for original toner cartridge (g)	Contribution in percent of NOx-emissions for original toner cartridge (%)	NOx-emissions for re-used toner cartridge (g)	Contribution in percent of NOx-emissions for re-used toner cartridge (%)
Freighter1	94,9	63,69	31,6	39,85
Electricity prod.	22,5	15,10	17,0	21,44
Freighter2	-	-	14,6	18,41
PS-production	16,3	10,94	5,44	6,86
Rest	15,3	10,27	10,66	13,44
Total	149	100	79,3	100

5.2 *Environmental impact assessment*

The result of the environmental impact assessment according to the characterisation method “Global warming (100 years)” and the three weighting methods, ”EPS 2000”, ”Eco Sweden 98” and ”Tellus” are presented here, divided to the two alternatives and scenarios.

5.2.1 Main scenario, with paper

All results are related to the functional unit “30 000 copies, 5 % average coverage” which correspond to three original toner cartridges or one toner cartridge re-used and restored two times.

5.2.1.1 Characterisation

The result of the characterisation with the method ”Global warming (100 years)” for each alternative are presented below. It is presented in table 10 and figure 11 as well as a percentage distribution for the two alternatives in table 11.

The tables and charts show that the original alternative is 13 % higher than the re-use alternative. The main reason for the difference is the consumption of electricity at the manufacturing of the toner cartridge. There is also a significant difference in the freight of toner cartridges between Japan and Sweden. The freight takes place three times in the original alternative compared to one time in the re-use alternative. Activities connected to the use of paper, mainly paper production, are dominating though, wherefore the difference is not greater, since these activities are just as big for both alternatives.

”Freighter 1” is the freight of toner cartridges, with freighter between Japan and Sweden. ”Heavy truck 41” is the transport between forestry and paper production.

Table 10. The environmental impact of the two alternatives, ”Global warming (100 years)”, main scenario, with paper

Characterisation method	Original (g CO2-equivalents)	Re-used (g CO2-equivalents)	Difference in percents, original/re-used (%)
Global warming (100 years)	93 100	82 100	13

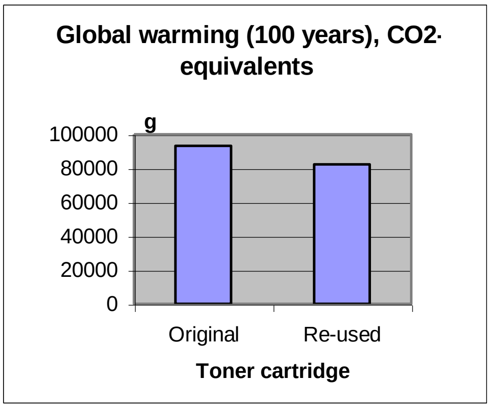

Figure 11. "Global warming (100 years)", CO2-equivalents, main scenario, with paper

Table 11. Percentage distribution of CO2-equivalents, "Global warming (100 years)", main scenario, with paper

Activity	CO2-equivalents for original toner cartridge (g)	Contribution in percent of CO2-equivalents for original toner cartridge (%)	CO2-equivalents for re-used toner cartridge (g)	Contribution in percent of CO2-equivalents for re-used toner cartridge (%)
Paper prod.	40 900	43,9	40 900	49,8
Electricity prod.	14 900	16,0	11 300	13,8
Heavy truck 41	10 600	11,4	10 600	12,9
Forestry	5 700	6,1	5 700	6,9
Freighter1	4 400	4,7	1 500	1,8
Rest	16 600	17,8	12 100	14,7
Total	93 100	100	82 100	100

5.2.1.2 Weighting

The result of the weighting with "EPS 2000", "Eco Sweden 98" and "Tellus", for the two alternatives, are presented here in table 12 and figures 12-14 plus a percentage distribution in table 13, where the five activities that gives the greatest environmental impact for each method have been included.

The tables and charts show that the original alternative is almost 20 % higher than the re-use alternative. The main reason for the difference is the consumption of electricity at the manufacturing of the toner cartridge. There is also a significant difference in the freight of toner cartridges between Japan and Sweden. The freight takes place three times in the original alternative compared to one time in the re-use alternative. Activities connected to the use of paper, mainly paper production, are dominating though, wherefore the difference is not greater, since these activities are just as big for both alternatives.

”Freighter 1” is the freight of toner cartridges, with freighter between Japan and Sweden. ”Heavy truck 41” is the transport between forestry and paper production.

Table 12. The environmental impact of the two alternatives, three weighting methods, main scenario, with paper

Weighting method	Original	Re-used	Difference in percents, original/re-used (%)
EPS 2000 (ELU)	12,9	10,9	18
Eco Sweden 98 (Ecopoints)	39 000	33 200	17
Tellus ($)	9,76	8,31	17

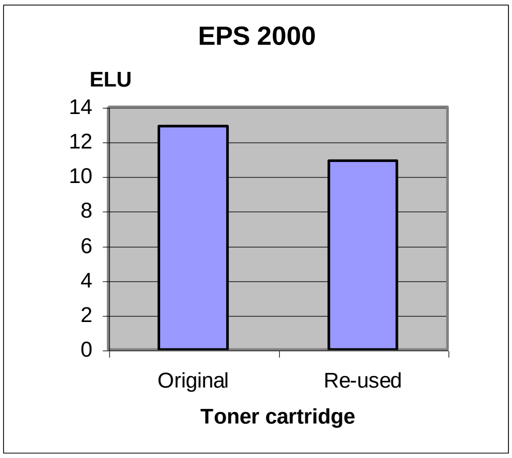

Figure 12. ”EPS 2000”, main scenario, with paper

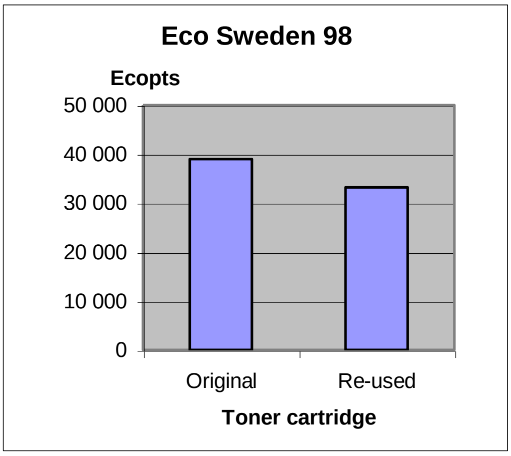

Figure 13. ”Eco Sweden 98”, main scenario, with paper

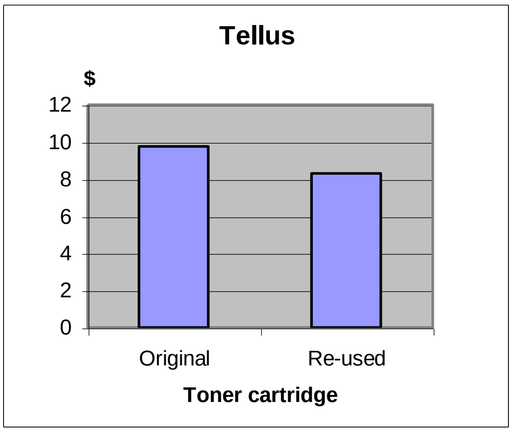

Figure 14. ”Tellus”, main scenario, with paper

Table 13. Percentage distribution, ”EPS 2000”, ”Eco Sweden 98” and ”Tellus”, main scenario, with paper

	EPS 2000				Eco Sweden 98				Tellus			
Activity	Original		Re-used		Original		Re-used		Original		Re-used	
	ELU	%	ELU	%	Ecop.	%	Ecop.	%	$	%	$	%
Paper prod.	5,16	40,0	5,16	47,3	12000	30,8	12000	36,1	4,08	41,8	4,07	49,0
Electricity pr.	1,69	13,1	1,29	11,8					0,56	5,7	0,42	5,1
Heavy tr. 41	1,31	10,2	1,31	12,0	3770	9,7	3770	11,4	1,06	10,9	1,06	12,8
Al-production	1,19	9,2	0,53	4,9								
Freighter1	0,81	6,3	0,27	2,5	4890	12,5	1630	4,9	1,63	16,7	0,54	6,5
Diesel prod.					7140	18,3	7210	21,7				
Heavy fuel oil					2850	7,3	1390	4,2				
Forestry									0,53	5,4	0,53	6,4
Rest	2,74	21,2	2,34	21,5	8350	21,4	7200	21,7	1,90	19,5	1,69	20,3
Total	12,9	100	10,9	100	39000	100	33200	100	9,76	100	8,31	100

5.2.2 Alternative scenario, without paper

All results are related to the functional unit “30 000 copies, 5 % average coverage” which correspond to three original toner cartridges or one toner cartridge re-used and restored two times.

5.2.2.1 Characterisation

The result of the characterisation with the method ”Global warming (100 years)” for each alternative are presented below. It is presented in table 14 and figure 15 as well as a percentage distribution for the two alternatives in table 15.

The tables and charts show that the original alternative is 63 % higher than the re-use alternative. The main reason for the difference is the consumption of electricity at the manufacturing of the toner cartridge and the production of PS, where 3 times as much material is needed for the original alternative. There is also a significant difference in the freight of toner cartridges between Japan and Sweden. The freight takes place three times in the original alternative compared to one time in the re-use alternative.

”Freighter 1” is the freight of toner cartridges, with freighter between Japan and Sweden.

Table 14. The environmental impact of the two alternatives, ”Global warming (100 years)”, alternative scenario, without paper

Characterisation method	Original (g CO2-equivalents)	Re-used (g CO2-equivalents)	Difference in percents, original/re-used (%)
Global warming (100 years)	28 600	17 600	63

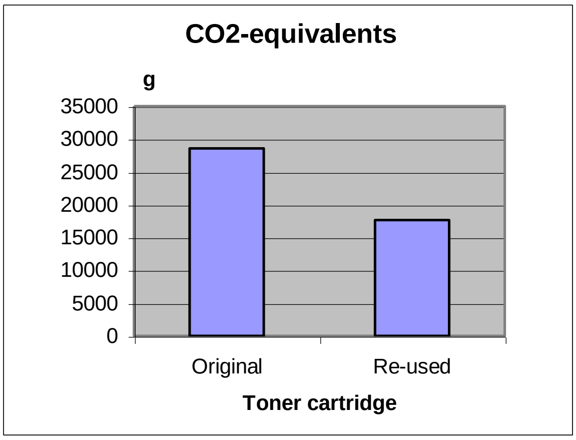

Figure 15. “Global warming (100 years)”, CO2-equivalents, alternative scenario, without paper

Table 15. Percentage distribution of CO2-equivalents, ”Global warming (100 years)”, alternative scenario, without paper

Activity	CO2-equivalents for original toner cartridge (g)	Contribution in percent of CO2-equivalents for original toner cartridge (%)	CO2-equivalents for re-used toner cartridge (g)	Contribution in percent of CO2-equivalents for re-used toner cartridge (%)
Electricity prod.	14 900	52,1	11 300	64,2
Freighter1	4 370	15,3	1 460	8,3
PS-production	4 260	14,9	1 420	8,1
Al-production	1 040	3,6	460	2,6
Heavy fuel oil	890	3,1	440	2,5
Rest	4 030	14,1	2 960	16,8
Total	28 600	100	17 600	100

5.2.2.2 Weighting

The result of the weighting with ”EPS 2000”, ”Eco Sweden 98” and ”Tellus”, for the two alternatives, are presented here in table 16 and figures 16-18 plus a percentage distribution for the different activities divided into each method in table 17.

The tables and charts show that the original alternative is up to 90 % higher than the re-use alternative. The main reason for the difference is the consumption of electricity at the manufacturing of the toner cartridge. There is also a significant difference in the freight of toner cartridges between Japan and Sweden. The freight takes place three times in the original alternative compared to one time in the re-use alternative.

”Freighter 1” is the freight of toner cartridges, with freighter between Japan and Sweden.

Table 16. The environmental impact of the two alternatives, three weighting methods, alternative scenario, without paper

Weighting method	Original	Re-used	Difference in percents, original/re-used (%)
EPS 2000 (ELU)	4,76	2,68	78
Eco Sweden 98 (Ecopoints)	12 400	6 650	86
Tellus ($)	3,09	1,64	88

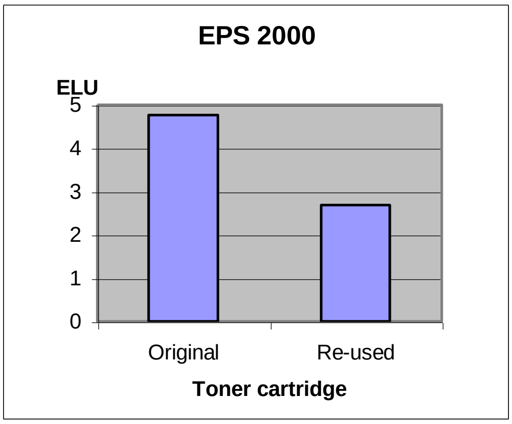

Figure 16. ”EPS 2000”, alternative scenario, without paper

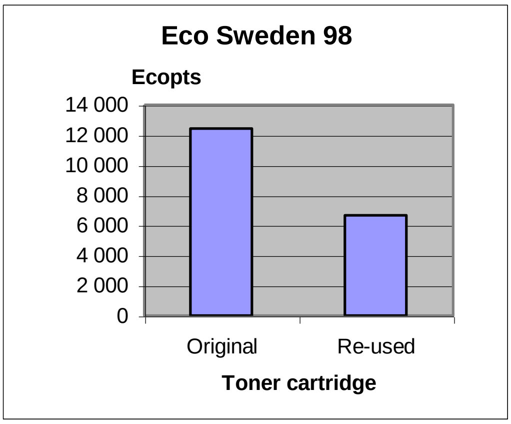

Figure 17. ”Eco Sweden 98”, alternative scenario, without paper

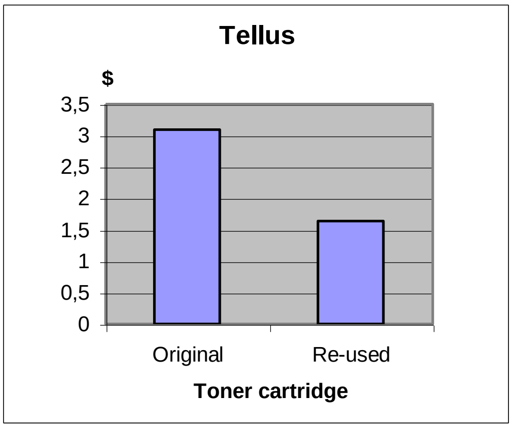

Figure 18. ”Tellus”, alternative scenario, without paper

Table 17. Percentage distribution, ”EPS 2000”, ”Eco Sweden 98” and ”Tellus”, alternative scenario, without paper

	EPS 2000				Eco Sweden 98				Tellus			
Activity	Original		Re-used		Original		Re-used		Original		Re-used	
	ELU	%	ELU	%	Ecop.	%	Ecop	%	$	%	$	%
Electricity pr.	1,69	35,5	1,29	48,1	1630	13,1	1230	18,5	0,56	18,1	0,42	25,6
Al-production	1,19	25,0	0,53	19,8	1170	9,4	520	7,8	0,47	15,2	0,21	12,8
Freighter1	0,81	17,0	0,27	10,1	4890	39,4	1630	24,5	1,63	52,8	0,54	32,9
PS-prod.	0,53	11,1	0,18	6,7	710	5,7	240	3,6	0,18	5,8	0,06	3,7
Heavy fuel oil	0,15	3,2	0,07	2,6	2850	23,0	1390	20,9	0,11	3,6	0,06	3,7
Rest	0,39	8,2	0,34	12,7	1150	9,3	1640	24,7	0,14	4,5	0,35	21,3
Total	4,76	100	2,68	100	12400	100	6650	100	3,09	100	1,64	100

5.2.2.3 Sensitivity analysis

A sensitivity analysis has been carried out for the alternative scenario, where the electricity consumption at use has been excluded. Table 18 shows that the difference in this case is over 100 %, up to 123 %, i.e. the environmental impact for the re-use alternative is less than half of the environmental impact for the original alternative.

Table 18. The environmental impact of the two alternatives, three weighting methods, alternative scenario, without paper, without electricity consumption at use

Weighting method	Original	Re-used	Difference in percents, original/re-used (%)
EPS 2000 (ELU)	3,75	1,68	123
Eco Sweden 98 (Ecopoints)	11 400	5 690	100
Tellus ($)	2,76	1,31	111

A sensitivity analysis has also been performed where the alternative with the higher energy consumption at the steel production has been used. This has been done for the alternative scenario, without paper. Table 19 presents an insignificant difference compared to the result with the lower data for the steel production, this despite that the difference in the energy consumption between the higher and lower alternative was about three times. This indicates that the steel production plays a minor part of the environmental impact in a toner cartridge's life cycle.

Table 19. The environmental impact of the two alternatives, three weighting methods, alternative scenario, without paper, with the higher energy consumption at the steel production

Weighting method	Original	Re-used	Difference in percents, original/re-used (%)
EPS 2000 (ELU)	5,06	2,82	79
Eco Sweden 98 (Ecopoints)	12 800	6 820	88
Tellus ($)	3,17	1,68	89

6 Discussion

The study shows that for the main scenario, with paper, where activities connected to the use of paper are included, a toner cartridge that is re-used twice, are between ten and twenty percents better, from an environmental point of view, than a toner cartridge that is sent to HP's recycling programme, according to the used data categories and methods for environmental impact assessment. If the paper is excluded from the environmental impact, the alternative scenario, without paper, there is a great difference in the result. The re-use alternative is in this case up to 90 % better with some methods of assessments. For all the methods the difference is less than two times though.

The activities that give the largest contribution to the environmental impact, for the main scenario, with paper, are practically exclusively activities connected to the production and transportation of paper. Besides that electricity consumption plays a significant part. For the alternative scenario, without paper, the dominating activities are the electricity consumption, the freighter transports from Japan to Sweden and the production of polystyrene.

One reason why the difference between the two alternatives is not greater than it is, is that the electricity consumption plays the major part that it does. Within this activity the main part is consumed at use. The electricity consumption at use are just as great for both alternatives, hence the percentage difference are not greater. The sensitivity analysis shows this clearly. When the electricity consumption at use were excluded the difference between the two alternatives was over 100 % for all weighting methods (123 % with "EPS 2000"). Accordingly the re-use alternative gives less than half the environmental impact as the alternative according to HP's recycling programme gives, on these conditions. This is about the same result that the life cycle assessment of ink cartridges that was carried out for Bläck & Write in 1995 [19] concluded.

The result after the sensitivity analysis mentioned above can be seen as the most fair, since this way of comparing the two alternatives deals with factors that can be effected within the two alternatives. Paper production and the electricity consumption for a printer on the other hand are more difficult to effect.

The sensitivity analysis with the higher energy consumption at steel production gave slightly higher values for the three weighting methods. The difference in percent however, was about the same as before.

The lack of data is major in some activities. This concerns foremost activities connected to HP's production, "Component manufacturing" and "Assemblage/packing" since HP, because of secrecy, does not give any information or data about which methods are used. Information about the production of toner is also lacking in the study. Besides that assumptions have been made regarding the processes at "Recycling HP". The electricity consumption has been estimated roughly for these activities. There are also uncertainties in the transport distances where standardised assumptions have been made. There is also a degree of uncertainty regarding the material in some components and hence production methods for example of plastics.

The lack of data has obviously influenced the result in such a way that it does not entirely correspond with reality. The delimitations that have been made influence the result in the same way. The data for the rest of the activities are reliable and presented by trade associations or other life cycle assessments.

7 Conclusion

The conclusion of the study is that it is motivated to re-use toner cartridges, and if possible that should be done to a greater extent.

That re-use in general is motivated is a common point of view, which is also established by Finnveden et al in the report Life Cycle Assessment of Energy from Solid Waste [6].

Nevertheless it is important to keep in mind that the toner cartridge does not answer for the major part of the environmental load when you look at the function that it is a part of, but paper and electricity adds a great contribution to the environmental load. That is probably also the case if you look at the entire printer, not just the toner cartridge, this has not been studied though.

A life cycle assessment of the entire laser printer should be an interesting future project, which would give a more complete and clearer picture of the resulting environmental load when using a laser printer. Such a study would place the toner cartridge in its right environment and give a fairer picture.

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Appendix

Appendix 1. Calculation of the electricity consumption per toner cartridge at Tepro

The total electricity consumption at Tepro during 2000 was 127 775 kWh, 95 % of this is estimated to be used in the production, i.e. 121 386 kWh [1]. The turnover of toner cartridges are 60 000 per year [1]. If all toner cartridges are assumed to use the equal amount of electricity, each toner cartridge consume 2,02 kWh.

Tepro also deals with some other products. But since this is done to such a small extent, it is considered negligible.

Appendix 2. Calculation of toner quantity

When the toner cartridges are “empty” there are some toner left in them. This is separated and collected when the toner cartridges are dismantled. The quantity left has been calculated to 77 grams for each toner cartridge. This is based on the fact that Tepro each year send 4 600 kg of toner for energy recovery from toner cartridges that they receive [1]. With 60 000 received toner cartridges per year this equals 77 grams per toner cartridge.

This amount leaves Tepro from each toner cartridge. There is 450 grams in a full toner cartridge, hence 373 grams is consumed when the toner cartridge is used.

Tepro also receive some other products, in which toner are left over. But since this is done to such a small extent, it is considered negligible.

Appendix 3. Paper consumption at use

Each toner cartridge C4127X gives 10 000 printouts with 5 % average coverage. An A4-paper has the area 210×297 mm and the density for an ordinary paper is 75 g/m^2. This give a weight of 4,6 grams for each A4-paper and a total of 46,8 kg for 10 000 papers.

Appendix 4. Electricity consumption at use

A printer has according to HP, three power levels, when printing, 385 W, stand-by, 26 W, and at rest 19 W [12]. The printer switches to position of rest when no printouts have been made for 30 minutes.

After conversation with responsible for the computers at University of Kalmar we came to the conclusion that a toner cartridges lasts for about four months. This is assumed to be an average period for companies and schools. The assumption that the printer is turned on day and night has also been made.

Four months = 120 days, of which 86 are working-days and the rest weekends. We assumed that the printer is at rest during weekends and 15 hours a day during working-days.

$34 \times 24 = 816$ h

$86 \times 15 = 1290$ h

816+1290 = 2106 h, that the printer is at rest, 19 W.

$86 \times 9 = 774$ h

The capacity of a printer is between 17 and 24 printouts per minute. This means that 10 000 printouts takes between 6,9 and 9,8 hours to be made. The assumption has been made that the period for 10 000 printouts are 8 hours. During these hours the power is 385 W.

During the rest 766 hours (774 – 8) the printer is at stand-by, 26 W.

Summation;

2106 (h) $\times$ 19 (W) = 40014 Wh

766 (h) $\times$ 26 (W) = 19916 Wh

8 (h) $\times$ 385 (W) = 3080 Wh

40014 + 19916 + 3080 = 63010 Wh = 63 kWh

Totally 63 kWh is consumed per toner cartridge at use.

Appendix 5. Choice of allocation for emissions from energy recovery

The chosen allocations that have been made in Sundqvist's report, for the emissions from burning of PVC, mixed plastics and toner are presented below.

Table 20 Choice of allocation for energy recovery

Substance	Method of allocation
CO	C allocation
CO2	Tot CO2
Dioxin	C + Cl allocation
Dust	Ash allocation
NOx	Ctot allocation
PAH	C allocation
SO2	Average Sweden
Electricity + heat	Production of both electricity and heat: Average Sweden

Appendix 6. Heating values of different energy sources

”Renewable”, that is present in some activities, has been approximated to biomass and the “coal” present in some has been approximated to pit coal.

In the activities where uranium is an energy source and has been presented in weight it has been transformed to energy content. The efficiency that is used to produce electricity has been used. Where electricity consumption has been presented in weight, the assumption that it is equal to the weight of uranium has been made, and calculations as above done.

Table 21. Heating values used for calculations of energy contents [9][11].

Energy source	Effective heating value (MJ/kg)	Source
Biomass	10	9, interpretation
Coal	27,2	9 (pit coal)
Diesel	43,0	9 (average)
Natural gas	51,9	9
Oil, heavy oil, light oil, crude oil	42,0	9 (average)
Peat	9,5	9
Renewable	10	9, interpretation
Bark	7,3	9 (bark chips)
Lignite	27,2	9 (pit coal)
Hard coal	27,2	9 (pit coal)
Light Petroleum Gas	51,9	9 (natural gas)
Electricity	504 000*0,35 (efficiency = 0,35)	11
Uranium, uranium in ore	504 000*0,35 (efficiency = 0,35)	11