CUSTOMIZED LCA FOR NETWORK CAMERAS

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ABSTRACT

The number of surveillance cameras installed for various purposes have increased substantially in society over the past decade. The environmental impacts from network cameras are relatively unknown and their rapid increase in number calls for studying the impacts from a life cycle perspective; from raw material extraction to decommissioning. The project is performed on request by Axis Communications AB (hereby referred to as Axis) with the main purposes to increase Axis's knowledge of the environmental impact from their products and establish a method for conducting simplified life cycle assessments (LCA) on Axis products. A case study LCA is conducted on a network camera developed by Axis; model AXIS Q6032-E PTZ. Concurrently a method for conducting simplified LCAs on other Axis cameras is developed as well as a platform to be used in product development processes to enhance life cycle thinking (LCT). The Eco-indicator 99 Method is used for the environmental impact assessment and for simulations and calculations the software program SimaPro 7.1 is used.

The results emphasize the life stages and their particular activities having the largest potential environmental impacts; primarily utilization and the production of electricity. For the scenario where the camera is installed in Europe the manufacturing comes as second, then raw material extraction and processing, followed by transportations. Decommissioning impacts with a negative value, i.e. impacts the environment in a positive way. The alternative scenario (where the camera is transported by air to U.S. and installed there) gives a total higher score and has the transportation category as the second highest regarding the total environmental impact. During the whole lifetime the camera emits 663 kg CO_2.

The results from using the developed model to conduct simplified LCAs only differ by 0.24% from the results of the case study LCA. The LCA is considered stable based on the performed sensitivity analysis.

Key words: Life Cycle Assessment, LCA, Network camera, Simplified LCA
Environmental impact, Impact categories, Damage categories

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Kundanpassad LCA för nätverkskameror

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SAMMANFATTNING

Antalet övervakningskameror i samhället ökar, samtidigt som deras miljöpåverkan är relativt okänd. För en produkt som tidigare bara utvärderats gällande prestanda, börjar kunderna nu efterfråga en kartläggning av miljöpåverkan. Kamerans miljöpåverkan studeras ur ett livscykelperspektiv: energi- och materialtillförsel samt utsläpp och avfall som berör allt ifrån råmaterialutvinning till slutåtervinning. Projektet är genomfört på begäran av, och för, Axis Communications AB (härmed refererade till som Axis) med huvudsyfte att öka Axis kunskap om deras produkters miljöpåverkan och utveckla en metod för genomförande av förenklade livscykelanalyser på Axis produkter. Livscykelanalysen, LCA, genomförs på en nätverkskamera utvecklad av Axis Communications AB; modell AXIS Q6032-E PTZ. Samtidigt togs metoden för förenklade livscykelanalyser fram för att möjliggöra jämförelse med andra kameramodeller i företagets produktportfolio. Även en plattform har skapats för att kunna användas i produktutvecklingens tidigare skede, för att redan där göra ett aktivt miljöval. Den metod som används för bedömning av miljöpåverkan är Eco-indicator 99. Simulering och beräkningar sker i LCA-programmet SimaPro 7.1.

Resultatet visar att den största miljöpåverkan kommer ifrån användningsfasen och behovet av elektricitet. För scenariot där kameran används i Europa har tillverkningen näst störst påverkan, därefter materialanvändningen och sist transporterna. Återvinningen påverkar med ett negativt värde, d.v.s. den påverkar miljön på ett positivt sätt. Det alternativa scenariot (där kameran flygs till USA och installeras där) ger en totalt större miljöpåverkan och har transporterna som andra värsta kategorin. Vid beräkningar för Europa släpper kameran ut 663 kg CO_2 under sin livstid. Den utvecklade modellen överensstämmer till 0,24% med resultatet ifrån simuleringsprogrammet. Modellen kan enligt den genomförda känslighetsanalysen anses stabil.

Nyckelord: Livscykelanalys, LCA, Nätverkskamera, Förenklad LCA, Miljlöpåverkan, Miljöpåverkan, Påverkanskategorier, Skadekategorier

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NOMENCLATURE

TERMS

$DALY$	Disability Adjusted Life Years. “A damage of 1 means one life year of one individual is lost, or one person suffers four years from a disability with a weight of 0.25.” (PRé b, 2000, p. 113)
$PDF \times m^2 yr$	Potentially Disappeared Fraction of Species. “A damage of one means all species disappear from one m^2 during one year; or 10% of all species disappear from 10 m^2 during one year; or 10% of all species disappear from 1 m^2 during 10 years.” (PRé b, 2000, p. 116)
$MJ\ surplus\ energy$	“A damage of 1 means that due to a certain extraction further extraction of this resource in the future will require one additional MJ of energy, due to the lower resource concentration, or other unfavorable characteristics of the remaining reserves.” (PRé b, 2000, p. 118)

ABBREVIATIONS

°C	Degree Celsius
CLC	Configuration and Logistics Center (in four different locations, 1-4)
CO_2	Carbon Dioxide
EQ	Ecosystem Quality
EU	European Union
HH	Human Health
IP	Internet Protocol
kg	Kilogram
km	Kilometers
kW	Kilowatt
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCT	Life Cycle Thinking
m	Meters
MJ	Mega joule
mPt	millipoints
NO_x	Nitrogen Oxides (gases)
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly

Pt	Point
PT	Pan, Tilt
PTZ	Pan, Tilt, Zoom
qty	Quantity
R	Resources
SO_x	Sulphur Oxides (gases)
t	tonne
tkm	Tonnes-kilometers
U.S.	United States (of America)
VOCs	Volatile Organic Compounds
V	Volt

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1. INTRODUCTION

This is the report of the master thesis conducted by Hanna Hillerström and Ulrika Troborg at Axis Communications AB (hereby referred to as Axis) during the time period September 2009 until February 2010. The master thesis was performed independently, but consulting Jenny Svensson and Carl Trotzig at Axis and Anna Hedlund Åström at Kungliga Tekniska Högskolan (The Royal Institute of Technology, Stockholm, Sweden). Briefly the thesis aims at increasing the knowledge of the environmental impact caused by network cameras. It is done by conducting a life cycle assessment, LCA, on one certain camera model (A case study of the AXIS Q6032-E network camera) and by developing a simplified LCA method to be able to perform quicker LCAs on other camera models.

1.1 Background and Problem Description

Axis Communications AB is an IT company offering network video products and solutions for professional IP-surveillance in the following customer segments: retail, transportation, education, industrial, city surveillance, government, banking and healthcare. Axis is driving the on-going transition from analogue to network video surveillance as the global market leader in network video. (Axis Annual Report, 2008)

The requirement of contractual manufacturers having to be ISO 14000 certified reflects the environmental concern of Axis (Axis Annual Report, 2008). Moreover, customers of Axis have expressed their interest in the environmental performance of Axis's network cameras. The global concern for environmental impacts associated with everything from raw material extraction to the decommissioning of products is continuously increasing and thereby also the interest in developing methods to better comprehend and reduce these impacts. One technique developed for this purpose is the Life Cycle Assessment, LCA. An LCA is used to identify the ways in which a product affects the environment throughout its entire life span, commonly referred to as “from cradle to grave”. Through the results of an LCA analysis it is possible to make decisions and improvements to current product designs and processes. The broad context in which an LCA may be applied speaks for customizing and thus facilitating the implementation of LCA in the product development process. The following thesis is customized for Axis.

1.2 Problem Definition

Considering environmental aspects throughout a product’s entire life cycle by incorporating LCA in practice and thinking in all product development processes defines the thesis problem. The aims and objectives, and necessary delimitations are stated below.

The aims and objectives of the thesis are the following:

- Increase Axis's knowledge of the environmental impact of the Axis developed and produced AXIS Q6032-E Network Camera by conducting an LCA (case study).
- Identify which phases in the life cycle of an AXIS Q6032-E Network Camera that have the highest environmental impact.
- Enable for the results of the LCA to be used as a platform in coming product development projects to improve the environmental performance of future products.
- Establish a method for conducting simplified LCAs on similar Axis products. The method should allow for Axis to compare the environmental performance of the AXIS Q6032-E and other Axis network cameras.
- Allow for Axis to use the results in customer communication.

Integrating the LCA method and the platform at Axis falls outside the scope of the thesis. An environmental engineer at Axis will instead be taught to use the tools properly and assigned to effectively implement them in the organization. Another responsibility of the environmental engineer is spreading the knowledge gained from the results of the thesis. Neither is validation and complete testing of the method and the platform included in the scope.

1.3 Method

The thesis project, completed over a 5 months period from September 2009 to February 2010, consists of a literature review and analysis of studies that assess LCA methodologies, as well as supplier consultations at Axis's production sites in Sweden and Poland.

There are two main phases of this project, see Figure 1. Phase one includes performing an LCA on the network camera and identifying which phases in its life cycle have the highest environmental impact (case study LCA). Phase two includes two stages. First stage is enabling for the results of the case study LCA to be used as a platform in coming product development projects to improve the environmental performance of future products. In the second stage a model to be used for conducting simplified LCAs on similar Axis products is developed. In practice, the two phases somewhat overlap; phase 2 is initiated before phase 1 is finished as Figure 1 illustrates.

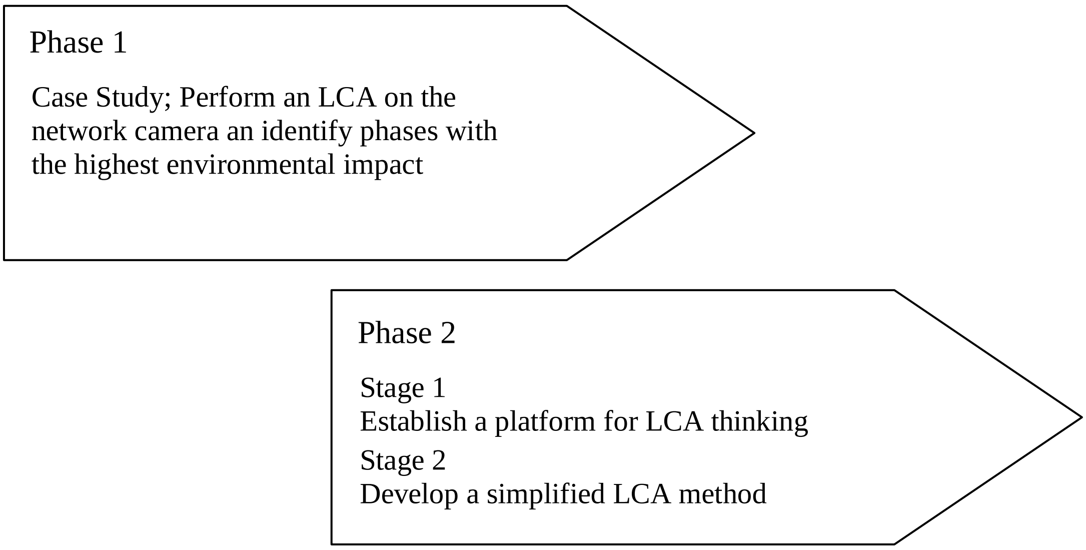

Figure 1. Visualization of the project phases. The two phases somewhat overlap; phase 2 is initiated before phase 1 is finished.

There are a few globally renowned LCA software programs to use to conduct LCAs; the most widely used tool SimaPro (Version 7.1) is used for simulation of this LCA. Another widely accepted tool is the GaBi Software. In this case the SimaPro software is used because of GaBi being more focused on chemical processes which does is not suitable in the case of studying a network camera. SimaPro adheres to the ISO 14044 series and is also the LCA software used at KTH which gives credibility. Moreover, it comes with as much as 11 databases for materials and processes which may be used as they are defined or be modified, to model an LCA. According to the EU Commission (EU Commission a, 2009) SimaPro databases are "very large and up to date". The main one is the SimaPro database which contains all add-on databases. The add-on databases are public and published by industries and well-known providers, e.g. universities. The database availability ease the otherwise very time consuming inventory assessment (LCI). As for the impact assessment (LCIA) methods can be copied to the LCA project, in this case the Eco-indicator 99 is chosen.

It is common practice to add an impact assessment method to the software that is used to conduct the LCA. In a broad sense the impact assessment method structures the LCA. One impact assessment method widely accepted in Europe is the Eco-indicator 99 Method. It gives a complete coverage of potential impact categories. Because of few previous LCAs of network cameras some environmental impacts may still be unknown wherefore it is important not to neglect possible ones at an early stage.

The choice of software and method has been discussed with Axis and chosen with their consent.

2. THEORETICAL FRAMEWORK

The theoretical framework gives the background to life cycle assessment and describes LCA in theory – it's content, assisting tools, practical incorporation, and limitations. An introduction to network camera surveillance is also part of the theoretical framework, including specific camera features and structure.

2.1 LCA in Theory

An increased awareness of environmental protection has resulted in an increased interest in developing methods to better comprehend and reduce the environmental impacts associated with products and services. Life Cycle Assessment is one technique that emerged and developed in the 1990's but as every method it is under constant development. There is no exclusive method for conducing LCA studies but the International Organization for Standardization, ISO, has series addressing LCA and there are several tools to assist in conducting LCAs. The software tool SimaPro 7.0 and the Eco-indicator 99 Method are used in this study. The International Organization for Standardization's Environmental Management – Life Cycle Assessment – Requirements and Guidelines (ISO 14044:2006) is a European standard for environmental management and life cycle assessment in particular. The purpose of the framework, principles, requirements and guidelines is to make both the study and the results accurate and transparent.

According to the International Organization for Standardization's Environmental Management – Life Cycle Assessment – Requirements and Guidelines (ISO 14044:2006) a life cycle assessment should include definition of the goals and the scope of the study, inventory analysis (LCI), impact assessment (LCIA) and interpretation of results. How the four parts relate is illustrated in Figure 2; the two-way arrows showing an LCA is an iterative process.

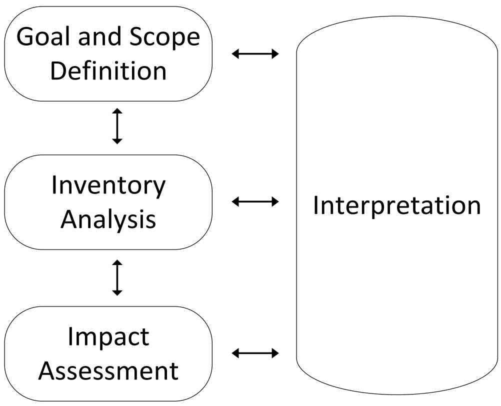

Figure 2. The four main stages of a Life Cycle Assessment based on ISO 14044:2006.

Performing an inventory analysis (LCI) is obtaining data on energy and material inputs, and emissions and wastes caused from processes within the scope of the LCA. The LCI is commonly initiated with a first quick screening study (conducted during a 2-3 days period in this study) to give a hint in what areas of the life cycle to focus later when conducting a more extensive data inventory. Only little data are known as the screening is done therefore estimations are made in all the areas where data has not yet been fetched. Areas which prove to have a large impact in the screening are particularly in focus during the full data inventory.

The impact assessment (LCIA) includes classification and characterization. Classification means assigning the LCI results to selected impact categories which is associating the release of an emission or the use of a resource to an environmental problem (e.g. SO_x contributes to

Acidification). Characterization of the results is converting the LCI results to common units by using assigned numerical damage factors. The impact categories can be aggregated into damage categories. It is grouping the environmental problems, e.g. the Eco-indicator 99 places ecotoxicity and acidification in the Ecosystem Quality category. Thus the number of categories is reduced.

To facilitate interpretation and comparisons between environmental impacts a normalization of the results can be done, giving all results one common unit. The magnitude of the characterization results is put in relation to a known value. It is done by using defined normalization factors. The normalization results may be gathered across impact categories by multiplying each normalized result by an assigned weighting factor (available in impact assessment methods such as Eco-indicator 99). It allows for the results to be added together across the impact categories. If no weighting is undertaken it is impossible to do so because the severity of the environmental impacts from the different categories varies. The weighting factor determines how severe the environmental impact is considered. The factors are value based and thus subjective. Therefore the so called weighting has to be transparent.

The results are interpreted and analyzed as the above steps are performed. Part of this is testing the stability of the final results in a so called sensitivity analysis. In short, it means changing the value of data (drastically increase or decrease it) to see what the effects on the final results are.

(Swedish Standards Institution, 2006)

2.2 SimaPro 7.0

Conducting an LCA using SimaPro begins with defining an assembly in which all materials are included. Once it is completed a process is created that consists of all manufacturing techniques. Transports and utilization is included the same way. A waste scenario is also created. Once the above parts are finished they are connected to make up a life cycle. The results are calculated and presented according to the impact assessment method used. Several methods are applicable in SimaPro 7.1; in this case the Eco-indicator 99 method is chosen.

When using the Eco-indicator 99 method the life cycle is presented graphically as a network, where the weighting of the results have already taken place. The characterization, normalization and weighting can also be viewed separately. Numerical values for all substances that are associated with the assemblies, processes and waste scenarios are documented in inventory lists. Extracts from SimaPro are available in Appendix A.

2.3 Eco-indicator 99; an LCA Method

The environmental impact categories included by the Eco-indicator 99 method are carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels (the only excluded impact category is noise). These impact categories are placed in three so called damage categories. The damage categories are Human Health, Ecosystem Quality and Resources. (PRé a, 2001)

The Eco-indicator 99 is available in three versions; based on egalitarian, individualist and hierarchic views respectively. To be able to compare the severity of various substances being emitted the environmental impact caused by materials and processes have to be ranked. This has been done by an interest panel ranking the damage categories. The result of the LCA depends on which version is chosen. (PRé b, 2000) The main differences between the three perspectives are shown in Table 1.

Table 1. Overview of what signifies the different environmental perspectives of the Eco-indicator 99 method. (PRé c, 2009)

	PERSPECTIVE Time View	Manageability	Level of Evidence
Individualist	Short time	Technology can avoid many problems	Only proven effects
Hierarchist	Balance between short and long term	Proper policy can avoid many problems	Inclusion based on consensus
Egalitarian	Very long term	Problems can lead to catastrophe	All possible effects

The individualist relies on technology to solve the issues instead, and only the proven effects are considered. The hierarchical version includes facts with scientific and political rooting. This perspective excludes damages which they believe may be avoided by proper management. The egalitarian however include all possible effects on the environment and assumes all problems could lead to disaster. The view chosen affects the damage factors and thus the characterization and normalization. It also defines the weighting of the normalization results. (PRé b, 2000)

2.4 Incorporating LCA in the Organization

A significant challenge in incorporating LCA in the organization lies in conducting simplified (sometimes referred to as "streamlined") LCAs, requiring less effort and time. On average it takes less than a year for Axis to launch a new camera model (Fransson, 2009); the pace is made possible due to quick decision-making. Hence, it is crucial the LCA assists in making efficient and reliable decisions relatively quick. Three identified factors for effective implementation are (Rebitzer et al, 2003 p.714):

- Clear internal tools for conducting LCAs.
- Ideally, an organization has its own data inventories for processes and products, in addition to external databases.
- Standards on how, to whom, when to apply LCA.

Moreover, adding LCT in product development processes is a supplement to actual LCAs which are commonly used on finalized products although they may be conducted during the development process to compare alternative choices. (Rebitzer et al, 2003 p.714)

2.5 Limitations of LCA

The most commonly mentioned or discussed limitations with LCA are summarized below. Analyzing a complete life cycle of a product or service requires a holistic approach wherefore it has to include assumptions and simplifications. Hence the results come out in broad terms; consequently making it difficult to extinguish what the local and regional environmental effects are. Moreover, LCAs are generally conducted based on linear effect calculations, which is mostly untrue for the environment. Another limitation with LCAs is that economic and social aspects are not included. (Guinée, 2002)

The time aspect is a limitation in more than one way when it comes to life cycle assessments. Data have to be renewed and the LCAs have to be updated; and the environmental effects are not specified in time (therefore commonly referred to as "potential impacts") (Swedish Standards Institution, 2006). The latter is also due to the commonly subjective choice of a functional unit. Only results from LCAs based on the same functional unit and scope may be compared which limits the use of LCAs. It aims to be a scientific tool but undeniably involves technical and value based assumptions and simplifications.

Obtaining new, high quality and comparable data are often times complicated. The data are also often accessed in blocks, as summed up processes, for instance "general aluminum production" which makes the LCA deviate from the intention to be product specific. (PRé d, 2000)

2.6 Network Camera Surveillance

Network cameras may not always be placed visible but they are a frequent topic of discussion due to their well-known spread and rapid increase in number. The U.K. has an estimated 1 camera per each 14 people (BBC, 2009) and the Chicago Mayor Daley stated that Chicago will have a surveillance camera on every street corner by the year of 2016 (Spielman, 2009). These are just two examples indicating the relevance of investigating the environmental consequences of an increased use of surveillance cameras in society at large, regardless of the intended purpose of installation.

Reflecting briefly, in one aspect digital surveillance becomes more environmentally sound than using analogue technique in requiring less cable and allowing for the cameras to be monitored at a distance (so called remote access). This report, though, does not cover such a valuation. Only a few official LCAs of network cameras have been conducted, major part of them performed at Panasonic Communications in Japan (JEMAI a, 2009). The results of their three most recent LCAs will be compared to the results of this one.

2.7 Camera Features

The AXIS Q6032-E PTZ Dome Network Camera E, see Figure 3, is designed for outdoor video surveillance in extreme temperatures day and night (may power up at -40 °C and operate in the range from -40 °C to 50 °C). PTZ stands for Pan Tilt Zoom; three features which may be used manually or in the auto-tracking function where the camera automatically detects and follow a moving object within the field of view. The AXIS Q6032-E is almost square in its dimensions, 232 times 235 millimeter. The disassembling resulted in 53 parts, not counting 96 screws and subcomponents of the 8 various sized PCBAs.

Figure 3. The network camera AXIS Q6032-E. (Axis Communications AB a, 2010)

There are several features which distinguish it from many other cameras. Night vision, high zoom, wide pan and tilt range, temperature endurance, remote access, and high security with multi-level password and HTTPS encryption are some characteristics of this camera. It is powered through High Power over Ethernet (PoE is a system to transfer electrical power, along with data, to remote devices over standard cable in an Ethernet network). See reference for more specifications. (Axis Communications AB b, 2009)

2.8 Camera Structure

This section gives an overview of the camera structure. The camera consists of three main assemblies: a so called unit assembly, an outer chassis assembly and a dome module assembly, see Figure 4.

Figure 4. Unit Assembly, Outer Chassis Assembly and Dome Module Assembly.

The *unit assembly* is built up of the actual camera with a cover, a pan-tilt mechanism with bracket, see Figure 5, and a larger PCBA (the camera contains two additional PCBAs) and a belonging bracket.

Figure 5. The pan-tilt mechanism within Unit assembly.

The *outer chassis assembly* contains an outer housing and an inner chassis which holds two PCBAs, a heat module and a fan module which in turn contain two smaller PCBAs.

The *dome module assembly* mainly consists of a clear dome, a cover ring and a sealing ring, and a bracket.

Obviously all three assemblies contain numerous screws, cables, smaller sealings and brackets, wire springs, tape, hooks and other units and solutions for connecting and holding together the components and the assemblies. Pictures of each assembly and all the included parts cannot be disclosed for confidentiality reasons. All components of the camera are considered in the LCA but for confidentiality reasons the exact design and structure of the camera cannot be disclosed.

The material composition of the camera is summarized in the life cycle inventory, LCI, and may be found in section 4.1 Raw Material Extraction and Processing.

3. GOAL AND SCOPE

Detailed descriptions of the goal and the scope of the case study LCA follow below. The goal specifies the application and purpose of the LCA, and the intended audience. The following tasks are part of the determining the scope: setting system boundaries and deciding upon delimitations, defining the so called functional unit, solving allocation problems, stating data quality requirements, determining what methods to use, and summarizing assumptions and simplifications which are to be made.

3.1 Goal

The goal of the study is summarized below stating the intended application of the LCA and the reasons for carrying it out, and also to whom the results are meant to be communicated. This LCA is of the so called stand-alone type. A stand-alone LCA is used to explore and describe a single product to become familiar with its important environmental effects and identify environmentally critical stages in its life cycle (Baumann & Tillman, 2004).

This study serves to increase Axis's knowledge on the environmental impact of the Axis developed and produced AXIS Q6032-E Network Camera and identify which phases in the life cycle of an AXIS Q6032-E Network Camera that have the highest environmental impact. Only a few official LCAs of network cameras have been conducted, major part of them performed in Japan (JEMAI a, 2009). A direct comparison to the results of this LCA is not possible since the LCA framework differences are too wide, but a rough comparison while considering the differences will be done.

The objectives of this study are to:

- Increase Axis's knowledge of the environmental impact of the Axis developed and produced AXIS Q6032-E Network Camera by conducting a life cycle assessment (LCA).
- Identify which phases in the life cycle of an AXIS Q6032-E Network Camera that have the highest environment impact.
- Allow for Axis to use the result in customer communication.

The study is intended for internal use. However, in case an expert reviews the study, the results may be communicated in an external context as an ISO-certified LCA. If not certified, the results may anyhow be handed out to customers upon request although with caution to its reliability. It may be emphasized that the environmental performance of a network camera is most likely not a critical aspect in a customer’s choice of cameras for surveillance; security comes first. Therefore the result of this LCA is not intended for marketing purposes, but may be shared if the results are communicated in a transparent manner.

3.2 System Boundaries and Delimitations

The product system studied is the Axis developed and manufactured video network camera AXIS Q6032-E. The life cycle assessment is of cradle-to-grave type; environmental impacts in defined categories from life stages ranging from raw material extraction to decommissioning are included in the study. The scope of the camera’s life cycle is determined by a predefined scenario from raw material extraction till decommissioning; hence both upstream and downstream material and energy flows are included. Upstream flows refer to all flows occurring up until “exploitation” of the finalized product under study (Lewandowska & Foltynowiczz, 2004). The life cycle is modeled in five categories; raw material extraction and processing, manufacturing and assembling, transportation, utilization and decommissioning. The boundaries of each category are described in the Life cycle inventory, LCI, section 4. The following general system boundaries and delimitations apply to the life cycle as a whole:

- Additional accessories available for the AXIS Q6032-E will not be included in the LCA, except the weight of the additional standard items included in the sales unit that is sent to distributors (one extra dome, fixture, etc.).
- Geographical: Running business on all continents, Axis is literally a world-wide company and geographical boundaries of Axis's products are extensive, including the AXIS Q6032-E. In the expected life scenario of this camera the suppliers, manufacturers and customers will be located in North America, Asia (Central and Northern) and Europe. Geographically suitable data are chosen in the SimaPro data libraries whenever possible.
- Physical: Nature makes up a physical boundary; emissions to air, soil and water from all life stages are included. When predefined data are used infrastructure, land use and capital goods are included with only a few exceptions. Personnel, accidents and occasional scenarios, though, are consistently excluded in this study.
- Temporal: The camera is estimated to remain in use for 10 years (Fransson, 2009). The LCIA is performed with a short to medium time perspective (view section 2.3 for explanation).

The process flow chart, Figure 7, below illustrates the scope of the LCA. This LCA is of the cradle-to-grave type, it begins with raw material extraction and processing, followed by manufacturing and assembling, utilization, and decommissioning. All transportations taking place during these life stages are added together into one category.

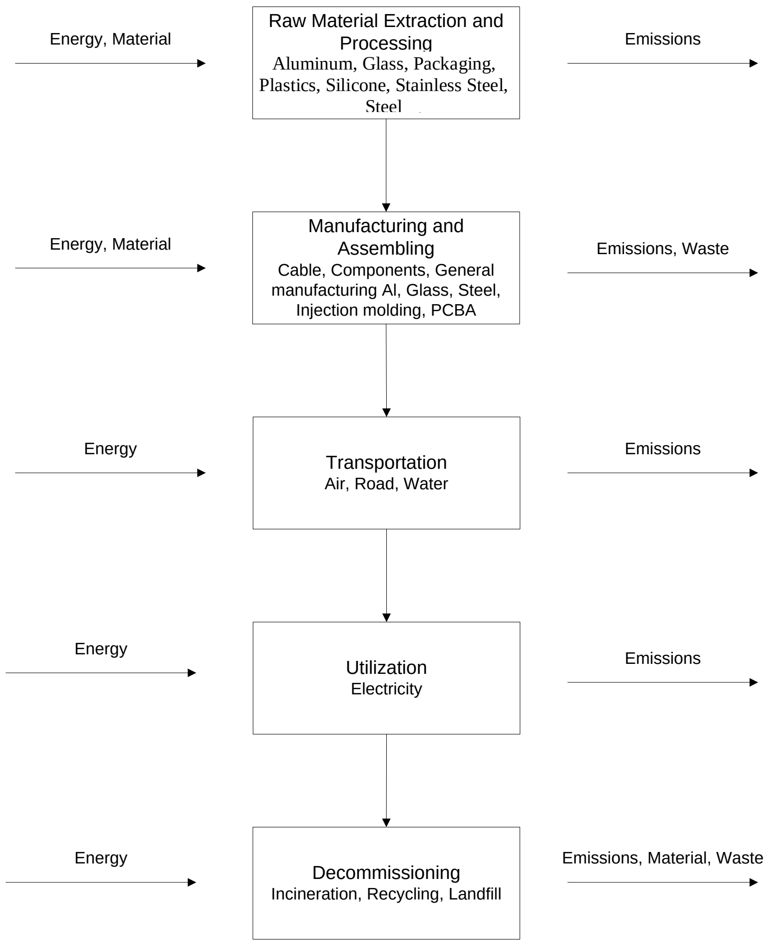

Figure 7. Process flow chart illustrating the scope of the LCA based on the defined life cycle categories.

The process flowchart in Figure 7 is simplified. Due to the great number of product components one single flow chart is not created. Instead, detailed flow charts were drawn for each category while conducting the LCA (obviously connected to each other). The above flowchart summarizes them roughly. The phrase 'Life cycle *category*' is used instead of for instance 'Life cycle *stage*' because transportations take place at all stages, but to facilitate the work of conducting the LCA all transportations are collected into one category.

3.3 Function and Functional Unit

The functional unit quantifies the performance of the camera and includes the efficiency. The camera serves to survey an area for various purposes; the function of the camera is surveillance. The functional unit is set to an area of 14,000 m^2 under constant surveillance. The camera is allowed to move (spin and tilt) wherefore parts of an area may be unsupervised for a limited period of time, one minute maximum. One minute is motivated by the camera's angle vision. At a 55.8 degree vision the camera needs to move approximately 3 times to supervise in approximately a 180 degree range (slightly less). Assuming the camera remains still in one spot for approximately 20 seconds and sweeps back and forth (without skipping a section) it leaves an area unsupervised for 20 seconds × 3 times, hence 60 seconds.

The area is set to 14,000 m^2 based on calculations. This camera is capable of reading license plates from a distance of 160 m (Axis Communications AB b, 2009). Setting the limit to 100 m allows for comparisons between other less advanced cameras. The angle of vision is 55.8 degrees. Consequently the area covered in one view is 486 m^2, according to Equation 1.

$$A = \frac{\theta}{2} r^2 = \frac{55.8 \times \frac{\pi}{180}}{2} \times 100^2 = 4869 \text{ m}^2 \qquad [1]$$

This figure has to be multiplied with the defined number of times the camera moves which is 3. Thus the camera covers an area of approximately 14,000 m^2, see Figure 6.

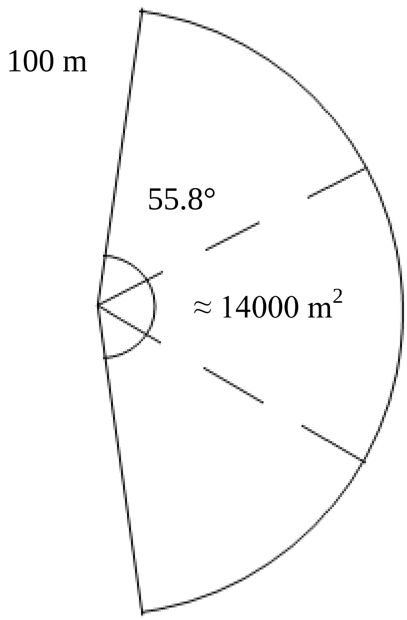

Figure 6. Illustration of the functional unit area.

The single functional quality standard is a video image resolution of no less than 640 × 480 pixels (Axis Communications AB c, 2009). There are an endless number of possible functional quality standards, but the difficulties in comparing cameras become greater as the number of standards increase. Though with only one functionality standard it has to be pointed out that the environmental impact has to be put in relation to the performance of the camera. A camera with night vision, high temperature endurance, high number of covered frames per second, excellent zoom (optical or digital), pan and tilt range and other advanced characteristics require higher power supply and more electricity both when being produced and while in use. This aspect can only be considered by making a non-scientific evaluation by the person viewing the result of the LCA. A positive aspect of not having a narrow functional unit is that it allows for interesting comparisons. For instance, if neglecting the quality standards the camera could be replaced by a number of guards walking the area.

The commercial service lifetime of the camera is estimated to 10 years although significant variations will occur depending on the modernity of the design. Until its design has aged and reveals it is inactive cameras commonly remain installed after their active phase because they give the impression of surveying the area and consequently provide the service of security even if only passively functioning. Since it does no longer fulfill the requirements defined in the functional unit, though, the commercial service lifetime of 10 years is used in the study. However it should be mentioned that a prolonged life time, probably even if passive, lowers the environmental impact since fewer cameras would have to be produced.

Thus to be able to fulfill the functional unit, surveying an area of 14,000 m^2 for 10 years, a camera is produced. It requires a certain amount of material to be extracted. The materials then have to be processed, manufactured and assembled into a camera. Components, assemblies and eventually also the camera itself have to be transported several distances. To fulfill the functional unit the camera will need electricity. When the camera no longer serves its purpose it has to be decommissioned. All these activities affect the environment and have to be considered in the LCA.

3.4 Data Quality and Data Quality Requirements

For the life cycle inventory it was decided to collect as complete, accurate and recent data as possible. The collection is a combination of predefined values from databases, supplier information, internal documents, industry specific information (e.g. El-kretsen, Chemtura and International Energy Agency), and in rare cases (e.g. data gaps) qualified assumptions. A total of 10 weeks was spent on data collection.

Data from multiple sources have consistently been compared to see variances and assure preciseness of the data chosen. When choosing data sources the age of the data (year), the location of compilation (region) and technological relevance (process) has been considered. A list of all data sources and their specifications is available in Appendix C, Data Sources. All camera components are consistently included in all stages of the LCA which give completeness; all material flows in raw material extraction and processing, product manufacturing and assembling, transportations throughout the life cycle, utilization and decommissioning are counted for. View the LCI, section 4, for more data specifications on each one of these categories.

The representativeness (technology wise, temporal, and geographically) of the data is evaluated. In cases of well-known recent improvements in technology, such as for transportation fuels and energy composition for electricity production, new data is a required. Whereas for raw material extraction and processing database values are older because there have been none, or only minor, upgrading of technology in that area. Therefore, as an exception, older data have been accepted. Moreover, for raw material extraction and processing figures for Europe are used because of a lack of data for Asia. Elsewhere, for the other life stages, the age of the data is pleasing, frequently collected between the years 2000 to 2007 and estimated to be accurate still.

Information received from suppliers and manufacturers is proprietary information, thus inevitably reducing the reproducibility of the study. It also comes with uncertainties since the data is not easily verified. Where the uncertainty is considered significant, the effects on the results are tested in a sensitivity analysis (Section 6.7).

3.5 Method for Inventory and Interpretation (LCI and LCIA)

First step of the inventory, LCI, is disassembling the camera and reading product specification sheets to identify materials and manufacturing techniques used to produce the components and units of the product. The materials and techniques are grouped and generalized. Data for general processes and materials come from databases in SimaPro. Other information is obtained from supplier visits and meetings, by handing out questionnaires, Appendix D, to suppliers and manufacturers, and Axis's data base for product specifications and material declarations (the Camel). Some data have been used to calculate factors to include general material waste in production, packaging material and extra weight during transportation.

A process flow chart is iteratively constructed during the inventory process to define the system boundaries of the LCA. The life categories are determined and modeled. A higher quality of data is required for the stages assumed to have significant impact on the results.

The classification, characterization, normalization and weighting of the LCIA are carried out using the Eco-indicator 99 method, because it is widely accepted in Europe. It is available in three versions; based on egalitarian, individualist and hierarchic views respectively. The standard method of impact assessment Eco-indicator 99 H/A is chosen. Axis agreed to use the standard method where H stands for Hierarchic and A for Average - using the average weighting set. The average view is signified by a rating of concern for human health and ecosystem quality to 40% each and resources to 20%. For details on the Eco-indicator 99 method view section 2.3.

3.6 Assumptions and Simplifications

Making assumptions and simplifications is inevitable when modeling the life cycle of a product in the LCI. Below follows what the major assumptions and simplifications of this particular LCA. In the raw material and processing category all materials are placed in a few groups, the most common materials and materials expected to have an impact on the environment constitute groups. In the manufacturing and assembling category the same type of simplification is made though with the most common manufacturing techniques. In case of unspecified manufacturing technique the type has been assumed based on qualified assumptions by the authors. The assembling is based on information gained from one supplier visit, and the results are applied for the assembling of all other camera units. The transportation category includes estimations of distances and for the utilization category a user pattern is estimated. The decommissioning of the camera is assumed to be ideal. A sensitivity analysis (Section 6.7) is carried out to measure the effects from the assumptions and simplifications made. Allocation is done according to weight. This type of allocation is used in section 4.3 when calculating transportation weights for example.

3.7 Presenting the Results and Critical Review

This report presents the results of the LCA and the simplified LCA method and the platform. There are two versions of the report, one official, the other one internal because of confidentiality reasons. The internal report is more extensive. Both are reviewed by Anna Hedlund Åström at the Department of Machine Design at the Royal Institute of Technology (KTH), Stockholm, Sweden. The LCA and report comply with the ISO Standards but is not peer reviewed for accreditation.

4. LIFE CYCLE INVENTORY, LCI

The life cycle inventory is divided into five categories: raw material extraction and processing, manufacturing and assembling, transportation, utilization, and decommissioning. A scenario is created for each category. The LCI below specifies where and how the data have been gathered. A summary of the data sources is available in Appendix C.

A screening was conducted on beforehand to identify areas of the actual LCA likely to be important. Most data are not yet fetched at the time of the screening; wherefore plenty of assumptions are made. Roughly, the screening only includes general data from common databases. It shows that the major part of the environmental impact is a result of the utilization. The effects on the results from both raw material extraction and processing and manufacturing are relatively minor, and transportation (except air transports) contribute even less. The impact from the decommissioning is negative, which means it has a positive effect on the environment. The categories besides utilization are nevertheless neglected. Regardless of category detailed data are fetched wherever data uncertainties occur, which is frequently. The case is the same whenever the potential magnitude of the impact is unknown because of data gaps. This is the case of the PCBA manufacturing and assembling where no general data exist in the common databases.

4.1 Raw Material Extraction and Processing

Nearly all material data are collected and summarized from material declarations from the Axis inside database “the Camel”. Material declarations for the camera module and the pan-tilt mechanism were not at hand though, and no further information was available from the suppliers. In these two cases the type of materials included have been determined after disassembling of the components and looking at the material characteristics of the subcomponents. Then the most similar material data, composition wise and geographically, is selected from the databases available in SimaPro (documented in Appendix C, Data Sources, Table 18). The environmental effects from the raw material extraction and processing of the materials (e.g. ingots) are included; the end-life treatment and disposal of the extracted materials are included in the decommissioning category.

All materials are categorized and grouped, with the exception of PCBAs and cables. The PCBA is included in the manufacturing category where complete cradle-to-gate (in this case from raw material extraction to manufacturing) data for PCBAs from SimaPro are used. Consequently the extraction of the PCBA materials is counted for although the PCBA is not directly included in the Raw material extraction and processing category. The case is the same with the cables.

The groups are Metals, Plastics (types are confidential), PCBA and Others. In turn Metals include aluminum alloy, steel and stainless steel and Others include cable, glass and silicone. Figure 8 shows the weight distribution among the groups in percentage (a letter-scale showing the weight in grams was used for weighing, see Appendix C for an exact weight allocation).

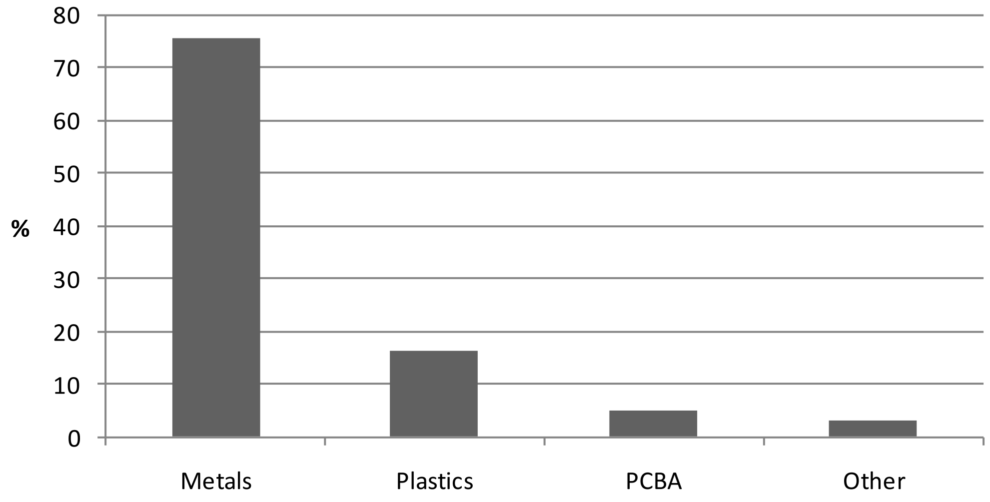

Figure 8. Weight distribution among the material groups in percentage.

4.1.1 Material Efficiency

There is always a loss of material during manufacturing. The material waste had also to be extracted which is calculated for in this LCA. The material efficiency expressed in a numerical value - the actual material output divided by the material input - will always be less than 1. The additional material needed for manufacturing has to be included in raw material extraction and processing and transportation to manufacturers since that extra material also has to be extracted and processed. The factor is 1.02 for steel, 1.10 for aluminum and 1.05 for plastics. The factors are based on supplier information (name is confidential) on annual material input and waste and calculated using Equation 2.

$$Waste\ factor = \frac{Annual\ \ input}{Annual\ \ waste} \qquad [2]$$

4.1.2 Packaging Material

Packaging materials such as cardboard, plastics etcetera for the three main sub-assemblies and the sales unit is included in the life cycle although they are not part of the actual product. These additional materials are included in the raw material extraction and processing category, the transportation category and the decommissioning category. Data on packaging materials are collected at a contract manufacturer (name is confidential) and CLC1 (located in Lund, Sweden) to cover incoming units, the three sub-assemblies, and the outgoing sales unit. Packaging material for other components is neglected in the study because the components are not as carefully wrapped; hence the weight of the packaging material in relation to component weights is insignificant (e.g. hundreds of screws are simply transported in a box or bag). Also, the plan is to start reutilizing packaging material for components in the supplier chain such as refilling boxes and reusing plastic wrapping which justifies neglecting smaller components. The data used are of the ‘cradle-to-gate’ type which means cellulose extraction and manufacturing of cardboard for instance is included.

4.2 Manufacturing and Assembling

Data from suppliers is not always sufficient to give comprehensive results regarding the manufacturing and assembling. Therefore the information obtained at manufacturers and suppliers has been used as a supplement to the predefined general data in SimaPro to create a manufacturing category which includes assembling. Data from the SimaPro libraries (the specific databases are documented in Appendix C, Data Sources, Table 19) are used as a base and modified when there is accessible information from suppliers.

An in-depth study of the manufacturing and assembling at a contracted manufacturer was conducted to avoid data gaps although it's minor contribution to the whole; the assembling of subparts solemnly constitute low energy consuming screwdrivers and heat durability testing. The exception is the PCBA assembling (from PCB to PCBA) which is a complex process and it has therefore been handled separately. Although all data are collected at a manufacturer located in Poland the data are assumed to represent the environmental impact at other manufacturers' as well. Unless stated otherwise the data in this section are based on the study at this particular PCBA manufacturer. Manufacturing and assembling sites are located in Malaysia, China, Singapore, Thailand, Japan, Poland, U.K. (United Kingdom), and Sweden. Whenever possible the geographical location has been considered when choosing general data, although not accomplished in a completely satisfying way as stated in section 3.4 Data Quality and Data Quality Requirements.

Camera units manufactured with the same or similar techniques are added together. The manufacturing techniques used are general casting of aluminum; general steel manufacturing; general glass manufacturing; general manufacturing of cables and the printed circuit boards and their subcomponents, and injection molding of plastics and silicone. When type of manufacturing is specified in SimaPro, capital goods are included unless stated otherwise. For detailed summary of the manufacturing data used view Appendix C, Data Sources, Table 19. The material waste from manufacturing is considered. Factors for the additional material needed for manufacturing of steel, aluminum and plastics are calculated, see section 4.1.1 Material Efficiency.

All the assembling, except for that of the PCBA, is done manually with electric screwdrivers. The power supply for the typical screwdriver is 24 W. The total number of screws in the camera is counted to 94. Fastening of one screw is estimated to take 1 second. Based on these figures the total energy consumption is 0.627 Wh. An energy consuming task of the assembling is the so called "burn-in" (of the Unit Assembly) where temperature testing of the cameras takes place at a temperature of 44.5 ± 2 °C. The power supply needed to keep the room at constant temperature is 6 kW. An average 80 cameras are in the room during the 4 to 6 hours of testing. During the time of testing a camera moves constantly and thereby demand a power supply of around 47W. The energy needed for 5 hours of burn-in is 0.615 kWh. There are no emissions associated with the assembling. For detailed summary of the assembling data used view Appendix C Data Sources, Table 19. The total amount of energy used in the assembling is thus 1.242 kWh.

For the manufacturing of PCBA components general data have been used. For details view Appendix C, Data Sources, Table 19. The sensitive PCBA components not mounted immediately onto a printed board are stored in a so called climate chamber, cooled by nitrogen. Amount of energy required is small, it is a closed system, and hence the gas is doing the work. Moreover, only very few components have to be stored in the chamber and the climate chamber is therefore neglected in the study.

So called surface mounting technique, SMT, is used for the mounting of components on the printed board. The parts are glued and covered by solder paste to remain in place; the amount of glue and solder paste is not large enough to affect the results and are therefore excluded in the study. The components are mounted to the board at a speed of 24 000 components per hour. There are around 525 components on this specific PCBA (according to the Axis inside tool the Camel) and the time needed is approximately 1.3 minutes. The energy required for this process is 5 kW. An energy consuming part of the procedure is the soldering process consisting of heating and cooling of the board when the components are put in place with glue and paste. The PCBs is heated from room temperature to 275°C and then cooled down to 40°C. This process requires a power supply of 50 kW and takes around 7 minutes for a frame existing of 4 PCBAs. The PCBAs are tested for dysfunctions automatically and manually (visually) and if encountered the PCBAs are repaired, not disposed. The automatic testing is an X-ray requiring a significant amount of power to run the testing, 4.2 kW. Testing one frame (qty 4) takes approximately 6 minutes. The energy required for the manual use of soldering pens for fixation of 24 spots on each printed board is calculated for; it requires 95 W and runs for an estimated one minute for each printed board. The total energy consumed during the PCBA assembling calculated with the figures above is 1.67 kWh.

The emissions caused from the assembling of one PCBA is calculated to be 3.13E-04 kg acetone and 2.1E-03 kg isopropanol. The figures come from internal emission documents compiled by the supplier/manufacturer in 2005 (confidential material). The documents include the emissions from the different manufacturing and assembling activities. Emissions are included in the manufacturing and assembling of the PCBA. A summary of the releases from 1 kg PCBA is available in Appendix C Data Sources, Table 19.

4.3 Transportation

Transportation occurs in between the life cycle stages but here they are put into one category to facilitate interpretation of the environmental impact from all transportation associated with the life cycle of the camera. The transportation category is separated into inbound and outbound transportation. Inbound is defined as the sum of all the transportations taking place before reaching CLC1 (Lund, Sweden) and outbound are all the transportations occurring after leaving CLC1. At Axis the responsibility for inbound and outbound transportation respectively lie on different departments, hence the subdivision into inbound and outbound will allow for quicker improvements since the results may be communicated directly to the department in control. All transportations connected to this specific camera are included in the study. Transportations are defined by distance, weight (expressed in tkm) and means of transportation.

The further from Axis you go the more complicated it gets to receive acceptable transportation data; also the routes become less certain, e.g. customer locations vary significantly in contrast to contract manufacturers. When difficult to define exact distances, means of transportation, or in case of great variations the transportation data have been estimated. The weight, though, is specified for all transports.

The transportations in chronological order begin with the material being transported from extraction to processing and further on to component manufacturer are estimated to be done by road by an average distance of 1500 km each. It equals approximately 15-20 hours of driving and it is natural to assume these distances should take less than 24 hours to cover because the of the convenience of locating the processing and basic component manufacturing rather close to the extraction site.
As for the transportation of components they are transported to the assembling where all transportation of components heavier than 100 *g*, or where the same manufacturer supply components with a total weight of 100 g or heavier, are mapped. Transportation of smaller components is estimated to be by road and by an average distance of 6845 km; the average of all calculated transportations.

From the assembling in Malaysia the parts are transported by air to CLC1 (Lund, Sweden). The assembly from Poland is transported by truck to Sweden. The sales unit is shipped from CLC1 to the U.S and Germany which are the main countries for export (measured in number of Axis cameras, all categories, exported). The sales units going to the main distributor in the U.S. (name is confidential) passes CLC4 (Atlanta, Georgia) on its way, whereas sales units leaving CLC1 for Germany is sent directly to the biggest distributor (name is confidential), located in Straubing. To the U.S. sales units are sent by plane, whereas to Germany they are transported by road. Sales units to customers are estimated to be sent by road in both cases, though the distance is set to 200 km in the U.S. and in Germany. To the final stage, the decommissioning, the distance is set to 30 km by road. A summary of the total transportation distances by road and air respectively are shown in Table 2. A detailed summary of all transportations is available in Appendix E. Google Maps is used to measure the distances.

Table 2. Total transportation distances by road and air (based on information specified in Appendix E).

Means of transportation	tkm	
	EU	U.S.
Air	-	58,99
Road	25,64	23,72
Water	78,95	78,95

The data for each type of transportation is fetched from a general database (for details view Appendix C, Data Sources, Table 20). The estimations made regarding transportation of materials, components, sales unit to customer and sales unit to place of decommissioning are satisfying.

In the initial stage of a product release a very small percentage (confidential information) of all cameras received by customers are sent back to CLC1 for reparations due to defects. The number is usually also drastically dropping to an even smaller percentage range once the product has been on the market for some time. Therefore the rare case of a camera being sent on a detour is not calculated for.

A factor is calculated to be multiplied with the weights of the components, units and assemblies to get their total transportation weight inbound; hence including packaging material and pallets. The factor is calculated from data obtained at a contract manufacturer (name is confidential) and at CLC1 (Lund, Sweden) where all packaging material and the belonging pallet (for transportation either by truck, plane or boat) were weighed. The factor is 1.2 for inbound transportations of components to assembling. It is 1.3 for assemblies going to CLC1. To include materials to component manufacturers a factor of 1.1 is estimated. The underlying calculations are visible in Appendix F.

No factor is calculated for outbound transportation; transportation of the sales unit. Instead the sales unit's exact weight is measured including packaging material (7.2 kg), only the pallet remains and it is added (weight according to Equation 3). The total weight of the sales unit in transportation is 8 kg.

$$Weight\ of Pallet\ per\ Sales\ unit = \frac{Weight\ of\ Pallet}{Number\ \ of\ Sales\ unit\ \ on\ a\ Pallet} = \frac{9.6}{12} = 0.8\ kg \qquad [3]$$

4.4 Utilization

The lifetime is set to 10 years. Maintenance is too rare during a camera's commercial service lifetime and is not included in the utilization category. A local repairer may fix slight errors and only in case of severe damage is the camera returned for reparation at CLC1 (Lund, Sweden).

Due to an extremely small number of cameras being sent back (the percentage is confidential information) such a rare case is not considered.

Using the maximum power supply values that are specified in the camera's technical data sheets is not accurate when modeling the utilization category. It is unrealistic in a common user scenario that the camera on an average basis should require 50 W power supply. Instead the electricity demand for a camera in the utilization category is estimated based on test results (documents are confidential). Required power input at two differently defined power consumption modes are measured: a highly active mode (21 W) and an idle mode (12.5 W). In the highly active mode the camera pans, tilts and zooms intensely, whereas in the idle mode it remains still. The time during which an average camera is used in a highly active mode and an idle mode is estimated to 4% and 96% respectively. (Fransson, 2009) Approximately 75% of customers will be using the camera in a guard tour scenario, meaning that it will be constantly rotating through presets. The other 25% will use it in an operator controlled environment in which they are actively monitoring the video and moving the camera manually (Gregory, 2009). These facts support using test values, since the 75% could be predicted to use the scenario created here (the 25% is more uncertain). According to the above specified conditions the average energy consumption equals 12.65 W, pursuant to Equation 4.

$$Average\ Energy\ Consumption = 0{,}04 \times 21\ W + 0{,}96 \times 12{,}3\ W = 12{,}65\ W \qquad [4]$$

A lifetime of 10 years equals 87600 hours. The total energy consumption in the user phase is approximately 1108 kWh, pursuant to Equation 5.

$$Total\ Energy\ Consumption = 12{,}65\ W \times 87600\ h = 1108\ kWh \qquad [5]$$

Two different scenarios are studied; the camera running on electricity produced from the average U.S. energy composition and the typical European energy composition. One scenario for a camera being installed somewhere in the E.U., and another in the U.S. General data for electricity production (include generation and distribution) from a SimaPro database are used. The data is country specific. The U.S. data is recently updated, though the data for Europe altogether is not. Therefore general data for each European country is used and added together; the larger the population the higher the contribution.

A limitation with SimaPro is that it does not reveal the energy composition for electricity production it is counting with. An option is finding information on the average energy composition for electricity production in Europe and the U.S. elsewhere and then using SimaPro data for each identified energy source. The general data for specific energy sources are aged though and therefore country specific data which are more recently updated is used instead.

To better comprehend the results from the electricity production charts showing the European and the U.S. energy compositions for electricity production are fetched from the International Energy Agency and the Energy Information Administration respectively (see below). The distributions among energy sources should satisfyingly correspond to the distributions SimaPro is counting with since the European chart figures are from 2006 which is close enough to be accurate (no appropriate sources provided information for 2004). The U.S. figures are from the same year as the data values, 2004. By doing this the results of the utilization category for Europe and the U.S. respectively could later be compared; the impact from a camera in the U.S. should be greater due to the significant share of coal used for electricity production etcetera. The charts will be used in interpreting the results of the LCA in the utilization category.

It should be noted that the technological advancements and the practical implementation of new technologies for electricity production in recent years is not included since the data are from 2004. A comprehensive update of this type of extensive data is difficult to perform frequently which explains the lack of new data.

European Union

SimaPro provides country specific data on electricity production, called “country mix”. In this case it is necessary the data of several European countries are added together. Each country cannot contribute with the same share. The approach is that the percentage share of an electricity country mix to the total European mix is proportional to how many percent of the European population that the country’s population constitutes. Germany constitutes 17.3% of the total European population, wherefore the Germany’s electricity country mix has contributed with the same percentage to the total European mix. The share is naturally bigger than that of Sweden for example. The population shares for each country are given by Regeringskansliet (Government Offices of Sweden, 2006). A few countries are not considered due to a lack of general electricity production data in SimaPro. The countries included are listed in Appendix C, Data Sources, Table 21).

The average European energy composition for electricity production is provided by the International Energy Agency, IEA (figures are from 2006), see Figure 9. Coal and nuclear are used nearly to the same extent; 31% and 30% respectively. Gas stands for 21% of the total Watt-hours produced (approximately the same amount as consumed; insignificant amounts is exported) per year in Europe. Out of the renewables hydropower makes up for 10%, whereas biomass and wind each contribute with 2% each.

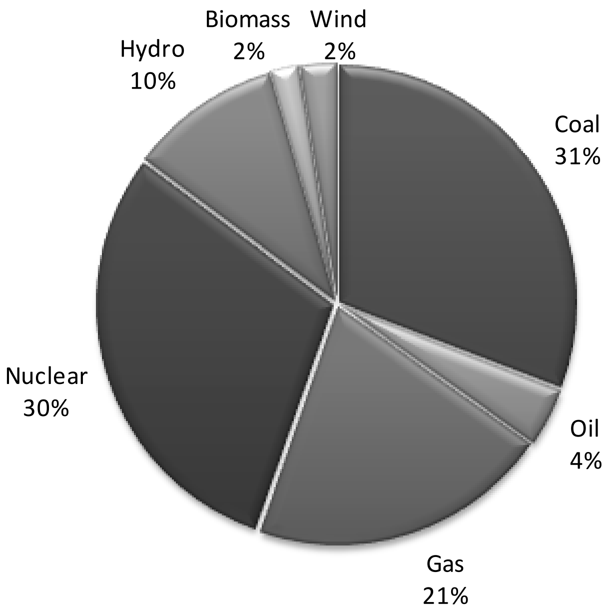

Figure 9. Average energy source composition for electricity production in the EU.

U.S.

The percentage distribution among energy sources for electricity production comes from official energy statistics, the U.S. Government (Energy Information Administration, 2009). The figures are from 2004, see Figure 10. Coal produce 50% of the total Watt-hours of electricity consumed in the U.S. each year. Gas makes up for 18% and includes both gas derived from fossil fuels and natural gas. The share of nuclear is 20%. Hydroelectric stands for 7% of the total, oil for 3%, and renewables for 2%. Other energy sources (e.g. municipal solid waste) are not included due to their small cut.

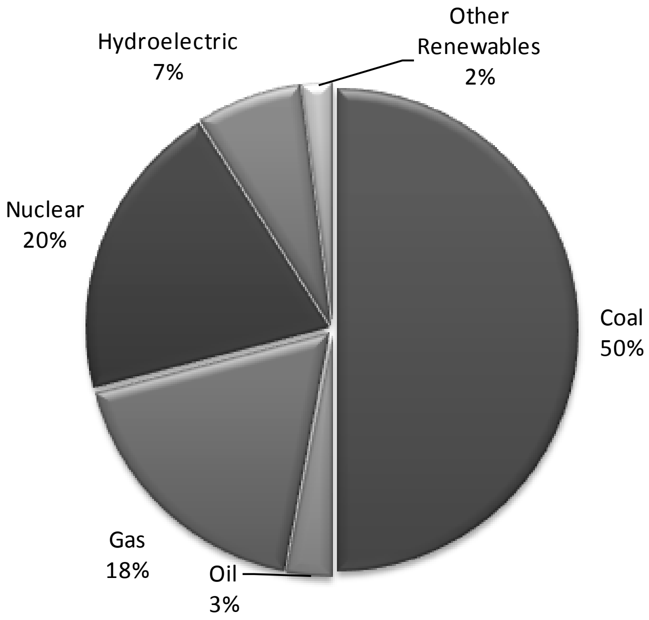

Figure 10. Energy source composition for electricity production in the U.S.

4.5 Decommissioning

The decommissioning of the camera refers to the end-of-life treatment and disposal of the camera. It is modeled according to Swedish standards using El-Kretsen[1]. Axis is a member of El-Kretsen and therefore the disposal scenario of this specific camera may be defined according to Swedish legislation and guidelines stated by El-Kretsen (El-Kretsen a, 2009). The camera is disassembled automatically (grinder) and manually. First, parts containing hazardous waste, such as PCBAs, are separated by hand for special treatment. The bulkier components of the PCBA are removed; the board is melted and its precious metals are recycled, e.g. the gold. The motors in the pan-tilt mechanism are not separated and pass through a grinder. The grinder separates parts by using magnetism and differences in density. Aluminum, copper, steel and stainless steel are melted down to be used again as raw material when there are no hazardous coatings, which there are none of in the camera. The copper content in cables is usually not detected in the grinder and is sorted with plastics, unfortunately lowering the quality of recycled plastics. Plastics are either recycled to be reused in plastic products, or recycled and used to produce energy for running the automatic recycling or for domestic heating. The plastic parts of the network camera are marked with a recycling label indicating they may be recycled. Recycled plastics are frequently used in the automotive industry. (Stockholmsregionens avfallsråd, 2007)

All combustible waste is incinerated and the heat is used for domestic heating or for production of electricity. The exhaustion and pollution is treated. Incombustibles which cannot be recycled are put in landfills. Martin Seger at El-kretsen estimates that about 95 percent of the camera would be recycled or combusted (ashes are placed in landfill), thus only 5% sent to landfill.

[1] Swedish nonprofit organization ensuring discarded electronics is treated according to Swedish law. Since 2005, a producer of electric and electronic products is responsible for the decommissioning of their products put on the market. Members pay an annual fee to El-Kretsen based on the level of treatment required when their products are disposed. (El-kretsen b, 2009)

El-Kretsen is the world leader in recycling electronic products (Martin Seger, El-kretsen) therefore the decommissioning scenario created in this LCA is ideal and not representative in a global perspective. The technology for handling electronic waste will probably have developed, though, before the first AXIS Q6032-E network cameras are decommissioned.

The amount of energy used in the automatic disassembling, grinding and other processes are too small to be taken into account.

5. LIFE CYCLE IMPACT ASSESSMENT, LCIA

This chapter describes how the Life Cycle Impact Assessment (LCIA) of the study is performed according to the Eco-indicator 99 Method. The calculation procedures that are conducted using SimaPro are also described.

Below follows descriptions of how classification, characterization, normalization and weighting of the results are carried out. The Eco-indicator 99 H/A is chosen as impact assessment and interpretation method. The hierarchic perspective (H) is chosen. It affects the damage factors and thereby the results of the characterization and the normalization. Further the average weighting factors (A) are chosen. The average weighting is signified by a rating of concern for Human Health (HH) and Ecosystem Quality (EQ) to 40% each and Resources (R) to 20%.

The selection of impact categories, category indicators, and classification and characterization models are indirectly done by choosing the Eco-indicator 99 as a method for conducting the LCA. Normalization and weighting are also carried out according to this method. All the information about the Eco-indicator 99 method which follows below can be found in the Eco-indicator 99 Method - Methodology Report (PRé a, 2001).

5.1 Classification & Characterization

Classification is assigning the LCI results to impact categories. The LCI results are all the emissions, substances, radiation, releases, material extraction and area exploitation caused by the product throughout its life. The classification proceeds with the characterization where the impact categories are placed in damage categories. The impact categories and damage categories are described in section 5.2 below. In the characterization category indicators are calculated to achieve common units. Emissions, substances, radiation, releases, material extraction and area usage all have an assigned damage factor which is a numerical value. The value is multiplied with the amount of the specific emission, substance, radiation, release, material extraction or area exploitation, Equation 6. The damage factor is a subjective value and differs depending on the chosen Eco-indicator perspective (Individualist, Hierarchic or Egalitarian). The results are given in one of the following units: $DALY$, $PDF \times m^2 yr$ or $MJ\ surplus\ energy$, depending on in which impact category the emissions, substances, radiation, releases, material extraction or area exploitation is placed. The units are described further below.

$$Category\ indicator = Amount\ \times Damage\ factor \qquad [6]$$

5.2 Definitions of Impact Categories and Damage Categories

There are eleven impact categories allocated on the three different damage categories Human Health, Ecosystem Quality and Resources. Each damage category and its belonging impact categories are presented below.

Human Health (HH)

The common unit for all impact categories belonging to the damage category Human Health is DALY, Disability Adjusted Life Years. The explanation given by the Eco-indicator 99 Method reads as follows: "A damage of 1 means one life year of one individual is lost, or one person suffers four years from a disability with a weight of 0.25." (PRé b, 2000, p. 113)

Carcinogens
Carcinogens are substances or exposures that can lead to cancer. Examples of emissions having a carcinogenic effect on human health are arsenic, cadmium and formaldehyde. The damage factors are within the magnitude 10^{-7} to 10^{+3}. Carcinogenic substances are expressed in DALY per kg emission.

Respiratory Organics
Volatile organic compounds (VOCs) are examples of substances degrading the respiratory system of humans. The respiratory organics are expressed in DALYs per kg emitted substance. The damage factors are within the magnitude 10^{-8} to 10^{-6}.

Respiratory Inorganics
All respiratory inorganics damaging human health by degrading the respiratory system are expressed in DALYs per kg emitted substance. Examples of emissions having a respiratory effect on human health caused by inorganics substances are NO_x (nitrogen oxides) and SO_x (sulfur oxides). The damage factors are within the magnitude 10^{-5} to 10^{-4}.

Climate Change
Climate change is expected to affect human health through for example thermal extremes causing cold and heat related illnesses to spread, and altered crops/food leading to malnutrition and hunger. The unit for emissions contributing to climate change is DALY per kg emission. The main contribution to climate change comes from carbon dioxide, CO_2. Methane and nitrous oxide are other green house gases (GHGs). The damage factors are within the magnitude 10^{-7} to 10^{-3}.

Radiation
Radiation can lead to cancer and is measured in DALYs per Becquerel (Bq). Examples of substances having a damage effect on human health caused by ionizing radiation are Xe-133 and U-238. The damage factors are within the magnitude 10^{-16} to 10^{-10}.

Ozone Layer
Depletion of the ozone layer leads to increased exposure of UV, which can lead to cancer and cataract. Ozone layer depleting substances are measured in DALYs per kg release. Examples of releases are CFCs (chlorofluorocarbons) and halons. The damage factors are within the magnitude 10^{-5} to 10^{-2}.

Ecosystem Quality (EQ)
Impact categories within the damage category Ecosystem Quality are expressed in $PDF \times m^2yr$. PDF is short for Potentially Disappeared Fraction of Species. The Eco-indicator 99 method describes the unit as follows: “a damage of one means all species disappear from one m^2 during one year; or 10% of all species disappear from 10 m^2 during one year; or 10% of all species disappear from 1 m^2 during 10 years.” (PRé b, 2000, p. 116)

Ecotoxicity
Ecotoxicity cause toxic stress on species. The unit $PDF \times m^2yr$ per kg release is used to express it. Examples of toxics lowering the quality of ecosystems are heavy metals such as arsenic and cadmium. The damage factors are within the magnitude 10^{-6} to 10^{5}.

Acidification/Eutrophication
Acidification and eutrophication affect the nutrient level and acidity to which species and plants are sensitive. Acidification and eutrophication are expressed in $PDF \times m^2yr$ per kg emission to air. Releases of NO_x (nitrogen oxides) and SO_x (sulfur oxides) are well known emissions causing

acidification and eutrophication and thus lowering the ecosystem quality are. The damage factors are within the magnitude 10^{-1} to 10^{1}.

Land Use
Land use refers to occupation or conversion of land. It could for instance be for infrastructure or cultivation. Land use displaces species and cause an imbalance in ecosystems which cause a decrease in the number of species. Land Use is expressed in $PDF \times m^2yr$ per area m^2. The damage factors are within the magnitude 10^{-1} to 10^{0}.

Resources (R)

The common unit in the Resources category is $MJ\ surplus\ Energy$. The Eco-indicator 99 method explains the unit as follows: "A damage of 1 means that due to a certain extraction further extraction of this resource in the future will require one additional MJ of energy, due to the lower resource concentration, or other unfavorable characteristics of the remaining reserves." (PRé b, 2000, p. 118)

Minerals
Extracting minerals directly lower mineral reserves. Thereby the amount of energy needed to extract them continuously increase as they become more remote. The extraction of minerals resulting in resource scarcity, and later depletion, is expressed in $MJ\ surplus\ energy$ per kg extracted material. Examples of minerals causing resource scarcity are aluminum, copper and zinc. The damage factors are within the magnitude 10^{-1} to 10^{2}.

Fossil fuels
The case is the same with fossil fuels as with minerals; resources are becoming more and more inaccessible. The use of fossil fuels such as coal and oil are expressed in $MJ\ surplus\ energy$ per kg of extracted fuel. The damage factors are within the magnitude 10^{-3} to 10^{0}.

5.3 Normalization

Normalizing the category indicator results (the results from the characterization) is calculating their magnitude in relation to a reference value, see Equation 7. The Eco-indicator method uses the environmental impact caused by an average European citizen during one year as a reference value. The category indicator result is divided by the normalization factor and the result is given in years.

$$Normalized\ result = \frac{Category\ \ indicator\ \ result}{Normalization\ \ Reference\ \ Value} \qquad [7]$$

The normalization reference values are based on 1994 figures. The Table 3 shows the normalization reference values per inhabitant in Europe according to damage category. Note that the normalization data are dependent on the perspective chosen.

Table 3. The normalization reference values (per inhabitant in Europe) for each damage category. The values are based on the hierarchical perspective (Pré a, 2001).

Damage Category	Normalization Reference Value	Unit
Human Health	1,54E-02	DALY/yr
Ecosystem Quality	5,13E+03	PDF×m^{2}yr/yr
Resources	8,41E+03	MJ/yr

The normalization values are expressed in years. The value in years refers to the environmental effect from an average inhabitant in Europe per year. If HH equals 0,022 years it is equivalent to a 2.2 % share of the total impact on the human health caused by an average European citizen during one year. In other words, the impact from a European during approximately 8 days (365×0.022).

5.4 Weighting

The weighting is based on values obtained from a panel consisting of an LCA interest group in Switzerland. The weighted results are therefore not to be viewed as the average European opinion. The weight for each damage category is shown in Table 4 based on each one of the three different perspectives, Individualist, Hierarchist and Egalitarian. An average weighting is also shown, which is the recommended one to use.

Table 4. The weighting factors for the different perspectives and their average weighting factor.

	Average	Individualist	Hierarchist	Egalitarian
Human Health	40%	55%	30%	30%
Ecosystem Quality	40%	25%	40%	50%
Resources	20%	20%	30%	20%

If the normalized results of the impact categories are not weighted they cannot be added together in order to achieve one value. This is due to the fact that the severity of the environmental effects depends on the impact category. To allow for the results to be added the normalized result for each impact category is multiplied with the category-specific weighting factor, Equation 8. The result is expressed in points, Pt. One Pt is equal to one thousandth of the environmental impact caused by one average European citizen during one year.

$$Weighted\ result = Normalized\ Result \times Weighting\ factor \times 1000 \qquad [8]$$

6. RESULT OF THE LCA

Below follow the results of the LCA; the inventory results, characterization, normalization and weighting. Results coming from elsewhere are summarized at the end as key findings. All results come from the European scenario unless stated otherwise.

6.1 Life Cycle Inventory Results

All the activities that are mapped in the life cycle inventory affect the environment. Table 5 shows an extraction of common substances from an inventory list in SimaPro. The lists present all substances released from the life cycle activities by name, impact medium and amount. The amount of SO_x appears to decrease. It is due to the decommissioning which calculates with so called avoided products; material extraction is avoided by recycling products.

Table 5. Inventory result for some common substances.

Substance	Impact medium	Amount, kg
Benzene, C_6H_6	Air	2,75E-03
Bromine, Br	Air	7,70E-04
Chlorine, Cl	Air	5,81E-04
Formaldehyde, H_2CO	Air	1,04E-03
Hydrocarbons, HC	Air	4,36E-02
Hydrogen chloride, HCl	Air	4,47E-02
Lead, Pb	Air	1,18E-04
Methane, CH_4	Air	6,05E-02
Nitrogen oxides, NO_x	Air	1,24E+00
Sulfur hexafluoride, SF_6	Air	1,72E-06
Sulphur oxides, SO_x	Air	-5,98E-02
Volatile organic compounds, VOCs	Air	7,03E-03
Bromine, Br	Water	1,33E-03
Cadmium, Cd	Water	1,04E-02
Chlorine, Cl	Water	6,15E-05
Cobalt, Co	Water	7,45E-04
Copper, Cu	Water	9,95E-03
Iron, Fe	Water	6,58E-01
Lead, Pb	Water	2,02E-03
Molybdenum, Mo	Water	6,46E-04
Nickel, Ni	Water	2,62E-03
Phthalate, dimethyl tere-, DMT	Water	1,02E-06
Phthalate, dioctyl-, DOP	Water	1,18E-13
Phthalate, p-dibutyl-, DBP	Water	1,62E-07
Selenium, Se	Water	2,35E-04
Titanium, Ti	Water	2,43E-02

6.2 Characterization Result

The underlying information on how the characterization is conducted is available in section 5. LCIA. The results of the characterization are presented here. Table 6 shows the results of each impact category. The results are allocated on each life cycle category. The total results of each impact category are shown in the right column. Note the three different units. Figures may not be compared unless expressed in the same unit. The fact that some results of the decommissioning of the camera have "positive" effects (figures are negative) is explained with so called avoided products, e.g. when aluminum is recycled, new extraction is avoided. The category Raw material extraction and processing is hereby referred to simply as Material.

Table 6. The characterization results for each impact category allocated on each life cycle category and with the total results in the right column.

	Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
Carcinogens	1,09E-06	7,10E-06	1,22E-07	4,35E-05	-1,36E-06	5,05E-05	DALY
Resp. Organics	2,21E-08	6,59E-08	1,05E-08	1,42E-07	-4,23E-08	1,98E-07	DALY
Resp. Inorganics	1,81E-05	5,24E-05	7,46E-06	2,91E-04	-1,44E-05	3,55E-04	DALY
Climate Change	6,08E-06	8,71E-06	1,21E-06	1,29E-04	-4,76E-06	1,40E-04	DALY
Radiation	4,47E-09	1,20E-07	1,13E-08	7,82E-06	0,00E+00	7,96E-06	DALY
Ozone layer	3,21E-09	2,17E-09	9,38E-10	2,75E-08	-8,28E-09	2,55E-08	DALY
Ecotoxicity	1,86E-01	2,06E+00	1,59E-01	4,10E+00	-2,59E-01	6,25E+00	PDF*m^2yr
Acidification/ Eutrophication	5,13E-01	1,37E+00	3,22E-01	7,99E+00	-3,29E-01	9,87E+00	PDF*m^2yr
Land use	8,25E-01	9,92E-01	7,95E-02	3,58E+00	0,00E+00	5,48E+00	PDF*m^2yr
Minerals	6,22E+00	1,38E+01	8,23E-02	1,80E+00	-4,01E+00	1,79E+01	MJ surplus energy
Fossil fuels	3,66E+01	3,93E+01	1,15E+01	4,51E+02	-2,60E+01	5,12E+02	MJ surplus energy

The impact categories expressed in $DALY$ (Disability Adjusted Life Years) belong to the damage category HH. It is foremost respiratory inorganics, but also climate change, contributing by far the most to this damage category. And it is the use of the camera causing the biggest release of respiratory inorganics and CO_2 which is the major greenhouse gas.

The impact categories measured in $PDF \times m^2 yr$ (PDF stands for Potentially Disappeared Fraction of Species) constitute the damage category EQ. Acidification/ Eutrophication has the highest impact on this category. Even here it is the emissions from utilization contributing the most, but a noticeable amount also comes from emissions and waste from manufacturing.

The last two impact categories, mineral and fossil fuels, are measured in $MJ\ surplus\ energy$ which refers to the additional energy required in the future to extract the same amount of that resource. It will be more troublesome and energy consuming as resources are becoming scarcer. Naturally the damage category is R. The contribution from fossil fuels significantly exceeds that of minerals. Again, utilization is the worst.

As a supplement to the impact categories of the Eco-indicator 99 Method the total amount of emitted CO_2 and energy consumed during the entire life cycle of the camera are calculated. This is done by adding the essential results from the SimaPro inventory. Table 7 shows the results per life cycle category and the totals.

Table 7. Total amount of emitted CO_2 and energy consumed per life cycle category during the whole life cycle of the camera.

	Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
CO_2	23,3	39,2	5,6	610,5	-16,0	662,6	kg
Energy	345,0	506,6	82,2	7122,7	-242,2	7814,4	MJ

The total amount of CO_2 which the camera emits during its life cycle reaches 662.6 kg. For comprehension this could be compared to the amount of CO_2 emitted per kilometer by the average passenger car in Europe which is approximately 0.13 kg/km.[2] Thus, the amount of CO_2 emitted by the camera during its life equals a car covering a distance of approximately 5100 km. Interestingly transportation emits the least CO_2 out of all the life cycle categories.

The amount of energy used by the camera during 10 years equals the amount of energy that a 60 W regular light-bulb consumes during constant use for approximately 4.2 years (Tekniska verken, 2008).

The impact categories are collected in damage categories in Table 8. Note that it is impossible to add the total for each life cycle category because of the different units. Comparing them is feasible only after the normalization and weighting of the results have been done. What the table does reveal though is which damage category each life cycle category contributes the most to.

Table 8. A summary of the characterization results for the three damage categories allocated on each life cycle category.

	Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
Human Health	2,53E-05	6,84E-05	8,81E-06	4,71E-04	-2,06E-05	5,53E-04	DALY
Ecosystem Quality	1,52E+00	4,42E+00	5,61E-01	1,57E+01	-5,88E-01	2,16E+01	PDF×m^{2}yr
Resources	4,28E+01	5,31E+01	1,16E+01	4,53E+02	-3,00E+01	5,30E+02	MJ surplus energy

The great majority of the damage caused by every life cycle category is done to the Earth's resources, in form of depleting them. The biggest damage comes from the utilization. Because of superb end-of-life treatment the effects from the decommissioning of the camera are positive, especially to the resource damage category. Little harm appears to be done to ecosystems and even less to the human health. This is somewhat deceiving since these are amounts of emissions and wastes added; the severity of the damage they cause is not considered. This is done by the normalization followed by the weighting.

6.3 Normalized Result

Normalization in theory is described in section 5. LCI, below are the results of the normalization of the camera. Table 9 shows the normalized results; the characterization results relative a reference value. The reference value is the environmental impact caused by an average European during one year.

At large, the normalization results agree with the characterization results since over all it is the utilization causing the greatest impact; the order of magnitude for its impact is -2 compared to the other categories which contribute in the range 10^{-4} to 10^{-3} (Table 9). Note that the results of the decommissioning of the camera have "positive" effects (numbers are negative). It could be

[2] The EU Commission has a limit value set for 2012 when 65% of all car manufacturers by legislation have to meet the emission limit of 130 g CO_2 /km for newly produced cars. The emission level is assumed to be slightly higher today but that could be neglected due to an inevitable error margin and uncertainties associated with the LCA of the camera. (The EU Commission b, 2009)

explained by so called avoided products, e.g. when aluminum is recycled, new extraction is avoided.

Table 9. The normalized results showing the damage caused by each life cycle category to the damage categories. The unit is years.

	Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
Human Health	1,65E-03	4,45E-03	5,74E-04	3,07E-02	-1,34E-03	3,60E-02	Year
Ecosystem Quality	2,97E-04	8,62E-04	1,09E-04	3,06E-03	-1,15E-04	4,21E-03	Year
Resources	5,09E-03	6,32E-03	1,38E-03	5,39E-02	-3,57E-03	6,31E-02	Year

In ranking the life cycle categories according to their impact on the damage categories Utilization places first, Manufacturing comes second to Utilization, followed by Material and then Transportation. Out of the three damage categories Utilization contribute the most to R, then HH and last EQ. Likewise with the Manufacturing and Material, although at a smaller scale. Transportation also contributes the most to R, but HH and EQ are about equally represented; the impact on them is of the same magnitude. Decommissioning has the most positive effect on R, then HH, and last EQ. The total scores in the right column in Table 9 show that resources suffer the greatest damage. It is more clearly visualized in Figure 11 which shows the magnitude of the impact on each damage category.

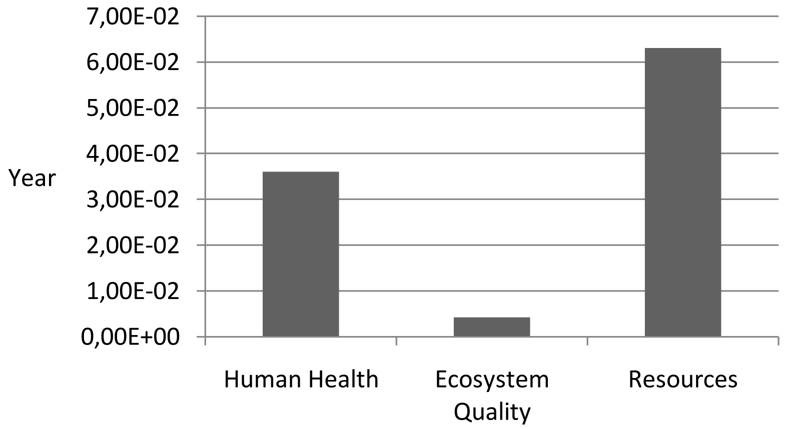

Figure 11. The magnitude of the impact from the entire life cycle of the camera on the damage categories HH, EQ and R

Looking at resources it will take approximately 23 days (6.31E-02 years) for an average European to contribute to resource degradation to the same extent as the camera does during its lifetime (10 years).

Total amount of emitted CO_2 and energy consumed by the camera during its life cycle are presented in Table 10. It is not additional CO_2 and energy; the values are fetched from the HH damage category (CO_2) and the R damage category (Energy) in the normalization. The CO_2 emitted and total amount of energy consumed are summarized from the inventory lists in SimaPro. To be able to add the energy values which are given in various units, information on energy content of the fuels are used (PRé b, 2000, p. 119).

Table 10. The normalized results showing the damage caused by $CO_2$and energy from each life cycle category. The unit is years.

	Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
CO_2	3,18E-04	5,36E-04	7,62E-05	8,34E-03	-2,19E-04	9,06E-03	Year
Energy	1,67E-02	4,60E-03	1,38E-03	5,38E-02	-3,10E-03	7,33E-02	Year

The values tells that it will take 3.3 days (9.06E-03 years × 365 days/year) for an average European to emit the same amount of CO_2 as the camera does during its lifetime (10 years). And it will take 27 days for an average European to consume the same amount of energy as the camera does during its lifetime.

6.4 Weighted Result

Weighting of normalized results is explained in section 5 LCIA. How and why a weighting is conducted is described in the same section. Below follow the results of the weighting in the LCA case study. Table 11 shows the weighted results in form of the impact from each life cycle category on the each one of the damage categories HH, EQ and R.

Table 11. The weighted results showing the damage caused by each life cycle category to the damage categories. The unit is Pt.

	Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
Human Health	0,66	1,78	0,23	12,30	-0,54	14,43	Pt
Ecosystem Quality	0,12	0,35	0,04	1,22	-0,05	1,68	Pt
Resources	1,02	1,26	0,28	10,80	-0,72	12,64	Pt

Again, just as the characterization and the normalization showed, utilization impacts the environment the most. Utilization is followed by Manufacturing, Material, Transportation, and Decommissioning (the environmental impact decreasing).

The weighting, though, replaced R by HH as the most impacted damage category. The characterization and the normalization showed the greatest impact is caused to the Earth's resources. By weighting the results HH scored higher and appears to be the more exposed damage category. It is a relatively close case though, HH and R has a total of 14.43Pt and 12.64Pt respectively. EQ however only has a total of 1.68Pt. The figures are more easily visualized in Figure 12 below.

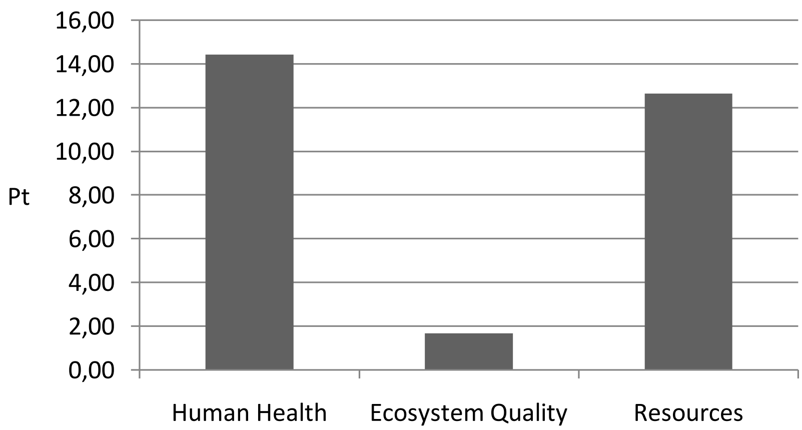

Figure 12. The magnitude of the impact from the camera on the damage categories (HH, EQ and R) after the results have been weighted.

The fact that EQ appears to be very little affected despite a weighting importance of 40%, compared to R at 20%, is interesting. It could possibly be explained by the fact that utilization is the most harmful activity in the life cycle, emitting large amounts of CO_2. And the CO_2 contributes to climate change which is an impact category placed in the damage category HH, not EQ.

The weighted results of total amount of CO_2 emitted by the camera during its life (10 years) equals 3.62 Pt, Table 12. The energy required by the camera during the entire life cycle causes a greater stress on the environment than does the CO_2 according to the weighted scores; the energy results in 12.20 Pt, Table 12. The amounts are not additional; they are extracted from the HH and R damage categories.

Table 12. The weighted results showing the damage caused by $CO_2$and energy to the damage categories. The unit is Pt.

	Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
CO_2	0,13	0,21	0,03	3,34	-0,09	3,62	Pt
Energy	0,87	0,94	0,27	10,74	-0,62	12,20	Pt

Almost all impact is caused by the utilization; the impacts from all the other life cycle categories are put in the shadow.

To determine which life cycle category has the highest impact on the environment the results of the damage categories (Table 11) are added into single scores (Table 13 for the EU; Table 14 for the U.S.). It further illustrates how utilization dominates the environmental impacts caused by the camera during its life cycle. The weighting makes it possible to add the impacts from the damage categories HH, EQ and R into single scores.

Table 13. Single scores, the EU.

Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
1,80	3,39	0,55	24,32	-1,30	28,76	Pt

The total environmental impact from the camera during its entire lifetime (10 years) represents 2.88% of the total environmental impact an average European has per year. Utilization is the activity dominating the impact, representing 2.43%. It is timidly followed by Manufacturing at 0.339%, then Raw Material extraction and Processing at 0.180%, Transportation at 0.058%. The decommissioning of the camera results in a positive contribution of 0.13%.

The percentage impact from each life cycle category on the total is viewed in Figure 13 for the EU and Figure 14 for the U.S. Utilization stands for approximately 85% of the total impact. Followed by Manufacturing at around 12%, Material slightly higher than 6%, Transportation at only 2% and Decommissioning has a negative effect of 4.5%.

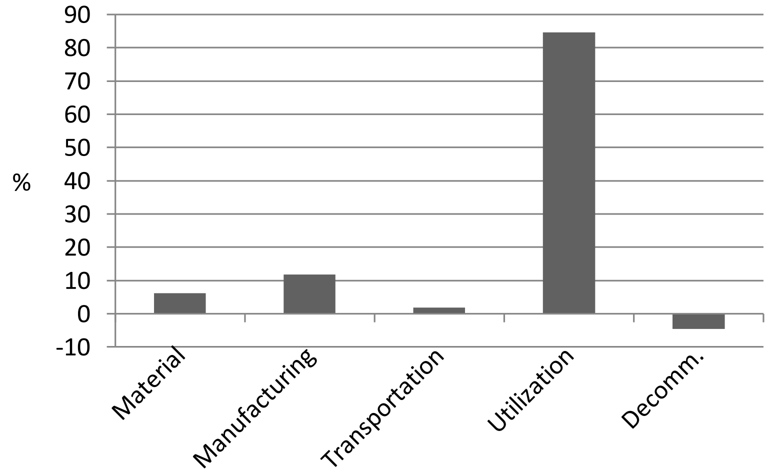

Figure 13. Percentage impact of each life cycle category on the total environmental impact in the EU.

The single scores for the US are shown in Table 14. The only differences occur in the Utilization and Transportation categories. The energy composition for electricity production is different (4.4.1 Energy Composition for Electricity) which increase the impact from utilization to a total of 30.5 Pt (for the EU it is 24.32 Pt). The increased impact from transportation (4.90 Pt compared to 0.55 Pt for the EU) is explained by the outbound transportations mainly being by air.

Table 14. Single scores, the U.S.

Material	Manufacturing	Transportation	Utilization	Decomm.	Total	
1,80	3,39	4,90	30,50	-1,30	39,29	Pt

The total impact from utilization measured in percent is lowered because transportations are responsible for a larger share compared to the case of the EU. Utilization in the U.S. represents slightly less than 80 percent of the total environmental impact whereas for Europe it is slightly above.

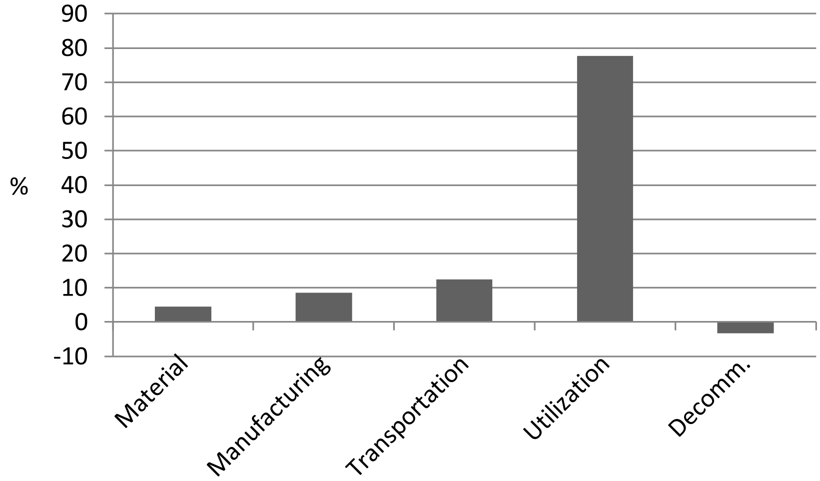

Figure 14. Percentage impact of each life cycle category on the total environmental impact in the US.

Three main types of transportation are used throughout the life cycle of the camera; air, water and road. Traveling one tkm by air results in a score of 0.074 Pt. Same distance by road and water results in 0.018 Pt and 0.0013 Pt respectively. Not surprisingly, air transportation causes has the highest impact on the environment. It explains the increase in impact from transportation in the U.S. scenario.

6.5 Key findings

Key findings summarize the results of each life cycle category that are not visible in the characterization, normalization or weighting. The results are weighted and illustrated in networks produced in SimaPro. The thickness of the arrows in a network indicates the magnitude of the environmental impact in relation to each other; the thicker the arrow the greater the environmental impact. The weighted impact results of the Raw material extraction and processing category are illustrated in such a network in Figure 15 (material names are confidential).

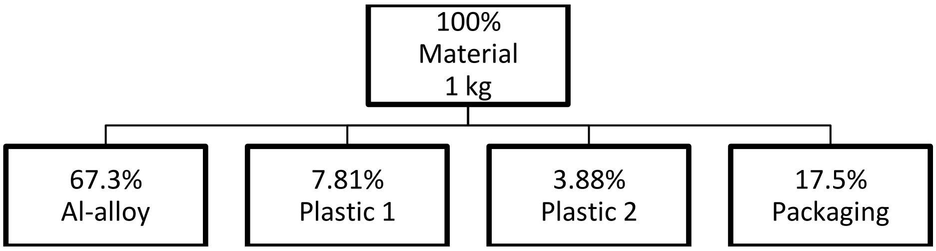

Figure 15. The weighted impact results of the Raw material extraction and processing category.

The greatest impact comes from the extraction of the aluminum needed to produce the camera. The contribution from its packaging material should be noticed, though. It is actually greater than that of producing Plastic 1 and Plastic 2. The magnitude of the impact is very much determined by the weight of the material used in the camera. The camera mostly consists of metals (Appendix C, Data Sources, Table 18).

The network of the weighted results of the Manufacturing shows that this category is almost exclusively impacted by the manufacturing of the PCBA (Figure 16). And the PCB is responsible for almost the entire share. An explanation to its position is that materials of the PCB are included here instead of in the Raw material extraction and processing category, increasing its impact in relation to other manufacturing and assembling.

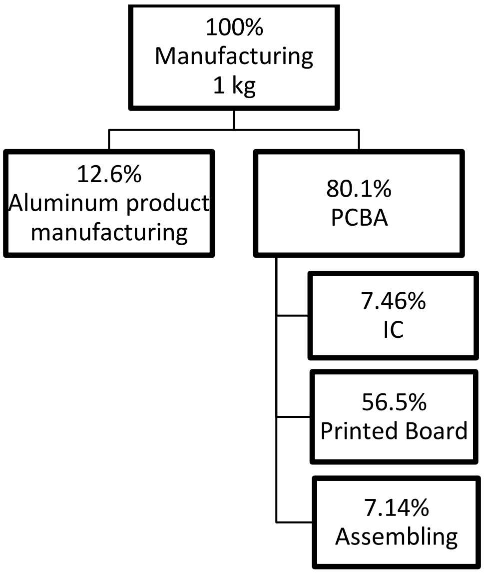

Figure 16. The network of the Manufacturing showing the weighted results. The PCBA stands for the greatest environmental impact.

The type of energy source used for producing electricity determines the outcome of the utilization category. Coal, gas and nuclear are the most common energy sources for both Europe and the U.S., Figure 9 and 10). Important to mention is that out of these sources SimaPro ranks nuclear as the best choice from an environmental perspective, coal places second and gas is considered the worst choice of energy source. Several factors influence such a ranking, such as the time perspective. This confirms the value-based nature of LCAs.

The overall impact from decommissioning proves to be positive for the environment due to the ideal end-of-life scenario. Therefore distinguishing one activity from another in this category is not motivated.

6.6 Results of other LCAs on Network Cameras

Only a few official LCAs of network cameras have been conducted. The major part of them performed at Panasonic Communications in Japan (JEMAI a, 2009). The results of their three most recent LCAs (JEMAI a, b, c, 2009) will be roughly compared to the results of this one. A detailed comparison is not motivated since the LCA frameworks are different.

The network cameras investigated by JEMAI emits between 66.2 to 69.3 kg CO_2 over the life cycle. The life time of the product is set to 5 years which is half of the life time of the AXIS Q6032-E which decrease the total energy. These figures equal 13.5 kg CO_2 emissions per year for the Panasonic Communications cameras, versus 66.3 kg for the AXIS Q6032-E (Lifetime of 10 years, total CO_2 of 662.8 kg). The greater amount of CO_2 emissions could partly be explained by the fact that AXIS Q6032-E is intended for outdoor use; increasing the energy demand and requiring more durable materials with special characteristics more costly to the environment to produce. Moreover, the AXIS Q6032-E possesses characteristics and features which require more energy. It should be emphasized that the Axis Q6032-E could for most purposes not be replaced by one of these less advanced Panasonic models. The advanced features of the AXIS Q6032-E explain why the average weight of the three Panasonic cameras (0.335, 0.340, 0.360 kg each) is only about 1/10 of the weight of the AXIS Q6032-E. For information on the characteristics of Axis cameras view the reference Axis Communications AB c, 2009; Panasonic Communications cameras see reference JEMAI a, b and c, 2009. The higher weight increase the CO_2 emissions related to raw material extraction and processing, manufacturing and transportations as well.

The above aspects also explain the differences in energy demand between the cameras. The three Panasonic cameras require in average 290 MJ/year (1463 MJ total), the AXIS Q6032-E require 780 MJ/year (7843 MJ total). Considering the advanced features of the AXIS Q6032-E, and a weight 10 times higher than that of the other cameras, the figures seem roughly accurate. Although several factors (of which many are value based and not considered here) determine the outcome of the LCA the calculated magnitude of impact from the cameras may be roughly compared to ensure the accuracy of the LCA, see Figure 17. Therefore, even if not considering special camera features and functionalities, it could be determined if the results are in the same range. The life time has been considered and the bars represent the total amount of CO_2 emitted and energy consumed during one life time year for each camera. The weight difference has been considered by assuming the CO_2 emissions and energy consumption during raw material extraction, material processing and manufacturing increase linearly, thus increase tenfold for the Panasonic cameras. The AXIS Q6032-E it is in the same “impact range” (looking at CO_2 and energy) as the Panasonic cameras it is being compared to (even if not including the special features) which assures the reliability of this LCA study.

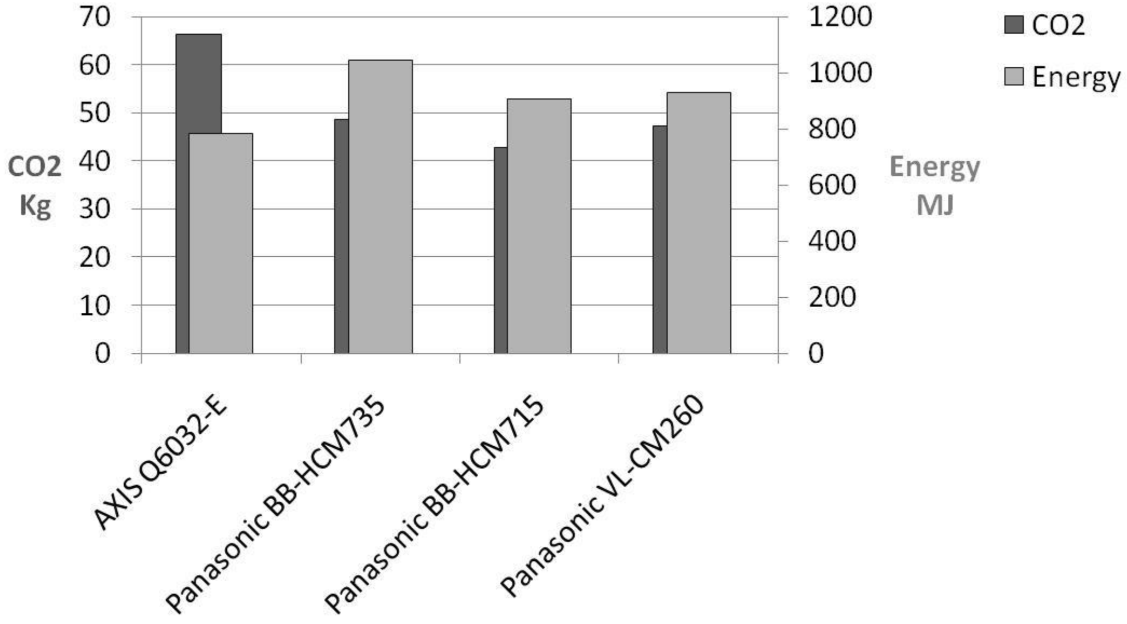

Figure 17. Comparison of the total amount of CO_2 emissions and energy consumed per life time year for AXIS Q6032-E and three types of Panasonic network cameras.

The life cycle is divided into the same type of categories in the Panasonic LCA study. According to each of the categories' magnitude of impact on the environment they are also ranked in the same order (with the exception of the decommissioning). Utilization/use dominates, followed by manufacturing/product production, raw material extraction and processing/raw material production, transportations/distribution. The difference is that the disposition (responding to the decommissioning in this study) does not involve so called product avoidance.

6.7 Sensitivity Analysis

A sensitivity analysis is performed to assure stability of the LCA results. Whenever the data used have been uncertain, assumed, estimated or crucial (in a key process such as utilization) drastic changes to the data have been made to see how sensitive the results are to the changes. The impact, Figure 15, shows how much (in percent) a change affects the result. The changes made are described in the left column, the reason for choosing the particular change is documented in under Motivation.

Table 15. Sensitivity analysis.

Change	Motivation	Impact	Comments
Amount of material spill tripled	Uncertain due to low quantity of data	+0,7%	e.g. The factor 1.05 (Plastics) becomes 1.15
Total impact from manufacturing doubled	Uncertain due to general data	+11,8%	It is uncertain how well the general data applies to this LCA in particular
+500% km of the distances that are estimated in the transportation category	Estimated distances	+3,8%	Rough estimations
All means of transportations assumed to be by road are changed to air	Assumed road delivery (not air)	+4,5%	When component/camera delivering is urgent air tranportations increase
+500% time in highly active mode (20% of the time in highly active mode, 60% in idle mode)	Estimated user pattern	+9,4%	The intensity of use may vary among different users therefore the time in highly active mode is increased
Entire camera in landfill when decommissioned	End-of-life scenario is ideal	+4,5%	In reality the ideal decommissioning might be overestimated, therefore it is interesting to see the effects on the results if the entire camera ends up in a landfill instead
Energy source for electricity production changed to wind power	Key process	-79,1%	The average energy composition for electricity production is used; however a user may actively choose a strictly renewable source. It is interesting to see the impact on the results from such a choice.

No changes cause a large reaction except the last change in the column. It is made to see how much the choice of energy source affects the results. The change is drastic; the camera only runs on wind power. Hence the 79.1% change of the results should not be interpreted as unstable modeling of the utilization category. The affects on the results caused by the changes in the sensitivity analysis are small; the overall percentage impact is acceptable.

7. INTERPRETATION

Interpretation of the case study LCA has been undertaken by the authors during the entire working process. The results of the interpretation are summarized and evaluated. Significant issues are identified and discussed. Overall conclusions from the case study are drawn and future recommendations are made.

7.1 Significant Results

The utilization dominates the environmental impact caused by the camera during its life. It is true for all the damage categories. On an impact category level it is foremost respiratory inorganics and climate change contributing to the HH damage category. Acidification and eutrophication has the highest impact on the EQ category. And the contribution from fossil fuels significantly exceeds that of minerals in the R damage category.

The normalization shows that out of the three damage categories Utilization contribute the most to R, then HH and last EQ. In the weighting, though, HH replaces R as the most affected damage category. The total environmental impact from the camera during its entire lifetime (10 years) represents 2.88% of the total environmental impact an average European has per year. Utilization is the activity dominating the impact at 2.43%.

The total amount of CO_2 which the camera emits during its life cycle reaches 662.6 kg; the amount equals what a car emits during a 5100 km trip. Interestingly transportation emits the least CO_2 out of all the life cycle categories. The amount of energy used by the camera during 10 years equals the amount of energy that a 60 W regular light-bulb consumes during constant use for approximately 4.2 years (Tekniska verken, 2008). The normalization reveals that it will take 3.3 days for an average European to emit the same amount of CO_2 as the camera does during its lifetime (10 years). And it will take 27 days for an average European to consume the same amount of energy as the camera does during its lifetime. According to the weighted scores the energy required by the camera during the entire life cycle causes a greater stress on the environment than does the CO_2 (12.20 Pt and 3.62 Pt respectively). CO_2 however is an effect of energy consumption wherefore the two scores cannot be compared to each other.

7.2 Significant Issues

Data quality is an inevitable issue with LCAs (2.5 Limitations of LCA). These LCA results will only be accurate for a limited time ahead since data must be updated. The year of issue should always be stated when the results are communicated.

Raw material extraction and processing might show better results than reality would prove since the decommissioning is ideal; hence indirectly reduce the impact from the raw material extraction and processing due to product avoidance (less material need to be extracted due to recycling). It causes a negative environmental impact from the decommissioning which may be too optimistic. The Eco-indicator 99 Method does not use this type of scenario and therefore some of the data, from the ETH database for instance, are not well suited to be used for this method. The only alternative is a data gap which is less accurate.

The emissions and waste from manufacturing and assembling is allocated based on one supplier visit where such an allocation was conducted, and then applied in the rest of the study. It is an acceptable simplification since the manufacturing and assembling of camera units proved to be relatively harmless. Except for this supplier visit the manufacturing data are general; a common limitation with LCAs (Discussed in section 2.1 Limitations of LCA). The lack of product specific manufacturing data is acceptable though. As previously stated, the electricity production represents the majority of the total environmental impact from the camera.

The estimations made in the transportation category are done on good information bases and are therefore not considered an issue. The information on manufacturer and supplier locations and means of transportations has been sufficient.

There are issues concerning the tools used to conduct the LCA. Limitations with the Eco-indicator 99 Method and the SimaPro 7.1 software are discussed below.

It is not clear why the Eco-indicator 99 method places the impact category climate change in the HH damage category instead of in EQ. A consequence is that the camera significantly impacts the human health more than the quality of ecosystems, and it is questionable if that is the case.

A limitation of SimaPro is that it does not present the results per lifetime year of the product but instead the total environmental impact for the entire life span. The life time of the product is never reported in SimaPro. The results have to be divided by the life time of the product to get the environmental impact on a yearly basis. It allows for comparisons of the environmental performance of two or more products or services expressed in same functional unit but with different commercial service lifetimes. One has to keep in mind that a long lifetime could mean avoiding having to purchase two cameras.

Another limitation of SimaPro is that it does not present the total amount of CO_2 emitted or the total energy consumption during the life cycle. These are commercially interesting facts because the values are easily understood and compared to common activities, such as how far a car may get on the same amount of energy or of far it has traveled when the same amount of CO_2 has been emitted by it. These comparisons are not precise or sufficiently extensive but the suggested facts on CO_2 and energy are useful to display to a less environmentally informed audience, and thus useful for a commercial business. To obtain the total CO_2 and energy values one has to scan the inventory lists for CO_2 and fuels. The amounts are given in several different units which have to be converted. The values then have to be multiplied with information on energy content for each fuel. This is a time consuming task.

Issues could arise concerning the roles and responsibilities of the actors involved with this LCA. As this thesis is handed over to Axis, the environmental engineers at Axis are responsible for how the information contained in this LCA is communicated. The results have to be communicated in a transparent manner. Whenever the results of this case study LCA are shared, whoever the receiver, the underlying value based information leading to the results has to be communicated in order for the LCA to be transparent for the receiver.

7.3 Case Study Conclusions and Future Recommendations

The goal to increase Axis's knowledge on the environmental impact of the Axis developed and produced AXIS Q6032-E Network Camera is considered reached. The phases in the life cycle of the camera that have the highest environment impact are identified. The presented results are transparent and therefore allow Axis to use them in customer communication.

A recommendation for the future is to consider other tools than SimaPro and the Eco-indicator 99 Method. Although other tools will have weaknesses of their own methods to conduct LCAs are rapidly improving and some tools may develop quicker than others. Not saying that the tools used here will not, simply recommending being open for other options.

The fact that the utilization by far causes the greatest environmental impact out of all the life stages should not result in the company “resigning from” the responsibility of lowering the environmental impact caused by their products and activities. It could happen because other activities are considered minor in comparison and the choice of energy source when running the camera is the customer’s. On the other hand, designers can work on lowering the power supply needed and energy consumption. Focusing on “the minor activities” can also result in monetary savings which may be motivating. Moreover, customers may be informed on the importance of choosing an environmentally sound energy supplier which receives their energy from renewable sources. Neither should all focus be on utilization. A variety of questions should be addressed, such as further developing cameras that could be upgraded without being entirely replaced.

8. MODEL FOR SIMPLIFIED LCA

This is part of Phase 2 of the thesis; establishing a method for conducting simplified LCAs on similar Axis products. The initial direction given by Axis is that the method should allow comparing the environmental performance of the AXIS Q6032-E network camera and other Axis network cameras. Other requirements emerged and a model was created in Microsoft Excel. The results of the model are compared to those of the case study LCA. The model is customized for Axis exclusively. Extracts from the model are available in Appendix G.

8.1 Requirements and Construction

A time limit is set to approximately one week to complete an LCA using the customized model. The estimated time to complete an LCA using the model is 2-3 days. The person operating the model is referred to as 'the user' in this text.

Requirements regarding usability refer to simplicity to conduct an LCA and to interpret the results. Obviously the calculations cannot be performed by hand if the above requirements are to be fulfilled. Microsoft Office Excel is complex enough to make the calculations yet easy to operate and thus fulfills the requirements. Comprehensive beginning instructions on how to operate the model are constructed as well as guiding comments in the model such as tips for filling in the variables and explanations on how to read the results after a graph or table presenting the results.

The model should encompass a full LCA (compared to the platform where this is not necessary) although simplified. All life stages having an impact on the environment are included in the model. Scenarios were defined for life cycle categories in the case study. The same categories and scenarios are used in the model. These scenarios are Raw material extraction and processing (simply referred to as Material in the model), Manufacturing, Transportations, Utilization and Decommissioning. The screening identified which materials and processes in these scenarios that have the highest impact. The case study later proved the indications of the screening to be accurate and therefore these are included in the model. The structure of the model is based on the case study.

It should be possible to compare the LCA results of different camera models to evaluate their environmental performance in relation to each other. Note that if comparing PTZ cameras to fixed cameras the number of fixed cameras needed to keep 14,000 m^2 constantly surveilled has to be estimated. Then multiply the number by the LCA results for one fixed camera.

In order for the model to work for various camera models common variations and similarities between the different models have to be investigated. Information from internal documents and Axis employees in combination with the sensitivity analysis results (Section 6.7) lead to a decision on what units, materials and processes should be treated as variables in the model. Those are the units, materials and processes that either vary significantly between different cameras, or are expected to have a significant impact on the final results if changed (e.g. source of electricity). Based on this the following aspects are considered:

- Total weight of the camera
- Chassis weight and material
- Pan-tilt mechanisms and domes are only part of PTZ cameras
- The amount of PCBA
- Transportations to and from CLC

- User pattern (time in each mode)
- The electricity production for utilization

All units, materials and processes vary according to weight or other factors. Even the ones known/expected/assumed to only slightly differ between various camera models. Only parts of the transportation category are constant. To create one model for various types of cameras the LCA case study is used as the base but split into sub-LCAs. To calculate the final results the results of the sub-LCAs are then added together.

All underlying values needed to calculate results using the model are fetched from the case study. The values come from own data inventories as well as general databases. For instance when calculating the PCBA results the data come from own inventories; the environmental impact from one kg of PCBA is determined and multiplied by the number of kg PCBA in the camera studied. An example of a general database value is the amount of CO_2 an average freight air craft emits per tkm during transportation. Once the user submits the weight of the camera and the number of km it travels by air the result is calculated by multiplying these figures. All underlying data are available in the 'Data' sheet in the model. If difficulties in quantifying a material or a process occur when fetching values to submit in the variable fields the user is encouraged to estimate a value rather than omit.

8.2 Variables and Constants

Below follows a description of what information and which values have to be fetched by the user to complete an LCA using this model (given by scenario).

Raw material extraction and processing
Sub-LCAs are conducted for three types of chassis (because it could be made out of aluminum, zinc or plastic) and a possible Pan-Tilt mechanism and a dome (because they only apply to PTZ cameras; in case of using the model for a fixed camera Pan-Tilts and domes do not exist). Information and values to be fetched include the total weight of the camera, chassis material and the amount of chassis in kg, the weights of a possible Pan-Tilt mechanism and dome in kg, and the amount of packaging material. The material composition of what remains of the camera when these parts have been removed is very similar among different camera models. Therefore the environmental impact caused by the remaining product consequently varies according to the remaining weight of the camera. The remaining weight is the total camera weight minus the weight of the chassis, a possible Pan-Tilt mechanism and dome, the PCBA (the amount of PCBA vary significantly between different cameras, see Manufacturing below). Another sub-LCA is created for the remains of the camera. That way all the material is included in the LCA model.

Packaging material is included in this category. The amount of packing is defined by the proportions within the network camera AXIS Q6032-E. The total amount of packaging material equals 95% of the weight of the camera. A camera weighing 10 kg could be expected to consume 9.5 kg of packaging material throughout its life cycle. Equation 9 below shows the factor 0.95 comes from dividing the weight of the packaging material by the total product weight.

$$Packaging\ material\ factor = \frac{3.325}{3.508} = 0.95 \quad [9]$$

Material waste is included in the model; the user multiplies the amount of material in the camera by the specific waste factors for aluminum, plastics and steel.

Manufacturing
The outline of the manufacturing is the same as in the Material category although the weight of the PCBA has to be submitted by the user. The other information is automatically transferred from the Material category to the Manufacturing category. Just as in the case study the PCBA is added to the Manufacturing category but the database values chosen include raw material extraction and processing wherefore that is included as well.

The amount of PCBA in each camera varies although the PCBA composition is generally unchanged, meaning the component distribution within the PCBAs are the same (Hansson, 2009). Therefore a free-standing LCA of a typical PCBA is conducted. From that, LCA figures on environmental impacts from 1 kg of PCBA are multiplied by the given amount of PCBA for the camera studied. Energy consumption associated with assembling is included and so is the waste in manufacturing. The factors used to include material waste from manufacturing are 1.1 for zinc and aluminum, and 1.05 for plastics and 1.057 for all other materials.

Transportation
The user has to calculate or estimate the amount of km that the camera travels by air, road and water from contract manufacturers to CLC (CLC1, Lund, Sweden for the AXIS Q6032-E) and from CLC to distributor. The weights of the arriving camera units and the departing sales unit at CLC have to be measured. The user has then to multiply each unit by the distance it has traveled and submit the values for air, road and water in tkm. Other transportation routes are constant because of relatively small variations between different camera models. It is expected that the case is the same with future camera models.

Utilization
The commercial service life time of the camera in years has to be estimated by the user. The user also has to submit the percent of time the camera is used in idle mode and active mode respectively and the power supply in Watts needed for each of the modes (Defined in section 4.4 Utilization). The required power supplies are available in documented test results of finalized cameras. Based on the above information the total electricity required is calculated. The user then selects either Europe or the U.S. depending on where the end customer is located. The model contains general values of the energy composition for power supply which are then used when calculating the results.

Decommissioning
The end-of-life scenario of the camera only varies according to the total weight of the camera.

8.3 Result Presentation

The results are first presented per impact category and damage category in a *damage assessment*. The impact categories are Carcinogens, Respiratory organics, Respiratory inorganics, Climate change, Radiation, Ozone layer, Ecotoxicity, Acidification/Eutrophication, Land use, Minerals and Fossil fuels which are sorted in the damage categories Human Health (HH), Ecosystem Quality (EQ) and Resources (R). The results are then normalized as well as weighted. The normalization is presented per impact category in the model. SimaPro presents it per damage category. By presenting the results per impact category instead the activity causing the impact is more easily identified.

Additionally, the total amount of energy that the camera consumes during its life as well as the total amount of CO_2 it emits is calculated. The CO_2 emitted and energy consumed are summarized the inventory lists in SimaPro. To be able to add the energy values which are given in various units in the inventory lists information on energy content of the fuels are used (PRé b, 2000, p. 119). The energy values are not normalized or weighted because it cannot be done without keeping coal, gas and oil apart. The unit MJ cannot be converted into MJ Surplus Energy in any other way which makes the processes (normalization and weighting) too complicated for a simplified model. A final score simply expressed in Eco-indicator points, Pt, is calculated last. A single score significantly facilitates comparisons between cameras although it should be considered this is a value based method and thus a subjective one. All results are per commercial service year. It enables comparisons between different Axis camera models.

8.4 Verification of the Model Accuracy

To detect how well the model is performing the results of the three different damage categories allocated on the five life cycle categories are compared. As well as the total weighted result. The check is performed by calculating the error margin (Equation 10).

$$Error\ Margin = \frac{SimaPro\ \ Result - Model\ \ Result}{SimaPro\ \ Result} \times 100 \qquad [10]$$

Table 16 shows how much the model results differs in percentage from the SimaPro results regarding the three different damage categories. For the raw material extraction and processing category the model gives a lower impact than SimaPro. The case is the opposite for manufacturing. Transportation differs both ways showing less and more impact depending on the damage category. Utilization is the most accurate category; probably because there is only one variable (the amount of energy needed). The values of the decommissioning are higher in SimaPro than in the model. It means the model's values are bit too negative which has a positive effect on the results.

Table 16. Difference in percentage between the result values of SimaPro and the values of the simplified LCA model.

	Material	Manufacturing	Transportation	Utilization	Decomm.	
Human Health	0,61	-0,93	-0,04	0,00	0,79	%
Ecosystem Quality	0,44	-0,58	0,24	-0,34	0,79	%
Resources	0,59	-0,05	-0,22	0,01	0,79	%

The accuracy is also verified for CO_2 and energy, as seen in Table 17. Also here are the SimaPro results slightly higher than for those of the model. Only for the utilization are the results lower in SimaPro, though almost exact.

Table 17. Differences between the SimaPro results and the results of the model regarding $CO_2$and energy.

	Material	Manufacturing	Transportation	Utilization	Decomm.	
CO2	0,8	1,4	1,2	-0,1	0,8	%
Energy	0,3	-1,8	-2,1	-0,4	0,0	%

The model's total weighted result is 28.69Pt, while the SimaPro result is 28.76Pt. This equals a 0.24 % error margin (Equation 10). The weighted results for CO_2 equal 3.65 Pt and 3.62 Pt for the model and SimaPro respectively. Hence, the error margin equals an error margin of -0.83%. There is no total weighted result for energy and therefore no error margin.

Considering it is a simplified LCA method the error margins are certainly considered low enough to be acceptable.

9. PLATFORM FOR THE PRODUCT DEVELOPMENT

To encourage LCA-thinking in the product development process and improve the product's environmental performance at an early stage a platform is created. The platform is developed based on the case study LCA and the simplified model. It is part of Phase 2 of the thesis.

The platform is a supplementary tool for the simplified LCA model to be used in the product development process. The model is intended for finalized products to calculate the total environmental impact from the product's full life cycle which requires a more extensive interpretation of the results than does the platform. Results from the platform are intended for internal use only and are not to be disclosed to the public. The platform is designed at and for Axis.

The platform is intended for the product designers. Therefore it only includes certain categories of the life cycle (the categories are defined in the case study LCA) - only the ones which designers can directly or indirectly affect in making their choices during the development of new camera. Raw material extraction and processing is directly determined by the materials chosen, manufacturing directly and indirectly depends on the design and choice of materials (e.g. some manufacturing processes are more energy demanding than others and certain manufacturing techniques are suitable for a particular material), and so does the decommissioning (e.g. the complexity of the decommissioning varies between different materials). Lowering the camera's energy consumption is a given goal because of the obvious thermodynamic advantages (the camera can get overheated), therefore it is could be assumed that the designer aims to do so without looking particularly at the environmental advantages. Moreover, the designers are partly capable of impacting the transportation category but the platform does not consider the design which could make transportations more efficient (by creating stackable units etcetera). The platform has to remain as simple as possible to increase the odds of it being used in the product development.

A smaller segment of the platform is available in Appendix H. The three separated stages; material (extraction and processing), manufacturing, and decommissioning contain fields to be filled in where applicable for the product. An amount, expressed in different units depending on the category, is multiplied with a specified indicator resulting in points, mPt. The higher the indicator is, the worse the environmental effects. If desirable, the points can be added together in the right column resulting in one final score. The platform is created to compare products, components and alternatives, hence the calculated values are only relevant in relation to each other; no absolute mPt values are of interest. One Pt is equal to one thousandth of the environmental impact caused by one average European citizen during one year.

The materials and manufacturing processes chosen to be included are the most common ones and the ones on a list of predicted future materials and manufacturing processes summarized by Axis. Various common ways of handling the decommissioning are included, and also techniques expected to be useful in that context.

The indicators are based on the Eco-indicator 99 Method for performing LCAs. For updated indicators view the document "Eco-indicator 99 Manual for Designers", available at www.pre.nl. When updating, be aware not to mix Eco-indicator 99 values with those of the older version Eco-indicator 95; they are not compatible and there are no conversion factors.

When Eco-indicator does not have an applicable indicator the IDEMAT, ETH and Eco-invent databases are used to fetch the values. It is important the values are consistent wherefore the average differences between Eco-indicator values and IDEMAT, ETH and Eco-invent values have to be calculated. The values which are available in Eco-indicator are also fetched from IDEMAT, ETH and Eco-invent to compare how much they generally differ. It shows that the IDEMAT and Eco-invent values are on average 33 percent higher, whereas the ETH database is 2% higher. When an indicator is not available in Eco-indicator, the value is thus fetched from either IDEMAT or ETH and multiplied with the factor of the database used (1.33 for IDEMAT, 1.02 for ETH) to be in line with other values which are predominantly fetched from Eco-indicator.

Simplifications when using the platform could include eliminating parts of the platform as long as the limitations are transparent and consistent to allow for fair comparisons. When choosing between two equally suitable materials, though, (with different magnitudes of environmental impact) comparing their indicators (with respect to the amount of material used) shows which one is the better alternative. Although a better result is given if manufacturing and disposal is considered as well.

10. DISCUSSION

Here follows the discussion of the thesis work; what might have affected the results and what could have been done differently.

This LCA gives a picture of the environmental impact from the AXIS Q6032-E Network Camera today. More precise however, the results reflects the impact the camera would have had if it existed about 5 years ago since the data used for the simulation are approximately of that age. Thus the results probably reflect the worst case scenario, since the technological development in combination with an increased environmental concern (sometimes agreeing with economic interests) has on the whole resulted in more environmentally sound products. It is difficult to verify the accuracy of the case study results. Comparing to previously performed LCAs can only give a hint due to system boundary differences, differently defined functional units and other dissimilarities among different life cycles assessments.

One limitation with the results from the case study certainly is the fact that Axis cannot directly compare their results with other camera producers. It is impossible to say who has the more environmental friendly camera as long as there is no common LCA framework for the industry.

The model is strongly affected by the chosen network camera type on which the case study is performed. Constants within the model and the material composition are according to the AXIS Q6032-E network camera. An overall review of the main differences between various camera types has been conducted, but no extended investigation. With more time at hand the next step would have been to conduct such an investigation to assure and maybe improve the accuracy of the model. However, an LCA on the AXIS Q6032-E is performed using the model and the results are compared to the SimaPro results from the case study. This is a form of verification (an exact resemblance of the results would be ideal) but the accuracy when conducting LCAs on other camera models cannot be assured. A comparison between the model results and SimaPro results of another camera model would have verified the model further. The model has been developed in close cooperation with the commissioner and is therefore considered validated even if no circumstantial validation has been done.

Regarding CO_2 and energy the model differs more than for the three different damage categories (HH, EQ and R) and the final single score. Since SimaPro does not summarize the CO_2 emissions and energy used during the life cycle as total values the incorrectness is probably due to miscalculations, despite many checks.

If time would have allowed the platform would have been validated as well. Today the platform is not validated by the product designers, who are the ones expected to use it. But the delivered platform is not static and can be modified any time. Updating the platform will however always be a delayed process; the environmental impact of new materials predicted to be used in future products is usually unknown until they have existed for a period of time. There are no indicators yet to compare the environmental performance of newly designed materials. It is therefore uncertain how useful the platform will be; instead the designer may have to actively search for information on the environmental impact from a prospect material and determine based on their own judgment if the material can be used in good conscience.

11. CONCLUSIONS

The overall conclusions of the thesis are here presented in bullet points.

- The aims and objectives of the thesis are considered fulfilled.

- The knowledge regarding the environmental impact from Axis developed and produced products are considered increased.

- Utilization is responsible for the major part of the total environmental impact caused by the camera during its life cycle.

- Customized tools, in form of a model for conducting simplified LCAs and a platform to enhance LCA-thinking in the product development, are expected to facilitate and assist in Axis's environmental work.

- The results carried out by the model for AXIS Q6032-E is 0.24% accurate (compared to the results of the case study LCA.) Regarding CO_2 the error margin is -0.83%.

- The platform will allow for product developers at Axis to systematically make environmentally aware choices in their work.

- It is possible to communicate LCA results to a customer (if done with transparency).

12. RECOMMENDATIONS

Below follow future recommendations based on the thesis as a whole; the LCA case study, the model and the platform.

Implementing the LCA in the organization is brought up in the theoretical framework of this thesis. Having clear internal tools for conducting LCAs is fulfilled with the model and the platform.

Ideally, an organization also has its own data inventories for processes and materials, in addition to external databases. More time is required to fulfill the task of creating an own database, though, and it falls outside of the scope of this thesis. It is recommended that an own database is created in the future. It does not exclude the use of general databases but some materials and processes used by Axis are not available in general databases. Fetching own values should be considered for those materials and processes not likely to be exchanged for others in the near future. An own database requires directions on how and when to update it though.

Standards on how, to whom and when to apply life cycle assessments are only vaguely defined because they may be changed by Axis in case of reorganizations. The model will foremost be used by the environmental and quality engineers at Axis. As for the platform it is highly recommended that an engineer in each product development project is assigned to be responsible for the LCA platform in order for it to be used properly and for the results to be documented for future interests.

The results are mainly for internal use. Generously sharing and spreading the results within the company could have a positive effect on the environmental concern of the employees by showing the company's interest in the products' environmental performance. Further, the results of the LCA could be used as an inspiration in setting the company's environmental goals and in further developing the environmental policy. If requested by a customer the results may be communicated. Using the results in commercial contexts however is not encouraged because of difficulties with transparency when communicating information to a big target group. To be able to compare the LCA results with those of competitors a common LCA framework, goal and scope, has to be agreed upon. A future recommendation is conducting such a framework.

Implementing LCA is an iterative work. Therefore it is recommended that Axis conduct an updated LCA on a new product sometime in the few coming years. Since Axis is interested in the emitted CO_2 and total amount of energy consumed there could be a better suited tool which provides the user with that information direct. Other software tools should be considered.

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APPENDIX A. SIMA PRO IN PICTURES

This is a selection of pictures from SimaPro while conducting the case study LCA, Figure I – IV.

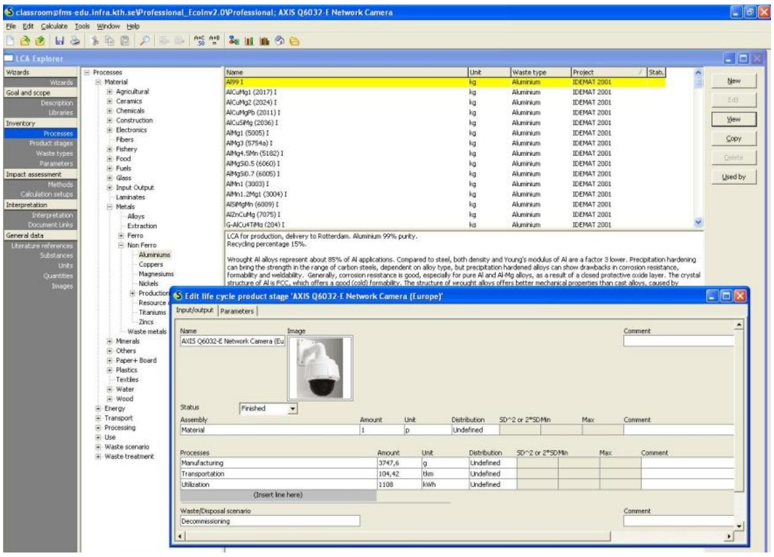
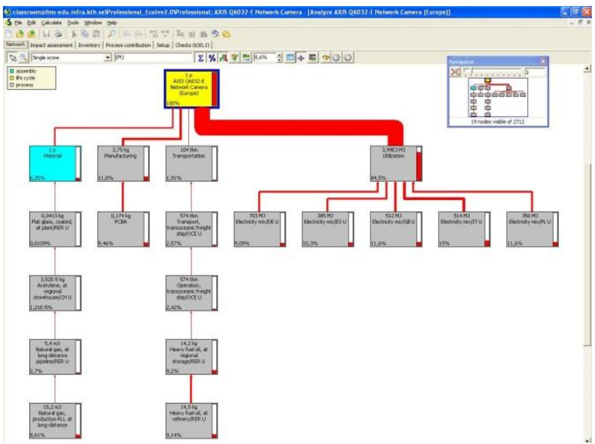


Figure I. The explorer view in SimaPro.



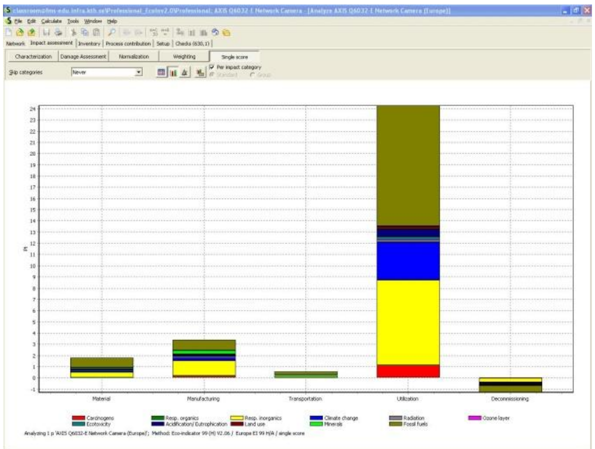
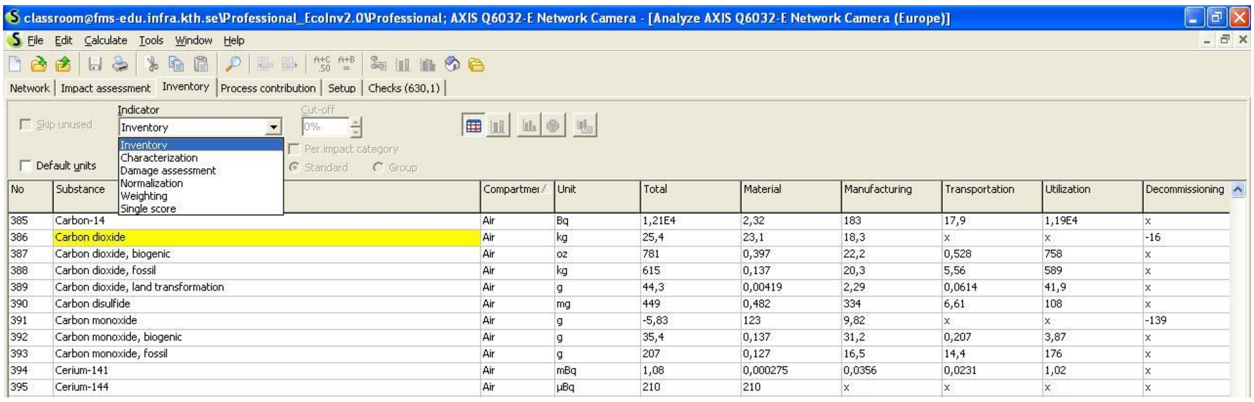


Figure II. The network view in SimaPro.

Figure III. The single score view in SimaPro.



No	Substance	Compartment	Unit	Total	Material	Manufacturing	Transportation	Utilization	Decommissioning
385	Carbon-14	Air	Bq	1,21E4	2,32	183	17,9	1,19E4	x
386	Carbon dioxide	Air	kg	25,4	23,1	18,3	x	x	-16
387	Carbon dioxide, biogenic	Air	oz	781	0,397	22,2	0,528	758	x
388	Carbon dioxide, fossil	Air	kg	615	0,137	20,3	5,56	589	x
389	Carbon dioxide, land transformation	Air	g	44,3	0,00419	2,29	0,0614	41,9	x
390	Carbon disulfide	Air	mg	449	0,482	334	6,61	108	x
391	Carbon monoxide	Air	g	-5,83	123	9,82	x	x	-139
392	Carbon monoxide, biogenic	Air	g	35,4	0,137	31,2	0,207	3,87	x
393	Carbon monoxide, fossil	Air	g	207	0,127	16,5	14,4	176	x
394	Cerium-141	Air	mBq	1,08	0,000275	0,0356	0,0231	1,02	x
395	Cerium-144	Air	µBq	210	210	x	x	x	x

Figure IV. The inventory list in SimaPro showing the total amount of CO_2 allocated on the different life cycle categories.

APPENDIX B. PHOTOS OF CAMERA COMPONENTS

The three different assemblies of the camera, disaggregated. All screws contained are showed separately, Figure V – VIII.

Confidential information

Figure V. Components within Unit assembly

Confidential information

Figure VI. Components within Outer chassis assembly

Confidential information

Figure VII. Components within Dome module assembly

Confidential information

Figure VIII. Screws within the camera

APPENDIX C. DATA SOURCES

All data used to conduct the case study LCA of the network camera AXIS Q6032-E are collected in this appendix called Data Sources, Table I – V. It is allocated on the different life cycle categories with specified amount, unit, data type, name of the process in SimaPro, data source (name of the library in SimaPro), the year when the data were collected, and the region it is from. The abbreviations in the Data Type field have the following meanings: C=calculated, E=estimated, M=measured. Descriptions of the data used in SimaPro are available in Table VI.

Table I. The data for the life cycle category Raw Material Extraction and Processing.

	Phase	Amount	Unit	Data Type	Process	Data source	Year	Region
Raw material								
1	Aluminum-Alloy			M		IDEMAT 2001	assumed late 90'	Europe
2	Glass			M		ETH-ESU 96 Unit Processes	1996	Western European
3	Packaging							
4	Cardboard			M		BUWAL 250	1993	Europe
5	Bubbel plastic			M		ETH-ESU 96 Unit Processes	1992	Europe
6	Expandable polystyrene	Confidential information		M	Confidential information	Industry data 2.0	-	-
7	Plastic 1			C/M		IDEMAT 2001	1992-1994	Europe
8				C/M		IDEMAT 2001	1995	Europe
9	Plastic 2			M		IDEMAT 2001	1992-1994	Europe
10	Silicone			M		Ecoinvent Unit Processes	1997-2001	Europe
11	Stainless Steel			M		IDEMAT 2001	assumed late 90'	Europe
12	Steel			M		IDEMAT 2001	assumed late 90'	Europe

Table II. The data for the life cycle category Manufacturing. Here is also the material data for the cable and PCBA included.

	Phase	Amount	Unit	Data Type	Process	Data source	Year	Region
	Manufacturing							
13	Assembling (Burn in and screw driver)	0,616	kWh	V	Electricity, medium voltage, production PL, at grid	Ecoinvent Unit Processes	1992-2004	Poland
14	Cable	16	g	E/M	Cable, ribbon cable, 20-Pin, with plugs, at plant/GLO U	Ecoinvent Unit Processes	2000-2006	Global
15	General aluminum manufacturing (Casting)	1954	g	C/M	Aluminium product manufacturing, average metal working/RER U	Ecoinvent Unit Processes	2006-2007	Europe
16	General glass manufacturing	38	g	C/M	Tempering flat glass/ RER U	Ecoinvent Unit Processes	-	Europe
17	General silicone manufactruing	46,88	g	C/M	Injection molding/RER U	Ecoinvent Unit Processes	1993-1997	Europe
18	General steel manufacturing	716,34	g	C/M	Steel product manufacturing, average metal working/RER U	Ecoinvent Unit Processes	2006-2007	Europe
19	Injection molding	573	g	C/M	Injection molding/RER U	Ecoinvent Unit Processes	1993-1997	Europe
20	PCBA (with composition per kilo according to below)	174	g	M				
21	Assembling PCBA	37,2	kWh/kg	V	Electricity, medium voltage, production PL, at grid	Ecoinvent Unit Processes	1992-2004	Poland
22	0,3 Battery	0,0016	/kg	C	Battery, LiIo, rechargeable, prismatic, at plant	Ecoinvent Unit Processes	2002-2006	Global
23	Capacitor	0,066	/kg	C	Capacitor, SMD type, surface-mounting, at plant	Ecoinvent Unit Processes	1994-2007	Global
24	Connector	0,0042	/kg	C	Connector, PCI bus, at plant	Ecoinvent Unit Processes	2004-2006	Global
25	Diode	0,015	/kg	C	Diode, glass-, SMD type, surface mounting, at plant	Ecoinvent Unit Processes	1994-2007	Global
26	Emission-Acetone	0,007	/kg	V	Output Acetone			
27	Emission- Isopropyl alcohol	0,046	/kg	V	Output Isopropyl acetate			
28	Ferrite	0,0015	/kg	C	Ferrite, at plant	Ecoinvent Unit Processes	1998-2006	Global
29	IC	0,021	/kg	C	Integrated circuit, IC, logic type, at plant	Ecoinvent Unit Processes	2000-2006	Global
30	Inductor	0,046	/kg	C	Inductor, ring core choke type, at plant	Ecoinvent Unit Processes	1994-2007	Global
31	PCB	0,685	/kg	C	Printed board	IDEMAT 2001	1995-1999	Western Europe
32	Resistor	0,0025	/kg	C	Resistor, SMD type, surface mounting, at plant	Ecoinvent Unit Processes	1994-2007	Global
33	Transformator	0,15	/kg	C	Transformer, low voltage use, at plant	Ecoinvent Unit Processes	1994-2007	Global
34	Transistor	0,0072	/kg	C	Transistor, SMD type, surface mounting, at plant	Ecoinvent Unit Processes	1994-2007	Global

Table III. The data for the life cycle category Transportation; EU and U.S. figures separated.

	Phase	Amount	Unit	Data Type	Process	Data source	Year	Region
	Transportation							
	Europe as final destination							
35	Air	0	tkm	E/S	Transport, aircraft, freight, intercontinental, RER	Ecoinvent Unit Processes	2000	Europe
36	Boat	78,95	tkm	E/S	Transport, transoceanic freight ship	Ecoinvent Unit Processes	1992-2000	Internationel
37	Road	25,47	tkm	E/S	Transport, lorry 20-28t, fleet average	Ecoinvent Unit Processes	2005	Swiss
	U.S. as final destination							
38	Air	58,99	tkm	E/S	Transport, aircraft, freight, intercontinental, RER	Ecoinvent Unit Processes	2000	Europe
39	Boat	78,95	tkm	E/S	Transport, transoceanic freight ship	Ecoinvent Unit Processes	1992-2000	Internationel
40	Road	31,73	tkm	E/S	Transport, lorry 20-28t, fleet average	Ecoinvent Unit Processes	2005	Swiss

Table IV. The data for the life cycle category Utilization. First the EU by country and the U.S. last.

	Phase	Amount	Unit	Data Type	Process	Data source	Year	Region
	Utilization							
41	*Electricity Europé (EU)*	1108	kWh	C,E,M				
42		0,017	/kWh		Electricity mix, AT	Ecoinvent Unit Processes	2004	Austria
43		0,022	/kWh		Electricity mix, BE	Ecoinvent Unit Processes	2004	Belgium
44		0,022	/kWh		Electricity mix, CZ	Ecoinvent Unit Processes	2004	Chez Republik
45		0,173	/kWh		Electricity mix, DE	Ecoinvent Unit Processes	2004	Germany
46		0,011	/kWh		Electricity mix, DK	Ecoinvent Unit Processes	2004	Denmark
47		0,095	/kWh		Electricity mix, ES	Ecoinvent Unit Processes	2004	Spain
48		0,011	/kWh		Electricity mix, FI	Ecoinvent Unit Processes	2004	Finland
49		0,127	/kWh		Electricity mix, FR	Ecoinvent Unit Processes	2004	France
50		0,127	/kWh		Electricity mix, GB	Ecoinvent Unit Processes	2004	United Kingdom
51		0,023	/kWh		Electricity mix, GR	Ecoinvent Unit Processes	2004	Greece
52		0,021	/kWh		Electricity mix, HU	Ecoinvent Unit Processes	2004	Hungary
53		0,009	/kWh		Electricity mix, IE	Ecoinvent Unit Processes	2004	Ireland
54		0,124	/kWh		Electricity mix, IT	Ecoinvent Unit Processes	2004	Italy
55		0,001	/kWh		Electricity mix, LU	Ecoinvent Unit Processes	2004	Luxenburg
56		0,034	/kWh		Electricity mix, NL	Ecoinvent Unit Processes	2004	Netherlands
57		0,081	/kWh		Electricity mix, PL	Ecoinvent Unit Processes	2004	Poland
58		0,022	/kWh		Electricity mix,PT	Ecoinvent Unit Processes	2004	Portugal
59		0,045	/kWh		Electricity mix, RO	Ecoinvent Unit Processes	2004	Romania
60		0,020	/kWh		Electricity mix, SE	Ecoinvent Unit Processes	2004	Sweden
61		0,004	/kWh		Electricity mix, SI	Ecoinvent Unit Processes	2004	Slovenia
62		0,011	/kWh		Electricity mix, SK	Ecoinvent Unit Processes	2004	Slovak Republic
63	*Electricity U.S.*	1108	kWh	C,E,M	Electricity mix/ US U	Ecoinvent Unit Processes	2004	U.S.

Table V. Data for the life cycle category Decommissioning.

	Phase		Amount	Unit	Data Type	Process	Data source	Year	Region
	Decommissioning								
64	Aluminum	Recycling	100	%	E, S	Recycling Aluminium B250	BUWAL250	-	-
65	Cardboard	Recycling	100	%	E	Recycling paper B250	BUWAL250	-	-
66	Glass	Landfill	100	%	E, S	Landfill Glass B250 (1998)	BUWAL250	1995 updated 1998	Europé
67	Remaining product (PCBA, cable, silicon)								
68		Incineration	55	%	E	Incin. PE 1995 B250 (98)	BUWAL250	1995	Europé
69		Landfill	45	%	E	Landfill PE B250	BUWAL250	1995	Europé
70	Plastics								
71		Landfill	12	%	E, S	Landfill PS B250	BUWAL250	1995	Europé
72		Recycling	88	%	E, S	Recycling Plastics (excl. PVC) B250	BUWAL250	-	-
73	Plastics packaging		100	%	E, S	Recycling Plastics (excl. PVC) B250	BUWAL250	-	-
74	Steel	Recycling	100	%	E, S	Recycling ECCS Steel	BUWAL250	-	-

Table VI. This table gives detailed information about the data used in the Sima Pro.

Data Scope

	Raw Material
1	Confidential information
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
	Manufacturing
13	Included are the electricity production in Poland, the transmission network and direct SF6-emissions to air. Electricity losses during medium-voltage transmission and transformation from high-voltage are accounted for.
14	Describes the production of a typical ribbon cable with connectors for a desktop computer. Calculated per 1 kg of ribbon cable. Included are the materials copper, brass, PVC and HDPE with their attributed manufacturing processes like wire drawing or extrusion. The infrastructure is calculated via the proxy "electronic component production plant". Further inventoried are the electricity for the assembly of the connector, the fuel oil, propane and water input, the disposal of plastic and rubber parts, the VOC and methanol emissions created during the processing, plus the road and rail transportation for input materials from the regional storage to the production site. The accumulated hazardous waste is also reported.
15	This dataset encompasses manufacturing processes to make a semi-manufactured product into a final product. It includes average values for the processing by machines as well as the factory infrastructure and operation. Furthermore, an additional aluminium input is considered for the loss during processsing. Degreasing is not included and has to be added if necessary. Average data from several loval to global sized companies
16	No appropriate data at hand. This is a process that make the glass stronger.
17	Contains the auxillaries and energy demand
18	This dataset encompasses manufacturing processes to make a semi-manufactured product into a final product. It includes average values for the processing by machines as well as the factory infrastructure and operation. Furthermore, an additional steel input is considered for the loss during processsing. Degreasing is not included and has to be added if necessary.
19	Contains the auxillaries and energy demand
20	
21	Included are the electricity production in Poland, the transmission network and direct SF6-emissions to air. Electricity losses during medium-voltage transmission and transformation from high-voltage are accounted for.
22	Including material, (Raw) materials, transport efforts, infrastructure, energy consumption and waste disposal for the production of a LiIo rechargable battery. No emissions to air or water are taken into account.
23	Including material and production efforts for the production of currently used SMD capacitors for surface mounting technology.
24	This dataset covers raw material input, energy consumption, infrastructure and transport efforts for the production of PCI bus type connectors.
25	Including material and production efforts for the production of currently used SMD diodes for surface mounting technology.
26	
27	
28	Including material, This module is a rough estimation of the composition by including raw materials, energy consumption, infrastructure, and transport efforts. Waste as well as all kind of emissions are not taken into account.
29	Including material, Describes all the processes required to produce a logic type microchip. Included are 'die separation', 'encapsulation', 'die attachment', 'lead bonding', 'plating', and 'marking'. These operations are represented by the material input of glass epoxy, metals, epoxy resin, doped silicon, glue, gold (wires) etc. and the assembly process energy used.The required the infrastructure, and the ship, train and road transport are also inventoried. Calculated for 1 kg of packaged logic IC.

Table VI. continued.

30	Covers raw material input and production efforts for the production of currently used ring core choke type inductors.
31	Including material
32	Including material, This dataset covers raw material input and production efforts for the production of currently used SMD resistors for surface mounting technology.
33	This dataset covers raw material input and production efforts for the production of power transformers used in the low voltage area, i.e. in an area of 5 up to about 25 V.
34	Including material, This dataset covers raw material input and production efforts for the production of currently used SMD transistors for surface mounting technology.
	Transportation
	Europe as final destination
35	Inventory refers to the entire transport life cycle (Operation and production of aircraft, construction and land use of airport; operation, maintenance and disposal
36	The module calls the modules addressing: operation of vessel; production of vessel; construction and land use of port; operation, maintenance and disposal of port.
37	Inventory refers to the entire transport life cycle. Operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road
	U.S. as final destination
38	Inventory refers to the entire transport life cycle (Operation and production of aircraft, construction and land use of airport; operation, maintenance and disposal
39	The module calls the modules addressing: operation of vessel; production of vessel; construction and land use of port; operation, maintenance and disposal of port.
40	Inventory refers to the entire transport life cycle. Operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road
	Utilization
41	It includes the shares of domestic electricity production by technology and imports from neighbouring countries (production mixes) at the busbar. It does not include transformation, transport nor distribution losses. Data apply to public and self producers in the specific country.
42	It includes imports from Switzerland, Czech Republic, Germany Hungary and Slovenia. Wind power plants are Swiss averages.
43	It includes imports from France and the Netherlands. Nuclear power plants are averages of UCTE countries other than CH, DE and FR. Wind power plants are RER (Europe) averages.
44	It includes imports from Austria, Germany, Poland and Slovak Republic. Natural gas, industrial gas and nuclear power plants are modelled using CENTREL (Central Europé) and UCTE averages, respectively.
45	It includes imports from Switzerland, Czech Republic, Denmark, France, Luxemburg, the Netherlands, Austria, Poland and Sweden. Wind power plants are an RER average. Photovoltaic power plants are modelled using Swiss conditions.
46	It includes imports from Norway, Sweden and Germany. Hard coal and natural gas power plants are modelled using NORDEL averages.
47	It includes imports from France and Portugal. Nuclear power plants are averages of UCTE countries other than CH, DE and FR. Wind power plants are RER (Europe) averages. Photovoltaic power plants are modelled using Swiss conditions.
48	It includes imports from Norway, Sweden and Russia. Peat power plants are modelled using average NORDEL (North of Europe) peat power plants. Hard coal, natural and industrial gas and nuclear power plants are modelled using NORDEL averages.
49	It includes imports from Belgium, Switzerland, Germany, Spain and Italy. Wind power plants are an RER average.
50	It includes imports from France. All power plants are modelled using UCTE averages except oil and natural gas power plants which represent a UK average.
51	It includes imports from Albania, Bulgaria and Former Yugoslav Republic of Macedonia. Natural gas and wind power plants are UCTE and RER averages respectively.
52	It includes imports from Austria, Slovak Republic and Ukraine. Natural gas, industrial gas and nuclear power plants are modelled using CENTREL and UCTE averages, respectively.
53	It includes imports from Great Britain. All power plants are modelled using UCTE averages except oil power plants which represent an Irish average. Peat power plant is modelled using a NORDEL average peat power plant.
54	It includes imports from Austria, Switzerland, France and Slovenia. Wind power plants are an RER average. Photovoltaic power plants are modelled using Swiss conditions.

Table VI continued.

55	It includes imports from Belgium and Germany. Wind power plants are an RER average.
56	It includes imports from Belgium and Germany. Nuclear power plants are averages of UCTE countries other than CH, DE and FR. Wind power plants are RER averages. Photovoltaic power plants are modelled using Swiss conditions.
57	It includes imports from Germany, Czech and Slovak Republic, Sweden and Ukraine. Natural gas, industrial gas and nuclear power plants are modelled using CENTREL and UCTE averages, respectively. Oil power plant is modelled using Czech average oil power plant.
58	It includes imports from Spain. Natural and industrial gas and wind power plants are UCTE and RER averages, respectively. Photovoltaic power plants are modelled using Swiss conditions.
59	It includes imports from Serbia, Hungary, Bulgaria, Ukraine and Moldova. (Ukraine and Moldova are approximated with the UCTE-Mix). Natural gas, industrial gas and nuclear power plants are modelled using CENTREL and UCTE averages, respectively. Oil and hydro power plants are modelled using SK-Data.
60	It includes imports from Denmark, Finland, Norway, Germany and Poland. Peat power plants are modelled using average NORDEL lignite power plants. Hard coal, natural and industrial gas and nuclear power plants are modelled using NORDEL and UCTE averages, respectively.
61	It includes imports from Austria, Italy and Croatia. Natural gas power plants are UCTE averages. Nuclear power plants are averages of UCTE countries other than CH, DE and FR.
62	It includes imports from Czech Republic, Poland and Ukraine. Natural gas, industrial gas and nuclear power plants are modelled using CENTREL and UCTE averages, respectively.
63	It includes the shares of domestic electricity production by technology and imports from neighbouring countries (described by their production mixes) at the busbar of power plants. It does not include transformation, transport nor distribution losses. Remark: Electricity domestic net production and import shares are based on year 2004 data. US-specific datasets for electricity production are only available in ecoinvent v2.0 for hard coal, nuclear, natural gas, and photovoltaic power plants (though with different modelling characteristics), which accounted together for about 85% of US electricity supply in year 2004. Other technologies are modeled using European datasets as first approximation. Electricity imports from Canada and Mexico were less than 1% of US electricity supply in 2004. Due to lack of datasets for these countries, electricity imports are modeled using for the different technologies the same datasets as for the US.
	Decommissioning
64	Data for the recycling of Aluminum. This waste treatment process is not part of the original BUWAL250 study and is not reviewed by EMPA.
65	
66	Final disposal of glass packaging waste in a landfill for municipal waste according to present technology (1995). Includes waste collection, waste water treatment, sludge treatment by landfarming and sludge incineration and energy recovery from biogas.
67	
68	Specific for Switzerland. Does not take "avoided emissions" into account.
69	Specific for Switzerland. Updated 1998.
70	
71	Final disposal of PS packaging waste in a landfill for municipal waste according to present technology. Includes waste collection, waste water treatment, sludge treatment by landfarming and sludge incineration and energy recovery from biogas.
72	Recycling of plastic houshold waste. This waste treatment process is not part of the original BUWAL250 study and is not reviewed by EMPA.
73	Recycling of plastic houshold waste. This waste treatment process is not part of the original BUWAL250 study and is not reviewed by EMPA.
74	Data for recycling of ECCS steel. Avoided product is ECCS steel. his waste treatment process is not part of the original BUWAL250 study and is not reviewed by EMPA.

APPENDIX D. QUESTIONNAIRES

This appendix contains the questionnaires used to collect data from manufacturers and suppliers during the LCI, Figure IX – XII.

LCA Questionnaire for product process or assembly

This is a gate to gate questionaire to collect inventory data from your process.
It will be used in conjunction with data from all manufacturers of components to the Axis Q6032-E Network Camera.
The Life Cycle Assessment aims to map the environmental performance of this specific camera.

* Please fill in data in the blue cells below
* Text in pink serve as example, please erase
* Data should be compiled on annual basis for latest complete year
* Do not include inputs/outputs associated with the facility
* Where inputs/outputs are shared by multiple products estimate the contribution for which this product is responsible
* When material declarations are accessible its most relevant information has been added, but please check and update if incorrect
* Specify data type in the right column: M=Measured, C=Calculated, A=Average, E=Estimated, U=Unknown
* Please contact us at hanna.hillerstrom@axis.com if you need assistance
* Feel free to alter worksheet (units, rows etc) to make the worksheet fit your process
* Use comment fields to note uncertainties or peculiarities

Send completed questionnaire to:
hanna.hillerstrom@axis.com

Thank you for your cooperation!

Manufacturer	[Name of manufacturer]
Country, City	[Location of manufacturer]
Item Number and Name	[Questionnaire applies to production of]
Describe the product's way through the production process and include the methods of manufacturing.	[Brief description of the production process]
Name Surname, e-mail	[Your name and contact details]

Output to technosphere from this process	Annual output [qty]*	Weight [kg/entity]	Data type
Item Number and Name			

***This information is critical for calculating resource/emissions use per unit of production**

Figure IX. Manufacturer questionnaire, first page.

Process inputs in production of this specific product

Inputs from nature, *reources*	Annual input	Unit	Data type
Water	7 000 000	liter	M
Aluminium	600 000	kg	M

Inputs from technosphere

Materials, *not naturally existing in nature; human produced*	Annual input	Unit	Data type
AlMg	502 000	kg	C
ABS-plastic	440 000	kg	A

Electricity by fuel, *energy use associated with the production of this specific product*	Annual input	Unit	Data type
Coal power plant	350 000	kWh	E
Nuclear power plant	298 000	TJ	M

Process outputs

Emissions to air	Annual amount	Unit	Data type
CO2	130 150	kg	M
SOx			
NOx			
VOCs (Volatile Organic Compounds)			
Radiation, electromagnetic			

Emissions to water	Annual amount	Unit	Data type
CO	10 790	kg	M
BOD (Biological Oxygen Demand)			
COD (Chemical Oxygen Demand)			
Pb			

Waste	Annual amount	Unit	Data type
Residues	50 000	kg	E
Aluminum waste	3059	kg	M

Comments

Figure X. Manufacturer questionnaire, second page.

LCA Questionnaire for product supply

This is a gate to gate questionaire to collect inventory data from your transportation process.
It will be used in conjunction with data from all suppliers of components to the Axis Q6032-E Network Camera.
The Life Cycle Assessment aims to map the environmental performance of this specific camera.

* Please fill in data in the blue cells below
* Text in pink serve as example, please erase
* Data should be compiled on annual basis for latest complete year
* Where inputs/outputs are shared by multiple products estimate the contribution for which this product is responsible
* Specify data type in the right column:
  M=Measured, C=Calculated, A=Average, E=Estimated, U=Unknown
* Please contact us at hanna.hillerstrom@axis.com if you need assistance
* Feel free to alter worksheet (units, rows etc) to make the worksheet fit your transportation
* Use comment fields to note uncertainties or peculiarities

Send completed questionnaire to:
hanna.hillerstrom@axis.com

Thank you for your cooperation!

Supplier	[Name of supplier]
From?	[Transportation: FROM]
To?	[Transportation: TO]
Item Name and Number	[Questionnaire applies to transportation of]
Name Surname, e-mail	[Your name and contact details]

Figure XI. Supplier questionnaire, first page.

Transportation routes (all routes should be included, regardless of distance)

From	To	Means of transportation*	Type of fuel	Travel distance [km]	Return trip empty [YES/NO]	Data type
Location of Manufacture	Airport X	Truck 16t	ethanol	27	YES	A
Airport X	Airport Y	Airplane intercontinental	diesel	5030	NO	M
Airport Y	Location of Assembly Facility	Container ship	diesel		NO	E

***Please be as specific as possible, e.g. Truck could be Truck 28t and Boat could be Containership**

Comments

Figure XII. Supplier questionnaire, second page.

APPENDIX E. TRANSPORTATION

Detailed information on inbound and outbound transportation; giving the purpose of transportation, location of the sender and the receiver, the weight of the item being transported, the distance of each route, the packaging factor to include packaging material in the LCA, the tkm traveled, means of transportation and data type. The information is divided into inbound and outbound transportations, Table VII & VIII respectively. Google Maps is used to measure the distances.

Table VII. Overview of the inbound transportations routes, estimated and mapped.

Category	From	To	Weight (g)	Distance (km)	Transportation weight factor	tkm	Means of transportation	Data Type	Supplier	Item
Material to component manufacturing	Extraction	Processing	3570*1	1500	1,1	5,89	Road	E		
	Processing	Component manufacturing	3570*1	1500	1,1	5,89	Road	E		
Components to assemling	London, UK	Sieradz, Poland	543	1513	1,2	0,98	Road	S		
	Penang, Malaysia	Hamburg, Germany	81	16093	1,2	1,56	Water	S		
	Selangor, Malaysia	Hamburg, Germany	151	16093	1,2	2,92	Water	S		
	Tokyo, Japan	Hamburg, Germany	236	20921	1,2	5,93	Water	S		
	Selangor, Malaysia	Hamburg, Germany	41	16093	1,2	0,79	Water	S	Confidential information	
	Hamburg, Germany	Sieradz, Poland	509	732	1,2	0,44	Road	S		
	Penang, Malaysia	Ipoh, Malaysia	1516	141	1,2	0,25	Road	S		
	Selangor, Malaysia	Ipoh, Malaysia	220	155	1,2	0,04	Road	S		
	Selangor, Malaysia	Ipoh, Malaysia	249	155	1,2	0,05	Road	S		
	Fuzhou, China	Ipoh, Malaysia	154	2092	1,2	0,38	Water	I		
	Pathumthani, Thailand	Ipoh, Malaysia	128	1307	1,2	0,20	Road	I		
	Other	Assembling	262	6845*2	1,2	1,79	Road	E		
Assemblies to configuration and logistics centre	Sieradz, Poland	Vellinge, Sweden	1 459	914	1,3	1,73	Road	S		
	Vellinge, Sweden	Lund, Sweden	1 459	40	1,3	0,08	Road	S		
	Ipoh, Malaysia	Lund, Sweden	2927	17703	1,3	67,37	Water	I		

E: Estimated I: Axis inside information S: Provided by supplier

*1 Total material weight multiplied with a factor 1,02 for wasted material in manufacturing

*2 Average distance of the compontents transports

Table VIII. Overview of the outbound transportations, both for Europe and the U.S.

Category		From	To	Weight g	Distance km	tkm	Means of transportation	Data Type	Supplier
Europe	Sales unit to distributor	Lund, Sweden	Straubing, Germany	8000	808	6,46	Road	S	Confidential information
	Distributor to customer	Straubing, Germany	Customer	8000	200	1,60	Road	E	
	Customer to disposal	Customer	Disposal	8000	30	0,24	Road	E	
U.S.	Sales unit to distributor	Lund, Sweden	Copenhagen, Denmark	8000	60	0,48	Road	S	
		Copenhagen, Denmark	Airport Atlanta, U.S.	8000	7374	58,99	Air	S	
		Airport Atlanta, U.S.	CLC Axis, Atlanta, U.S.	8000	7,4	0,06	Road	M	
		CLC Axis, Atlanta, U.S.	Distributor	8000	500	4	Road	E	
	Distributor to customer	Distributor	Customer	8000	200	1,6	Road	E	
	Customer to disposal	Customer	Disposal	8000	30	0,24	Road	E	

E: Estimated I: Axis inside information M: Measured S: Provided by supplier

APPENDIX F. TRANSPORTATION TOTAL WEIGHT FACTORS

A factor is calculated to ensure that both packaging and pallet weight is included in the weight for transportation.

Packaging and pallet weights are fetched at a supplier's. The information is summarized in Table IX. Total weight per component includes packaging and pallet weight. It is allocated on each component and a single factor is calculated using Equation I.

$$Packaging\ factor_{Components} = \frac{Total\ weight\ per\ component}{Weight\ per\ single\ component} \quad [I]$$

The final factor 1.2 is calculated as an average value of the five different factors.

Table IX. The information from contract supplier on which the transportation total weight factor for components are based.

Axis specific component number	Weight per single component kg	Weight of one box kg	Components in one box	Approximatly boxes on pallet	Pallet weight kg	Total weight per pallet kg	Total amount of components per pallet	Total weight per component kg	Transportation weight factor for components
Confidential information	0,041	7	176	40	10	290	7040	0,0411	1
	0,543	7	10	20	10	150	200	0,75	1,38
	0,081	4	50	80	10	330	4000	0,0825	1,02
	0,103	2	18	20	10	50	360	0,139	1,35
	0,236	14	50	40	10	570	2000	0,285	1,21
									1,2

The factor for the total weight for transporting assemblies to CLC is set to 1.3. This factor is later on checked, which shows that 1.4 would have been more accurate according to Table X.

Table X. Transportation weight for assemblies when including the weight of the packaging materials and the pallet.

Assembly name	Weight per assembly kg	Weight of one box kg	Assemblies in one box	Boxes per pallet	Pallet weight kg	Total weight per assembly kg	Transportation weight factor for assemblies
Unit Assembly	1,223	1,459	1	24	10	1,88	1,54
Assembly Outher Chassis	1,846	4,339	2	24	10	2,38	1,29
Assembly Dome Module	0,642	3,030	4	24	10	0,865	1,35
							1,4

For the transportation of materials to component manufacturers the factor is estimated to 1.1.

Here follows selected parts from the simplified LCA model developed for network cameras.

Instructions for operating the model are presented on the first sheet, see Figure XIII. In the 'Variables' sheet camera specific data are submitted, see Figure XIV. All grey fields should contain a figure, the ones that do not apply equal zero. If it is difficult quantifying a material or process estimate a value rather than omit it. Note that the energy consumption figure needs to be copied into the appropriate box, either Europe or U.S.

Three types of results are presented in chronological order, each with the same structure. The damage assessment is presented first, followed by the normalized results and thereafter the weighted results. In Figure XV the damage assessment result view from the model is showed. The underlying data are summarized in the 'Data' sheet in the model, see Figure XVI.

The results are consistently presented with same structure:

1st page:	The results summarized per impact/damage category in tables.
	A short description of how each result should be read follows each presentation.
2nd page:	The results of every impact/damage category for each scenario
3rd page:	The results from page 2 presented in graphs to facilitate interpretation.

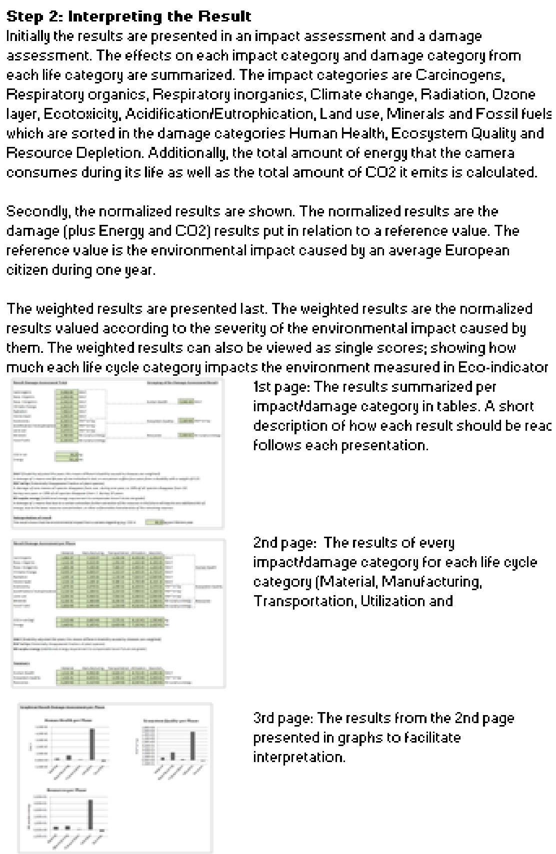


Figure XIII. Part of 'Operating Instructions Step-by-Step'.

Variables

Raw Material Extraction and processing

Weight	1,42622	kg	[Remaining product weight after subtracting the weight of the Chassis, PT and PCBA]
Chassis Al	1,24	kg	
Chassis Plastic	0	kg	[Fill in for the appropriate material of the Chassis, put zeros in the remaining two fields]
Chassis Zink	0	kg	
PT	0,515	kg	[Equals zero if there is no PT]
Dome	0,153	kg	
Packaging	3,3	kg	[Atomatically calculated when the total weight is defined (below), equals 95% of the total weight (according to the AXIS Q6032-E)]

Manufacturing

Weight	1,42622	kg	[This five green boxes are the same as above and automatically adopt the same values. Do not change them.]
Al manufacturing	1,24	kg	
Injection moulding	0,153	kg	
Zink manufacturing	0	kg	
PT	0,515	kg	
Weight of PCBA	0,174	kg	[Include only the PCBA designed by Axis, not the ones in the camera module]

Transportation [Include transportation from contract manufacturer to CLC and from CLC to distributor. Other routes are constant]

Air	0	tkm	[tkm: multiply the weight expressed in tonnes by the distance expressed in km]
Road	8,27	tkm	
Water	67,37	tkm	

Figure XIV. An extract from the 'Variables' sheet.

Result Damage Assessment per Phase

	Material	Manufacturing	Transportation	Utilization	Decomm.		
Carcinogens	1,08E-07	7,22E-07	1,23E-08	4,35E-06	-1,35E-07	DALY	Human Health
Resp. Organics	2,21E-09	6,62E-09	1,05E-09	1,42E-08	-4,20E-09	DALY	
Resp. Inorganics	1,80E-06	5,28E-06	7,46E-07	2,90E-05	-1,43E-06	DALY	
Climate Change	6,03E-07	8,86E-07	1,21E-07	1,30E-05	-4,72E-07	DALY	
Radiation	4,50E-10	1,20E-08	1,13E-09	7,82E-07	0,00E+00	DALY	
Ozone layer	3,21E-10	2,18E-10	9,38E-11	2,75E-09	-8,21E-10	DALY	
Ecotoxicity	1,87E-02	2,07E-01	1,59E-02	4,10E-01	-2,57E-02	PDF*m^2yr	Ecosystem Quality
Acidification/ Eutrophication	5,11E-02	1,38E-01	3,21E-02	7,99E-01	-3,26E-02	PDF*m^2yr	
Land use	8,20E-02	9,96E-02	7,95E-03	3,58E-01	0,00E+00	PDF*m^2yr	
Minerals	6,15E-01	1,38E+00	8,23E-03	1,81E-01	-3,98E-01	MJ surplus energy	Resources
Fossil fuels	3,65E+00	3,94E+00	1,15E+00	4,51E+01	-2,58E+00	MJ surplus energy	

CO2 in air [kg]	2,31E+00	3,86E+00	5,57E-01	6,11E+01	-1,59E+00	kg
Energy	3,44E+01	5,16E+01	8,40E+00	7,15E+02	-2,42E+01	MJ

Figure XV. The model view from ‘Damage assessment result’ sheet.

[Data for sheet "Result Damage Assessment"]

	Raw Material Extraction and Production						
	Remaining product 1 kg	Chassis Aluminum 1 kg	Chassis Plastic 1 kg	Chassis Zink 1 kg	PanTilt 1 kg	Dome 1 kg	Packaging 1 kg
Carcinogens	1,91E-07	4,50E-07	2,09E-08	2,31E-07	2,02E-07	1,80E-08	1,93E-08
Resp. Organics	3,52E-09	3,04E-09	6,62E-09	1,98E-09	2,25E-09	9,79E-09	2,97E-09
Resp. Inorganics	3,37E-06	6,51E-06	2,30E-06	3,62E-06	3,07E-06	4,15E-06	5,12E-07
Climate Change	1,12E-06	2,15E-06	8,38E-07	7,93E-07	9,67E-07	1,28E-06	2,07E-07
Radiation	3,39E-10	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,20E-09
Ozone layer	2,03E-10	3,47E-10	0,00E+00	1,80E-10	1,32E-10	0,00E+00	7,10E-10
Ecotoxicity	2,86E-02	4,41E-02	1,10E-03	2,82E-01	4,04E-02	3,39E-03	1,83E-02
Acidification/ Eutrophication	9,94E-02	1,63E-01	9,14E-02	1,18E-01	8,80E-02	1,56E-01	1,98E-02
Land use	1,58E-01	3,48E-01	3,13E-02	1,38E-01	1,76E-01	3,36E-02	1,85E-03
Minerals	1,09E+00	2,85E+00	2,82E-04	5,24E+00	1,12E+00	3,82E-04	1,90E-03
Fossil fuels	6,53E+00	9,09E+00	9,49E+00	4,09E+00	4,17E+00	1,16E+01	3,03E+00
CO2 in air	4,35E+00	7,91E+00	3,67E+00	3,52E+00	3,68E+00	5,60E+00	8,64E-01
Energy	6,40E+01	9,83E+01	7,06E+01	4,38E+01	5,14E+01	8,47E+01	2,16E+01

Figure XVI. Part of the ‘Data’ sheet in the model.

APPENDIX H. THE PLATFORM

This appendix shows an extract of the platform.

The platform is developed to be used in product development processes to improve a product's environmental impact. The platform is intended for the design engineer, facilitating incorporation of environmental aspects in the choice of materials, type of manufacturing, and possible disposal scenarios depending on material. There are three separated stages, material (extraction and processing), manufacturing, and disposal, which contain fields to be filled in where applicable for the product. An amount, expressed in different units depending on stage, is multiplied with a specified indicator resulting in points, mPt. If desired, the points are added together in the right column resulting in one final score. Figure XVII shows a part of the platform.

Disposal (Material and process)		Amount (kg)	Indicator	Result	
Recycling of waste	Recycling PE		-240	0	*1 If not mixed with other plastics
	Recycling PP		-210	0	*1 If not mixed with other plastics
	Recycling PS		-240	0	*1 If not mixed with other plastics
	Recycling PVC		-170	0	*1 If not mixed with other plastics
	Recycling Glas		-15	0	*1 Recycling avoids virgin glass production
	Recycling Aluminium		-720	0	*1 Recycling avoids primary aluminum
	Recycling Ferro metals		-70	0	*1 Recycling avoids primary steel production
Incineration	Incineration PE		-19	0	*1 Indicator can be used for both HDPE and LDPE
	Incineration PP		-13	0	*1
	Incineration PS		-5,3	0	*1 Relatively low energy yield, can also be used for ABS, HIPS, GPPS, EPS
	Incineration PVC		37	0	*1 Relatively low energy yield
	Incineration PVDC		66	0	*1 Relatively low energy yield
	Incineration Steel		-32	0	*1 40% magnetic separation for recycling, avoiding crude iron (European average)
	Incineration Aluminum		-110	0	*1 15% magnetic separation for recycling, avoiding primary aluminum
	Incineration Glass		5,1	0	*1 Almost inert material, indictor can be used for other inert materials
Landfill	Landfill PE		3,9	0	*1
	Landfill PP		3,5	0	*1
	Landfill PS		4,1	0	*1 Indicator can also be used for landfill of ABS
	Landfill PVC		2,8	0	*1 Excluding leaching of metal stabilizer
	Landfill PVDC		2,2	0	*1
	Landfill Glass		1,4	0	*1 Almost inert material, indicator can also be used for other inert materials
	Landfill Steel		1,4	0	*1 Almost inert material on landfill, indicator can also be used for ferro metals
	Landfill Aluminum		1,4	0	*1 Almost inert material on landfill, indicator is valid for primary and recycled aluminum.
	Landfill of 1 m^3 volume		140	0	*1 Landfill of volume per m^3, use for voluminous waste, like foam and products
			Total	0	mPt
		Total of all phases		0	**mPt**

Figure XVII. A selection from the platform showing the indicators for different materials.