Life Cycle Assessment of a High-Density Datacenter Cooling System: TeliaSonera's 'Green Room' Concept

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Abstract

The increasingly power load of datacenters worldwide and consequently, the increase on heat dissipation by electronic components, have been highlighting the importance of efficiently designing cooling solutions for such systems. In fact, bad management of the cooling system can greatly increase the total electricity consumption in a datacenter. This being said, TeliaSonera in order to decrease the total electricity consumption in its datacenters, has developed a new cooling solution known as the Green Room concept. Therefore in order to evaluate the potential environmental benefits related to this product, this work was developed. The Life Cycle Assessment methodology in accordance to ISO 14040/43 standards was applied to assess its environmental performance, from cradle-to-grave. Moreover the software SimaPro, the Ecoinvent database and the ReCiPe impact assessment method were also utilized.

The results emphasized the phases and activities during Green Room life cycle presenting the highest potential impacts. This being said, the utilization phase presented for every impact category analyzed the highest potential impacts, with exception of ozone depletion category, which was dominated by material extraction and manufacturing phase, due to the presence of R134a refrigerant. In addition transportation phase presented the lowest values for every category and the end of life phase exposed considerable impact mitigation for the whole life cycle. Moreover extraction and manufacturing phases presented copper, steel and the refrigerant R134a as the most impacting materials for damage to human health, damage to ecosystems and damage to resources, respectively. Finally, improvements were proposed in order to increase the environmental performance of this cooling system.

Keywords: life cycle assessment, LCA, cooling, cooling system, datacenter, green room, teliasonera, simapro, recipe, ecoinvent.

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Definitions

Cooling production: refers to the process of cooling water by the chillers in order to provide Green Room with water in the desired temperature to be utilized by the SEE coolers.

Environmental Product Declaration (EPD): An EPD is a standardized (ISO 14025/TR) and LCA based tool to communicate the environmental performance of a product or system, and is applicable worldwide for all interested companies and organizations. An EPD declaration is based on a Life Cycle Assessment. It includes information about the environmental impacts associated with a product or service, such as raw material acquisition, energy use and efficiency, content of materials and chemical substances, emissions to air, soil and water and waste generation. It also includes product and company information (Environdec, 2012).

Free-cooling: refers to the approach of lowering the air temperature in a datacenter by means of a natural source of cool air or water, without the utilization of mechanical refrigeration, as for example chillers (SearchDataCenter.com, 2012).

Geothermal cooling: it is the cooling production approach where the cool temperature of Earth's underground is used to exchange heat with a coolant medium. It is achieved by drilling numerous holes into Earth's surface and placing within the holes a closed-loop pipe system, inside where a coolant medium travels, allowing in this way a natural heat exchanging between the coolant and the Earth (DCK, 2012).

Safe temperature limit: it is defined in this report by the thermal guidelines for datacenters, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers. It corresponds to the air temperature, in the inlet of datacenter equipments, ranging from 18°C to 27°C (ASHRAE, 2011).

1 Introduction

This report is the result of a master thesis performed in cooperation between Kungliga Tekniska Högskolan (The Royal Institute of Technology) and the company TeliaSonera AB. It aims at assessing the environmental performance of TeliaSonera's datacenter cooling system, the 'Green Room', recently developed by this company. In order to accomplish the thesis' aim, the life cycle assessment (LCA) methodology based on the guidelines provided by the ISO 14040-43 family, were applied for this purpose, even though no external revision occurred so far.

1.1 Background

In 1975 Gordon E. Moore, the co-founder of Intel Corporation, projected that the number of transistors on a silicon chip would approximately double every two years (Moore, 1975). Interestingly, more than 35 years later, his projection can still be observed on the modern development of chips. The miniaturization process has allowed transistors to be placed into increasingly smaller areas on chips therefore increasing their performance and allowing the production of smaller electronic devices. However this extra performance comes accompanied of higher heat dissipation as well. And when considering that modern chips aggregate millions or billions of transistors within an area of few hundred square millimeters, the heat produced can be such a considerable amount.

Given that electronic components have a safe operational temperature range in order to keep reliability and proper functionality, it is imperative to have means of controlling such temperature delimitation, especially when the activity involved demands high degree of trustworthiness, such as telecommunications or storage systems, for example. Therefore, cooling solutions that are capable to dissipate the heat produced by electronic compounds are an essential part for the proper operation of electronic devices.

Datacenters are modern examples where the development of effective cooling solutions are necessary in order to create an appropriate environment for hundreds or even thousands of electronic components, populated in a number of racks. It is obvious that on such environments the cooling system is dependent on, among other characteristics, the area of the room where the racks are displaced and the power density (Wm^{-2}) distributed within the room. Nevertheless despite the type of solution implemented, it is essential the existence of some sort of cooling system for these environments in order to guarantee their proper functioning.

Such reasons have led to the development of numerous cooling systems for activities that demand utilization of a large number of electronic devices agglomerated in 'small' areas, such as the telecommunication field, which relies on the use of datacenters containing numerous computer servers and network devices grouped in racks in order to manage the modern demand for telecommunication services. In fact, cooling systems implemented in cases like this, can consume more than 50% of the total datacenter power (Izadi and El Azzi, 2012; Sun and Lee, 2006; Aebischer et al., 2003)!

As stated above, this high demand of energy accounted for the cooling system constitutes a large share of the electricity consumption on datacenters, which besides impacting on the electricity expenses of the company it is usually correlated to environmental impacts during its production. This being said, the development of new cooling systems able to dissipate large amounts of heat and at the same time presenting high energy efficiency is a challenge for engineers in order to keep in pace with current policies dealing with responsible energy use.

For instance, in order to illustrate the current scenario on energy efficiency in Europe, the European Union aims to achieve by 2020, through its Energy Efficiency Action Plan (European Commission, 2006), savings up to 20% in the annual primary energy consumption, in comparison with a given baseline scenario, as described on European Commission reports (European Commission, 2005, 2006). In order to do so, key areas with highest potential for energy savings were identified leading to the proposal of numerous measures and actions to be taken in the EU and national levels (European Commission, 2008). Actually, one of the actions promoted is to improve the energy efficiency of the Information and Communication Technologies (ICT), which are closely related to datacenters. For instance, the Institute for Energy of the Joint Research Centre in the European Commission released in the end of 2009 a Code of Conduct on Datacenters Energy Efficiency and a Best Practices guideline for datacenter operators in the EU (European Commission, 2009a; b). These documents clearly reflect the European concern over such important issue.

Also important to be mentioned is the increasing trend on electricity price on the European Union, and specifically in Sweden for example. Both EUROSTAT (Eurostat, 2012a) and Statistics Sweden (SCB, 2012) offices, report a growing tendency on electricity prices on their statistics data. In Sweden, EUROSTATS pointed out an average price increase for industrial consumers rising from 0,035 €/KWh in 1999 to 0,080 €/KWh in 2010 (Eurostat, 2012b). Hence, cooling solutions presenting higher energy efficiency will keep playing an important role on datacenters worldwide, regarding savings on electricity consumption as well as decreasing environmental impacts originated from its production.

1.2 TeliaSonera and the Green Room concept

TeliaSonera is the leading telecommunication company in Sweden and the major operator in the Nordic countries, being present in more than 28 countries worldwide. In 2010 more than 1 TWh of electricity was consumed by the company globally (TeliaSonera, 2010). In order to improve the energy efficiency within the company many projects have been developed and among them the reconstruction and renovation of cooling system of important datacenters and technical sites has been initiated. For instance just one datacenter situated south of Stockholm in Sweden, was responsible itself in 2008 for 26 GWh of electricity consumption (TeliaSonera, 2010).

The most recent project of a datacenter cooling system implemented by TeliaSonera is known as the 'Green Room' concept. This new cooling system approach for High Power Density server racks is able to dissipate a heating load up to 30 kW/rack in order to keep the temperature of electronic components below a safe specified limit (see definitions table), while at the same time presenting lower energy consumption when compared to conventional systems. According to Izadi and El Azzi (2012), the efficiency of Green Room could be explained by the structural features and equipments found in this system, such as the presence of aisle containement, preventing the mix of hot and cold air in the datacenter room; the distinctive layout of the coolers in the room, parallel to the server racks; high efficient cable management, preventing possible obstacles for proper air flow; and the existence of high performance coolers, especially designed for high power density datacenters. Further description of the system is available in section 5.

Recent tests showed that the Green Room is able to achieve values lower than 10% of the total energy consumption of a datacenter (Izadi and El Azzi, 2012), which in the long run, could significantly decrease the total energy utilization in such technical site. Actually, preliminary internal calculations performed by TeliaSonera have shown that under optimum conditions the savings with the Green Room concept, if installed in all TeliaSonera's datacenter in Sweden, could be more than 64 million SEK per year for the company (Izadi and El Azzi, 2012). Therefore it is likely that from an environmental perspective, especially regarding energy consumption, the 'Green Room' concept could present a superior performance than other available cooling solutions aiming at technical sites with high power demanding equipments.

This being said, the recognition of potential environmental benefits associated with the employment of Green Room concept, due to its efficient energy utilization, led TeliaSonera to initiate the execution of this study, in order to investigate the environmental performance of this new datacenter cooling approach through a life cycle perspective. Hence not just the impacts derived from energy consumption are of TeliaSonera's interest, but all the environmental impacts related to Green Room's life cycle, from cradle-to-grave.

2 Aims of the study

This study investigates the environmental performance of the Green Room cooling system, throughout its whole life cycle, aiming at defining the following aspects: 1) the specific environmental impacts associated to Green Room's life cycle; 2) the activities during Green Room's life cycle responsible for the greatest environmental impacts; and 3) the possible improvements that could be applied in order to promote the environmental performance of Green Room's life cycle.

3 Methodology framework

The methodology applied in this work, in order to achieve the defined aims, is the life cycle assessment (LCA) methodology, based on the guidelines provided by ISO 14040-43 standards (ISO, 1998, 2000a; b, 2006). Moreover this study was performed with the aid of the software SimaPro (Pré, 2012), the Ecoinvent database (SCLCI, 2012) and the ReCiPe impact assessment (ReCiPe, 2012). Bellow follows an introduction to the LCA methodology as well as a description of the SimaPro software, the Ecoinvent database and the ReCiPe methodology.

3.1 Life Cycle Assessment (LCA)

According to ISO 14040 (ISO, 2006), LCA is a methodology used to assess the environmental aspects and potential impacts associated with a product (or service), throughout its whole life cycle, from raw material acquisition all the way through production, use and disposal. The result of this assessment is presented through specific environmental impact categories, which can be gather in three major groups: resource use, human health and ecological consequences.

Due to its holistic view over the mentioned environmental impact categories, LCA studies can assist industries, governments and non-governmental organizations on identifying critical environmental aspects at any point of a product's life cycle; on the selection of relevant indicators of environmental performance; on improving marketing and or communication of a product, such as for the development of an Environmental Product Declaration; and also on decision-making, such as for product design or redesign, for example (ISO, 2006).

Many are the guidelines developed to assist on the execution of a LCA study, such as the ones developed by the Society of Environmental Toxicology and Chemistry (SETAC, 1993 cited in Baumann and Tillman, 2004); the Dutch guidelines (CML/NOH, 1992 cited in Baumann and Tillman, 2004); the Nordic Countries guidelines (Nord, 1995 cited in Baumann and Tillman, 2004); the Danish guidelines

(EDIP, 1997 cited in Baumann and Tillman, 2004) and the US guidelines (US-EPA, 1993 cited in Baumann and Tillman, 2004). However this work will focus on the international standards series, ISO 14040-14043 (ISO, 1998, 2000a; b, 2006) which has its methodology for a LCA study execution presented on Figure 1 below.

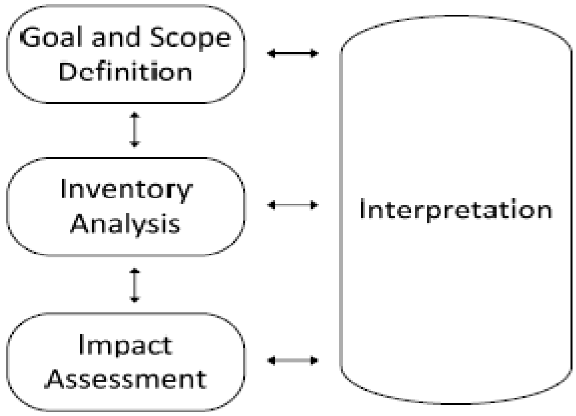

Figure 1: Life Cycle Assessment methodology (adapted from ISO 14040)

Goal and scope definition, in a simple description, shall clearly state what the goal of the LCA study is and the methodological approach that is going to be used to answer the questions raised when defining the goal. On one hand the goal provides information about the reasons which led to the execution of the LCA study, intended application of it, as well as the aimed audience to whom the study will be communicated to. On the other hand the scope is related to the methodology used to perform the LCA study, leading to the definition of important key aspects, such as (Baumann and Tillman, 2004; ISO, 2006):

Functional unit: the functional unit (f.u.) is defined in relation to a specific function of the product system under study and should quantify the performance of the functional outputs of this same system (ISO, 2006). In other words it is a quantitative measure of the functions provided by the studied system, in order to ensure comparability of the LCA results.

System boundaries: in order to determine which processes should be included within the LCA study. They need to be specified in several dimensions (Baumann and Tillman, 2004):

- Natural systems (processes modeled that are affected by technical systems);
- Technical systems (processes modeled that are under human control);
- Geography (in order to answer questions such 'where the impacts are happening?' or 'what are the ecosystems affected?')
- Time ('which temporal horizon the study is valid for?').

Allocation procedures: it is necessary to identify what is (are) the selected method(s) of allocation for the modeled system. According to Finnveden et al. (2009) there are three types of allocation problems: multi-output (when a process produces several products); multi-input (when a process receives several material inputs); and open-loop recycling (in which one waste product is recycled into another product).

In fact there are two main ways of handling allocation problems. The first one relies on the partitioning of the environmental impacts between the products, basing it on a physical parameter for example. The second approach aims at avoiding allocation by dividing the process into sub processes or expanding the system boundaries to include all the affected processes (Finnveden et al., 2009). In spite of the method chosen to tackle such problem, allocation is one of the most discussed issues in LCA, and the reader can find further explanation available in Finnveden et al. (2009).

Data quality requirements: the quality of the data collected and used in a LCA study will certainly define the precision of the results; therefore it is necessary to define the relevance, reliability and accessibility of the used data (Baumann and Tillman, 2004; ISO, 2006).

Inventory analysis probably is the most time demanding step in a LCA study. It is here where all the inputs and outputs flows of materials, energy and emissions are collected. Usually it starts with the construction of a flowchart where all the modeled activities and flows between them are exposed in accordance to the boundaries defined in the goal and scope definition. This procedure is followed by data collection, where quantitative and qualitative data for all inflows and outflows, such as raw materials, energy, ancillary products, land use and emissions are gathered. The next step in inventory analysis is to calculate the amount of resource used and emissions of the studied system in relation to its functional unit. For this operation it is very common to have the aid of computer software (Baumann and Tillman, 2004; ISO, 2006).

The next phase, the **impact assessment** is the association of the data gathered in the inventory analysis with specific environmental impacts. During the inventory analysis, huge amount of data regarding resource utilization or emissions are gathered, however they do not directly report to any kind of environmental impacts. Hence it is during the impact assessment phase that this data is associated to environmental impacts, adding consequently environmental significance to the results (Baumann and Tillman, 2004; ISO, 2006).

According to ISO 14042 (ISO, 2000a) the impact assessment should include three compulsory steps, *impact category definition, classification* and *characterization*. Classification is used to assign impact categories to the inventoried data according to the environmental impact they contribute to. For example, both SO_2 and NO_x contribute for acidification potential, therefore they should be assigned to this same impact category. During the next step, characterization, the relative contributions of elements assigned for the same impact category will be quantified according to *equivalence factors*, meaning that a common denominator should be used to calculate this contribution. For example, acidification potential can be measured by the release of ions H^+ per kilo of substance relatively to the SO_2 (the reference substance) (Baumann and Tillman, 2004). The equation below expresses this relation:

$$\textit{Impact indicator} = \textit{Amount of substance x Equivalence factor}$$

Other optional steps to be conducted under the impact assessment phase are:

Normalization: the characterization results can be normalized to a different magnitude of impacts by dividing it by a reference number. In fact this reference can expose for example the total impact occurring in a country or region for a given impact category. In other words the normalization step can increase the environmental significance of the impact assessment results since it can be compared to a chosen reference value (Baumann and Tillman, 2004).

$$\textit{Normalized indicator} = \frac{Impact\ indicator}{Reference\ value}$$

Grouping: involves sorting the characterization results into fewer categories of impacts. Examples can be global; regional or local impacts, or even grouping the results into high; medium or low priority impacts. Grouping can facilitate the understanding of an impact assessment for the common audience (Baumann and Tillman, 2004).

Weighting: in this step relative importance is attributed to the different impact categories resulted from characterization or normalization, making possible therefore a direct comparison between them. In order to do so it assigns weight, expressed by weighting factors, to the different impact categories according to their relative importance. Due to its subjectivity ISO 14042 standard (ISO, 2000a) recommends that weighting methods and operations used in a LCA shall be documented to provide transparency (Baumann and Tillman, 2004).

Weighted indicator = Indicator x Weighting factor

Finally the **interpretation** in LCA is an iterative process which is present during all other phases of the study. It is here where the findings of the inventory analysis and impact assessment are combined in order to achieve recommendations and conclusions for the study (ISO, 2000b).

3.2 SimaPro and the Ecoinvent database

Depending on the system being analyzed, usually huge amount of data must be collected in order to perform the study, and afterwards this same data must be 'treated' in order to provide a precise result with high environmental significance. In fact many are the computer software developed to aid during the execution of such study. In this work the software SimaPro, in its version 7.2, developed by the Dutch company Pré (Pré, 2012) was used. This software presents a friendly interface, can be easily manipulated and it is in accordance to the ISO 14040-14043 set.

In order to model a life cycle scenario in this software, the practitioner first need to define all assemblies which will be inserted in the model. It is in this first step where all primary materials are included. After that, all processes that are related to the manufacturing techniques are also included. Transport related processes are also integrated in the same way. In addition an end-of-life scenario is created. Once finished the above described steps, the software is able to perform the life cycle inventory and calculate the results, presenting it according to a selected assessment method.

In the utilized version of SimaPro, the database Ecoinvent v.2.0 was chosen to be used for modeling Green Room's life cycle. The reason is the wide acceptance of Ecoinvent among LCA practitioners. This database is developed by the Swiss Centre for Life Cycle Inventories and is supported by different Swiss federal offices and European organizations. The database encompasses more than 4000 validated life cycle inventory (LCI) datasets for processes, products and services, divided under groups, such as energy, transport, metals, electronics, mechanical engineering, plastics, waste treatment, and others (Frischknecht et al., 2007). Every dataset comprises material and energy flows, including infrastructure, as well as emissions related to the specific process execution.

3.3 ReCiPe Impact Assessment Methodology

ReCiPe is a recent life cycle impact assessment (LCIA) methodology developed in 2008 by the company Pré Consultants (among others) which also created SimaPro. The method is a follow up of the methods Eco-Indicator 99 and CML 2002 aggregating the endpoint approach of the former and the midpoint approach of the latter. On one hand the midpoint approach is composed of 18 impact categories having considerably low uncertainty on their characterization, however presenting hard interpretation of the values due to their pretty abstract meaning (for example how to objectively compare climate change potential with acidification potential?). On the other hand, in order to facilitate the interpretation of the results, the impact categories can be converted into three endpoint damage categories: damage to human health; damage to ecosystem diversity and damage to resource availability. Although easier to be interpreted, the outcome of such assessment presents a higher uncertainty, due to subjective evaluation (Goedkoop, Heijungs and Huijbregts, 2009).

This being said the results of both 'midpoint' and 'endpoint' ReCiPe approaches will be presented in this work. Below follows an overview of impact and damage categories used in the method (Table 1):

Table 1: ReCiPe impact and damage categories

Impact Category	Abbr.	Unit	Characterization Factor Name	Damage Category
Climate change	CC	Kg (CO_2 to air)	Global warming potential	HH, ED
Ozone depletion	OD	Kg (CFC-11** to air)	Ozone depletion potential	HH
Terrestrial acidification	TA	Kg (SO_2 to air)	Terrestrial acidification potential	ED
Freshwater eutrophication	FE	Kg (P to freshwater)	Freshwater eutrophication potential	ED
Marine eutrophication	ME	Kg (N to freshwater)	Marine eutrophication potential	N/A
Human toxicity	HT	Kg (DCB* to urban air)	Human toxicity potential	HH
Photch. oxidant formation	POF	Kg (NMVOC*** to air)	Photochemical oxidant potential	HH
PM formation	PMF	Kg (PM_{10} to air)	Particulate matter form. potential	HH
Terrestrial ecotoxicity	TET	Kg (DCB* to soil)	Terrestrial ecotoxicity potential	ED
Freshwater ecotoxicity	FET	Kg (DCB* to freshwater)	Freshwater ecotoxicity potential	ED
Marine ecotoxicity	MET	Kg (DCB* to marine water)	Marine ecotoxicity potential	ED
Ionizing radiation	IR	Kg (U^{235} to air)	Ionizing radiation potential	HH
Agric. land occupation	ALO	m^2.yr (agricultural land)	Agricultural land occupation potential	ED
Urban land occupation	ULO	m^2.yr (urban land)	Urban land occupation potential	ED
Natural land transformat.	NLT	m^2.yr (natural land)	Natural land transformation potent.	ED
Water depletion	WD	m^3 (water)	Water depletion potential	N/A
Mineral resource deplet.	MRD	Kg (Fe)	Mineral depletion potential	RA
Fossil resource deplet.	FD	Kg (oil)	Fossil depletion potential	RA

**DCB: 1,4 dichlorobenzene*
*** CFC: Chlorofluorocarbon*
**** NMVOC: Non Methane Volatile Organic Carbon compound*

As seen on Table 1 not all impact categories are linked to a specific damage category in ReCiPe assessment method. This is clearly a drawback in the methodology since no quantitative connection could be established between the midpoint and endpoint approach for marine eutrophication and water depletion impact categories, for example. In fact the connection between impact categories and damage categories are possible through the development of environmental models. These models often take in consideration a great number of variables such as the fate of the studied chemical in the environment, the effect factor of the substance, the distribution of the exposed species, cultural perspectives, etc. Therefore it is likely that an incomplete representation of reality could occur during such connections, since some environmental systems are still not fully understood.

For instance, Goedkoop et al. (2009) states that beside freshwater eutrophication and water depletion, no links could be made between the damage caused on ecosystem diversity due to ozone depletion, ionizing radiation and photochemical oxidant formation categories. Moreover a number of other links have been established in an incomplete manner, for example when modeling human health effects due to climate change. This exposes the importance on understanding the limitations of such environmental impact assessment methodology. Further explanation of the models applied in this method are available in Goedkoop et al. (2009).

3.3.1 Midpoint Characterization

All impact categories described in this section are referenced from Pré (2010).

Climate change: the characterization factor of climate change category is the global warming potential, in reference to CO_2 equivalents.

Ozone depletion: the characterization factor of depletion of the ozone layer is based on the destruction of the stratospheric ozone layer due to anthropogenic emissions of ozone depleting substances, in reference to CFC-11 equivalents.

Terrestrial acidification: the characterization factor of terrestrial acidification category is derived from the base saturation (BS – the higher the better) indicator of a soil, in reference to SO_2 equivalents.

Freshwater eutrophication: the characterization factor of freshwater eutrophication relates to the environmental persistence of the emission of phosphorus containing nutrients, in reference to P emissions to freshwater equivalents.

Marine eutrophication: the characterization factor of freshwater eutrophication relates to the environmental persistence of the emission of nitrogen containing nutrients, in reference to N emissions to freshwater equivalents.

Human toxicity/Ecotoxicity: the characterization factor of human toxicity and ecotoxicity accounts to the persistence and accumulation in the human food chain, as well as the toxic effect of a chemical, in relation to 1,4-dichlorobenzene equivalents.

Photochemical oxidant formation: the characterization factor of photochemical oxidant formation relates to the marginal change in the 24h-average European concentration of ozone (in the lower atmosphere) due to a marginal change in the emission of a determined substance, in reference to non-methane volatile organic carbon compounds (NMVOC) emissions.

Particulate matter formation: the characterization factor of particulate matter formation relates to the marginal change in the intake factor of PM_{10} of the European population due to a marginal change in the emission of a determined substance, in reference to PM_{10} equivalents.

Ionizing radiation: the characterization factor of ionizing radiation accounts to the level of exposure in reference to U^{235} equivalents.

Agricultural and urban land occupation: relates to the amount of both agricultural and urban land occupied for a certain time, in m^2 *year.

Natural land transformation: relates to the amount of natural land transformed and occupied for a certain time, in m^2 *year.

Water depletion: is directly related to the amount of water consumed, in m^3.

Mineral resources depletion: The characterization factor of mineral resources depletion is based on the increase in the price of the commodity, due to extraction, in reference to Fe extraction equivalents.

Fossil resources depletion: The characterization factor of fossil resources depletion relates to the amount of fossil fuel extracted, based on the upper heating value, in reference to crude oil equivalents.

3.3.2 Endpoint Characterization

Damage to Human Health (HH): Damage to human health is assessed in ReCiPe using the DALY (disability-adjusted life years) concept. This concept derives from statistics on human health, in a determined region, on life years both lost and disabled caused by a disease (Goedkoop and Spriensma, 2001). Still according to Goedkoop and Spriensma (2001) "a damage of 1 means that one life year of one individual is lost, or one person suffers four years from a disability with a weight of 0,25". The impact categories associated to damage to human health are: climate change; ozone depletion; human toxicity; photochemical oxidation formation; particulate matter formation and ionizing radiation.

Damage to Ecosystem Diversity (ED): In ReCiPe method it is assumed that the diversity of species directly represent the quality of ecosystems (Goedkoop, Heijungs and Huijbregts, 2009). Therefore damage to ecosystem diversity is expressed as the loss of species over a certain area, during a certain time (Pré, 2010), represented as $PDF*m^2*years$, where PDF means the *Potentially Disappeared Fraction of Species*. According to Goedkoop and Spriensma (2001) "a damage of 1 means that 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". The impact categories associated to damage to ecosystem diversity are: climate change; terrestrial acidification; freshwater eutrophication; terrestrial ecotoxicity; freshwater ecotoxicity; marine ecotoxicity; and land occupation and transformation.

Damage to Resource Availability (RA): Damage to resource availability in ReCiPe method is based on how the use of mineral and fossil resources lead to marginal increased costs of extraction due to the effects that result from continuing extraction (declining of ore grade, for minerals, and exploitation of less conventional fuels, for fossil resources) (Goedkoop, Heijungs and Huijbregts, 2009). The impact categories associated to damage to resource availability are: mineral and fossil resources depletion.

3.3.3 Perspectives

In order to tackle the uncertainty present in the models used to define the characterization factors in ReCiPe, three different perspectives are used to group similar types of assumptions and choices performed in the models. They are:

- **Individualist perspective (I):** Time perspective is short-term (100 years or less). Only substances with complete proof regarding their impacts are included. Damages are assumed to be recovered by technological and economic development (Pré, 2010).
- **Egalitarian perspective (E):** Time perspective is extremely long-term. Substances are included if there is only an indication regarding their impacts. Damages cannot be avoided and may lead to catastrophic events (Pré, 2010).
- **Hierarchical perspective (H):** Time perspective is long-term. Substances are included if there is consensus about their effects. Damages are assumed avoidable by good management (Pré, 2010).

It is important to state that the hierarchist perspective is the default option in ReCiPe assessment, since the values used under this perspective are generally scientific and politically accepted (Pré, 2010). Therefore it is also the perspective chosen to be applied in this work.

3.3.4 Normalization

The normalization in the ReCiPe assessment is given by total emissions or resources consumed in Europe (or world) divided by its total population, having the year 2000 as base year, therefore representing the impact of one average European during one year (in this case the year 2000) (Pré, 2010). Clearly, the normalization data depends on the perspective chosen.

3.3.5 Weighting

In ReCiPe a panel formed by members of the Swiss discussion platform on LCA performed the weighting of the three damage categories - human health, ecosystem diversity and resource availability – for each perspective. Moreover the average weighting of the panel is also calculated and chosen as default to be used in ReCiPe (Goedkoop and Spriensma, 2001; Pré, 2010). This being said this work applies the hierarchist perspective with the average weighting set of the panel: 40% human health; 40% ecosystem diversity; and 20% resource availability.

4 Literature Review

There are numerous studies in the literature focusing on operational energy utilization of datacenters. For instance, Sun and Lee (2006); Aebischer et al. (2003); EPA (2007) and Karlsson and Moshfegh (2005) expose the highest share of energy consumption that the cooling system presents on the overall energy consumption of a datacenter. In addition Cho and Kim (2011); Aebischer et al. (2003); Intel Corporation (2006) and EPA (2007) provide recommendations on increasing the energy efficiency of datacenters, specially including improvements on cooling systems; while The Green Grid (2009) and European Commission (2009a) propose guidelines to be implemented in European datacenters regarding the efficient use of energy.

Interestingly even though energy utilization and energy efficiency of datacenters are commonly discussed in the literature, the same cannot be said about the assessment of their environmental performance. In fact few studies focusing on environmental impact assessment of datacenters could be found in the literature during the execution of this report, and none of them focused solely on the cooling system. For instance Meza et al. (2010) applies the life cycle assessment methodology in order to propose a new datacenter solution, 'with novel approaches to address material and infrastructure impact on sustainability'. This assessment is focused on the life time *exergy* consumption and surprisingly the cooling system of the datacenter had just its energy consumption considered, since the study focuses mostly on the IT equipment.

On one hand this apparently lack of studies aiming at assessing the environmental performance of datacenters (or datacenter cooling systems) might represent: 1) the low relevance of such subject for the scientific community in general; or 2) the studies exist but they are not published, being purposed for internal use of companies or organizations, for example. In any case, given the scarcity of studies investigating such issue, it is clear that new studies should be encouraged, in order to develop the knowledge in this area. Thus this report represents to the best of knowledge, the first work investigating the environmental performance of a datacenter cooling system, in such holistic way.

5 Overview of the Green Room concept

The studied Green Room is located in the southeast of Stockholm, where TeliaSonera owns a site constructed under a rock shelter. Although the Green Room name makes reference to a 'room', which in turn is an allusion to the datacenter room (the delimited area where all electronic devices are installed in cabinets), the elements that are part of the Green Room considered in this study are just the elements related to the cooling system of the datacenter, which are distributed in a greater area than just the ‘room’ reserved for the datacenter in this technical site. In fact this mentioned cooling system, from now on just Green Room, consists of a large number of elements, and in order to facilitate the data inventory process which is described further in section 7.2, this work split the Green Room into four main parts: SEE Coolers, SEE Pump Racks, Infrastructure and Cooling Production materials, explained below.

The first elements, the coolers (Figure 2), are the equipments directly responsible for blowing cooled air in the datacenter in order to maintain all electronics, such as routers and servers, under a safe temperature limit. They are specially designed for high density datacenters and present extremely high energy efficiency. These coolers are strategically disposed inside the datacenter room in such way that the outlet ‘cold’ air from the SEE Coolers faces the air intake of the electronic devices into the cabinets which increases the efficiency of the cooling process. In fact there are 2 rows consisting of 5 identical units of the model SEE HDZ-3 each (in this work the coolers are cited as “SEE Coolers” just).

Figure 2: SEE Cooler HDZ-3 – the SEE Cooler (www.seecooling.com)

In order to provide a better idea, Figure 3 below describes simply the airflow inside the datacenter room. The red arrows represent the hot air coming out from the server racks containing the electronics. As can be seen, the hot air flow is directed to the top of the coolers, without being mixed with the cold air, where it will be cooled down by the coolant medium, in this case fresh water. This water is pumped to the SEE Coolers in a closed-loop circuit from the SEE Pump Racks, which will be described further down. Once inside the SEE Coolers, the hot air flow exchanges heat with the coolant medium through coils installed in the cooler equipment, inside where the water travels. After being cooled down to a desired temperature, the cold air flow represented by the blue arrows in the picture is blown by fans to the cold aisle, maintaining the temperature of the electronics under a specific limit. The whole process is continuous.

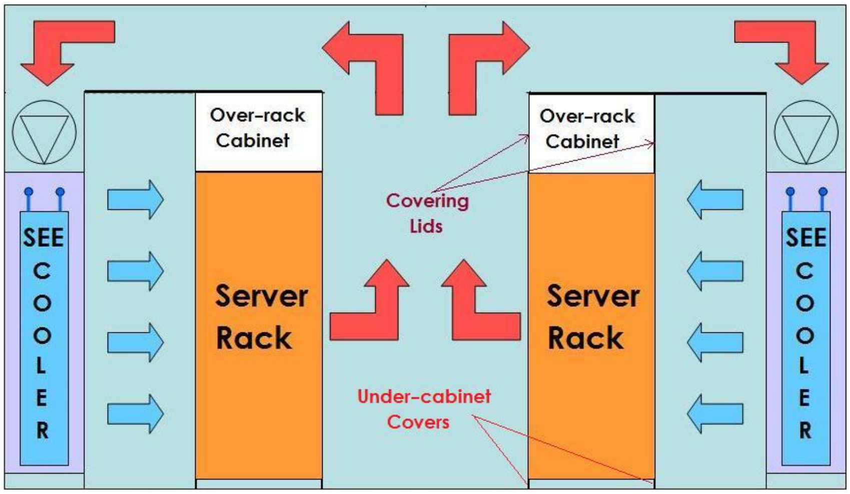

Figure 3: Airflow inside Green Room (Izadi and El Azzi, 2012)

The SEE pump racks, shown in the Figure 4, play a vital role on the air cooling process since they are responsible for pumping the coolant medium into the SEE Coolers. In the Green Room the coolant medium being used is water which is kept in a closed-loop between the Pump Rack and the coolers. In order to maintain this water at suitable temperature - therefore making possible to cool down the air in the datacenter room - the water travels through a heat exchanger where it exchanges heat with a secondary source of water obtained from a lake in the vicinity of the site. It is important to state that the system is based on an indirect heat exchanging process where two independent closed-loop circuits are used. This means that the water from the lake do not travels all the way up to the SEE Coolers.

In addition, in case the water of the lake is not cold enough (depending on the season of the year) the drawn water is first sent through chillers, which bring the temperature down to the desired value, and afterwards is used to cool the water in the SEE Coolers-SEE Pump Racks circuit.

Figure 4: SEE Pump Racks – the SEE Racks (www.seecooling.com)

This being said it is obvious that the energy consumption of the Green Room will be directly affected by the source of cooling production. Clearly the consumption is lower when a free-cooling approach is used (thus just pumps are involved in order to draw and circulate water from the lake) rather than using chillers in the process; however for the technical site where Green Room is installed, the utilization of free-cooling is not possible throughout the year. During the warmest months a chiller-based solution is necessary in order to provide the whole site with enough cooling. In fact five chiller units are installed at TeliaSonera's technical site and in this study these units are modeled as Cooling Production equipment.

Nevertheless it is important to state that the Green Room concept can be coupled with different cooling production approaches, such as just free-cooling when favorable environmental conditions are available; chillers as explained before; or geothermal cooling, when existing favorable geological conditions (see definitions section).

Finally infrastructure materials refer to all components related to the Green Room used to connect its different elements to each other, and that control the system in some manner, such as electric cables, pipes, tubes, valves, UPS, switchgear and electronics. In principle all the above mentioned elements are subject to assessment in this study; and a more detailed explanation is given further in Appendix 2: Data Sources. Figure 5 and Figure 6 below provide a better overview of Green Room components.

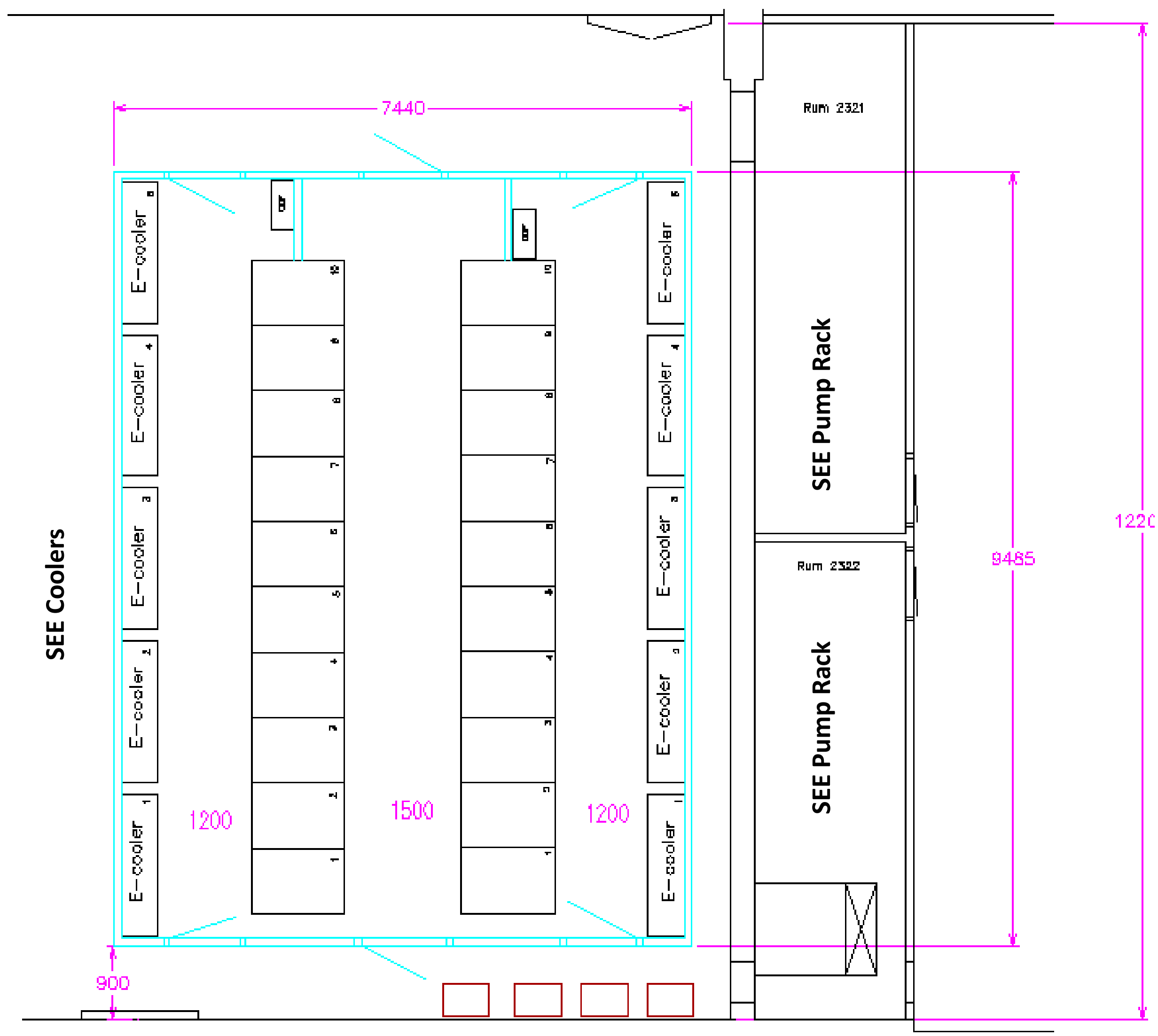

Figure 5: Green Room layout - coolers are located in an area of approximately 70 m2 (Izadi and El Azzi, 2012)

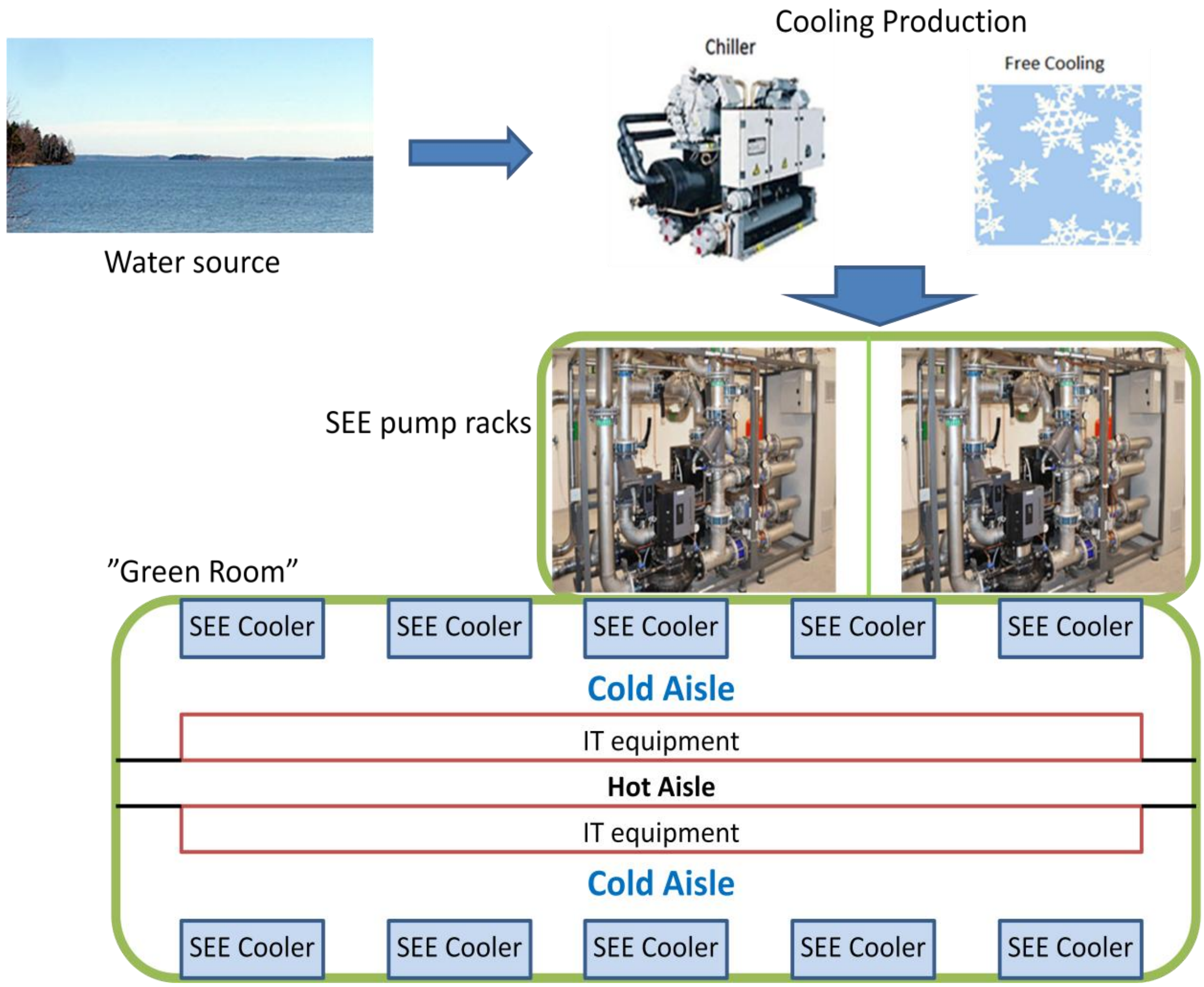

Figure 6: Overall functioning of Green Room and its main components.

6 Goal and Scope Definition

6.1 Goal of the study

This LCA study has as general goal the investigation of the environmental performance associated to the raw material extraction and manufacturing processes of the Green Room, as well as the environmental impacts involved during its use and end-of life phases. Another desirable achievement after the conclusion of this work is to make available a suitable framework for datacenter cooling systems LCA, therefore encouraging the development of other studies of this type. In order to achieve the general goal, this study will aim to answer the following research questions described below:

- What are the specific environmental impacts associated to Green Room’s life cycle, from cradle to grave?
- What activities during the Green Room’s life cycle are responsible for the greatest environmental impacts?

- Which possible improvements could be applied in order to promote the environmental performance of Green Room's life cycle?

This study is according to Baumann and Tillman (2004), defined as a *stand-alone* LCA, meaning that it is used to describe a single product in an exploratory way in order to get acquainted with the product's environmental performance, identifying its 'hot spots' (the critical environmental impacts in the life cycle). This being said this study is intended to increase the knowledge of TeliaSonera concerning the environmental performance of the Green Room. Moreover once completed, this study should be a starting point for the development of an Environmental Product Declaration, which may be subject to a future study.

In addition, it is important to state that any external communication of the results as they stand here must clearly expose the limitations of the study, including the fact that it has not undergone external peer review.

6.2 Scope definition

As described in section 3.1, the scope definition in a LCA study is composed of different requirements to be fulfilled. According to ISO (1998) and Baumann and Tillman (2004) the following points should be addressed:

6.2.1 Function of the product system

The main function of the Green Room cooling system is to dissipate the heat produced by electronic equipment, maintaining a suitable temperature for their operation without malfunction. This is achieved by delivering cooled air to the inlet of electronic devices such as routers and servers in a temperature which is able to 'stabilize' their internal temperature under a specific limit, in order to maintain their functionality. This 'service' is provided continuously, 24 hours per day, 365 days per year.

6.2.2 Functional unit (FU)

The functional unit defined is one unit of the Green Room cooling system, here comprised by two SEE Racks; ten SEE Coolers; Cooling Production and Infrastructure materials (refer to section 5) necessary to dissipate a heat load of 5 kW/m^2 maintaining a temperature no higher than 22°C to the inlet of electronics devices.

The heat load was defined assuming a total power load of electronic components as 350 kW spread in an area of 70 m2, while the temperature limit was defined based on the efficiency tests of Green Room performed by Izadi and El Azzi (2012), in which the temperature in the inlet of electronic components was never higher than 22°C.

6.2.3 Impact categories and impact assessment method

This work will make use of ready-made impact assessment methods existent in the SimaPro software. In fact, SimaPro offers a wide range of impact assessment methods which have great acceptance by LCA practitioners worldwide. In this work the methods ReCiPe Midpoint and ReCiPe Endpoint (Goedkoop, Heijungs and Huijbregts, 2009), both under the hierarchist perspective were chosen. Further explanation about the ReCiPe method can be found on section 3.3.

6.2.4 System boundaries

This study comprehends the whole life cycle of the Green Room, denominated cradle-to-grave, covering raw material extraction, manufacturing processes, use phase and end of life phase, here comprised by recycling, land filling and incineration processes. This being said, emissions to natural compartment such as air, soil and water are being taken into consideration in this LCA.

Although the Green Room is assembled entirely in Sweden, most of its components are manufactured in a number of different European countries, therefore this study presents whenever possible specific data for the country in question.

As for time boundary, it is defined a life span of 20 years for the Green Room according to TeliaSonera's expectation. In addition, for the impact assessment methods, the results are presented in a balance between a short and medium time perspective, known as the hierarchist perspective (the reader is referred to section 3.3.3).

6.2.5 Data quality requirements

It is of great importance for a LCA study to understand the quality of the data used to model a system under investigation, especially concerning the reliability of the final results. Pålsson (1999, cited in Baumann and Tillman, 2004) lists three different aspects of data quality: relevance, reliability and accessibility. Relevance indicates to what extent the referred data represents what it is supposed to represent (for ex. time coverage, geographical coverage, etc.). Reliability as the name says is related to the numerical accuracy and uncertainty of the used data. Finally accessibility concerns how accessible the data is in order to reproduce the results obtained (Baumann and Tillman, 2004).

All this being said, this study aimed at fulfilling, whenever possible, the above mentioned requirements (data relevance, reliability and accessibility) by the following actions:

- Obtaining information direct from equipment manufacturers, through questionnaires, documents or internal reports, regarding material composition, manufacturing processes and energy utilization;
- Utilizing a mature and recognized database for modeling the data collected from manufacturers, here represented by the Ecoinvent v.2.0 database;
- Whenever using data from Ecoinvent, selecting the geographically correspondent, most similar manufacturing technology of the real process and the most recent data stored in the database.

It is important also to state that despite how carefully the data collection during this study was performed, due to numerous variables which were impossible to be controlled, this study failed at fulfilling those requirements for a few components presented in the Green Room (a detailed list of components is available in Appendix 2: Data Sources), hence making use of an educated guess based on visual judgment, estimations by TeliaSonera expertise or common knowledge, for those data gaps. However, whenever uncertainty in the data is considered significant, a sensitivity analysis was performed and can be seen on section 9.1.

6.2.6 Study limitations

Theoretically a life cycle assessment should quantify all material and energy flows that are presented during the whole life time of a studied product or service, from raw material extraction until its 'return' to the environment. However in practice it is clear that assumptions and simplifications are needed to be made in such studies, mainly due to time, resources and data limitations. Accordingly, during the execution of this study, reasonable decisions had to be taken regarding processes, flows and materials that should or not be included in the assessment, due to the limitations described above.

The major assumptions and simplifications made in this study are described as follows:

- Modeling the Green Room in the software SimaPro was to some extent simplified from the real materials and processes involved in its construction, due to lack of precise data about the exact composition of raw materials and constructive processes. Most of the material composition of components was gathered from direct contact with manufacturers or documents obtained on manufacturer's website. Another parcel was gathered from studies on similar products (complete description is available in Appendix 2: Data Sources). This being said it was pretty straight to define the total value of steel or aluminum alloy contained in different equipments, for example; however it was impossible to define the exact amount of other elements presented in the previous mentioned alloys, in order to define its exact composition (e.g. chromium or magnesium percentages in these alloys). For this reason, all raw materials when modeled in SimaPro were selected as the most similar as the real materials existent in the Ecoinvent database. The same procedure was applied to manufacturing processes, where the most common manufacturing techniques were selected. Tables with details about all data inserted in SimaPro can be seen in Appendix 2: Data Sources;

- Unfortunately not all transportation distances for Green Room components could be taken into account due to data limitation. Therefore a transportation scenario was created and is described in section 7.2.2;

- The end of life scenario presented data gaps, as further demonstrated in section 7.2.4.

- Allocation according weight is used for the environmental assessment of transportation phase, as Ecoinvent database applies the unit 'ton*km' for calculation purposes. Moreover a similar allocation procedure is used in order to model the switchgear and the chiller manufacturing, as demonstrated in Appendix 2: Data Sources (Infrastructure and Cooling Production components).

- Due to data limitation, just the chillers used for 'cooling production' had its manufacturing material and energy flows modeled (Appendix 2: Data Sources). No data for pumps and tubes used for cooling production could be retrieved.

- Some assumptions were necessary in order to define the value used as the total energy consumption in the Green Room. A description is available on section 7.2.3.

7 Life Cycle Inventory

This section exposes the defined phases for Green Room life cycle, as well as data collection procedure for each phase. Detailed information regarding sources for all data collected in this work is available in Appendix 2: Data Sources.

7.1 Flow Chart

A simplified flowchart aiming at illustrating the different phases of Green Room life cycle is presented on Figure 7 below.

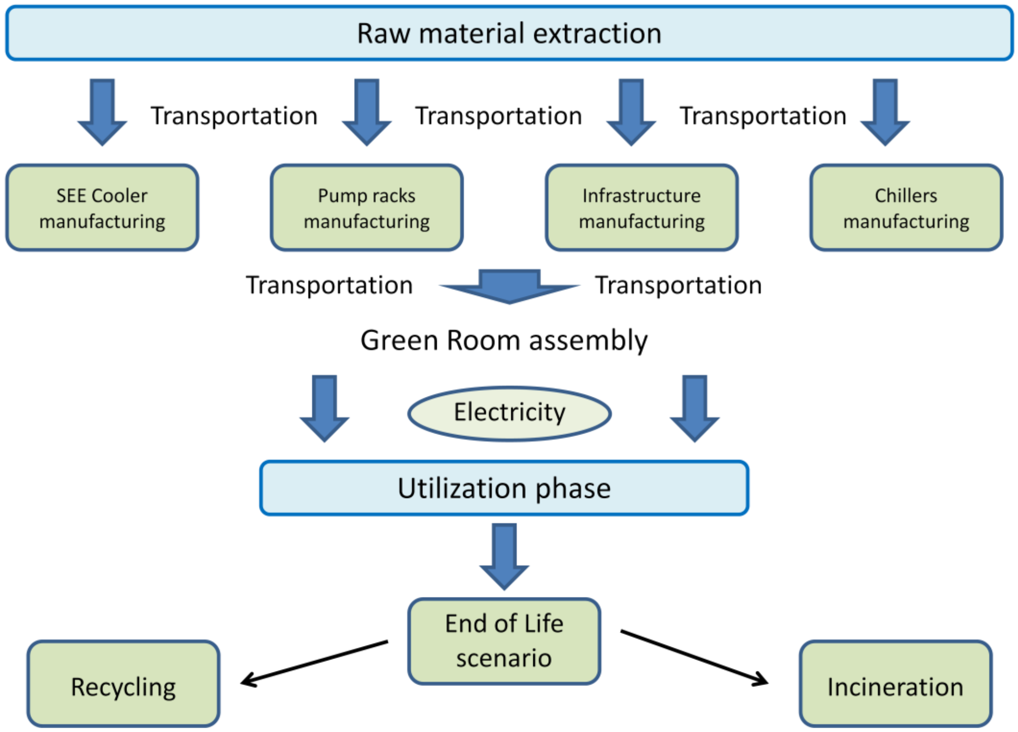

Figure 7: Flow diagram of Green Room Life Cycle

7.2 Data Collection and Modeling

Due to the complexity of the studied product, the collection of data and the system modeling were probably the most time consuming activities in the whole project. This was partially due to delays in the Green Room tests but also due to the need of information provided from many different companies and people, which in some way revealed that good communication is vital when developing a LCA.

The data collected and modeled in this study represents all phases of Green Room's life cycle, named Extraction/Manufacturing; Transportation; Utilization and End of Life. In order to define what should and what should not be inserted in the model, it was first necessary to define all processes involved during the above mentioned phases. In other words, the definition of which materials, which constructive processes, which kind of transport, which source of electricity and which end of life treatment should be used in the model. Once defined, the specific process could be selected in the Ecoinvent database and modeled accordingly.

Below follows a description of data collection and modeling for all phases of Green Room's life cycle assessment. In addition, the components and processes inserted in SimaPro, for each phase, are described in Appendix 2: Data Sources.

7.2.1 Extraction/Manufacturing phase

The first life cycle phase modeled in SimaPro, Extraction/Manufacturing, was meant to represent all material and energy flows accounted during the extraction of raw materials and manufacturing processes used in the Green Room. In order to facilitate the data collection for this phase, the Green

Room was divided in four main component groups: SEE Coolers, SEE Pump Racks, Cooling Production and Infrastructure, as explained previously in section 5. Once divided, each group had its sub-components identified, which made the data collection easier to be organized and presented. The tables below expose the sub-components identified for each of the four main component groups in Green Room. (For a complete description of the equipments the reader is referred to Appendix 2: Data Sources (Extraction/Manufacturing phase)).

Table 2: SEE Cooler components

SEE Cooler components (valid for 1 SEE Cooler unit; there are 10 units in total)		
Component name	**Amount**	**Weight (kg)/unit**
Radiator	1 unit	155.8
External Encasement	1 unit	206.7
Fan	3 units	6.2
Condensation Pump	1 unit	1.1
Control Unit	1 unit	0.5

Table 3: SEE Pump Rack components

SEE Pump Rack components (valid for 1 SEE Pump Rack unit; there are 2 units in total)		
Component name	**Amount**	**Weight (kg)/unit**
Tubes and flanges	n/a	286.0
Heat exchanger	1 unit	128.0
Pump	2 units	84.0
Strainer	2 units	33.5
Butterfly valves	8 units	5.2
Butterfly valve	1 unit	6.9
Electric actuator	1 unit	2.4
Document cabinet	1 unit	8.8

Table 4: Infrastructure components

Infrastructure components		
Component name	**Amount**	**Weight (kg)/unit**
Valves	20 units	3.0
Valves	6 units	8.0
Valves	20 units	4.5
Tubes and flanges	n/a	1184.3
Electric cables	n/a	65.0
Electric cables	n/a	8.0
UPS	1 unit	185.0
Batteries (UPS)	2 units	510.0
Switchgear	1 unit	28.0[(a)]
Expansion tank	2 units	12.0
Computer	2 units	n/a
Document cabinet	2 units	70.0
Roof cover	140 m^2	40 kg/m^3
Aluminum sheets	45 units	1.05

Table 5: Cooling Production components

Cooling Production components		
Component name	**Amount**	**Weight (kg)/unit**
Chiller	5 units	723.1

The initial approach of data collection for extraction/manufacturing phase was to gather information about material composition of the equipments and their manufacturing processes directly from the companies responsible for their manufacturing – through for example questionnaires or information available on the company's website. In fact this approach was successful for collecting information about material composition of equipments; however almost no information regarding manufacturing processes (and their energy consumption) or emissions could be obtained. Actually this was something already expected, and probably the strongest reason to have selected Ecoinvent as database in this study.

As explained before (section 3.2), the Ecoinvent database comprises more than 4000 life cycle inventories datasets, which suited perfectly the modeling process in this study. In fact each dataset in Ecoinvent provides material and energy flows, as well as emissions related to the process. Therefore, even with the lack of data from manufacturer companies, it was possible to model Green Room's life cycle using the Ecoinvent database. The limitations of this study are briefly exposed on section 6.2.6. Moreover Appendix 2: Data Sources exposes a deeper explanation regarding the data used for modeling Green Room life cycle. In addition a sensitivity analysis of the results can be seen on section 9.1.

This being said, modeling raw material extraction was pretty straight: the specific material which the equipment is made of, and defined according the manufacturer, was selected directly from the database. However due to the absence of information regarding manufacturing processes, these processes were modeled having as source the general manufacturing techniques available on the Ecoinvent database. This was meant to homogenize the manufacturing processes for the whole study due to the lack of specific data (refer to Appendix 2: Data Sources, for the complete list of materials and processes used in Green Room, as well as their description).

After collecting data for material composition of Green Room, it was possible to define the total weight of the system, as well as the exact share of each material, as seen in Figure 8 and Table 6 below. They expose just the materials that represent more than 1% of the total weight of Green Room. For those that lie under 1% of total contribution, they are grouped under 'Other materials' and they can be seen on Table 7.

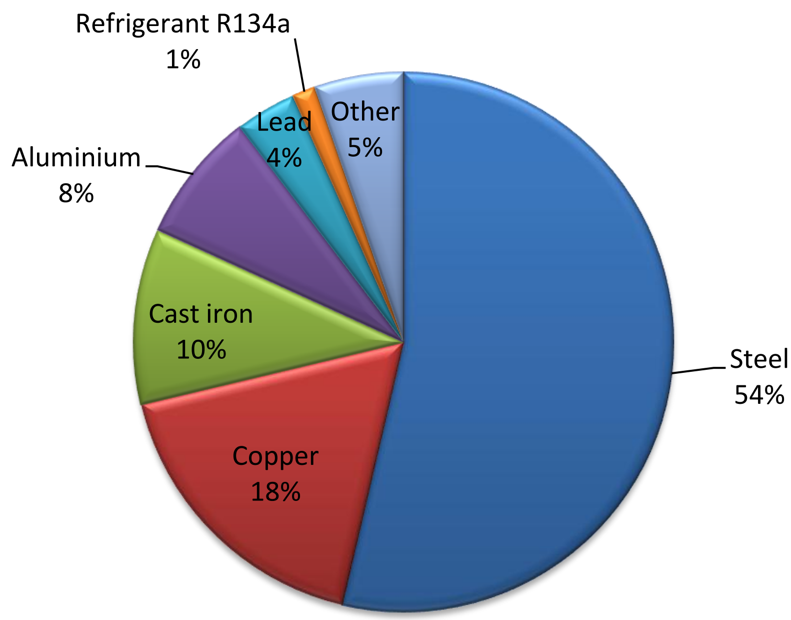

Figure 8: Green Room material breakdown

Table 6: Material breakdown of Green Room

Component	Weight (kg)	Contribution (%)
Steel	6391,3	53,7
Copper	2100,2	17,6
Cast iron	1251,1	10,5
Aluminum	935,9	7,9
Lead	432,0	3,6
Refrigerant (R134a)	165,0	1,4
Other materials[a]	636,3	5,3
TOTAL	11911,8	100%

[a] Materials representing less than 1% contribution of total Green Room weight.

Table 7: Other materials

Other materials	Weight (kg)	Contribution (%)
Softened water	115,2	0,98
Glass wool	112,0	0,95
Polypropylene	93,0	0,79
Brass	88,5	0,74
Polycarbonate	85,9	0,72
Sulfuric acid	72,0	0,60
Polyethylene	18,3	0,15
Glass fiber	14,4	0,12
Antimony	14,4	0,12
Synthetic rubber	9,7	0,0
Epoxy resin	4,9	0,04

ABS	3,2	0,03
Tetrafluoroethylene	1,9	0,02
Bronze	1,9	0,02
PCB	1,0	0,01
TOTAL	636,3	5,34

7.2.2 Transportation

In order to facilitate the interpretation of the environmental impacts associated with transportation; this category was modeled separately in this study. Unfortunately it was impossible to gather exact transport information for all materials and equipments pertained to the Green Room. In fact this task posed itself to be virtually impossible, thus simplifications were made.

This being said the transportation phase was modeled in this study as being composed by the transportation of all Green Room four main components (SEE Coolers, SEE Racks, Infrastructure materials and Cooling Production equipments) through an average distance of 1500 km by road, using a lorry with maximum load of 32 tons. These values were judged appropriate to represent all transports occurring in reality – the metal ore being transported from the mine to the processing plant; as well as all components being delivered at TeliaSonera, in Stockholm.

The transportation phase was not considered as a 'hot spot' in Green Room's life cycle, as seen on the result section (7.2.2), and sensitivity analysis (section 9.1). However one must be aware that the low contribution on the environmental impacts due to the transportation phase might have been resulted from the simplifications applied. Moreover a table with all transportation values inserted in SimaPro is available in Appendix 2: Data Sources (Transportation phase).

7.2.3 Utilization phase

In order to model the utilization phase, it was initially necessary to define the life time of the Green Room cooling system. Svante Enlund (Enlund, personal communication, 2012b), the developer of the SEE Coolers and the Green Room concept, defined the technical life time for the system modeled in this study as 20 years, even though the cooler units can be in operation even longer, due to the few number of moving parts that these coolers present. This is based on information from the previous model of the SEE coolers, known as SE coolers, which are in the market and operating since 1996 presenting really low rate of maintenance (Enlund, personal communication, 2012b). Regarding the SEE racks and chillers it is likely that electric motors present in those components would undergo some sort of maintenance at a certain time; however this fact is not considered in this study.

Actually an important concern to be taken into consideration regards the refrigerant R134a present in the chiller units, which is expected to leak to the environment during the utilization phase. In this study it is assumed that 13.8 kg of R134a refrigerant are released to the environment during this phase. Description and calculations used to achieve this value are described in Appendix 2: Data Sources (Utilization phase).

This being said the next step was to define the value of the electricity consumption of Green Room, also assessed under utilization phase. Actually the Green Room has been in operation for just few months thus no values of electricity consumption for a whole year are known so far. Therefore, in order to obtain consumption information to be modeled for 20 years life span, real site tests and computer modeling were used for this purpose.

Real site tests took place before the execution of this study and were performed by TeliaSonera personnel and KTH students during September/2011. These values were retrieved through the report "Green Room: A Giant Leap in Development of Green Datacenters" (Izadi and El Azzi, 2012). Moreover proprietary computer software was also used in order to simulate the Green Room electricity consumption, allowing comparison between real and theoretical values.

It is important to state that the total electricity consumption of Green Room is given by the electricity consumption for cooling production – the largest share, and basically represented by chiller's energy consumption – plus the electricity consumption within the room – here represented by fans and pumps.

Izadi and El Azzi (2012) present the power of cooling production as being 31.612 kW during the 'winter', the period of the year when no chillers are necessary to cool the water; and 101.493 kW during the 'summer', or the period when the necessary water temperature is achieved by using the chillers (as explained in section 5). Therefore in order to obtain an average value to be considered during the modeling, it was necessary to define the number of weeks that represents 'summer' and 'winter'. This was achieved through an Excel sheet provided by the electricity supplier (TeliaSonera internal reports, 2012) from where a graphic analysis exposed that the 'summer' period corresponds to approximately 12 weeks during the whole year, while the 'winter' period corresponds to the remaining 40 weeks.

This being said the average power of cooling production, during one year, is given by:

$$Cooling\ prod. = \frac{(31.612\ kW \cdot 40\ weeks) + (101.493\ kW \cdot 12\ weeks)}{52\ weeks}$$

$$\therefore Cooling\ production \cong 47.7\ kW$$

The power of cooling production within the room, given by coolers fans and the pumps responsible to circulate the water within the SEE Coolers, was retrieved from computer modeling and confirmed by real site tests as being around 3.2 kW. However given that the tests performed were intended to verify that it is possible to achieve such low values under real conditions, it is likely that slightly higher values would better represent daily utilization (Enlund, personal communication, 2012a). Therefore a 'correction' of 25% was added, resulting in 4.0 kW as the final cooling production power within the room.

This being said, the yearly average cooling production power is given by,

$$Cooling\ production\ power = 47.7\ kW + 4.0\ kW = 51.7\ kW$$

Taking into consideration the life time defined of 20 years,

$$Electricity\ consumption = 51.7\ kW * 20\ years = 1034\ kWyears$$

Knowing that 1 year contains 8760 hours (365*24), this defines a total electricity consumption of,

$$Electricity\ Consumption = 1034\ kW * 8760\ h = 9057840\ kWh\ \cong 9058\ MWh$$

Once defined the amount of electricity consumed, it was necessary to define the source of this electricity. According to the environmental manager of TeliaSonera, Dag Lundén (Lundén, personal communication, 2012), the Green Room is totally supplied by certified hydropower electricity, therefore this was also the electricity source inserted in SimaPro. A table containing information of utilization phase as modeled in SimaPro can be seen in Appendix 2: Data Sources (Utilization phase).

7.2.4 End of Life phase

Given that Green Room is in operation for just few months, there are no data available regarding its end of life phase. Therefore an ideal scenario was created for Green Room's end of life in order to solve this data gap. The modeled data in SimaPro is showed in Appendix 2: Data Sources (End of Life phase).

The end of life of the Green Room is assumed to be disassembly based, following the same conception described by Legarth et al. (2000). As explained in the mentioned report, it is believed that the metal value found in the Green Room components are enough to assure that disassembling will occur during this phase. Being so, it is expected all metals to be recycled and all non-metals assumed to be incinerated or recycled, in a 50%-50% share. For a few materials, no data could be retrieved from the database; therefore they were not included in the modeling (a complete description of data modeled in this phase is available in Appendix 2: Data Sources End of Life phase). The end of life is not considered as a 'hot spot' in this study, as seen on results (section 8.1.5) and sensitivity analysis (section 9.1). However one must be aware that the environmental impact mitigation achieved by the end of life phase might have been resulted from the model used to represent this phase which contains data gap for some materials, as described on Appendix 2: Data Sources (End of Life phase).

In addition, the recycling processes modeled are based on the 'avoided products' approach, meaning that the recycling of "x" kg of a specific material, avoids the extraction of "y" kg of the same material, which leads to a positive effect on the overall result of the LCA. More information is available in Appendix 2: Data Sources (End of Life phase).

7.3 Life Cycle Inventory results

After collection and process of the necessary data, a table exposing inputs and outputs necessary to process one unit of Green Room during its life cycle was generated and is available in Appendix 1: Life Cycle Inventory Results.

8 Life Cycle Impact Assessment (LCIA)

In this section the results of Green Room life cycle assessment are exposed and discussed. The results were obtained through the ReCiPe assessment method, as described in section 3.3.

8.1 LCIA Results

8.1.1 Extraction/Manufacturing phase

The results of the life cycle assessment for raw material extraction and manufacturing phase are exposed below. Table 8 shows *characterization* results according to the ReCiPe midpoint method. It is easy to identify higher emissions from Cooling Production equipment and the SEE Coolers, comparatively to Infrastructure materials and the SEE racks. This is possibly explained by the fact that the former components present considerably higher total mass than the latter. In fact, the chillers used for cooling production and the 10 units of SEE Coolers represent together more than 60% of all raw material extraction and manufacturing processes utilized in the Green Room. Moreover, it is also easily noticed the higher value that Cooling Production phase presents for ozone depletion category in comparison to other components. Such number is directly related to the manufacturing process of refrigerant R134a present in the chiller units, as further explained in Appendix 2: Data Sources (Chiller).

Table 8: Characterization results for Extraction/Manufacturing phase through Midpoint approach

Impact category	Unit	Total	Infrastructure	SEE Rack	SEE Cooler	Cooling Production
Climate change	kg CO2 eq	**6.95E+04**	1.40E+04	7.35E+03	1.97E+04	2.86E+04
Ozone depletion	kg CFC-11 eq	**1.74E+00**	1.90E-02	4.73E-04	1.39E-03	1.72E+00
Human toxicity	kg 1,4-DB eq	**3.18E+05**	5.23E+04	1.19E+04	1.09E+05	1.45E+05
Photochemical oxidant formation	kg NMVOC	**2.28E+02**	5.26E+01	2.42E+01	7.75E+01	7.36E+01
Particulate matter formation	kg PM10 eq	**2.53E+02**	6.03E+01	2.99E+01	7.90E+01	8.38E+01
Ionizing radiation	kg U235 eq	**1.59E+04**	4.75E+03	1.84E+03	5.62E+03	3.64E+03
Terrestrial acidification	kg SO2 eq	**5.21E+02**	1.04E+02	3.86E+01	1.76E+02	2.02E+02
Freshwater eutrophication	kg P eq	**1.62E+02**	2.74E+01	7.07E+00	5.66E+01	7.11E+01
Marine eutrophication	kg N eq	**7.58E+01**	1.77E+01	7.95E+00	2.53E+01	2.49E+01
Terrestrial ecotoxicity	kg 1,4-DB eq	**2.00E+01**	4.06E+00	1.51E+00	6.62E+00	7.78E+00
Freshwater ecotoxicity	kg 1,4-DB eq	**4.21E+03**	9.79E+02	4.43E+02	1.25E+03	1.53E+03
Marine ecotoxicity	kg 1,4-DB eq	**4.73E+03**	1.06E+03	4.71E+02	1.43E+03	1.77E+03
Agricultural land occupation	m2a	**1.27E+03**	3.66E+02	1.80E+02	3.91E+02	3.37E+02
Urban land occupation	m2a	**9.96E+02**	2.37E+02	1.16E+02	3.18E+02	3.25E+02
Natural land transformation	m2	**1.11E+01**	2.28E+00	1.14E+00	4.38E+00	3.26E+00
Water depletion	m3	**6.37E+02**	1.53E+02	6.48E+01	2.02E+02	2.18E+02
Metal depletion	kg Fe eq	**1.33E+05**	3.15E+04	1.65E+04	3.76E+04	4.71E+04
Fossil depletion	kg oil eq	**1.60E+04**	4.08E+03	2.23E+03	5.65E+03	4.03E+03

It is important to state that even though the bill of emissions with the *characterization* factors applied is presented, these numbers are difficult to be interpreted since it is impossible to compare them to each other or define a broader picture of their impact extension. For this reason, *normalized* values play an important role on exposing significant contribution that an impact category has to the overall environmental problem (European, in this case) (Pré, 2008). This being said, ReCiPe *normalized* values are given by the *characterization* results divided by the total emissions or resources used in Europe in the year 2000, in a per capita basis.

Normalized values are presented on Table 9. Although these values embed higher environmental significance, one must be aware of the greater uncertainty of these values comparatively to *characterization* values.

Table 9: Normalization results for Extraction/Manufacturing phase through Midpoint approach

Impact category	Total	Infrastructure	SEE Rack	SEE Cooler	Cooling Production
Marine ecotoxicity	**5.64E+02**	1.26E+02	5.62E+01	1.71E+02	2.12E+02
Human toxicity	**5.36E+02**	8.80E+01	2.01E+01	1.83E+02	2.44E+02
Freshwater eutrophication	**3.91E+02**	6.62E+01	1.70E+01	1.36E+02	1.71E+02
Freshwater ecotoxicity	**3.85E+02**	8.96E+01	4.06E+01	1.15E+02	1.40E+02
Metal depletion	**1.86E+02**	4.41E+01	2.31E+01	5.27E+01	6.61E+01
Ozone depletion	**7.90E+01**	8.63E-01	2.15E-02	6.31E-02	7.81E+01
Natural land transformation	**6.85E+01**	1.41E+01	7.05E+00	2.71E+01	2.02E+01
Particulate matter formation	**1.70E+01**	4.05E+00	2.01E+00	5.30E+00	5.62E+00
Terrestrial acidification	**1.51E+01**	3.04E+00	1.12E+00	5.11E+00	5.87E+00
Fossil depletion	**9.61E+00**	2.45E+00	1.34E+00	3.40E+00	2.42E+00
Climate change	**6.20E+00**	1.25E+00	6.55E-01	1.75E+00	2.55E+00
Photochemical oxidant formation	**4.29E+00**	9.90E-01	4.56E-01	1.46E+00	1.39E+00
Marine eutrophication	**3.99E+00**	9.33E-01	4.18E-01	1.33E+00	1.31E+00
Ionizing radiation	**2.54E+00**	7.60E-01	2.95E-01	9.00E-01	5.82E-01
Urban land occupation	**2.45E+00**	5.82E-01	2.86E-01	7.82E-01	7.99E-01
Terrestrial ecotoxicity	**2.43E+00**	4.95E-01	1.85E-01	8.07E-01	9.48E-01
Agricultural land occupation	**2.82E-01**	8.10E-02	3.99E-02	8.65E-02	7.45E-02

Despite uncertainties, it is clear that human toxicity, freshwater eutrophication, freshwater ecotoxicity, marine ecotoxicity and metal depletion present higher values than any other impact categories when compared to the impacts potentially caused by an average European in the year 2000. Analyzing the model in SimaPro it is possible to define the sources of such numbers.

Copper extraction and copper product manufacturing, mostly from Cooling Production and SEE Coolers, are the greatest responsible for human toxicity in Green Room extraction/manufacturing phase, emitting together more than 35 times dichlorobenzene equivalents than the third most impacting element, brass (Table 10). It is also important to mention the high impact that the production of antimony presents over the human toxicity category. For instance, 14.4 kg of antimony exposed a higher impact on this category than all stainless steel used in Green Room, weighting more than 1800 kg!

Regarding freshwater and marine ecotoxicity, copper production also presents the greatest share on the emission of dichlorobenzene equivalents on water compartments. As for freshwater eutrophication, again copper production is by far the most impacting element on this category, but this time due to phosphorus equivalent emissions. Following the same tendency, metal depletion is mostly influenced by copper extraction and its utilization in Green Room. Other metals having lower contribution on this impact category are chromium steel and low-alloyed steel.

Table 10: Most impacting processes on damage to Human Health during Extraction/Manufacturing phase

Process	Unit	Total
Copper, at regional storage/RER S	kg 1,4-DB eq	**2.34E+05**
Copper product manufacturing, average metal working/RER S	kg 1,4-DB eq	**3.47E+04**
Brass, at plant/CH S	kg 1,4-DB eq	**7.37E+03**
Steel, low-alloyed, at plant/RER S	kg 1,4-DB eq	**6.30E+03**
Antimony, at refinery/CN S	kg 1,4-DB eq	**6.08E+03**
Chromium steel 18/8, at plant/RER S	kg 1,4-DB eq	**5.55E+03**
Steel product manufacturing, average metal working/RER S	kg 1,4-DB eq	**4.39E+03**
Aluminium, production mix, at plant/RER S	kg 1,4-DB eq	**3.60E+03**

Table 11 and Table 12 present the assessment for extraction/manufacturing phase under the ReCiPe endpoint approach. As explained on section 3.3 this is also a method applied in order to increase the environmental significance of the results despite its higher subjectivity and uncertainty compared to the midpoint approach.

Table 11: Characterization results for Extraction/Manufacturing phase through Endpoint approach (impact categories).

Impact category	Unit	Total	Infrastructure	SEE Rack	SEE Cooler	Cooling Production
Climate change Human Health	DALY	**9.73E-02**	1.96E-02	1.03E-02	2.75E-02	4.00E-02
Ozone depletion	DALY	**3.14E-03**	5.76E-05	1.14E-06	3.37E-06	3.07E-03
Human toxicity	DALY	**2.23E-01**	3.66E-02	8.35E-03	7.62E-02	1.01E-01
Photochemical oxidant formation	DALY	**8.89E-06**	2.05E-06	9.45E-07	3.02E-06	2.87E-06
Particulate matter formation	DALY	**6.58E-02**	1.57E-02	7.79E-03	2.05E-02	2.18E-02
Ionizing radiation	DALY	**2.60E-04**	7.79E-05	3.02E-05	9.22E-05	5.97E-05
Climate change Ecosystems	species.yr	**5.51E-04**	1.11E-04	5.83E-05	1.56E-04	2.26E-04
Terrestrial acidification	species.yr	**3.02E-06**	6.06E-07	2.24E-07	1.02E-06	1.17E-06

Freshwater eutrophication	species.yr	**7.13E-06**	1.21E-06	3.11E-07	2.49E-06	3.12E-06
Terrestrial ecotoxicity	species.yr	**2.54E-06**	5.15E-07	1.92E-07	8.41E-07	9.88E-07
Freshwater ecotoxicity	species.yr	**1.10E-06**	2.55E-07	1.15E-07	3.26E-07	3.99E-07
Marine ecotoxicity	species.yr	**3.79E-09**	8.45E-10	3.77E-10	1.14E-09	1.42E-09
Agricultural land occupation	species.yr	**1.43E-05**	4.11E-06	2.03E-06	4.39E-06	3.78E-06
Urban land occupation	species.yr	**1.92E-05**	4.57E-06	2.25E-06	6.14E-06	6.27E-06
Natural land transformation	species.yr	**1.67E-05**	3.32E-06	1.57E-06	6.84E-06	4.96E-06
Metal depletion	$	**9.48E+03**	2.25E+03	1.18E+03	2.69E+03	3.37E+03
Fossil depletion	$	**2.57E+05**	6.56E+04	3.58E+04	9.08E+04	6.48E+04

Table 12: Characterization results for Extraction/Manufacturing phase through Midpoint approach (damage categories).

Damage category	Unit	Total	Infrastructure	SEE Rack	SEE Cooler	Cooling Production
Human Health	DALY	**3.89E-01**	7.20E-02	2.65E-02	1.24E-01	1.66E-01
Ecosystems	species.yr	**6.15E-04**	1.25E-04	6.49E-05	1.78E-04	2.47E-04
Resources	$	**2.67E+05**	6.79E+04	3.70E+04	9.35E+04	6.82E+04

By the endpoint approach it is possible to compare impact categories having the same unit, 'DALY'; 'species*yr' or '$'. Being so, summing the impact categories causing damage to human health (DALY unit), the extraction/manufacturing phase presents a total value of 3.89×10^{-1} DALY. Once again copper production and manufacturing have the biggest share on this total value: almost 60% is derived just from processes involving copper (Table 13). It is also important to state that human toxicity is appointed as the impact category presenting higher damages (Table 11).

Table 13: Contribution of copper related processes to damage to human health (Extraction/Manufacturing phase).

Process	Unit	Total	Contribution (%)
Copper, at regional storage/RER S	DALY	**1.94E-01**	**50**
Copper product manufacturing, average metal working/RER S	DALY	**3.19E-02**	**8**
Other processes	DALY	**1.63E-01**	**42**
TOTAL	DALY	**3.89E-01**	**100**

Regarding damage to ecosystem diversity, the extraction/manufacturing phase presents a total value of 6.15×10^{-4} species.yr, having climate change as the category presenting higher damages. Interestingly copper did not posed itself as the element causing the highest impacts; representing around 10% of the total damages on ecosystem diversity. In fact, this category is greatly affected by production and manufacturing of R134a refrigerant – 22% of total damages – followed by stainless steel and aluminum production, representing respectively 12% and 11% of the total value.

As for damage to resource availability, stainless steel and low-alloyed steel are the elements causing higher damage in this category, representing 55% of the total value of $ 267,000. Interestingly this picture is mostly due to fossil resources depletion which represents 96% (Table 11) of the total damage to resources (as coal, natural gas and oil are consumed in those industrial activities). On the other hand, copper production is the most significant process concerning depletion of mineral resources, being responsible itself for more than 50% of metal depletion impacts in Green Room extraction/manufacturing phase.

The results presented on Table 14 expose the *single score* values for the ReCiPe endpoint approach. S*ingle score* values are the characterization results after *normalization* and *weighting* under the conditions explained on section 3.3.5. These values expose in a straightforward way where the impacts are derived from. However one must be aware of uncertainties and subjectivity embedded to these values.

According to Table 14 below, five impact categories (out of 17) concentrate almost 98% of the total impacts derived from extraction/manufacturing phase. They are: human toxicity; fossil depletion; climate change for human health; particulate matter formation and climate change for ecosystems.

Table 14: Single Score results for Extraction/Manufacturing phase through Endpoint approach (impact categories).

Impact category	Unit	Total	Infrastructure	SEE Rack	SEE Cooler	Cooling Production
Human toxicity	Pt	**4.42E+03**	7.26E+02	1.66E+02	1.51E+03	2.01E+03
Fossil depletion	Pt	**1.93E+03**	3.88E+02	2.04E+02	5.46E+02	7.93E+02
Climate change Human Health	Pt	**1.92E+03**	4.90E+02	2.67E+02	6.78E+02	4.84E+02
Particulate matter formation	Pt	**1.31E+03**	3.11E+02	1.54E+02	4.07E+02	4.32E+02
Climate change Ecosystems	Pt	**1.26E+03**	2.54E+02	1.33E+02	3.57E+02	5.18E+02
Metal depletion	Pt	**7.08E+01**	1.68E+01	8.80E+00	2.01E+01	2.51E+01
Ozone depletion	Pt	**6.22E+01**	1.14E+00	2.27E-02	6.68E-02	6.10E+01
Urban land occupation	Pt	**4.40E+01**	1.05E+01	5.15E+00	1.41E+01	1.44E+01
Natural land transformation	Pt	**3.82E+01**	7.59E+00	3.60E+00	1.57E+01	1.14E+01
Agricultural land occupation	Pt	**3.28E+01**	9.42E+00	4.64E+00	1.01E+01	8.66E+00
Freshwater eutrophication	Pt	**1.63E+01**	2.76E+00	7.12E-01	5.69E+00	7.15E+00
Terrestrial acidification	Pt	**6.92E+00**	1.39E+00	5.13E-01	2.34E+00	2.68E+00
Terrestrial ecotoxicity	Pt	**5.81E+00**	1.18E+00	4.41E-01	1.93E+00	2.26E+00
Ionizing radiation	Pt	**5.16E+00**	1.55E+00	6.00E-01	1.83E+00	1.18E+00

Freshwater ecotoxicity	Pt	**2.51E+00**	5.84E-01	2.64E-01	7.47E-01	9.14E-01
Photochemical oxidant formation	Pt	**1.76E-01**	4.07E-02	1.87E-02	5.99E-02	5.69E-02
Marine ecotoxicity	Pt	**8.67E-03**	1.94E-03	8.64E-04	2.62E-03	3.25E-03
Total	**Pt**	**1.11E+04**	**2.22E+03**	**9.50E+02**	**3.57E+03**	**4.38E+03**

Human toxicity is largely derived from manganese and arsenic emissions during copper production (Table 15), which by its turn is being mainly utilized in the chillers (Cooling Production) and the SEE Coolers. Interestingly according to the model in SimaPro, both the emissions of manganese and arsenic ion to water compartments are almost entirely derived from sulphidic mine tailings (> 99%), and since such emissions are modeled for a considerably long period (60,000 years) in ReCiPe method, this explains the high impacting share of manganese and arsenic ion emissions on damage to human health category.

Fossil depletion is originated mainly from consumption of coal, natural gas and oil largely used during the production of aluminum and steel (both stainless and low-alloyed). The greatest share of impacts from climate change for human health category, results from carbon dioxide emissions from fossil fuels burning, having as main responsible processes steel and aluminum extraction/manufacturing. It is also important to mention the role that the refrigerant HFC-R134a plays on this impact category, releasing to air during its production, organic compounds having thousands of times higher climate change impact potential than carbon dioxide. The same explanation is valid for climate change for ecosystems. Finally, particulate matter formation derives greatly from emissions of sulfur dioxide, $PM_{2,5}$ and PM_{10} resulting mainly from production and manufacturing of copper, steel and aluminum products.

Table 15: Most impacting substances on damage to human health during Extraction/Manufacturing phase.

Substances impacting Human Toxicity	Unit	Total	Contribution (%)
Manganese, to water	DALY	**1.21E-01**	**54**
Arsenic ion, to water	DALY	**3.41E-02**	**15**
Arsenic, to air	DALY	**2.31E-02**	**11**
Other substances	DALY	**4.49E-02**	**20**
TOTAL	DALY	**2.23E-01**	**100**

Figure 9 below is a snapshot of SimaPro network obtained through ReCiPe endpoint method and *single score* step. Despite uncertainties and higher subjectivity of the *single score* step, this figure in fact represents the overall trend observed on *characterization* and *normalization* for both ReCiPe midpoint and endpoint approaches; being possible to identify the elements and processes presenting higher impacts on this life cycle phase. Note that just contributions higher than 5% to the overall impact are visible.

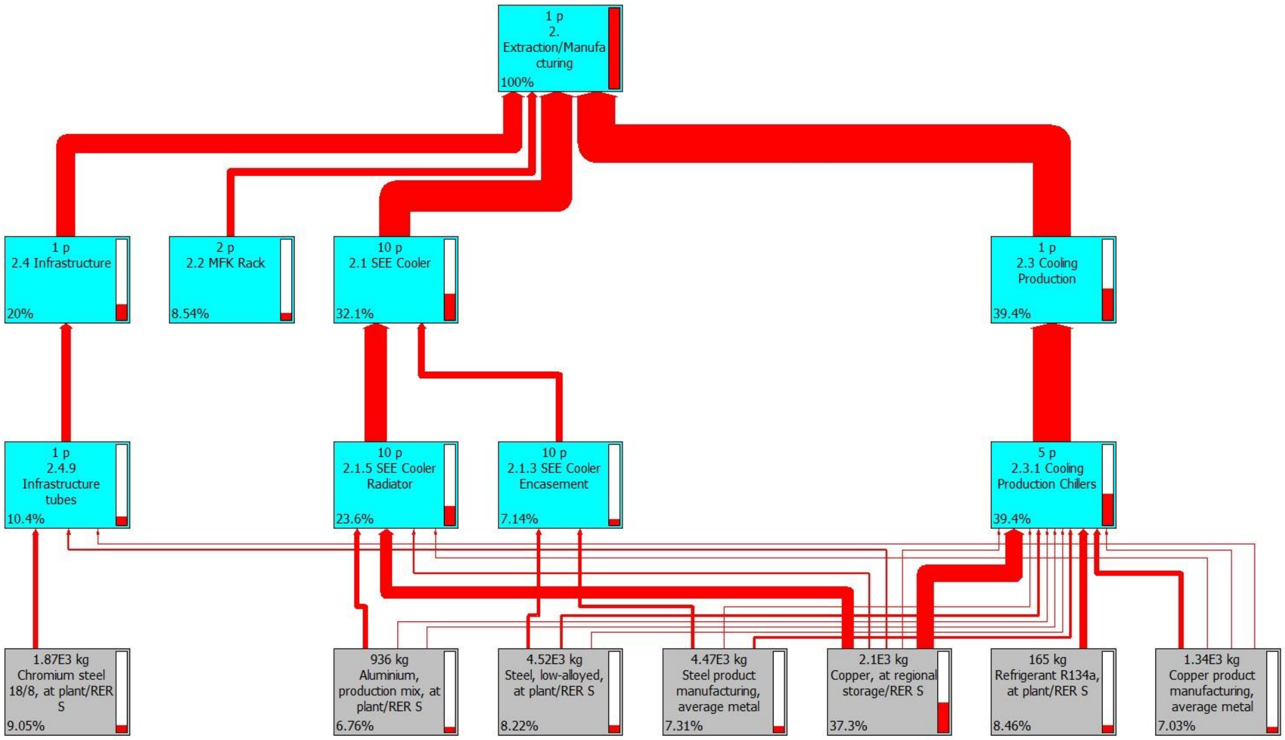

Figure 9: Snapshot from SimaPro exposing *single score* result for Extraction/Manufacturing phase. The percentages represent the contribution on the overall *single score* value for each component in this phase.

8.1.2 Utilization phase

As mentioned before (section 7.2.3), the impacts originated from utilization phase of the Green Room are mostly related to electricity consumption and in a small share to the leakage of refrigerant R134a to the environment. The electricity is derived from certified renewable sources, assuring that in this case, almost 98% is hydropower generated and the rest 2% is composed of other certified sources, such as wind power, photovoltaic, biomass and biogas. These values are pre-defined by the Ecoinvent dataset utilized (the reader is referred to Appendix 3: Dataset Descriptions).

Table 16 shows *characterization* results for ReCiPe midpoint approach on utilization phase. The total emissions and resources characterized for a reference substance/unit are exposed. However due to the hard interpretation of these results, a different approach is used in order to discuss these values. This being said, the endpoint methodology is applied and exposed on Table 17.

Table 16: Characterization results for Utilization phase through Midpoint approach.

Impact category	Unit	Total	Electricity consumption	Refrigerant leakage
Climate change	kg CO2 eq	**1.61E+05**	1.40E+05	2.15E+04
Ozone depletion	kg CFC-11 eq	**6.08E-03**	6.08E-03	0.00E+00
Human toxicity	kg 1,4-DB eq	**6.96E+05**	6.96E+05	2.13E+00
Photoch. oxidant formation	kg NMVOC	**6.22E+02**	6.22E+02	0.00E+00
Particulate matter formation	kg PM10 eq	**6.68E+02**	6.68E+02	0.00E+00
Ionizing radiation	kg U235 eq	**1.76E+04**	1.76E+04	0.00E+00
Terrestrial acidification	kg SO2 eq	**1.08E+03**	1.08E+03	0.00E+00

Freshwater eutrophication	kg P eq	**3.33E+02**	3.33E+02	0.00E+00
Marine eutrophication	kg N eq	**2.03E+02**	2.03E+02	0.00E+00
Terrestrial ecotoxicity	kg 1,4-DB eq	**3.22E+02**	3.22E+02	0.00E+00
Freshwater ecotoxicity	kg 1,4-DB eq	**7.22E+03**	7.22E+03	0.00E+00
Marine ecotoxicity	kg 1,4-DB eq	**8.35E+03**	8.35E+03	0.00E+00
Agricultural land occupation	m2a	**2.38E+04**	2.38E+04	0.00E+00
Urban land occupation	m2a	**2.37E+03**	2.37E+03	0.00E+00
Natural land transformation	m2	**1.99E+02**	1.99E+02	0.00E+00
Water depletion	m3	**1.13E+03**	1.13E+03	0.00E+00
Metal depletion	kg Fe eq	**2.21E+05**	2.21E+05	0.00E+00
Fossil depletion	kg oil eq	**2.58E+04**	2.58E+04	0.00E+00

Firstly the results are showed by damage category, highlighting the most impacting categories of utilization phase in Green Room. For instance human toxicity is the impact category presenting higher values for damages to human health. This is caused by utilization of copper in the distribution network of electricity, which as explained before, leads to emission of manganese and arsenic, contributing to increasing human toxicity (Table 15). Climate change and particulate matter formation are also important damage contributors for human health.

Table 17: Characterization results for Utilization phase through Endpoint approach.

Impact category	Unit	Total	Electricity	Refrigerant leakage
Climate change Human Health	DALY	**2.26E-01**	1.96E-01	3.00E-02
Ozone depletion	DALY	**1.60E-05**	1.60E-05	0.00E+00
Human toxicity	DALY	**4.87E-01**	4.87E-01	1.49E-06
Photochemical oxidant formation	DALY	**2.43E-05**	2.43E-05	0.00E+00
Particulate matter formation	DALY	**1.74E-01**	1.74E-01	0.00E+00
Ionizing radiation	DALY	**2.88E-04**	2.88E-04	0.00E+00
Climate change Ecosystems	species.yr	**1.28E-03**	1.11E-03	1.70E-04
Terrestrial acidification	species.yr	**6.27E-06**	6.27E-06	0.00E+00
Freshwater eutrophication	species.yr	**1.46E-05**	1.46E-05	0.00E+00
Terrestrial ecotoxicity	species.yr	**4.08E-05**	4.08E-05	0.00E+00
Freshwater ecotoxicity	species.yr	**1.88E-06**	1.88E-06	0.00E+00
Marine ecotoxicity	species.yr	**6.68E-09**	6.68E-09	0.00E+00
Agricultural land occupation	species.yr	**2.67E-04**	2.67E-04	0.00E+00
Urban land occupation	species.yr	**4.58E-05**	4.58E-05	0.00E+00
Natural land transformation	species.yr	**3.46E-04**	3.46E-04	0.00E+00
Metal depletion	$	**1.58E+04**	1.58E+04	0.00E+00
Fossil depletion	$	**4.14E+05**	4.14E+05	0.00E+00

As for damage to ecosystem diversity the most impacting category is climate change, followed in a lower scale by agricultural land occupation and natural land transformation. In fact climate change damage to ecosystem diversity is mostly related in this case to the release of carbon dioxide and methane. The former is originated from fossil fuel burning during electricity production and distribution (it is important to remember that some processes within the hydropower plant as well as manufacturing processes of the distribution network in fact use fossil fuels), while the latter is influenced by releases from the power plant reservoir as well as production of biogas.

Agricultural land occupation causing damage to ecosystem diversity is given by a small share of electricity that is produced from biomass, while natural land transformation is derived from the area occupied by the hydropower plant reservoir.

Regarding damage to resource availability the greatest impact is related to fossil depletion – more than 96% of the total value in this category (Table 17). The processes contributing the most are electricity distribution network and electricity generation at the hydro plant. Once more it is important to state that the Ecoinvent database accounts for capital goods in these processes, therefore considering the utilization of fossil fuels in activities related to electricity distribution and hydropower electricity generation.

In fact through the endpoint approach it is also possible to identify that as in extraction/manufacturing phase, the most prominent impact categories given by *single score* results (Table 18) are human toxicity, climate change (both human health and ecosystem), particulate matter formation and fossil depletion, being responsible for more than 90% of the total impacts in this phase.

Table 18: *Single Score* results for Utilization phase through Endpoint approach (impact categories).

Impact category	Unit	Total	Electricity	R134a leakage
Human toxicity	Pt	**9.66E+03**	9.66E+03	2.96E-02
Climate change Human Health	Pt	**4.49E+03**	3.90E+03	5.95E+02
Particulate matter formation	Pt	**3.44E+03**	3.44E+03	0.00E+00
Fossil depletion	Pt	**3.09E+03**	3.09E+03	0.00E+00
Climate change Ecosystems	Pt	**2.93E+03**	2.55E+03	3.88E+02
Natural land transformation	Pt	**7.92E+02**	7.92E+02	0.00E+00
Agricultural land occupation	Pt	**6.13E+02**	6.13E+02	0.00E+00
Metal depletion	Pt	**1.18E+02**	1.18E+02	0.00E+00
Urban land occupation	Pt	**1.05E+02**	1.05E+02	0.00E+00
Terrestrial ecotoxicity	Pt	**9.35E+01**	9.35E+01	0.00E+00
Freshwater eutrophication	Pt	**3.35E+01**	3.35E+01	0.00E+00
Terrestrial acidification	Pt	**1.44E+01**	1.44E+01	0.00E+00
Ionizing radiation	Pt	**5.71E+00**	5.71E+00	0.00E+00
Freshwater ecotoxicity	Pt	**4.30E+00**	4.30E+00	0.00E+00
Photoch. oxidant formation	Pt	**4.82E-01**	4.82E-01	0.00E+00
Ozone depletion	Pt	**3.17E-01**	3.17E-01	0.00E+00
Marine ecotoxicity	Pt	**1.53E-02**	1.53E-02	0.00E+00
Total	**Pt**	**2.54E+04**	**2.44E+04**	**9.84E+02**

8.1.3 End of Life

The end of life scenario modeled for Green Room is considered as ideal, and therefore presents negative results for every impact category evaluated. It is important to state that negative values in this phase represent the mitigation of impacts, having a positive effect on the overall result.

This being said, Table 19 shows *characterization* results for the ReCiPe midpoint approach. On this table, the lower the values the higher is the amount of emission or resource utilization avoided. For instance metal depletion stands as the lower value for an impact category, meaning in this case that the utilization of $9.72*10^4$ kg of Fe_{eq} was avoided due to the end of life phase.

Table 19: Characterization results for End of Life phase through Midpoint approach.

Impact category	Unit	Total
Climate change	kg CO2 eq	**-2.09E+04**
Ozone depletion	kg CFC-11 eq	**-9.94E-03**
Human toxicity	kg 1,4-DB eq	**-9.62E+04**
Photochemical oxidant formation	kg NMVOC	**-9.62E+01**
Particulate matter formation	kg PM10 eq	**-1.19E+02**
Ionizing radiation	kg U235 eq	**-2.88E+03**
Terrestrial acidification	kg SO2 eq	**-1.61E+02**
Freshwater eutrophication	kg P eq	**-5.59E+01**
Marine eutrophication	kg N eq	**-3.06E+01**
Terrestrial ecotoxicity	kg 1,4-DB eq	**-2.39E+00**
Freshwater ecotoxicity	kg 1,4-DB eq	**-1.25E+03**
Marine ecotoxicity	kg 1,4-DB eq	**-1.26E+03**
Agricultural land occupation	m2a	**-4.09E+02**
Urban land occupation	m2a	**-2.58E+02**
Natural land transformation	m2	**-3.37E+00**
Water depletion	m3	**-2.05E+02**
Metal depletion	kg Fe eq	**-9.72E+04**
Fossil depletion	kg oil eq	**-6.32E+03**

In order to give more significance to the results, it is applied a more tangible approach which is exposed on Table 20. This table presents the *characterization* results through ReCiPe endpoint method. Despite its higher uncertainty and subjectivity comparatively to midpoint approach, this method serves as providing a picture of where the higher damage mitigation occurs in the end of life phase.

Table 20: Characterization results for End of Life phase through Endpoint approach.

Impact category	Unit	Total
Climate change Human Health	DALY	**-2.93E-02**
Ozone depletion	DALY	**-3.00E-05**
Human toxicity	DALY	**-6.73E-02**
Photochemical oxidant formation	DALY	**-3.75E-06**
Particulate matter formation	DALY	**-3.09E-02**
Ionizing radiation	DALY	**-4.72E-05**
Climate change Ecosystems	species.yr	**-1.66E-04**
Terrestrial acidification	species.yr	**-9.36E-07**
Freshwater eutrophication	species.yr	**-2.46E-06**
Terrestrial ecotoxicity	species.yr	**-3.04E-07**
Freshwater ecotoxicity	species.yr	**-3.26E-07**
Marine ecotoxicity	species.yr	**-1.01E-09**

Agricultural land occupation	species.yr	**-4.59E-06**
Urban land occupation	species.yr	**-4.99E-06**
Natural land transformation	species.yr	**-5.32E-06**
Metal depletion	$	**-6.94E+03**
Fossil depletion	$	**-1.02E+05**

Damage to human health category is positively affected by recycling of copper, aluminum and steel (Figure 10). The reason is that avoiding copper production it decreases human toxicity and particulate matter formation impact categories, while avoiding aluminum and steel production, climate change impact is decreased.

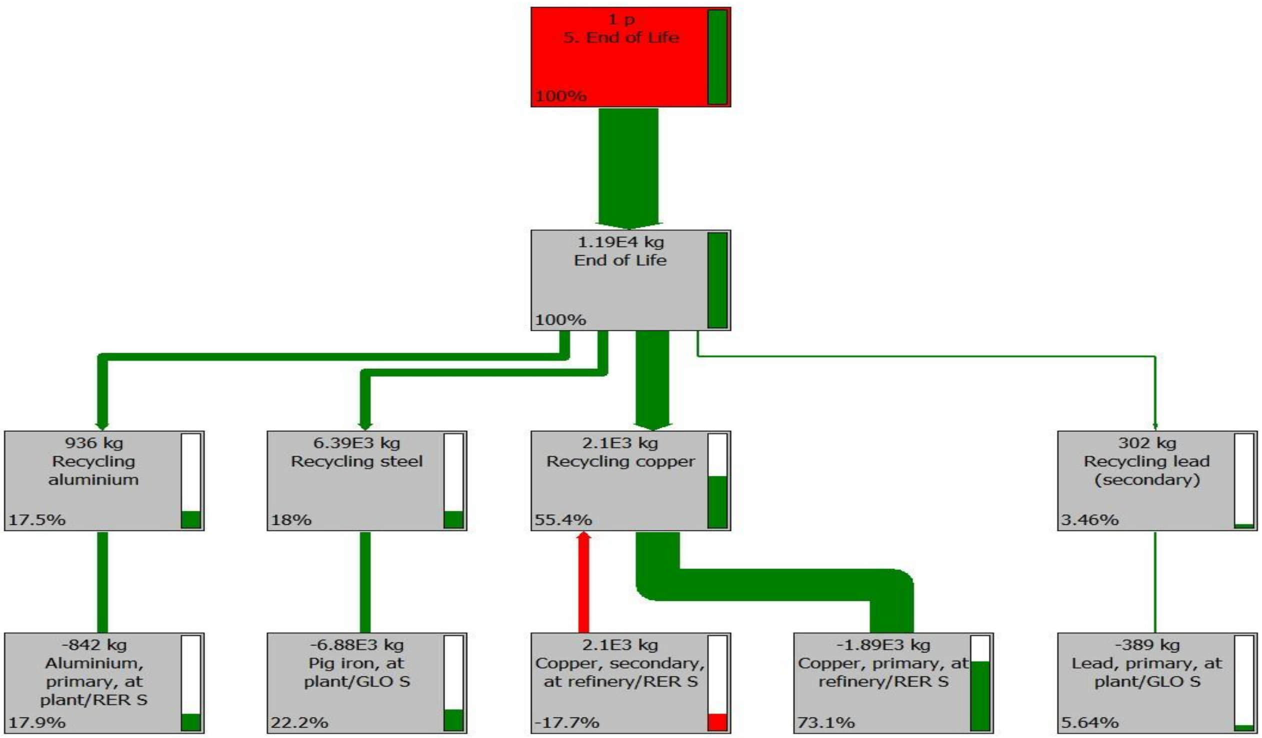

Figure 10: Snapshot from SimaPro exposing damage to human health for End of Life phase. Positive percentages represent the contribution on the overall damage mitigation during this phase.

As for damage to ecosystem diversity, the impact mitigation is greatly affected by recycling of aluminum and recycling of steel. This was somewhat expected since climate change (for ecosystems) presents the lower value on Table 20 for this damage category (remembering: the lower the better), and since the consumption of non-renewable fuels during its production is a concern, recycling these elements leads to lower fuel consumption, lower CO_{2eq} emission and consequently lower climate change impact.

Damage to resource availability is greatly dependent on fossil depletion impact category; therefore the greatest mitigation is again due to recycling of aluminum and steel (Figure 11). Copper by its turn, plays an important role on metal depletion impact mitigation, due to its great presence in Green room equipment and its high *characterization* factor in this impact category, compared to other metals present in Green Room.

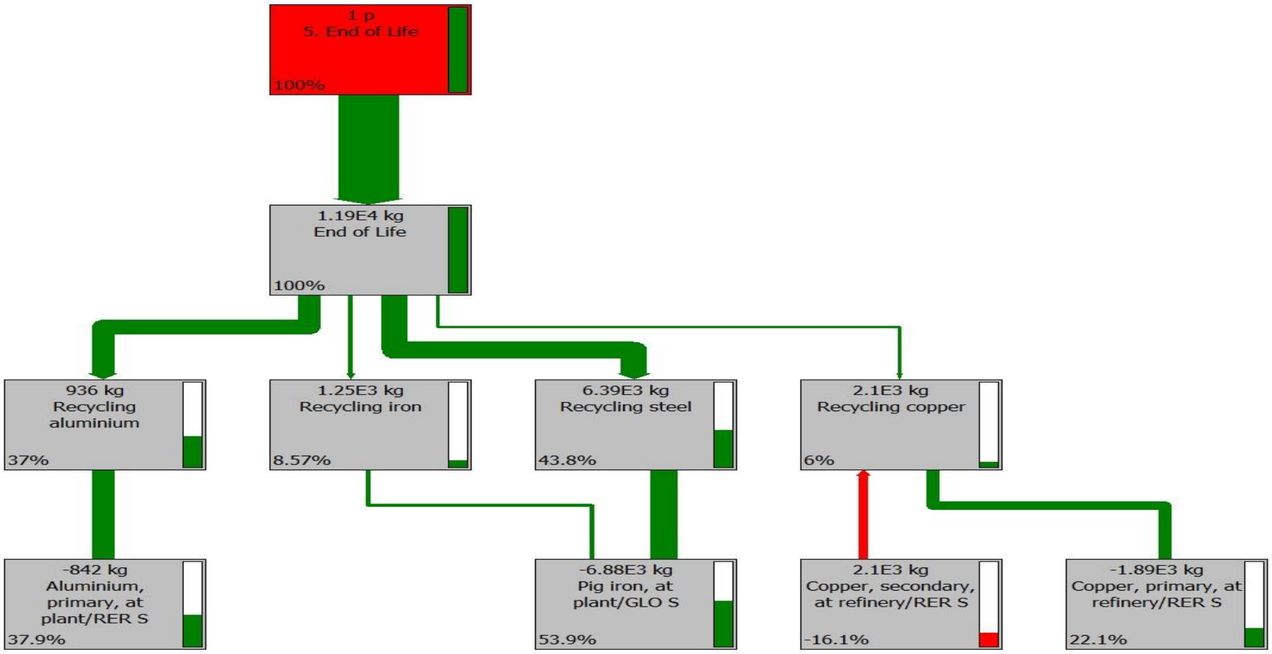

Figure 11: Snapshot from SimaPro exposing damage to resource availability for End of Life phase. Positive percentages represent the contribution on the overall damage mitigation during this phase.

8.1.4 Transportation phase

Due to the low significance of the transportation phase on the overall impacts of Green Room's life cycle (refer to section 8.1.5) this phase will be briefly analyzed in this section. Thus the *single score* approach is exposed on Table 21 in order to identify the most impacting categories for this phase.

Table 21: *Single Score* results for Transportation phase through Endpoint approach.

Impact category	Unit	Total
Fossil depletion	Pt	**1.32E+02**
Climate change Human Health	Pt	**8.31E+01**
Climate change Ecosystems	Pt	**5.44E+01**
Particulate matter formation	Pt	**2.06E+01**
Human toxicity	Pt	**4.87E+00**
Natural land transformation	Pt	**3.79E+00**
Urban land occupation	Pt	**1.61E+00**
Agricultural land occupation	Pt	**3.02E-01**
Terrestrial ecotoxicity	Pt	**1.49E-01**
Terrestrial acidification	Pt	**1.20E-01**
Ionizing radiation	Pt	**9.22E-02**
Metal depletion	Pt	**7.49E-02**
Freshwater eutrophication	Pt	**2.69E-02**

Ozone depletion	Pt	**2.47E-02**
Photoch. oxidant formation	Pt	**1.07E-02**
Freshwater ecotoxicity	Pt	**4.48E-03**
Marine ecotoxicity	Pt	**1.68E-05**
Total	Pt	**3.02E+02**

It is clear that due to the utilization of diesel during the transportation phase, the most impacting categories are fossil depletion (due to non-renewable fuel use), climate change (due to CO_{2eq} emissions) and particulate matter formation (emission of PM associated to diesel burning).

8.1.5 Green Room: the whole picture

The results of Green Room life cycle are exposed below. Here all phases described above are added together and the whole life cycle picture can be thoroughly investigated. The first values on Table 22 are *characterization* results calculated through ReCiPe midpoint method. This table exposes the whole emissions and resources utilized in the Green Room, grouped in impact categories.

Table 22: Characterization results for Green Room Life Cycle through Midpoint approach.

Impact category	Unit	Total	Extr./Manuf.	Transportation	Utilization	End of Life
Climate change	kg CO2 eq	**2.13E+05**	6.95E+04	2.99E+03	1.61E+05	-2.09E+04
Ozone depletion	kg CFC-11 eq	**1.73E+00**	1.74E+00	4.73E-04	6.08E-03	-9.94E-03
Human toxicity	kg 1,4-DB eq	**9.18E+05**	3.18E+05	3.51E+02	6.96E+05	-9.62E+04
Photochemical oxidant formation	kg NMVOC	**7.68E+02**	2.28E+02	1.38E+01	6.22E+02	-9.62E+01
Particulate matter formation	kg PM10 eq	**8.06E+02**	2.53E+02	3.99E+00	6.68E+02	-1.19E+02
Ionizing radiation	kg U235 eq	**3.08E+04**	1.59E+04	2.83E+02	1.76E+04	-2.88E+03
Terrestrial acidification	kg SO2 eq	**1.45E+03**	5.21E+02	9.02E+00	1.08E+03	-1.61E+02
Freshwater eutrophication	kg P eq	**4.40E+02**	1.62E+02	2.67E-01	3.33E+02	-5.59E+01
Marine eutrophication	kg N eq	**2.52E+02**	7.58E+01	4.09E+00	2.03E+02	-3.06E+01
Terrestrial ecotoxicity	kg 1,4-DB eq	**3.40E+02**	2.00E+01	5.13E-01	3.22E+02	-2.39E+00
Freshwater ecotoxicity	kg 1,4-DB eq	**1.02E+04**	4.21E+03	7.52E+00	7.22E+03	-1.25E+03
Marine ecotoxicity	kg 1,4-DB eq	**1.18E+04**	4.73E+03	9.15E+00	8.35E+03	-1.26E+03
Agricultural land occupation	m2a	**2.47E+04**	1.27E+03	1.15E+01	2.38E+04	-4.09E+02
Urban land occupation	m2a	**3.15E+03**	9.96E+02	3.65E+01	2.37E+03	-2.58E+02

Natural land transformation	m2	**2.08E+02**	1.11E+01	1.08E+00	1.99E+02	-3.37E+00
Water depletion	m3	**1.57E+03**	6.37E+02	1.12E+01	1.13E+03	-2.05E+02
Metal depletion	kg Fe eq	**2.57E+05**	1.33E+05	1.40E+02	2.21E+05	-9.72E+04
Fossil depletion	kg oil eq	**3.65E+04**	1.60E+04	1.10E+03	2.58E+04	-6.32E+03

As explained before, negative values showed on end of life phase represent mitigation of impacts due to so called 'avoided products'. For instance recycling of copper avoids extraction and production of primary copper, leading to a positive effect on the overall life cycle result.

On one hand, when comparing the different phases to each other, it is noticeable the almost negligible impacts that are accounted for transportation. On the other hand utilization phase presents the highest potential impacts. Except for ozone depletion, which is dominated by the refrigerant R134a during extraction/manufacturing phase, the utilization phase presented the highest values for all impact categories.

Going further, the *normalized* values on Table 23 expose an interesting figure: four impact categories presented values more than thousand times higher than an average European citizen presented in the year 2000, for the same impact categories. However, it is important to have in mind that despite the magnitude of the normalized values, these numbers do not directly represent the extension of damages to the environment, but just picture the most relevant categories compared to the overall European emissions and resources utilization, during that year.

Table 23: Normalization results of Green Room Life Cycle through Midpoint approach.

Impact category	Total	Extrac./Manuf.	Transportation	Utilization	End of Life
Human toxicity	**1.55E+03**	5.36E+02	5.91E-01	1.17E+03	-1.62E+02
Marine ecotoxicity	**1.41E+03**	5.64E+02	1.09E+00	9.97E+02	-1.51E+02
Natural land transformation	**1.29E+03**	6.85E+01	6.71E+00	1.23E+03	-2.09E+01
Freshwater eutrophication	**1.06E+03**	3.91E+02	6.44E-01	8.03E+02	-1.35E+02
Freshwater ecotoxicity	**9.32E+02**	3.85E+02	6.88E-01	6.61E+02	-1.15E+02
Metal depletion	**3.60E+02**	1.86E+02	1.97E-01	3.10E+02	-1.36E+02
Ozone depletion	**7.89E+01**	7.90E+01	2.15E-02	2.77E-01	-4.52E-01
Particulate matter formation	**5.41E+01**	1.70E+01	2.67E-01	4.48E+01	-7.97E+00
Terrestrial acidification	**4.22E+01**	1.51E+01	2.62E-01	3.14E+01	-4.69E+00
Terrestrial ecotoxicity	**4.14E+01**	2.43E+00	6.25E-02	3.92E+01	-2.91E-01
Fossil depletion	**2.20E+01**	9.61E+00	6.64E-01	1.55E+01	-3.80E+00
Climate change	**1.90E+01**	6.20E+00	2.67E-01	1.44E+01	-1.87E+00
Photochemical oxidant formation	**1.45E+01**	4.29E+00	2.60E-01	1.17E+01	-1.81E+00
Marine eutrophication	**1.33E+01**	3.99E+00	2.15E-01	1.07E+01	-1.61E+00
Urban land occupation	**7.73E+00**	2.45E+00	8.96E-02	5.83E+00	-6.35E-01
Agricultural land occupation	**5.47E+00**	2.82E-01	2.54E-03	5.28E+00	-9.04E-02
Ionizing radiation	**4.93E+00**	2.54E+00	4.53E-02	2.81E+00	-4.60E-01

Human toxicity and marine ecotoxicity (as well as freshwater ecotoxicity) are directly affected by manganese emissions to water compartments, due to copper utilization in Green Room (components manufacturing) and the copper present in the electricity distribution network. Interestingly the same explanation is valid for freshwater eutrophication, but in this case due to the release of phosphate to freshwater compartments. Another important category according to *normalized* results is natural land transformation which is related, in a great share, to the hydropower plant used as electricity supplier and the 'natural' area occupied by its reservoir.

In fact in order to increase the environmental significance of the results the endpoint approach is applied and showed on Table 24. Here the *characterized* results are exposed according to damage categories and their contributing impact categories. As expected, utilization phase presents the higher potential damages for every damage category, and similarly to the midpoint approach, ozone depletion is the only impact category presenting higher damages for human health under extraction/manufacturing phase. As explained before, the reason lies on the manufacturing of the HFC-R134a refrigerant.

Table 24: Characterization results for Green Room Life Cycle through Endpoint approach.

Impact category	Unit	Total	Extrac./Manuf.	Transportation	Utilization	End of Life
Climate change Human Health	DALY	**2.99E-01**	9.73E-02	4.19E-03	2.26E-01	-2.93E-02
Ozone depletion	DALY	**3.12E-03**	3.14E-03	1.25E-06	1.60E-05	-3.00E-05
Human toxicity	DALY	**6.42E-01**	2.23E-01	2.46E-04	4.87E-01	-6.73E-02
Photoch. oxidant formation	DALY	**2.99E-05**	8.89E-06	5.39E-07	2.43E-05	-3.75E-06
Particulate matter formation	DALY	**2.10E-01**	6.58E-02	1.04E-03	1.74E-01	-3.09E-02
Ionizing radiation	DALY	**5.05E-04**	2.60E-04	4.65E-06	2.88E-04	-4.72E-05
Climate change Ecosystems	species.yr	**1.69E-03**	5.51E-04	2.37E-05	1.28E-03	-1.66E-04
Terrestrial acidification	species.yr	**8.41E-06**	3.02E-06	5.23E-08	6.27E-06	-9.36E-07
Freshwater eutrophication	species.yr	**1.93E-05**	7.13E-06	1.17E-08	1.46E-05	-2.46E-06
Terrestrial ecotoxicity	species.yr	**4.31E-05**	2.54E-06	6.52E-08	4.08E-05	-3.04E-07
Freshwater ecotoxicity	species.yr	**2.65E-06**	1.10E-06	1.95E-09	1.88E-06	-3.26E-07
Marine ecotoxicity	species.yr	**9.47E-09**	3.79E-09	7.32E-12	6.68E-09	-1.01E-09
Agricultural land occupation	species.yr	**2.77E-04**	1.43E-05	1.32E-07	2.67E-04	-4.59E-06
Urban land occupation	species.yr	**6.07E-05**	1.92E-05	7.04E-07	4.58E-05	-4.99E-06
Natural land transformation	species.yr	**3.59E-04**	1.67E-05	1.65E-06	3.46E-04	-5.32E-06
Metal depletion	$	**1.84E+04**	9.48E+03	1.00E+01	1.58E+04	-6.94E+03

Fossil depletion	$	**5.87E+05**	2.57E+05	1.77E+04	4.14E+05	-1.02E+05

Still according to Table 24 the most prominent impact categories regarding damages to human health are human toxicity, climate change and particulate matter formation, being together virtually responsible for the totality of human health damage (1.15) DALY (Table 25). In fact through Table 25 it is possible to calculate the exact damage share for each life cycle phases. Utilization represents around 77% of damages to human health; extraction/manufacturing 33.7%; transport around 0.5%; while end of life phase represents a mitigation of 11.1% of the total damage to human health.

Table 25: Characterization results for Green Room Life Cycle through Endpoint approach (damage categories).

Damage category	Unit	Total	Extrac./Manuf.	Transportation	Utilization	End of Life
Human Health	DALY	**1.15E+00**	3.89E-01	5.48E-03	8.87E-01	-1.28E-01
Ecosystems	species.yr	**2.46E-03**	6.15E-04	2.63E-05	2.00E-03	-1.85E-04
Resources	$	**6.06E+05**	2.67E+05	1.78E+04	4.30E+05	-1.09E+05

As noticed the sum of damages are higher than 100%, reaching a total of 111.1%. This is explained by the fact that extraction/manufacturing, utilization and transport phases cause together a total damage to human health 11.1% higher (1.28 DALY) than the final value of 1.15 DALY. By its turn, the final DALY value of 1.15 is achieved by damage mitigation derived from the superb end of life phase, which decreases 0.128 DALY from the former value, 1.28 DALY. The same explanation is applied to other damage categories and these values can be seen on Table 26.

Table 26: Damage and damage mitigation during Green Room Life Cycle

Damage category	Unit	Damages	Mitigation	Final Result
Human Health	DALY	**1.28E+00**	**-1.28E-01**	**1.15E+00**
Ecosystems	species.yr	**2.65E-03**	**-1.85E-04**	**2.46E-03**
Resources	$	**7.14E+05**	**-1.09+05**	**6.06E+05**

Damage to ecosystem diversity presents climate change, agricultural land occupation and natural land transformation as the impact categories having higher damages (Table 24). Together they are responsible for 94% of the total damage in this category. Regarding the life cycle phases, utilization is responsible for the highest share of total damages for ecosystem diversity, representing around 81.5% of the total. Extraction/manufacturing phase presents damage of 6.15E-04 species.yr or around 25% of the total share. The portion accounted for transportation is almost negligible, being responsible for around 1% of total damage to ecosystem diversity. On the other hand, end of life phase represents a mitigation of 7.5% of the total damage.

The last category, damage to resource depletion, is greatly influenced by fossil depletion impact category, where utilization again plays the most influent role. This phase accounts for almost 71 % of the total damage in this category, while extraction/manufacturing reaches 44% and transportation presents its highest damage share: almost 3%. Due to the 'avoided products' in the end of life, this phase reaches its maximum overall contribution, representing almost 18% of damage mitigation on the total value of $ 1.09E+05.

Interestingly the *normalized* values of the endpoint approach exposed on Table 27, do not present the same magnitude as seen on the *normalized* values calculated through the midpoint approach (Table 23). It is important to state that in that case, the midpoint approach exposes total emissions and resource utilization for different impact categories, while the endpoint method applies a different environmental pathway to expose damages caused by those emissions and utilized resources, for three damage categories. Thus the different results obtained.

Table 27: Normalization results of Green Room Life Cycle through Endpoint approach.

Impact category	Total	Extrac./Manuf.	Transportation	Utilization	End of Life
Human toxicity	**3.19E+01**	1.10E+01	1.22E-02	2.41E+01	-3.34E+00
Fossil depletion	**2.19E+01**	9.59E+00	6.62E-01	1.54E+01	-3.79E+00
Climate change Human Health	**1.48E+01**	4.83E+00	2.08E-01	1.12E+01	-1.45E+00
Particulate matter formation	**1.04E+01**	3.26E+00	5.14E-02	8.61E+00	-1.53E+00
Climate change Ecosystems	**9.68E+00**	3.16E+00	1.36E-01	7.34E+00	-9.51E-01
Natural land transformation	**2.05E+00**	9.56E-02	9.46E-03	1.98E+00	-3.04E-02
Agricultural land occupation	**1.59E+00**	8.20E-02	7.56E-04	1.53E+00	-2.63E-02
Metal depletion	**6.85E-01**	3.54E-01	3.75E-04	5.90E-01	-2.59E-01
Urban land occupation	**3.48E-01**	1.10E-01	4.03E-03	2.62E-01	-2.86E-02
Terrestrial ecotoxicity	**2.47E-01**	1.45E-02	3.73E-04	2.34E-01	-1.74E-03
Ozone depletion	**1.55E-01**	1.56E-01	6.19E-05	7.92E-04	-1.49E-03
Freshwater eutrophication	**1.11E-01**	4.08E-02	6.72E-05	8.38E-02	-1.41E-02
Terrestrial acidification	**4.82E-02**	1.73E-02	3.00E-04	3.59E-02	-5.36E-03
Ionizing radiation	**2.51E-02**	1.29E-02	2.30E-04	1.43E-02	-2.34E-03
Freshwater ecotoxicity	**1.52E-02**	6.27E-03	1.12E-05	1.08E-02	-1.87E-03
Photoch. oxidant formation	**1.49E-03**	4.41E-04	2.67E-05	1.20E-03	-1.86E-04
Marine ecotoxicity	**5.42E-05**	2.17E-05	4.19E-08	3.83E-05	-5.79E-06

Following the same trend presented on extraction/manufacturing and utilization phases, the overall picture of Green Room's life cycle also exposes human toxicity, climate change, fossil depletion and particulate matter formation as most impacting categories for the *single score* step, as seen on Table 28. Figure 12 shows, also for *single score* values, the contribution of each life cycle phase and processes used in Green Room. Note that just contributions higher than 1% to the overall impacts are visible.

Table 28: ***Single Score*** **results for Green Room Life Cycle through Endpoint approach.**

Impact category	Unit	Total	Extrac./Manuf.	Transportation	Utilization	End of Life
Human toxicity	Pt	**1.27E+04**	4.42E+03	4.87E+00	9.66E+03	-1.33E+03
Climate change Human Health	Pt	**5.92E+03**	1.93E+03	8.31E+01	4.49E+03	-5.81E+02
Fossil depletion	Pt	**4.38E+03**	1.92E+03	1.32E+02	3.09E+03	-7.58E+02
Particulate matter formation	Pt	**4.16E+03**	1.31E+03	2.06E+01	3.44E+03	-6.13E+02
Climate change Ecosystems	Pt	**3.87E+03**	1.26E+03	5.44E+01	2.93E+03	-3.80E+02
Natural land transformation	Pt	**8.22E+02**	3.82E+01	3.79E+00	7.92E+02	-1.22E+01
Agricultural land occupation	Pt	**6.35E+02**	3.28E+01	3.02E-01	6.13E+02	-1.05E+01
Urban land occupation	Pt	**1.39E+02**	7.08E+01	7.49E-02	1.18E+02	-1.14E+01
Metal depletion	Pt	**1.37E+02**	4.40E+01	1.61E+00	1.05E+02	-5.18E+01
Terrestrial ecotoxicity	Pt	**9.88E+01**	5.81E+00	1.49E-01	9.35E+01	-6.96E-01
Ozone depletion	Pt	**6.20E+01**	6.22E+01	2.47E-02	3.17E-01	-5.96E-01
Freshwater eutrophication	Pt	**4.42E+01**	1.63E+01	2.69E-02	3.35E+01	-5.63E+00
Terrestrial acidification	Pt	**1.93E+01**	6.92E+00	1.20E-01	1.44E+01	-2.14E+00
Ionizing radiation	Pt	**1.00E+01**	5.16E+00	9.22E-02	5.71E+00	-9.36E-01
Freshwater ecotoxicity	Pt	**6.07E+00**	2.51E+00	4.48E-03	4.30E+00	-7.47E-01
Photochemical oxidant formation	Pt	**5.94E-01**	1.76E-01	1.07E-02	4.82E-01	-7.45E-02
Marine ecotoxicity	Pt	**2.17E-02**	8.67E-03	1.68E-05	1.53E-02	-2.32E-03
Total	**Pt**	**3.31E+04**	**1.11E+04**	**3.02E+02**	**2.54E+04**	**-3.76E+03**

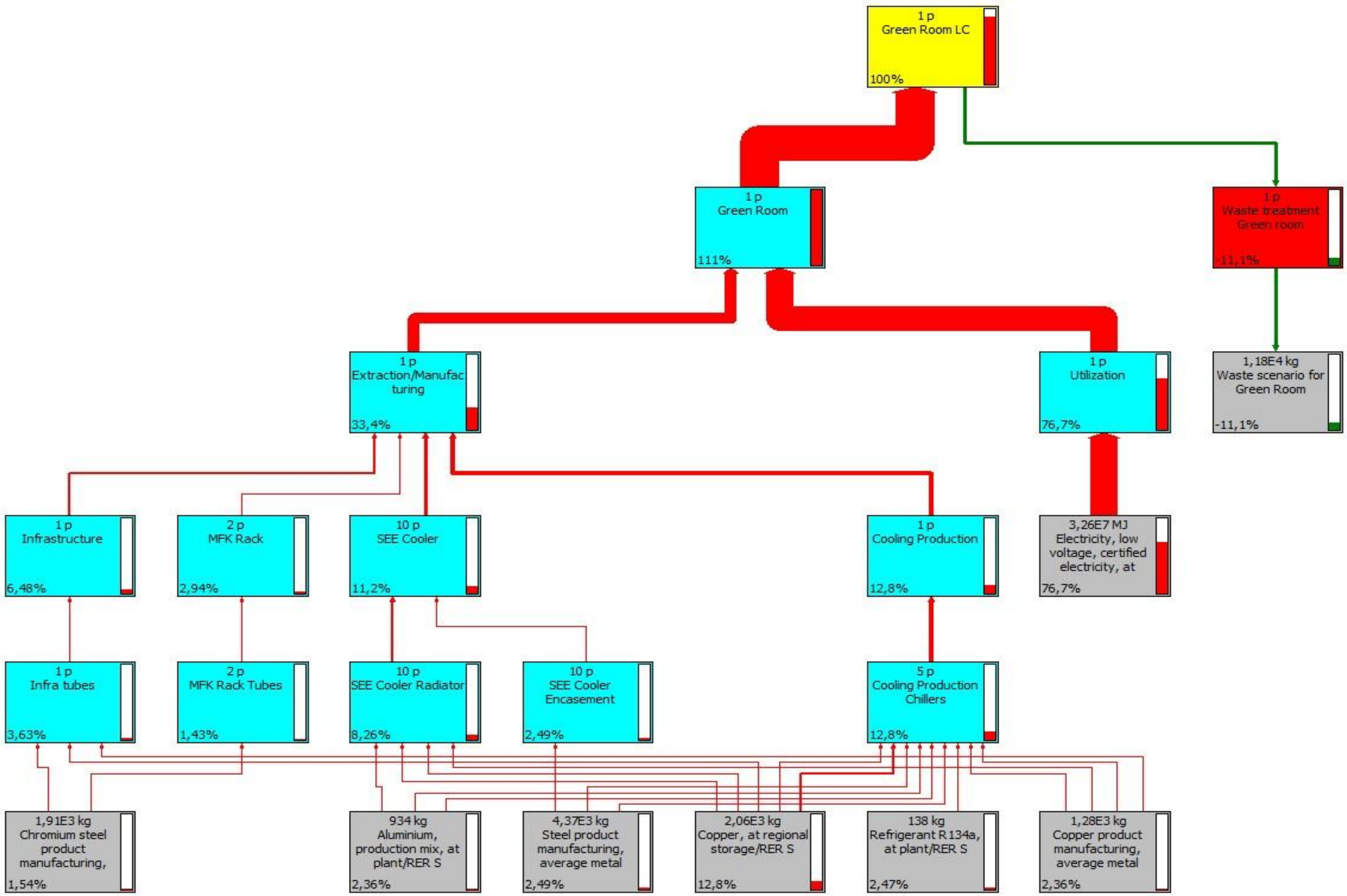

Figure 12: Snapshot from SimaPro exposing single score result for Green Room Life Cycle. The percentages represent the contribution on the overall single score value for each component in this phase (1% *cut-off*).

9 Discussion

9.1 Sensitivity analysis of the results

A sensitivity analysis is performed in this section in order to assure stability of the results described in section 8.1. Here the data of several elements in the model were modified in order to verify how sensible the overall result obtained is to specific data variations. The sensitivity is exposed under the *single score* step of ReCiPe endpoint method, comparing the overall results obtained before and after data modification.

The first modification regards the end of life phase. As explained before this phase can be described as an ideal end of life scenario and might be overestimated. This being said, a scenario where Green Room is land filled provides an interesting figure of how sensible the overall result is regarding the end of life phase. This scenario was created using an available Ecoinvent dataset which addresses waste streams to be disposed on a sanitary landfill. This dataset is described in Appendix 3: Dataset Descriptions (Table 57). The second variation was made in order to verify the effect that changes on extraction/manufacturing phase would cause to the overall result. This being said all raw material extraction and manufacturing processes used in the model were increased by 30%.

One might argue about the almost negligible impacts caused by transportation phase, as discussed before. Hence all transportation occurring during Green Room's life cycle was increased by 100%. This was meant in order to fulfill general gaps that unfortunately occurred during data collection for this phase.

The final data variations were applied to utilization phase. First an increase of 20% was added to the total electricity consumption since the value modeled might contain uncertainties, as no long-term data for electricity consumption is available (section 7.2.3). Secondly the process of electricity production was changed to European production mix; Swedish production mix and US production mix (the reader is referred again to Table 57 in Appendix 3: Dataset Descriptions). This was motivated in order to visualize the impacts on running Green Room under different shares of non-renewable energy. Table 29 below exposes the obtained values:

Table 29: Sensitivity analysis results according *single score* values

Data Modified	Overall result before data modification (Pt)	Overall result after data modification (Pt)	Variation
Transportation phase increased by 100%	3.31E+04	**3.34E+04**	+0.9%
30% increase on raw material and manufacturing processes utilized	3.31E+04	**3.53E+04**	+6.7%
Green Room is entirely land filled	3.31E+04	**3.70E+04**	+11.8%
Electricity consumption (from renewable sources) increased by 20%	3.31E+04	**3.81E+04**	+15.1%

Electricity production: Swedish mix	3.31E+04	**7.53E+04**	+127.5%
Electricity production: European mix	3.31E+04	**5.10E+05**	+1440.8%
Electricity production: US mix	3.31E+04	**6.52E+05**	+1869.8%

As seen on Table 29 none of the first four modifications led to more than 20% variation on the overall result. This finding exposes that despite data uncertainties the model is considered stable when representing the environmental impacts during Green Room's life cycle. However one condition exposed critical variation on the model: there is considerable sensitivity to which kind of source is being used to produce the electricity consumed by Green Room. For instance even an increase of 20% in the total electricity consumption, given that this is supplied by renewable certified sources (which is the actual situation in Green Room), did not lead to as high impacts as operating Green Room in the US, or supplying the system through the European mix of electricity production.

These variations (more than 1000%) are directly related to a higher or lower extent of fossil fuels being utilized by different countries in order to produce electricity. For example, the electricity produced in Sweden according to Ecoinvent database, is mostly originated from nuclear (50%) and hydropower (40%) plants; while in the US, almost 50% is derived from hard coal, which led to significant variation seen on the overall impacts.

It is important to state that the model created on SimaPro strictly represents the actual situation of Green Room located in Stockholm: it runs on 100% renewable certified electricity production. Therefore one must be aware of potentially higher impacts when applying the Green Room cooling concept using different sources of electricity production.

9.2 Possible improvements

The results presented on section 8.1.5 exposed two major 'hot spots' on Green Room's life cycle: utilization and extraction/manufacturing phases. Being so, this section aims at providing possible improvements in order to decrease the environmental impacts originated from these two phases.

9.2.1 Utilization phase

The first analyzed 'hot spot', the utilization phase, is responsible for the greatest impacts on Green Room's life cycle. According to ReCiPe midpoint approach this phase is accountable for around 75% of all CO_{2eq} and 1,4-DB_{eq} emissions (Table 22), while the endpoint approach shows that utilization is responsible for about 77% of the potential damages to human health; 81% for ecosystem diversity and 71% for resources, just to cite some important parameters evaluated by these methods (Table 25). Actually two factors are directly responsible for higher or lower impacts on the utilization phase: the electricity source and the total electricity consumption; therefore possible improvements concerning these factors might be achieved through adoption of cleaner fuels and measures to decrease consumption.

The electricity supplied to Green Room is derived 100% from renewable certified sources, having hydropower accounting for virtually the entire share. This means that the impacts are greatly reduced if compared to the employment of non-renewable sources for electricity production, as seen on sensitivity analysis results (section 9.1). For instance the ReCiPe *single score* result for 1 kWh of electricity at the grid, produced according the Swedish mix, presents a value almost 173% higher than 1 kWh of certified electricity, in the same conditions (Table 30).

Table 30: *Single score* results for two different Ecoinvent datasets.

Ecoinvent process	Unit	Single score result
Electricity, low voltage, production Sweden, at grid	1 kWh	**7.36E-03**
Certified electricity, low voltage, production Sweden, at grid	1 kWh	**2.70E-03**

This being said, this work assumes that the fact of Green Room being supplied by renewable certified electricity is already an improvement, which means that this study will focus on means of decreasing the total electricity consumption in Green Room, during utilization phase. Hence, as observed in section 7.2.3, the highest share of the electricity consumed by the whole system is due to the chillers, used for water cooling purposes during 'summer'. In fact the electricity consumption could be drastically reduced by the employment of geothermal energy in order to cool down the water used in the system, replacing the conventional existent chillers.

Preliminary figures obtained by software modeling (Izadi and El Azzi, 2012), points geothermal cooling to a total power consumption of around 10 kW, which added to the electricity consumed within the room, 4 kW (section 7.2.3), leads to a total value of 14 kW. As a result, during 20 years of utilization, the Green Room with 'geo-cooling' approach would lead to a total electricity consumption of approximately 2453 MWh – about 73% lower than the actual consumption of 9058 MWh!

For instance, if assumed that raw material extraction and processes involved during manufacturing of the geothermal cooling system could be similar to those modeled for conventional chillers, the environmental 'gains' would be derived greatly from the lower energy consumption and in a lower scale from the absence of the R134a refrigerant, since no such element is necessary with this technology. Table 31 below presents the result from *single score* approach obtained by modeling Green Room with 'geo-cooling' technology, under the conditions described above.

Table 31: *Single score* result for Green Room with geothermal cooling technology.

Data Modified	Overall result before data modification (Pt)	Overall result after data modification (Pt)	Variation
Green Room with geothermal cooling system	3.31E+04	**1.33E+04**	**-59.8%**

As seen, the total impacts would be decreased by almost 60%, and interestingly under the described condition, the extraction/manufacturing phase, rather than utilization, would be responsible for the highest share of impacts (76% and 50%, respectively), as seen on Figure 13. However one must be aware that this is just an illustration of the potential improvement that could be achieved with the 'geo-cooling' technology, meaning that in order to obtain more accurate values a thorough study on the geothermal cooling solution is necessary, which may well be performed in a future work.

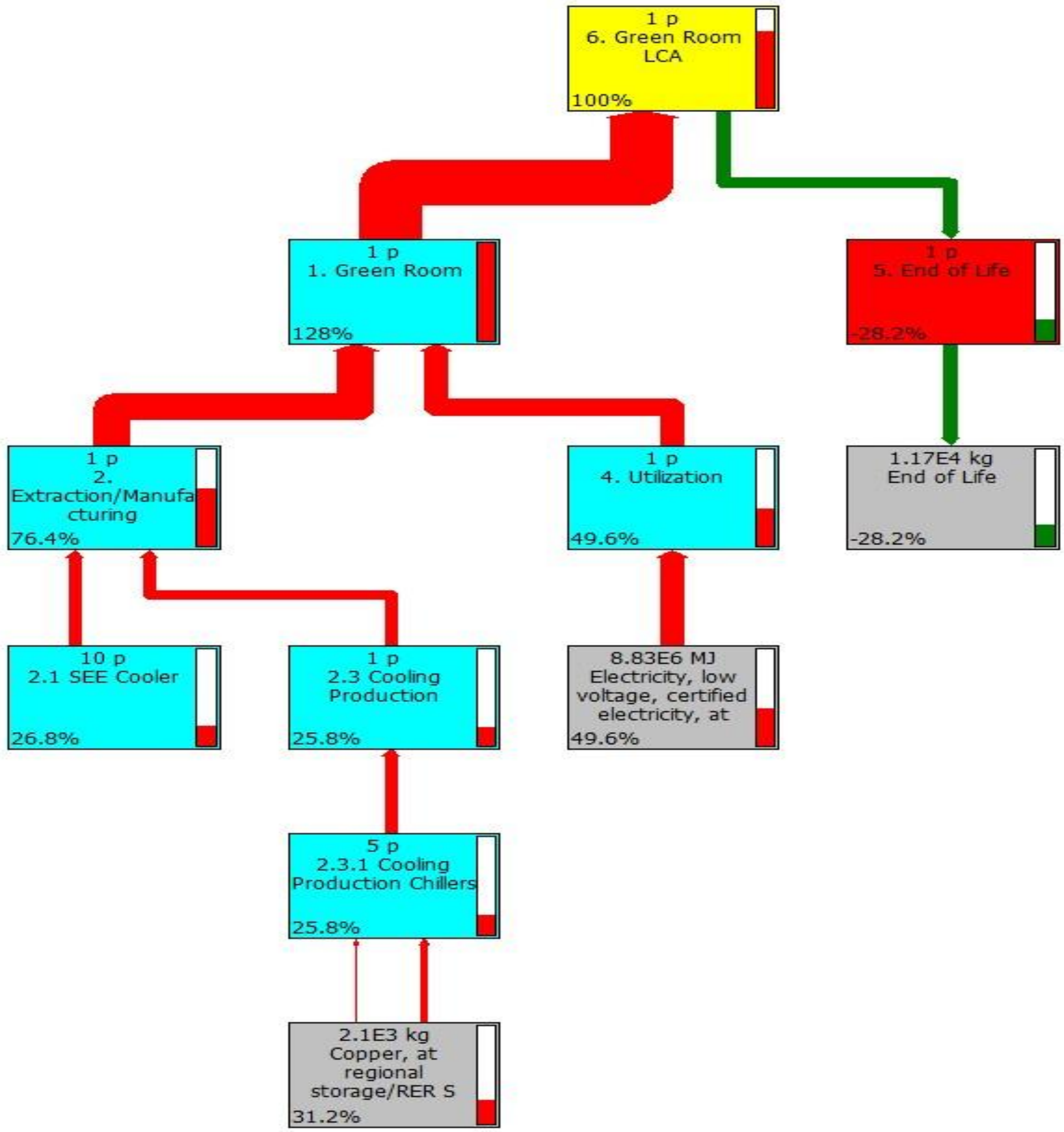

Figure 13: Snapshot from SimaPro exposing *single score* result for Green Room Life Cycle with geothermal cooling technology (3% *cut-off*). The percentages represent the contribution on the overall *single score* value for each component.

9.2.2 Extraction/Manufacturing phase

As presented on section 8.1.1, the two most potentially impacting components during extraction/manufacturing phase are the chillers, used for cooling production, and the SEE coolers. According to both, midpoint and endpoint approach of ReCiPe method, these elements presented the highest values for every impact and damage category during extraction/manufacturing phase.

In order to investigate possible improvements that could promote the environmental performance of raw material extraction and components manufacturing in Green Room, it is necessary to expose the most impacting processes occurring during this phase. According to Table 32, obtained through *single score* step, copper extraction and copper product manufacturing are responsible together for around 45% of all potential impacts, being by far the most impacting processes during this phase. In order to better illustrate this statement, other elements considerably contributing on the impacts, according to their importance to extraction/manufacturing phase are: stainless steel (chromium steel); R134a refrigerant; low-alloyed steel; and aluminum.

Table 32: Processes contribution on Extraction/Manufacturing impacts (*single score*; 2.2% *cut-off*)

Ecoinvent process	Unit	Total	Contribution (%)
Copper, at regional storage/RER S	Pt	4.15E+03	37.3
Chromium steel 18/8, at plant/RER S	Pt	1.01E+03	9.1
Refrigerant R134a, at plant/RER S	Pt	9.41E+02	8.5
Steel, low-alloyed, at plant/RER S	Pt	9.14E+02	8.2
Steel product manufacturing, average metal working/RER S	Pt	8.13E+02	7.3
Copper product manufacturing, average metal working/RER S	Pt	7.82E+02	7.0
Aluminum, production mix, at plant/RER S	Pt	7.51E+02	6.8
Chromium steel product manufacturing, average metal working/RER S	Pt	4.83E+02	4.4
Aluminum product manufacturing, average metal working/RER S	Pt	2.98E+02	2.7
Remaining processes	Pt	9.80E+02	8.7
Total of all processes	**Pt**	**1.11E+04**	**100**

As a result of this analysis this chapter investigates the possible substitution of copper during extraction/manufacturing phase, for an 'equivalent' material that could provide the system with comparable performance while at the same time lowering the overall impacts during Green Room's life cycle. However it is important to state that the mentioned material substitution is focused on an environmental perspective, therefore not aiming at assessing any possible implication(s) of copper substitution on the overall efficiency of the system, but to suggest a superior option for enhancing the environmental performance of Green Room.

In fact as seen on Figure 14, out of 2100 Kg of copper present in Green Room, almost 87% (1826 Kg) is accounted for chiller units (48%) and SEE Coolers radiators (38.9%). Even though, due to lack of data the chiller units could not be modeled in the same way as the SEE Coolers – for which information of all components could be gathered (refer to Appendix 2: Data Sources SEE Cooler) – the copper presented in these units are also in the form of tubes used in the heat exchanging process, as exposed in IBU (2011).

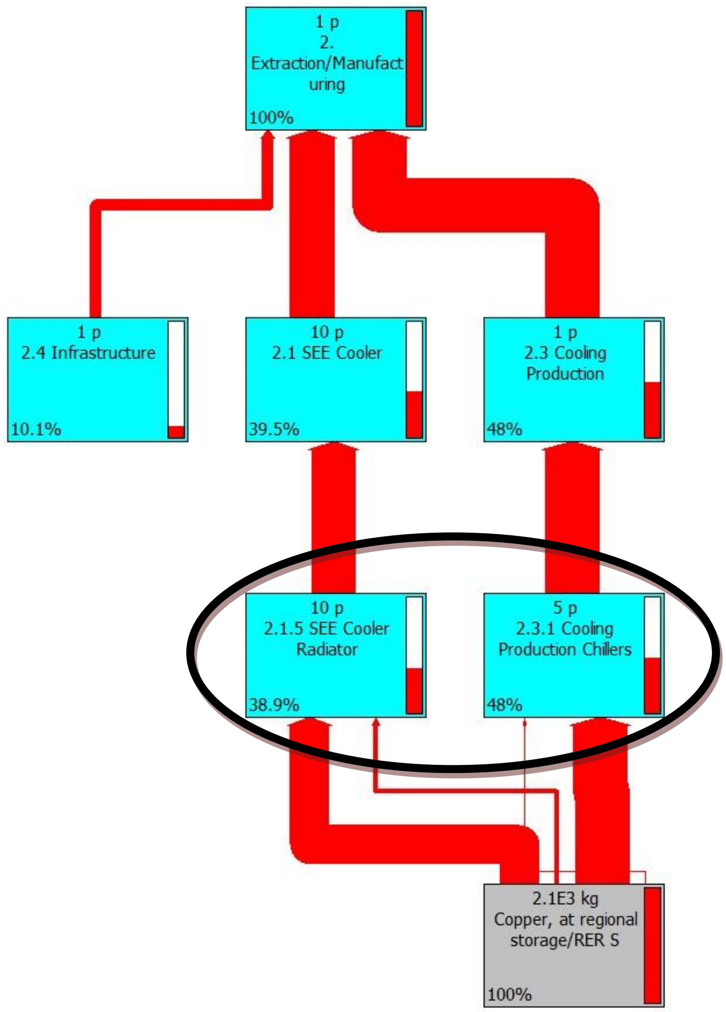

Figure 14: SimaPro snapshot exposing components share on the total amount of copper present in Green Room (10% *cut-off*).

Hence in order to investigate the most environmental 'friendly' alternative for copper substitution on the mentioned components, a research on the available tube material options used on heat exchangers is necessary. In this case the material alternatives offered by AIA, the manufacturer of SEE Cooler radiators, are selected as ground for this assessment. In fact AIA offers, beside pure copper, tubes manufactured out of tinned copper; cupronickel; aluminum; stainless steel and titanium, as seen on (AIA, 2012).

Out of the five presented alternatives, just aluminum and stainless steel are considered as suitable copper replacement materials in this situation. Clearly the first two options are disregarded due to their copper content; while titanium is rejected due to its high price on the international market (Table 33 adapted from MetalPrices.com, 2012).

Table 33: Metal prices comparison

Titanium ingot, 90% Ti (Dec, 2007)	Stainless Steel, flat rolled (Apr, 2009)	Aluminum billet, 99% Al (Oct, 2011)
US$ 17,700/ton	US$ 1,982/ton	US$ 2,500/ton

Therefore, after defining the replacement materials for copper, the data inserted in SimaPro could be modified through the replacement of copper components in the chillers and SEE cooler radiators by aluminum and stainless steel, which provided new results for the overall impacts. The following Table 34 and

Table 35 present the model results obtained through the *single score* step of ReCiPe endpoint method, after the copper substitution during extraction/manufacturing phase:

Table 34: Life cycle impact assessment results for Extraction/Manufacturing phase.

Data Modified	Where	Extrac./Manuf. phase result, before data modification (Pt)	Extrac./Manuf. phase result, after data modification (Pt)	Variation
Aluminum instead of copper	SEE Cooler radiator and Chillers	1.11E+04	**8.84E+03**	**-20.4%**
Stainless steel instead of copper	SEE Cooler radiator and Chillers	1.11E+04	**8.09E+03**	**-27.1%**

Table 35: Life cycle impact assessment results for Green Room Life Cycle*. All phases included.

Data Modified	Where	Overall GRLC* result, before data modification (Pt)	Overall GRLC* phase result, after data modification (Pt)	Variation
Aluminum instead of copper	SEE Cooler radiator and Chillers	3.31E+04	**3.02E+04**	**-8.8%**
Stainless steel instead of copper	SEE Cooler radiator and Chillers	3.31E+04	**3.10E+04**	**-6.3%**

Both the replacement of copper by aluminum or stainless steel tubes promoted environmental gains on the analyzed phase, being that the utilization of stainless steel tubes on heat exchangers could provide Green Room's extraction/manufacturing phase with the highest environmental gains. On the other hand, aluminum tubes exposed better overall result for Green Room life cycle.

Interestingly the reason for those differences on analyzing just extraction/manufacturing phase or the whole Green Room's life cycle is that according the *single score* assessment, stainless steel production presents lower overall impact than aluminum production, which favors stainless steel during extraction/manufacturing phase. However, when considering the whole life cycle, including the end of life phase, aluminum is favored, since the same *single score* assessment exposes recycling of aluminum presenting higher impact mitigation than recycling of stainless steel. Thus the material presenting lower impact according the present model is dependent on the inclusion or not of the end of life phase on the evaluation.

In spite of the perspective chosen to define which material presents the lowest environmental impact for *single score* assessment, it is true that according the exposed values both materials presented environmental gains over copper. In fact, Figure 15 and Figure 16 below expose that the gains are greatly derived from the lower damage to human health category, which was possible by the great reduction of copper from the system; even though a slightly increase on damage to ecosystem diversity and resource depletion occurred.

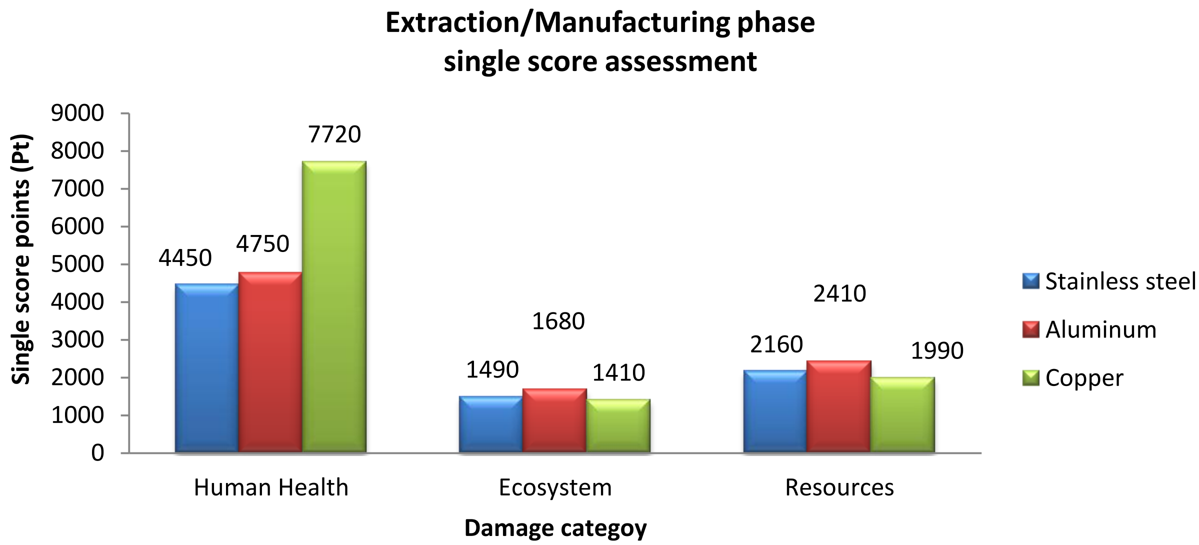

Figure 15: ***Single score*** **results for damage categories, according to material utilized (Extraction/Manufacturing phase)**

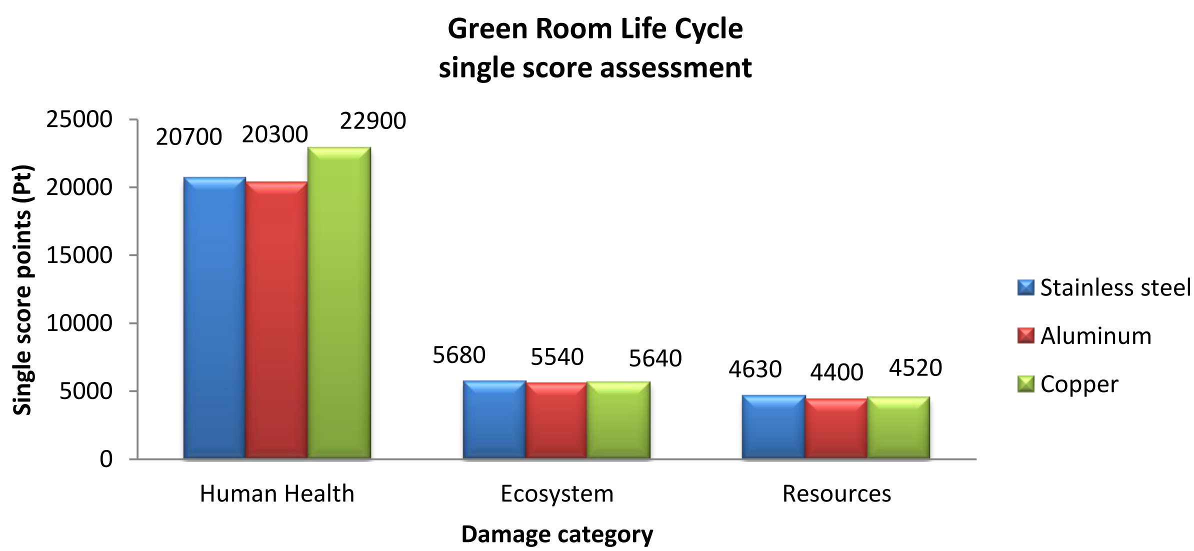

Figure 16: ***Single score*** **results for damage categories, according to material utilized (Green Room Life Cycle – all phases included).**

The noticed increase on damage to resources and ecosystem diversity occurs due to the higher energy demand during stainless steel and aluminum manufacturing (compared to copper) for which the Ecoinvent database translates into higher utilization of fossil fuels, which impacts resources; and higher emissions of CO_{2eq}, which impacts ecosystem diversity category. However, even though further investigation would be necessary in order to precisely define the real extension of variations occurring in the results, it is expected that the substitution of copper tubes by stainless steel or aluminum tubes in the heat exchangers equipments, would lead Green Room to a better environmental performance overall.

9.3 Green Room life cycle and the exergy consumption-based assessment

As mentioned earlier in this report, on section 4, no study focusing exclusively on the assessment of environmental impacts related to a high power-density datacenter cooling system could be found in the literature, until the completion of this work. As also explained, this could be reasoned by the lack of interest of the scientific community on such issue; the absence of published works due to confidentiality reasons, for example; or even the inability of the author of this study on finding available sources.

However, one study that could be retrieved from the literature is worth mentioning in this discussion section (even though impossible to be directly compared with Green Room study). The work of Meza et al. (2010) assesses the life cycle of an entirely datacenter through an exergy consumption-based analysis. Given that exergy is defined as “the maximum work retrievable when a system is brought into thermodynamic equilibrium with its surroundings”, which in other words means “the ability of a system to do useful work” (Lettieri et al., 2009); the quantification of exergy consumption in a system, can thus be seen as an indicator of resource quality demand, through the weighting of each resource by its theoretical energetic usefulness (Bösch et al., 2007). Hence not surprisingly this metric is applied for sustainability purposes in order to identify how ‘efficiently’ energy and material resources are being utilized in a system.

This being said, even though the above mentioned study does not focus solely on the datacenter cooling system and does not apply the same assessment method as used in Green Room life cycle assessment, it still raised some interesting points that could be highlighted in this discussion section. The first point is the exergy metric approach itself, which could be useful to be applied in Green Room life cycle assessment in order to provide a picture of its environmental performance by exposing an overview of how ‘useful’ energy and ‘useful’ matter, are being depleted during its whole life cycle.

Another interesting point is that, even though Meza et al. (2010) did not take into consideration material flows related to the datacenter cooling system in the assessment, the suggestions proposed in that work, in order to improve the environmental performance of the cooling system, are aligned with the possible improvement for the utilization phase, described in this work, here presented in section 9.2.1. Meza et al. (2010) ground most of its cooling system improvements on the decrease of electricity consumption by the cooling infrastructure, which could be based on physical modifications in the system. Interestingly this is also the scenario presented for Green Room.

Conclusively it is not an easy task to relate the results of this work, acquired through ReCiPe assessment method, to the exergy consumption-based method applied by Meza et al. (2010). Clearly both methods expose different bias of the environmental performance of the analyzed systems. For instance ReCiPe focus on providing a direct track of emissions occurring during the life cycle of a product or service, identifying where they occur and which processes are responsible for it. This is clearly a drawback of exergy consumption-based methodologies, since this feature is not taken into consideration in the assessment. On the other hand ReCiPe does not provide a thorough quantification of the different qualities of energy that are consumed in a system. The only metric available that relates to energy in some way, is the fossil depletion impact category, which defines the total oil equivalent consumed in the system assessed. In contrast the assessment used by Meza et al. (2010) in his work, presents its strong point precisely on the quantification of the energy (and its quality) being consumed within a product or service life cycle. Therefore it is understood in this work that both ReCiPe and exergy consumption-based methods could be complementary to each other. A future study assessing Green Room through an exergy consumption-based method could provide different aspects of the environmental performance of this cooling system, which might have not been highlighted by ReCiPe impact assessment method.

9.4 The Functional Unit

One important aspect to be taken into consideration in a future study could be the further development of the functional unit (f.u.) defined in this work. In fact as for the time of completion of this work, there was no common LCA framework for datacenter cooling systems in the literature, which could make the comparison of the environmental performance of two or more systems a hard task. Therefore many hours were spent on the definition of a suitable f.u. for Green Room that could allow future comparisons with other systems.

During this investigative process, a number of variables that could influence on the functional output of a cooling system such as Green Room were highlighted. For instance, the main 'service' provided by Green Room is cooling the air that reaches the inlet of electronic components at a specific temperature, which in this case is defined as 'no higher than 22°C'. This aimed temperature should clearly be part of the f.u., however just the temperature limit obviously does not completely represent the functional output of Green Room. Therefore in order to define a more comprehensive f.u. it was necessary to identify some 'characteristics' of the environment for which this air temperature should be achieved.

This being said two main variables were defined as most relevant in this case: the area (or volume) of the datacenter room and the total heat dissipated in this room. Both are fundamental for designing a suitable cooling system that will be able to 'stabilize' the air in the room at a maximum temperature of '22°C'. A bigger area will clearly demand more power from the cooling system, due to the higher volume of air that need to be cooled, while following the same trend, the higher the heat dissipation in the room the higher is the power of the cooling system necessary to 'stabilize' the room's temperature.

Therefore the area and the heat dissipation in the room were defined in this study as the 'heat load' of the datacenter room, which is the power of all electronic racks divided by the area of the room. This resulted in 5 kW/m2 (350 kW ÷ 70 m2), and the functional unit was finally defined as "*one unit of 'Green Room' necessary to dissipate a heat load of 5 KW/m^2 maintaining a temperature no higher than 22°C to the inlet of electronic devices*."

However even though this was the functional unit defined in this work, it is believed that there is still room for improvements in the definition of a proper functional unit. Clearly the f.u. should be as "universal" as possible, in order to allow the comparison of Green Room with any other datacenter cooling system presenting the same functional output. This being said it could be interesting to evaluate other variables that could be relevant on defining a comprehensive functional unit, such as, the airflow volume necessary inside the datacenter room (in m3/s) to achieve the desired temperature; the power load of the electronic racks; and even the definition of a different temperature limit.

All these above mentioned variables are supposed to influence on how Green Room delivers its 'service'. For instance, in order to achieve the temperature of 22°C to the inlet of the electronic components, a particular airflow volume is necessary. And by its turn, the airflow volume is directly affected by the speed of pumps and fans utilized in Green Room. Hence this raised a question: how influential is the definition of a specific speed for the system's pumps and fans, on the definition of Green Room's functional unit? In other words, should those variables be stated on the f.u. description also? Unfortunately this question could not be answered before the completion of this report, but it is stated here as a matter of possible investigation in a future work.

Moreover, one other interesting consideration would be attempting to define Green Room's functional unit based on the average power load of its computer racks divided by the area utilized by the racks (also called work cell), as defined in Intel Corporation (2006) and Patterson et al. (2007). This metric, which is explained in the mentioned reports, is likely to expose in a straightforward way that Green Room is designed to be applied in a high-power density datacenter, therefore allowing simpler comparisons with similar systems.

Finally, also as a matter of future consideration, the temperature limit to the inlet of electronic components could be modified. For example, if increased to a value higher than 22°C, the total electricity consumption of the system could be decreased (since the cooling power within the room would be also decreased). Hence this modification would lead this work to different overall results and perhaps leading to improved environmental performance.

As seen, many could be the variables that possibly influence on the definition of Green Room functional unit, however even though it is suggested that the f.u. being used in this work should undergo a 'deeper' investigative process in order to expose any other important variable that could have been missed, it is believed that this functional unit still provides a fair basis for general comparison between Green Room and similar systems, given that there is not in the literature any other study dealing with environmental performance of high-density datacenter cooling systems through a life cycle perspective.

10 Conclusion and future recommendations

The results of this study exposed large dominance of the utilization phase on the overall outcome of Green Room's life cycle assessment. This is true for all damage and impact categories, with one exception: the potential impact from ozone depletion category is dominated by extraction/manufacturing phase, due to the presence of R134a refrigerant.

In fact according to the *characterization* results of ReCiPe endpoint method, the utilization phase was responsible for 77% of total potential damage on human health; 81% on ecosystem diversity and 71% on resources availability. In addition, following the same trend, utilization phase contributed for 77% of the total potential impacts, according the *single score* step.

The potential impacts and damages originated from transportation phase were almost negligible in comparison to the overall result. They were distributed as 0.5% of total potential damage on human health; 1% on ecosystem diversity and 3% on resources availability. As for the *single score* step this phase was accounted for roughly 1% of the total value.

The end of life phase presented negative contributions for all environmental categories, providing considerable mitigation of total impacts for the whole life cycle. The greatest result of this phase was achieved on damage to resource availability, greatly derived from recycling of aluminum and steel, where a mitigation of almost 18% of the total damage in this category was verified. As for the *single score* result, the end of life phase presented an overall potential impact mitigation of 11%.

The extraction/manufacturing phase was responsible for approximately 34% of the overall damage to human health category, being that chillers and SEE cooler units played the most important role on this damage category due to the large amount of copper present in these equipments. As for damage to ecosystem diversity the overall result contribution of this phase was 25%, having the manufacturing of refrigerant R134a and steel as the main impacting processes. In addition it was on damage to resource availability category that extraction/manufacturing phase presented its higher contribution share: 44% of the overall potential damages were derived from this phase, with highest impacts resulted from steel and aluminum related processes. Finally *single score* results exposed a total contribution of around 34% in the total life cycle potential impacts.

Overall, the most impacting categories on Green Room's life cycle were human toxicity, representing 55% of total damage to human health category; climate change, responsible for 26% of total damage to human health and 69% of damage to ecosystem diversity; and fossil depletion, with 97% share on total damage to resource availability.

Furthermore a sensitivity analysis was carried out and revealed an acceptable stability of the model regarding data uncertainty from extraction/manufacturing, transport, utilization and end of life phases. On the other hand this analysis also exposed that the results of the life cycle assessment are radically influenced by the source being used for electricity production. For instance, utilizing the electricity production mix of United States, which is greatly derived from coal to supply electricity to Green Room, would increase the overall life cycle result in more than 1800%, according to the *single score* step of ReCiPe endpoint method (Table 29).

Finally two possible improvements were suggested in order to promote the environmental performance of Green Room life cycle: reduction of electricity consumption and copper substitution from the system. The former was based on the replacement of conventional chillers for geothermal cooling technology, which could lead to an overall reduction on the impacts of 60% (Table 31). The latter was reasoned on the substitution of copper tubes present in the SEE coolers and chillers, by stainless steel or aluminum tubes, which could lead to a reduction of around 27% on the impacts of extraction/manufacturing phase (Table 34), or 9% reduction on the overall Green Room's life cycle result (Table 35).

Despite any drawback and obstacles that are pertinent to the execution of a life cycle assessment, the defined goals of this study are considered reached. TeliaSonera's knowledge of Green Room's environmental performance was increased by the clear identification of the most impacting phases during Green Room's life cycle; the identification of the specific impacts occurring during the whole life cycle and through the suggestion of possible improvements in order to promote Green Room's environmental performance.

However even though this study has fulfilled its objectives, it is important to state that any external communication of this report as it is, should clearly state the lack of external validation. Nevertheless this work is the initial step towards an Environmental Product Declaration of Green Room concept, meaning that an external revision and possible improvements on this life cycle assessment are likely to be performed in the near future.

Besides external validation of this report, a future recommendation is to consider the utilization of a different method (or methods) of impact assessment, rather than ReCiPe, and a different database (or databases), other than Ecoinvent. It is likely that different aspects of Green Room's life cycle could be exposed through different assessment approaches.

In addition it is obvious that regardless all efforts made in order to maximize the reliability of this study, there still are areas in this LCA that could be improved in the future. This is true especially on what regards data collection for materials and manufacturing processes. Even though the model did not exposed high sensitivity to extraction/manufacturing phase, it would be recommended that TeliaSonera could develop an internal database for processes and materials in order to provide more accurate values in future studies of this kind. Moreover following the same explanation, the end of life scenario could be thoroughly investigated, since it is likely to be leading to too optimistic results.

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Appendices

Appendix 1: Life Cycle Inventory Results

Table 36: Green Room Life Cycle Inventory result

No	Substance	Compartment	Unit	Total
1	Aluminum, 24% in bauxite, 11% in crude ore, in ground	Resource input	kg	5.59E+02
2	Anhydrite, in ground	Resource input	kg	4.46E-03
3	Barite, 15% in crude ore, in ground	Resource input	kg	5.99E+01
4	Basalt, in ground	Resource input	kg	3.49E+01
5	Borax, in ground	Resource input	kg	8.10E+00
6	Bromine, 0.0023% in Water emissions	Resource input	kg	8.99E-04
7	Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground	Resource input	kg	1.98E-01
8	Calcite, in ground	Resource input	kg	3.49E+04
9	Carbon dioxide, in Air emissions	Resource input	kg	1.42E+05
10	Carbon, in organic matter, in Soil emissions	Resource input	kg	5.22E-02
11	Cerium, 24% in bastnasite, 2.4% in crude ore, in ground	Resource input	kg	6.32E-03
12	Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	Resource input	kg	9.58E+02
13	Chrysotile, in ground	Resource input	kg	3.50E-02
14	Cinnabar, in ground	Resource input	kg	3.53E-03
15	Clay, bentonite, in ground	Resource input	kg	1.59E+02
16	Clay, unspecified, in ground	Resource input	kg	1.37E+04
17	Coal, brown, in ground	Resource input	kg	1.15E+04
18	Coal, hard, unspecified, in ground	Resource input	kg	2.22E+04
19	Cobalt, in ground	Resource input	kg	4.08E-04
20	Colemanite, in ground	Resource input	kg	2.30E+01
21	Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore, in ground	Resource input	kg	7.69E-08
22	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	Resource input	kg	3.79E+02
23	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Resource input	kg	2.10E+03
24	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	Resource input	kg	5.58E+02
25	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Resource input	kg	9.14E+02
26	Diatomite, in ground	Resource input	kg	2.66E-05
27	Dolomite, in ground	Resource input	kg	5.81E+01
28	Energy, gross calorific value, in biomass	Resource input	MJ	9.79E+05
29	Energy, gross calorific value, in biomass, primary forest	Resource input	MJ	3.62E+00
30	Energy, kinetic (in wind), converted	Resource input	MJ	3.74E+05
31	Energy, potential (in hydropower reservoir), converted	Resource input	MJ	3.79E+07
32	Energy, solar, converted	Resource input	MJ	1.29E+05
33	Europium, 0.06% in bastnasite, 0.006% in crude ore, in ground	Resource input	kg	1.58E-05
34	Feldspar, in ground	Resource input	kg	4.14E-03
35	Fluorine, 4.5% in apatite, 1% in crude ore, in ground	Resource input	kg	8.66E-01
36	Fluorine, 4.5% in apatite, 3% in crude ore, in ground	Resource input	kg	3.87E-01
37	Fluorspar, 92%, in ground	Resource input	kg	3.37E+02
38	Gadolinium, 0.15% in bastnasite, 0.015% in crude ore, in ground	Resource input	kg	3.95E-05
39	Gallium, 0.014% in bauxite, in ground	Resource input	kg	3.68E-04

40	Gas, mine, off-gas, process, coal mining/m3	Resource input	m3	2.19E+02
41	Gas, natural, in ground	Resource input	m3	1.09E+04
42	Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	Resource input	kg	2.25E-04
43	Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	Resource input	kg	4.13E-04
44	Gold, Au 1.4E-4%, in ore, in ground	Resource input	kg	4.94E-04
45	Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	Resource input	kg	7.55E-04
46	Gold, Au 4.3E-4%, in ore, in ground	Resource input	kg	1.87E-04
47	Gold, Au 4.9E-5%, in ore, in ground	Resource input	kg	4.48E-04
48	Gold, Au 6.7E-4%, in ore, in ground	Resource input	kg	6.94E-04
49	Gold, Au 7.1E-4%, in ore, in ground	Resource input	kg	7.82E-04
50	Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	Resource input	kg	4.69E-05
51	Granite, in ground	Resource input	kg	3.25E-06
52	Gravel, in ground	Resource input	kg	2.63E+05
53	Gypsum, in ground	Resource input	kg	3.76E-01
54	Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground	Resource input	kg	2.57E-02
55	Iodine, 0.03% in Water emissions	Resource input	kg	1.98E-04
56	Iron, 46% in ore, 25% in crude ore, in ground	Resource input	kg	1.26E+04
57	Kaolinite, 24% in crude ore, in ground	Resource input	kg	4.23E+00
58	Kieserite, 25% in crude ore, in ground	Resource input	kg	1.64E-02
59	Krypton, in Air emissions	Resource input	kg	2.21E-05
60	Lanthanum, 7.2% in bastnasite, 0.72% in crude ore, in ground	Resource input	kg	1.90E-03
61	Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	Resource input	kg	-8.18E+01
62	Lithium, 0.15% in brine, in ground	Resource input	kg	1.35E-02
63	Magnesite, 60% in crude ore, in ground	Resource input	kg	2.12E+02
64	Magnesium, 0.13% in Water emissions	Resource input	kg	1.72E+00
65	Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	Resource input	kg	1.38E+02
66	Metamorphous rock, graphite containing, in ground	Resource input	kg	2.94E+00
67	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	Resource input	kg	1.70E+01
68	Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	Resource input	kg	7.32E+00
69	Molybdenum, 0.016% in sulfide, Mo 8.2E-3% and Cu 0.27% in crude ore, in ground	Resource input	kg	1.18E-09
70	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	Resource input	kg	1.49E+00
71	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	Resource input	kg	2.68E+01
72	Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	Resource input	kg	3.00E+00
73	Neodymium, 4% in bastnasite, 0.4% in crude ore, in ground	Resource input	kg	1.04E-03
74	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	Resource input	kg	1.30E-01
75	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Resource input	kg	2.28E+03
76	Occupation, arable, non-irrigated	Resource input	m2a	2.01E+01
77	Occupation, construction site	Resource input	m2a	2.68E+01
78	Occupation, dump site	Resource input	m2a	1.25E+03
79	Occupation, dump site, benthos	Resource input	m2a	5.23E+00
80	Occupation, forest, intensive	Resource input	m2a	1.98E+02
81	Occupation, forest, intensive, normal	Resource input	m2a	2.44E+04
82	Occupation, forest, intensive, short-cycle	Resource input	m2a	9.08E-01
83	Occupation, industrial area	Resource input	m2a	2.04E+02
84	Occupation, industrial area, benthos	Resource input	m2a	5.16E-02

85	Occupation, industrial area, built up	Resource input	m2a	5.11E+02
86	Occupation, industrial area, vegetation	Resource input	m2a	2.54E+02
87	Occupation, mineral extraction site	Resource input	m2a	1.63E+02
88	Occupation, permanent crop, fruit, intensive	Resource input	m2a	1.15E+00
89	Occupation, shrub land, sclerophyllous	Resource input	m2a	6.32E+01
90	Occupation, traffic area, rail embankment	Resource input	m2a	2.28E+01
91	Occupation, traffic area, rail network	Resource input	m2a	2.53E+01
92	Occupation, traffic area, road embankment	Resource input	m2a	2.57E+02
93	Occupation, traffic area, road network	Resource input	m2a	4.28E+02
94	Occupation, urban, discontinuously built	Resource input	m2a	3.01E-02
95	Occupation, Water emissions bodies, artificial	Resource input	m2a	6.99E+04
96	Occupation, Water emissions courses, artificial	Resource input	m2a	3.61E+04
97	Oil, crude, in ground	Resource input	kg	1.24E+04
98	Olivine, in ground	Resource input	kg	3.10E-03
99	Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Resource input	kg	8.25E-05
100	Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Resource input	kg	1.98E-04
101	Peat, in ground	Resource input	kg	1.51E+01
102	Phosphorus, 18% in apatite, 12% in crude ore, in ground	Resource input	kg	1.58E+00
103	Phosphorus, 18% in apatite, 4% in crude ore, in ground	Resource input	kg	3.46E+00
104	Praseodymium, 0.42% in bastnasite, 0.042% in crude ore, in ground	Resource input	kg	1.11E-04
105	Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Resource input	kg	1.24E-04
106	Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Resource input	kg	4.43E-04
107	Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Resource input	kg	2.22E-05
108	Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Resource input	kg	6.97E-05
109	Rhenium, in crude ore, in ground	Resource input	kg	4.48E-07
110	Samarium, 0.3% in bastnasite, 0.03% in crude ore, in ground	Resource input	kg	7.89E-05
111	Sand, unspecified, in ground	Resource input	kg	4.04E+01
112	Shale, in ground	Resource input	kg	1.30E-02
113	Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	Resource input	kg	4.35E-02
114	Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	Resource input	kg	3.16E-02
115	Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	Resource input	kg	2.88E-03
116	Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	Resource input	kg	6.57E-03
117	Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	Resource input	kg	6.44E-03
118	Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	Resource input	kg	4.25E-03
119	Sodium chloride, in ground	Resource input	kg	2.90E+03
120	Sodium nitrate, in ground	Resource input	kg	2.45E-06
121	Sodium sulphate, various forms, in ground	Resource input	kg	7.22E+00
122	Stibnite, in ground	Resource input	kg	1.81E+01
123	Sulfur, in ground	Resource input	kg	1.86E+00
124	Sylvite, 25 % in sylvinite, in ground	Resource input	kg	1.40E+00
125	Talc, in ground	Resource input	kg	4.84E-01
126	Tantalum, 81.9% in tantalite, 1.6E-4% in crude ore, in ground	Resource input	kg	2.75E-02
127	Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground	Resource input	kg	4.75E-03
128	Tin, 79% in cassiterite, 0.1% in crude ore, in ground	Resource input	kg	4.09E-01
129	TiO2, 54% in ilmenite, 2.6% in crude ore, in ground	Resource input	kg	1.50E+01

130	TiO2, 95% in rutile, 0.40% in crude ore, in ground	Resource input	kg	1.89E-04
131	Transformation, from arable	Resource input	m2	5.99E+00
132	Transformation, from arable, non-irrigated	Resource input	m2	3.71E+01
133	Transformation, from arable, non-irrigated, fallow	Resource input	m2	6.76E-02
134	Transformation, from dump site, inert material landfill	Resource input	m2	1.11E+01
135	Transformation, from dump site, residual material landfill	Resource input	m2	1.51E+00
136	Transformation, from dump site, sanitary landfill	Resource input	m2	2.96E-02
137	Transformation, from dump site, slag compartment	Resource input	m2	2.53E-02
138	Transformation, from forest	Resource input	m2	1.85E+01
139	Transformation, from forest, extensive	Resource input	m2	1.97E+02
140	Transformation, from forest, intensive, clear-cutting	Resource input	m2	3.24E-02
141	Transformation, from industrial area	Resource input	m2	1.08E-01
142	Transformation, from industrial area, benthos	Resource input	m2	2.71E-04
143	Transformation, from industrial area, built up	Resource input	m2	1.23E-03
144	Transformation, from industrial area, vegetation	Resource input	m2	2.09E-03
145	Transformation, from mineral extraction site	Resource input	m2	3.73E+00
146	Transformation, from pasture and meadow	Resource input	m2	2.49E+02
147	Transformation, from pasture and meadow, intensive	Resource input	m2	3.03E-02
148	Transformation, from sea and ocean	Resource input	m2	5.25E+00
149	Transformation, from shrub land, sclerophyllous	Resource input	m2	2.38E+02
150	Transformation, from tropical rain forest	Resource input	m2	3.24E-02
151	Transformation, from unknown	Resource input	m2	4.94E+02
152	Transformation, to arable	Resource input	m2	1.35E+00
153	Transformation, to arable, non-irrigated	Resource input	m2	3.71E+01
154	Transformation, to arable, non-irrigated, fallow	Resource input	m2	1.23E-01
155	Transformation, to dump site	Resource input	m2	8.46E+00
156	Transformation, to dump site, benthos	Resource input	m2	5.23E+00
157	Transformation, to dump site, inert material landfill	Resource input	m2	1.11E+01
158	Transformation, to dump site, residual material landfill	Resource input	m2	1.51E+00
159	Transformation, to dump site, sanitary landfill	Resource input	m2	2.96E-02
160	Transformation, to dump site, slag compartment	Resource input	m2	2.53E-02
161	Transformation, to forest	Resource input	m2	1.50E+01
162	Transformation, to forest, intensive	Resource input	m2	1.32E+00
163	Transformation, to forest, intensive, clear-cutting	Resource input	m2	3.24E-02
164	Transformation, to forest, intensive, normal	Resource input	m2	1.93E+02
165	Transformation, to forest, intensive, short-cycle	Resource input	m2	3.24E-02
166	Transformation, to heterogeneous, agricultural	Resource input	m2	7.16E-01
167	Transformation, to industrial area	Resource input	m2	3.48E+00
168	Transformation, to industrial area, benthos	Resource input	m2	2.27E-02
169	Transformation, to industrial area, built up	Resource input	m2	2.30E+01
170	Transformation, to industrial area, vegetation	Resource input	m2	6.28E+00
171	Transformation, to mineral extraction site	Resource input	m2	2.39E+01
172	Transformation, to pasture and meadow	Resource input	m2	5.47E-02
173	Transformation, to permanent crop, fruit, intensive	Resource input	m2	1.61E-02
174	Transformation, to sea and ocean	Resource input	m2	2.71E-04

175	Transformation, to shrub land, sclerophyllous	Resource input	m2	1.26E+01
176	Transformation, to traffic area, rail embankment	Resource input	m2	5.31E-02
177	Transformation, to traffic area, rail network	Resource input	m2	5.84E-02
178	Transformation, to traffic area, road embankment	Resource input	m2	1.97E+00
179	Transformation, to traffic area, road network	Resource input	m2	1.13E+01
180	Transformation, to unknown	Resource input	m2	5.69E-01
181	Transformation, to urban, discontinuously built	Resource input	m2	5.99E-04
182	Transformation, to Water emissions bodies, artificial	Resource input	m2	4.57E+02
183	Transformation, to Water emissions courses, artificial	Resource input	m2	4.46E+02
184	Ulexite, in ground	Resource input	kg	8.10E-01
185	Uranium, in ground	Resource input	kg	6.04E-01
186	Vermiculite, in ground	Resource input	kg	2.88E-02
187	Volume occupied, final repository for low-active radioactive waste	Resource input	m3	1.15E-03
188	Volume occupied, final repository for radioactive waste	Resource input	m3	2.83E-04
189	Volume occupied, reservoir	Resource input	m3y	3.00E+05
190	Volume occupied, underground deposit	Resource input	m3	5.30E-02
191	Water emissions, cooling, unspecified natural origin/m3	Resource input	m3	2.34E+03
192	Water emissions, lake	Resource input	m3	3.10E+01
193	Water emissions, river	Resource input	m3	6.69E+02
194	Water emissions, salt, ocean	Resource input	m3	4.20E+01
195	Water emissions, salt, sole	Resource input	m3	8.30E+00
196	Water emissions, turbine use, unspecified natural origin	Resource input	m3	3.77E+08
197	Water emissions, unspecified natural origin/m3	Resource input	m3	7.33E+02
198	Water emissions, well, in ground	Resource input	m3	1.37E+02
199	Wood, hard, standing	Resource input	m3	2.50E+01
200	Wood, primary forest, standing	Resource input	m3	3.36E-04
201	Wood, soft, standing	Resource input	m3	7.21E+01
202	Wood, unspecified, standing/m3	Resource input	m3	6.74E-05
203	Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	Resource input	kg	5.97E+01
204	Zirconium, 50% in zircon, 0.39% in crude ore, in ground	Resource input	kg	8.11E-03
205	1-Butanol	Air emissions	kg	4.86E-08
206	1-Pentanol	Air emissions	kg	7.69E-08
207	1-Pentene	Air emissions	kg	5.81E-08
208	1-Propanol	Air emissions	kg	1.65E-03
209	1,4-Butanediol	Air emissions	kg	7.16E-06
210	2-Aminopropanol	Air emissions	kg	3.96E-09
211	2-Butene, 2-methyl-	Air emissions	kg	4.29E-08
212	2-Methyl-1-propanol	Air emissions	kg	1.37E-07
213	2-Nitrobenzoic acid	Air emissions	kg	6.25E-09
214	2-Propanol	Air emissions	kg	1.47E-02
215	Acenaphthene	Air emissions	kg	8.48E-08
216	Acetaldehyde	Air emissions	kg	1.13E-01
217	Acetic acid	Air emissions	kg	1.66E-01
218	Acetone	Air emissions	kg	7.38E-02
219	Acetonitrile	Air emissions	kg	3.52E-05

220	Acrolein	Air emissions	kg	4.15E-05
221	Acrylic acid	Air emissions	kg	6.44E-05
222	Actinides, radioactive, unspecified	Air emissions	Bq	2.75E+01
223	Aerosols, radioactive, unspecified	Air emissions	Bq	2.29E+02
224	Aldehydes, unspecified	Air emissions	kg	2.08E-02
225	Aluminum	Air emissions	kg	5.62E+01
226	Ammonia	Air emissions	kg	3.32E+01
227	Ammonium carbonate	Air emissions	kg	1.55E-02
228	Aniline	Air emissions	kg	3.04E-07
229	Anthranilic acid	Air emissions	kg	4.56E-09
230	Antimony	Air emissions	kg	1.89E-01
231	Antimony-124	Air emissions	Bq	3.85E-03
232	Antimony-125	Air emissions	Bq	4.01E-02
233	Argon-41	Air emissions	Bq	1.02E+05
234	Arsenic	Air emissions	kg	1.42E+00
235	Arsine	Air emissions	kg	7.51E-10
236	Barium	Air emissions	kg	2.00E-02
237	Barium-140	Air emissions	Bq	2.61E+00
238	Benzal chloride	Air emissions	kg	9.97E-12
239	Benzaldehyde	Air emissions	kg	1.79E-05
240	Benzene	Air emissions	kg	1.23E+00
241	Benzene, 1-methyl-2-nitro-	Air emissions	kg	5.40E-09
242	Benzene, 1,2-dichloro-	Air emissions	kg	2.37E-07
243	Benzene, ethyl-	Air emissions	kg	4.04E-02
244	Benzene, hexachloro-	Air emissions	kg	1.46E-04
245	Benzene, pentachloro-	Air emissions	kg	1.88E-05
246	Benzo(a)pyrene	Air emissions	kg	2.52E-03
247	Beryllium	Air emissions	kg	6.05E-04
248	Boric acid	Air emissions	kg	2.34E-07
249	Boron	Air emissions	kg	3.66E-01
250	Boron trifluoride	Air emissions	kg	1.57E-03
251	Bromine	Air emissions	kg	8.49E-02
252	Butadiene	Air emissions	kg	6.29E-06
253	Butane	Air emissions	kg	9.53E-01
254	Butene	Air emissions	kg	1.70E-02
255	Butyrolactone	Air emissions	kg	1.56E-06
256	Cadmium	Air emissions	kg	4.92E-01
257	Calcium	Air emissions	kg	5.19E+00
258	Carbon-14	Air emissions	Bq	1.00E+06
259	Carbon dioxide, biogenic	Air emissions	kg	1.42E+05
260	Carbon dioxide, fossil	Air emissions	kg	1.21E+05
261	Carbon dioxide, land transformation	Air emissions	kg	2.79E+00
262	Carbon disulfide	Air emissions	kg	2.58E+01
263	Carbon monoxide, biogenic	Air emissions	kg	3.08E+01
264	Carbon monoxide, fossil	Air emissions	kg	5.54E+02

265	Cerium-141	Air emissions	Bq	6.33E-01
266	Cesium-134	Air emissions	Bq	3.03E-02
267	Cesium-137	Air emissions	Bq	5.37E-01
268	Chloramine	Air emissions	kg	2.77E-07
269	Chlorine	Air emissions	kg	2.60E-01
270	Chloroacetic acid	Air emissions	kg	4.71E-06
271	Chloroform	Air emissions	kg	2.87E-02
272	Chlorosilane, trimethyl-	Air emissions	kg	1.84E-05
273	Chlorosulfonic acid	Air emissions	kg	4.33E-08
274	Chromium	Air emissions	kg	3.23E+00
275	Chromium-51	Air emissions	Bq	4.06E-02
276	Chromium VI	Air emissions	kg	8.04E-02
277	Cobalt	Air emissions	kg	4.60E-02
278	Cobalt-58	Air emissions	Bq	5.65E-02
279	Cobalt-60	Air emissions	Bq	4.99E-01
280	Copper	Air emissions	kg	4.63E+00
281	Cumene	Air emissions	kg	2.96E-02
282	Cyanide	Air emissions	kg	5.95E-02
283	Cyanoacetic acid	Air emissions	kg	3.55E-08
284	Cyclohexane	Air emissions	kg	8.29E-06
285	Diethyl ether	Air emissions	kg	2.59E-05
286	Diethylamine	Air emissions	kg	1.37E-07
287	Diethylene glycol	Air emissions	kg	1.66E-05
288	Dimethyl malonate	Air emissions	kg	4.45E-08
289	Dinitrogen monoxide	Air emissions	kg	6.02E+01
290	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air emissions	kg	3.33E-07
291	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air emissions	kg	9.85E-08
292	Dipropylamine	Air emissions	kg	8.54E-08
293	Ethane	Air emissions	kg	2.07E+00
294	Ethane, 1,1-difluoro-, HFC-152a	Air emissions	kg	4.75E-02
295	Ethane, 1,1,1-trichloro-, HCFC-140	Air emissions	kg	2.65E-07
296	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air emissions	kg	1.82E+01
297	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air emissions	kg	1.65E+00
298	Ethane, 1,2-dichloro-	Air emissions	kg	2.69E+00
299	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air emissions	kg	4.33E-04
300	Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	Air emissions	kg	1.65E+00
301	Ethane, hexafluoro-, HFC-116	Air emissions	kg	1.33E-02
302	Ethanol	Air emissions	kg	2.67E-02
303	Ethene	Air emissions	kg	7.23E-01
304	Ethene, chloro-	Air emissions	kg	1.46E+00
305	Ethene, tetrachloro-	Air emissions	kg	6.47E-01
306	Ethyl acetate	Air emissions	kg	2.10E-01
307	Ethyl cellulose	Air emissions	kg	1.79E-04
308	Ethylamine	Air emissions	kg	4.41E-07
309	Ethylene diamine	Air emissions	kg	4.86E-06

310	Ethylene oxide	Air emissions	kg	4.83E-04
311	Ethyne	Air emissions	kg	6.04E-02
312	Fluorine	Air emissions	kg	2.06E-01
313	Fluosilicic acid	Air emissions	kg	1.39E-02
314	Formaldehyde	Air emissions	kg	4.17E-01
315	Formamide	Air emissions	kg	1.41E-07
316	Formic acid	Air emissions	kg	3.61E-04
317	Furan	Air emissions	kg	6.69E-05
318	Heat, waste	Air emissions	MJ	4.18E+06
319	Helium	Air emissions	kg	4.53E-02
320	Heptane	Air emissions	kg	1.49E-01
321	Hexane	Air emissions	kg	4.10E-01
322	Hydrocarbons, aliphatic, alkanes, cyclic	Air emissions	kg	7.04E-04
323	Hydrocarbons, aliphatic, alkanes, unspecified	Air emissions	kg	7.33E+00
324	Hydrocarbons, aliphatic, unsaturated	Air emissions	kg	2.69E+00
325	Hydrocarbons, aromatic	Air emissions	kg	6.23E-01
326	Hydrocarbons, chlorinated	Air emissions	kg	9.80E-01
327	Hydrogen	Air emissions	kg	1.24E+00
328	Hydrogen-3, Tritium	Air emissions	Bq	5.46E+06
329	Hydrogen chloride	Air emissions	kg	7.35E+00
330	Hydrogen fluoride	Air emissions	kg	1.03E+00
331	Hydrogen peroxide	Air emissions	kg	2.46E-04
332	Hydrogen sulfide	Air emissions	kg	8.00E+00
333	Iodine	Air emissions	kg	1.87E-02
334	Iodine-129	Air emissions	Bq	9.61E+02
335	Iodine-131	Air emissions	Bq	4.00E+04
336	Iodine-133	Air emissions	Bq	6.66E+00
337	Iodine-135	Air emissions	Bq	7.68E+00
338	Iron	Air emissions	kg	1.07E+00
339	Isocyanic acid	Air emissions	kg	5.39E-04
340	Isoprene	Air emissions	kg	3.11E-06
341	Isopropylamine	Air emissions	kg	1.19E-07
342	Krypton-85	Air emissions	Bq	3.20E+05
343	Krypton-85m	Air emissions	Bq	4.26E+04
344	Krypton-87	Air emissions	Bq	1.22E+04
345	Krypton-88	Air emissions	Bq	1.40E+04
346	Krypton-89	Air emissions	Bq	4.95E+03
347	Lactic acid	Air emissions	kg	6.69E-08
348	Lanthanum-140	Air emissions	Bq	2.23E-01
349	Lead	Air emissions	kg	4.13E+00
350	Lead-210	Air emissions	Bq	9.13E+03
351	m-Xylene	Air emissions	kg	1.00E-01
352	Magnesium	Air emissions	kg	7.30E-01
353	Manganese	Air emissions	kg	7.24E-01
354	Manganese-54	Air emissions	Bq	2.08E-02

355	Mercury	Air emissions	kg	2.33E-02
356	Methane, biogenic	Air emissions	kg	8.81E+02
357	Methane, bromo-, Halon 1001	Air emissions	kg	2.28E-12
358	Methane, bromochlorodifluoro-, Halon 1211	Air emissions	kg	4.44E-04
359	Methane, bromotrifluoro-, Halon 1301	Air emissions	kg	4.36E-04
360	Methane, chlorodifluoro-, HCFC-22	Air emissions	kg	9.94E-02
361	Methane, dichloro-, HCC-30	Air emissions	kg	9.77E-04
362	Methane, dichlorodifluoro-, CFC-12	Air emissions	kg	2.93E-02
363	Methane, dichlorofluoro-, HCFC-21	Air emissions	kg	1.96E-05
364	Methane, fossil	Air emissions	kg	2.22E+02
365	Methane, monochloro-, R-40	Air emissions	kg	1.16E-04
366	Methane, tetrachloro-, CFC-10	Air emissions	kg	3.16E-03
367	Methane, tetrafluoro-, CFC-14	Air emissions	kg	1.10E-01
368	Methane, trichlorofluoro-, CFC-11	Air emissions	kg	3.18E-05
369	Methane, trifluoro-, HFC-23	Air emissions	kg	6.23E-03
370	Methanesulfonic acid	Air emissions	kg	3.58E-08
371	Methanol	Air emissions	kg	1.06E-01
372	Methyl acetate	Air emissions	kg	1.45E-09
373	Methyl acrylate	Air emissions	kg	7.31E-05
374	Methyl amine	Air emissions	kg	5.80E-07
375	Methyl borate	Air emissions	kg	2.88E-08
376	Methyl ethyl ketone	Air emissions	kg	2.10E-01
377	Methyl formate	Air emissions	kg	2.82E-07
378	Methyl lactate	Air emissions	kg	7.35E-08
379	Molybdenum	Air emissions	kg	2.61E-03
380	Monoethanolamine	Air emissions	kg	8.66E-03
381	Nickel	Air emissions	kg	2.82E+00
382	Niobium-95	Air emissions	Bq	2.47E-03
383	Nitrate	Air emissions	kg	8.09E-03
384	Nitrobenzene	Air emissions	kg	4.12E-07
385	Nitrogen fluoride	Air emissions	kg	4.58E-06
386	Nitrogen oxides	Air emissions	kg	5.45E+02
387	NMVOC, non-methane volatile organic compounds, unspecified origin	Air emissions	kg	9.17E+01
388	Noble gases, radioactive, unspecified	Air emissions	Bq	9.24E+09
389	Ozone	Air emissions	kg	4.58E+01
390	PAH, polycyclic aromatic hydrocarbons	Air emissions	kg	6.70E-02
391	Particulates, < 2.5 um	Air emissions	kg	2.45E+02
392	Particulates, > 10 um	Air emissions	kg	3.53E+02
393	Particulates, > 2.5 um, and < 10um	Air emissions	kg	2.17E+02
394	Pentane	Air emissions	kg	1.35E+00
395	Phenol	Air emissions	kg	3.83E-02
396	Phenol, 2,4-dichloro-	Air emissions	kg	9.61E-09
397	Phenol, pentachloro-	Air emissions	kg	2.28E-04
398	Phosphine	Air emissions	kg	1.07E-02
399	Phosphoric acid	Air emissions	kg	8.29E-06

400	Phosphorus	Air emissions	kg	2.60E-01
401	Phosphorus trichloride	Air emissions	kg	2.89E-03
402	Platinum	Air emissions	kg	3.28E-06
403	Plutonium-238	Air emissions	Bq	1.31E-04
404	Plutonium-alpha	Air emissions	Bq	3.01E-04
405	Polonium-210	Air emissions	Bq	1.63E+04
406	Polychlorinated biphenyls	Air emissions	kg	2.26E-04
407	Potassium	Air emissions	kg	1.97E+01
408	Potassium-40	Air emissions	Bq	2.30E+03
409	Propanal	Air emissions	kg	8.67E-04
410	Propane	Air emissions	kg	1.32E+00
411	Propene	Air emissions	kg	1.42E-01
412	Propionic acid	Air emissions	kg	5.02E-03
413	Propylamine	Air emissions	kg	4.46E-08
414	Propylene oxide	Air emissions	kg	6.46E-03
415	Protactinium-234	Air emissions	Bq	1.38E+02
416	Radioactive species, other beta emitters	Air emissions	Bq	4.27E+04
417	Radium-226	Air emissions	Bq	6.79E+03
418	Radium-228	Air emissions	Bq	6.36E+03
419	Radon-220	Air emissions	Bq	4.79E+04
420	Radon-222	Air emissions	Bq	1.81E+10
421	Ruthenium-103	Air emissions	Bq	5.42E-04
422	Scandium	Air emissions	kg	1.79E-03
423	Selenium	Air emissions	kg	1.47E-01
424	Silicon	Air emissions	kg	1.98E+00
425	Silicon tetrafluoride	Air emissions	kg	2.59E-05
426	Silver	Air emissions	kg	7.64E-03
427	Silver-110	Air emissions	Bq	5.37E-03
428	Sodium	Air emissions	kg	1.28E+00
429	Sodium chlorate	Air emissions	kg	2.82E-04
430	Sodium dichromate	Air emissions	kg	8.86E-02
431	Sodium formate	Air emissions	kg	3.25E-05
432	Sodium hydroxide	Air emissions	kg	7.50E-04
433	Sodium tetrahydroborate	Air emissions	kg	3.04E-03
434	Strontium	Air emissions	kg	2.43E-02
435	Styrene	Air emissions	kg	1.04E-03
436	Sulfate	Air emissions	kg	5.21E+00
437	Sulfur dioxide	Air emissions	kg	1.06E+03
438	Sulfur hexafluoride	Air emissions	kg	4.46E-01
439	Sulfur trioxide	Air emissions	kg	3.34E-06
440	Sulfuric acid	Air emissions	kg	2.69E-04
441	t-Butyl methyl ether	Air emissions	kg	4.45E-04
442	t-Butylamine	Air emissions	kg	1.61E-07
443	Terpenes	Air emissions	kg	2.94E-05
444	Tetramethyl ammonium hydroxide	Air emissions	kg	1.10E-01

445	Thallium	Air emissions	kg	4.50E-04
446	Thorium	Air emissions	kg	1.92E-04
447	Thorium-228	Air emissions	Bq	7.19E+02
448	Thorium-230	Air emissions	Bq	5.56E+02
449	Thorium-232	Air emissions	Bq	6.58E+02
450	Thorium-234	Air emissions	Bq	1.38E+02
451	Tin	Air emissions	kg	2.09E-01
452	Titanium	Air emissions	kg	7.03E-02
453	Toluene	Air emissions	kg	4.78E-01
454	Toluene, 2-chloro-	Air emissions	kg	1.29E-07
455	Trimethylamine	Air emissions	kg	2.57E-09
456	Tungsten	Air emissions	kg	1.88E-04
457	Uranium	Air emissions	kg	2.41E-04
458	Uranium-234	Air emissions	Bq	1.64E+03
459	Uranium-235	Air emissions	Bq	7.74E+01
460	Uranium-238	Air emissions	Bq	3.39E+03
461	Uranium alpha	Air emissions	Bq	7.45E+03
462	Vanadium	Air emissions	kg	1.68E-01
463	Water emissions	Air emissions	kg	9.74E+03
464	Xenon-131m	Air emissions	Bq	6.00E+04
465	Xenon-133	Air emissions	Bq	2.06E+06
466	Xenon-133m	Air emissions	Bq	4.91E+03
467	Xenon-135	Air emissions	Bq	8.34E+05
468	Xenon-135m	Air emissions	Bq	5.11E+05
469	Xenon-137	Air emissions	Bq	1.36E+04
470	Xenon-138	Air emissions	Bq	1.07E+05
471	Xylene	Air emissions	kg	3.07E-01
472	Zinc	Air emissions	kg	3.70E+00
473	Zinc-65	Air emissions	Bq	1.04E-01
474	Zirconium	Air emissions	kg	2.23E-04
475	Zirconium-95	Air emissions	Bq	1.01E-01
476	1-Butanol	Water emissions	kg	7.62E-04
477	1-Pentanol	Water emissions	kg	1.85E-07
478	1-Pentene	Water emissions	kg	1.40E-07
479	1,4-Butanediol	Water emissions	kg	2.86E-06
480	2-Aminopropanol	Water emissions	kg	9.91E-09
481	2-Methyl-1-propanol	Water emissions	kg	3.28E-07
482	2-Methyl-2-butene	Water emissions	kg	1.03E-07
483	2-Propanol	Water emissions	kg	6.61E-07
484	4-Methyl-2-pentanone	Water emissions	kg	5.92E-08
485	Acenaphthene	Water emissions	kg	4.07E-06
486	Acenaphthylene	Water emissions	kg	2.55E-07
487	Acetaldehyde	Water emissions	kg	1.37E-03
488	Acetic acid	Water emissions	kg	2.45E-01
489	Acetone	Water emissions	kg	3.26E-06

490	Acetonitrile	Water emissions	kg	2.97E-08
491	Acetyl chloride	Water emissions	kg	1.45E-07
492	Acidity, unspecified	Water emissions	kg	1.61E-02
493	Acrylate, ion	Water emissions	kg	1.53E-04
494	Actinides, radioactive, unspecified	Water emissions	Bq	1.56E+03
495	Aluminum	Water emissions	kg	8.48E+02
496	Ammonium, ion	Water emissions	kg	1.99E+00
497	Aniline	Water emissions	kg	7.33E-07
498	Antimony	Water emissions	kg	3.06E+00
499	Antimony-122	Water emissions	Bq	1.55E+00
500	Antimony-124	Water emissions	Bq	3.01E+02
501	Antimony-125	Water emissions	Bq	2.90E+02
502	AOX, Adsorbable Organic Halogen as Cl	Water emissions	kg	2.36E-02
503	Arsenic, ion	Water emissions	kg	9.01E+00
504	Barite	Water emissions	kg	3.26E+00
505	Barium	Water emissions	kg	4.84E+00
506	Barium-140	Water emissions	Bq	6.79E+00
507	Benzene	Water emissions	kg	1.23E-01
508	Benzene, 1,2-dichloro-	Water emissions	kg	6.11E-04
509	Benzene, chloro-	Water emissions	kg	1.26E-02
510	Benzene, ethyl-	Water emissions	kg	1.57E-02
511	Beryllium	Water emissions	kg	1.20E+00
512	BOD5, Biological Oxygen Demand	Water emissions	kg	2.38E+02
513	Borate	Water emissions	kg	1.44E-05
514	Boron	Water emissions	kg	2.45E+02
515	Bromate	Water emissions	kg	1.85E-01
516	Bromide	Water emissions	kg	7.60E-04
517	Bromine	Water emissions	kg	9.70E-01
518	Butene	Water emissions	kg	4.91E-03
519	Butyl acetate	Water emissions	kg	9.90E-04
520	Butyrolactone	Water emissions	kg	3.76E-06
521	Cadmium, ion	Water emissions	kg	5.67E+00
522	Calcium, ion	Water emissions	kg	1.06E+04
523	Carbon disulfide	Water emissions	kg	1.05E-05
524	Carbonate	Water emissions	kg	2.11E+00
525	Carboxylic acids, unspecified	Water emissions	kg	2.79E+00
526	Cerium-141	Water emissions	Bq	2.72E+00
527	Cerium-144	Water emissions	Bq	8.27E-01
528	Cesium	Water emissions	kg	6.55E-04
529	Cesium-134	Water emissions	Bq	2.33E+02
530	Cesium-136	Water emissions	Bq	4.82E-01
531	Cesium-137	Water emissions	Bq	1.80E+05
532	Chloramine	Water emissions	kg	2.48E-06
533	Chlorate	Water emissions	kg	1.51E+00
534	Chloride	Water emissions	kg	1.76E+03

535	Chlorinated solvents, unspecified	Water emissions	kg	2.40E-02
536	Chlorine	Water emissions	kg	3.49E-02
537	Chloroacetic acid	Water emissions	kg	6.14E-04
538	Chloroacetyl chloride	Water emissions	kg	1.32E-08
539	Chloroform	Water emissions	kg	2.82E-05
540	Chlorosulfonic acid	Water emissions	kg	1.08E-07
541	Chromium-51	Water emissions	Bq	6.22E+02
542	Chromium VI	Water emissions	kg	6.59E+00
543	Chromium, ion	Water emissions	kg	3.63E-02
544	Cobalt	Water emissions	kg	1.92E+01
545	Cobalt-57	Water emissions	Bq	1.53E+01
546	Cobalt-58	Water emissions	Bq	3.48E+03
547	Cobalt-60	Water emissions	Bq	2.89E+03
548	COD, Chemical Oxygen Demand	Water emissions	kg	4.36E+02
549	Copper, ion	Water emissions	kg	4.92E+01
550	Cumene	Water emissions	kg	7.12E-02
551	Cyanide	Water emissions	kg	1.07E+00
552	Dichromate	Water emissions	kg	3.29E-01
553	Diethylamine	Water emissions	kg	3.30E-07
554	Dimethylamine	Water emissions	kg	4.12E-07
555	Dipropylamine	Water emissions	kg	2.05E-07
556	DOC, Dissolved Organic Carbon	Water emissions	kg	1.61E+02
557	Ethane, 1,1,1-trichloro-, HCFC-140	Water emissions	kg	3.91E-09
558	Ethane, 1,2-dichloro-	Water emissions	kg	7.86E-03
559	Ethanol	Water emissions	kg	1.76E-03
560	Ethene	Water emissions	kg	2.12E-02
561	Ethene, chloro-	Water emissions	kg	2.86E-03
562	Ethyl acetate	Water emissions	kg	4.44E-07
563	Ethylamine	Water emissions	kg	1.06E-06
564	Ethylene diamine	Water emissions	kg	1.17E-05
565	Ethylene oxide	Water emissions	kg	8.18E-05
566	Fluoride	Water emissions	kg	4.66E+02
567	Fluosilicic acid	Water emissions	kg	2.51E-02
568	Formaldehyde	Water emissions	kg	4.14E-03
569	Formamide	Water emissions	kg	3.38E-07
570	Formate	Water emissions	kg	4.95E-05
571	Formic acid	Water emissions	kg	9.80E-08
572	Glutaraldehyde	Water emissions	kg	4.02E-04
573	Heat, waste	Water emissions	MJ	7.42E+04
574	Hydrocarbons, aliphatic, alkanes, unspecified	Water emissions	kg	8.51E-02
575	Hydrocarbons, aliphatic, unsaturated	Water emissions	kg	7.85E-03
576	Hydrocarbons, aromatic	Water emissions	kg	3.51E-01
577	Hydrocarbons, unspecified	Water emissions	kg	4.70E-01
578	Hydrogen-3, Tritium	Water emissions	Bq	4.12E+08
579	Hydrogen peroxide	Water emissions	kg	3.84E-03

580	Hydrogen sulfide	Water emissions	kg	2.76E-01
581	Hydroxide	Water emissions	kg	4.79E-02
582	Hypochlorite	Water emissions	kg	2.00E-02
583	Iodide	Water emissions	kg	6.87E-02
584	Iodine-131	Water emissions	Bq	5.99E+01
585	Iodine-133	Water emissions	Bq	4.26E+00
586	Iron-59	Water emissions	Bq	1.17E+00
587	Iron, ion	Water emissions	kg	2.21E+03
588	Isopropylamine	Water emissions	kg	2.87E-07
589	Lactic acid	Water emissions	kg	1.61E-07
590	Lanthanum-140	Water emissions	Bq	7.23E+00
591	Lead	Water emissions	kg	4.87E+00
592	Lead-210	Water emissions	Bq	1.19E+04
593	Lithium, ion	Water emissions	kg	1.52E-02
594	m-Xylene	Water emissions	kg	7.91E-07
595	Magnesium	Water emissions	kg	6.21E+03
596	Manganese	Water emissions	kg	6.94E+02
597	Manganese-54	Water emissions	Bq	2.14E+02
598	Mercury	Water emissions	kg	2.78E-02
599	Methane, dichloro-, HCC-30	Water emissions	kg	8.12E-03
600	Methanol	Water emissions	kg	1.37E-02
601	Methyl acetate	Water emissions	kg	3.47E-09
602	Methyl acrylate	Water emissions	kg	1.43E-03
603	Methyl amine	Water emissions	kg	1.39E-06
604	Methyl formate	Water emissions	kg	1.13E-07
605	Molybdenum	Water emissions	kg	5.73E+00
606	Molybdenum-99	Water emissions	Bq	2.49E+00
607	Nickel, ion	Water emissions	kg	2.49E+01
608	Niobium-95	Water emissions	Bq	2.86E+01
609	Nitrate	Water emissions	kg	1.27E+02
610	Nitrite	Water emissions	kg	8.83E-02
611	Nitrobenzene	Water emissions	kg	1.65E-06
612	Nitrogen	Water emissions	kg	6.33E-01
613	Nitrogen, organic bound	Water emissions	kg	5.79E+00
614	o-Xylene	Water emissions	kg	3.11E-07
615	Oils, unspecified	Water emissions	kg	3.98E+01
616	PAH, polycyclic aromatic hydrocarbons	Water emissions	kg	1.01E-02
617	Phenol	Water emissions	kg	7.20E-02
618	Phosphate	Water emissions	kg	1.33E+03
619	Phosphorus	Water emissions	kg	4.29E-02
620	Polonium-210	Water emissions	Bq	1.71E+04
621	Potassium-40	Water emissions	Bq	3.81E+03
622	Potassium, ion	Water emissions	kg	3.52E+03
623	Propanal	Water emissions	kg	2.67E-07
624	Propanol	Water emissions	kg	2.89E-07

625	Propene	Water emissions	kg	6.10E-02
626	Propionic acid	Water emissions	kg	4.59E-08
627	Propylamine	Water emissions	kg	1.07E-07
628	Propylene oxide	Water emissions	kg	1.55E-02
629	Protactinium-234	Water emissions	Bq	2.53E+03
630	Radioactive species, alpha emitters	Water emissions	Bq	2.97E+01
631	Radioactive species, Nuclides, unspecified	Water emissions	Bq	9.36E+05
632	Radium-224	Water emissions	Bq	3.27E+04
633	Radium-226	Water emissions	Bq	1.64E+06
634	Radium-228	Water emissions	Bq	6.55E+04
635	Rubidium	Water emissions	kg	6.55E-03
636	Ruthenium-103	Water emissions	Bq	5.26E-01
637	Scandium	Water emissions	kg	2.09E+00
638	Selenium	Water emissions	kg	4.33E+00
639	Silicon	Water emissions	kg	4.77E+03
640	Silver-110	Water emissions	Bq	2.71E+03
641	Silver, ion	Water emissions	kg	3.14E-01
642	Sodium-24	Water emissions	Bq	1.89E+01
643	Sodium formate	Water emissions	kg	7.82E-05
644	Sodium, ion	Water emissions	kg	1.85E+03
645	Solids, inorganic	Water emissions	kg	5.01E+01
646	Solved solids	Water emissions	kg	4.34E+01
647	Strontium	Water emissions	kg	1.02E+02
648	Strontium-89	Water emissions	Bq	5.77E+01
649	Strontium-90	Water emissions	Bq	1.11E+06
650	Sulfate	Water emissions	kg	3.83E+04
651	Sulfide	Water emissions	kg	9.90E-03
652	Sulfite	Water emissions	kg	5.67E-02
653	Sulfur	Water emissions	kg	1.13E-01
654	Suspended solids, unspecified	Water emissions	kg	2.20E+01
655	t-Butyl methyl ether	Water emissions	kg	1.25E-03
656	t-Butylamine	Water emissions	kg	3.86E-07
657	Technetium-99m	Water emissions	Bq	5.74E+01
658	Tellurium-123m	Water emissions	Bq	2.99E+01
659	Tellurium-132	Water emissions	Bq	1.44E-01
660	Thallium	Water emissions	kg	5.28E-01
661	Thorium-228	Water emissions	Bq	1.31E+05
662	Thorium-230	Water emissions	Bq	3.45E+05
663	Thorium-232	Water emissions	Bq	4.90E+02
664	Thorium-234	Water emissions	Bq	2.53E+03
665	Tin, ion	Water emissions	kg	5.51E+00
666	Titanium, ion	Water emissions	kg	1.47E+01
667	TOC, Total Organic Carbon	Water emissions	kg	1.62E+02
668	Toluene	Water emissions	kg	8.19E-02
669	Toluene, 2-chloro-	Water emissions	kg	2.64E-07

670	Tributyltin compounds	Water emissions	kg	2.66E-03
671	Triethylene glycol	Water emissions	kg	4.94E-03
672	Trimethylamine	Water emissions	kg	6.16E-09
673	Tungsten	Water emissions	kg	7.69E+00
674	Uranium-234	Water emissions	Bq	3.03E+03
675	Uranium-235	Water emissions	Bq	5.01E+03
676	Uranium-238	Water emissions	Bq	1.37E+04
677	Uranium alpha	Water emissions	Bq	1.46E+05
678	Urea	Water emissions	kg	3.10E-07
679	Vanadium, ion	Water emissions	kg	3.77E+00
680	VOC, volatile organic compounds, unspecified origin	Water emissions	kg	2.35E-01
681	Xylene	Water emissions	kg	6.64E-02
682	Zinc-65	Water emissions	Bq	2.56E+02
683	Zinc, ion	Water emissions	kg	3.03E+02
684	Zirconium-95	Water emissions	Bq	2.96E+00
685	2,4-D	Soil emissions	kg	1.20E-05
686	Aclonifen	Soil emissions	kg	5.34E-05
687	Aldrin	Soil emissions	kg	1.99E-06
688	Aluminum	Soil emissions	kg	2.67E+00
689	Antimony	Soil emissions	kg	8.00E-06
690	Arsenic	Soil emissions	kg	8.86E-04
691	Atrazine	Soil emissions	kg	5.22E-07
692	Barium	Soil emissions	kg	1.60E-01
693	Benomyl	Soil emissions	kg	7.54E-08
694	Bentazone	Soil emissions	kg	2.73E-05
695	Boron	Soil emissions	kg	2.24E+00
696	Cadmium	Soil emissions	kg	1.61E-03
697	Calcium	Soil emissions	kg	3.27E+01
698	Carbetamide	Soil emissions	kg	1.17E-05
699	Carbofuran	Soil emissions	kg	4.13E-05
700	Carbon	Soil emissions	kg	3.03E+00
701	Chloride	Soil emissions	kg	2.60E+01
702	Chlorothalonil	Soil emissions	kg	2.01E-03
703	Chromium	Soil emissions	kg	2.34E-02
704	Chromium VI	Soil emissions	kg	1.26E+01
705	Cobalt	Soil emissions	kg	2.01E-03
706	Copper	Soil emissions	kg	7.91E+00
707	Cypermethrin	Soil emissions	kg	6.15E-06
708	Fenpiclonil	Soil emissions	kg	8.09E-05
709	Fluoride	Soil emissions	kg	8.56E+00
710	Glyphosate	Soil emissions	kg	1.93E-03
711	Heat, waste	Soil emissions	MJ	2.73E+06
712	Iron	Soil emissions	kg	7.06E+00
713	Lead	Soil emissions	kg	8.03E-03
714	Linuron	Soil emissions	kg	4.12E-04

715	Magnesium	Soil emissions	kg	3.81E+00
716	Mancozeb	Soil emissions	kg	2.61E-03
717	Manganese	Soil emissions	kg	2.21E+00
718	Mercury	Soil emissions	kg	1.71E-05
719	Metaldehyde	Soil emissions	kg	2.71E-06
720	Metolachlor	Soil emissions	kg	2.98E-03
721	Metribuzin	Soil emissions	kg	9.19E-05
722	Molybdenum	Soil emissions	kg	4.24E-04
723	Napropamide	Soil emissions	kg	4.80E-06
724	Nickel	Soil emissions	kg	6.53E-03
725	Oils, biogenic	Soil emissions	kg	3.23E-01
726	Oils, unspecified	Soil emissions	kg	4.00E+01
727	Orbencarb	Soil emissions	kg	4.96E-04
728	Phosphorus	Soil emissions	kg	1.09E+00
729	Pirimicarb	Soil emissions	kg	2.58E-06
730	Potassium	Soil emissions	kg	6.11E+00
731	Silicon	Soil emissions	kg	9.55E+00
732	Sodium	Soil emissions	kg	8.21E+00
733	Strontium	Soil emissions	kg	3.23E-03
734	Sulfur	Soil emissions	kg	1.26E+00
735	Sulfuric acid	Soil emissions	kg	8.36E-08
736	Tebutam	Soil emissions	kg	1.14E-05
737	Teflubenzuron	Soil emissions	kg	6.13E-06
738	Thiram	Soil emissions	kg	1.34E-07
739	Tin	Soil emissions	kg	8.56E-05
740	Titanium	Soil emissions	kg	1.52E-01
741	Vanadium	Soil emissions	kg	4.35E-03
742	Zinc	Soil emissions	kg	2.26E-01

Appendix 2: Data Sources

1 Extraction/Manufacturing phase

In order to model the extraction/manufacturing phase, all raw materials and manufacturing processes utilized in Green Room were defined, as explained in section 7.2.1. The following section exposes the values of the data collected for each component in Green Room and reproduces the way as it was modeled in SimaPro. References are exposed on the end of each section.

1.1 SEE Cooler

There are a total of ten units of SEE Coolers in Green Room. These coolers are assembled by AIA, Asarum Industri AB, a company situated in the city of Asarum, in the south of Sweden. Information about all components installed within the coolers was obtained during a visit to AIA and through email exchanges with the manager of the production line in the company, Magnus Rosenius (Rosenius, personal communication, 2011). A table containing the information collected is reproduced below:

Table 37: SEE Cooler components.

SEE Cooler				
Component name	**Model**	**Manufacturer**	**Amount**	**Weight (kg)/unit**
Radiator	n/a	AIA	1 unit	155.8
External Encasement	n/a	Urshults MaskinTeknik AB	1 unit	206.7
Fan	FN040-6IK.BF.V7P	Ziehl-Abegg	3 units	6.2
Condensation Pump	ETU 100	Eckerle Industrie-Elektronik GmbH	1 unit	1.1
Control Unit	n/a	Honeywell	1 unit	0.5

The material breakdown of one unit of the SEE Cooler is shown below:

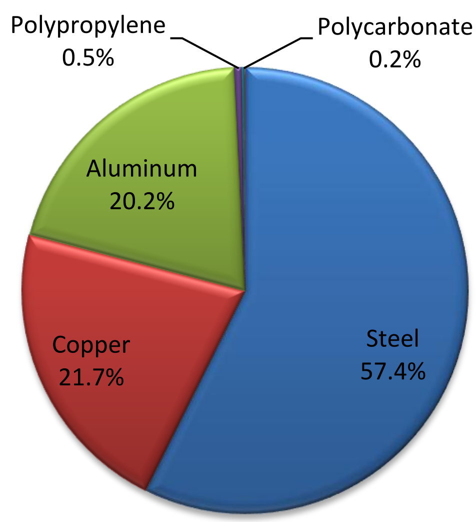

Figure 17: SEE Cooler material breakdown

Table 38: SEE Cooler material breakdown and weight contribution.

Material	Weight (kg)	Contribution (%)
Steel	219.4	57.3
Copper	83.0	21.7
Aluminum	77.2	20.2
Polypropylene	2.1	0.5
Polycarbonate	0.7	0.2
PCB	0.1	0.2
TOTAL	382.5	100.0

Follow bellow a description of each component found in one SEE Cooler unit:

1.1.1 Radiator

As stated in the list above, the radiator is the only cooler constituent which is manufactured at AIA. All other components come from supplier companies and are transported to AIA in order to just be assembled within the cooler. This being said, data collection about material composition were obtained through AIA's production line responsible Magnus Rosenius (Rosenius, personal communication, 2011).

The radiator in question is composed by two materials: aluminum (74.2 kg or 47% of its total weight) and copper (81.6 kg or 53% of its total weight). Aluminum alloy makes the composition of the radiator fins, which are responsible for heat transfer, while copper is the component of the tubes in contact with the fins. The aluminum is delivered to AIA in the form of strips from a company in Belgium. On the other hand copper comes from Finland and it is delivered as ready-made tubes to be used as radiator pipes and as copper strips, used to manufacture the radiator headers. After manufacturing, fins, coils and headers are assembled together and the radiator is ready to be sent to a testing pool where leakages can be identified. Once assured the quality of the product, the radiator is ready to be assembled inside the SEE Cooler.

As for manufacturing processes inserted in the model, it was assumed that the aluminum strips delivered to AIA are just rolled, while the manufacturing of aluminum fins at AIA are represented by the 'average aluminum product manufacturing' dataset in Ecoinvent. Moreover, copper tubes delivered to AIA are assumed to have similar manufacturing process of 'wire drawing', while copper headers manufactured at AIA are represented by the 'average copper product manufacturing' dataset in Ecoinvent (refer to Appendix 3: Dataset Descriptions).

1.1.2 Fan

The fans are manufactured and assembled by the company Ziehl-Abegg and delivered to AIA. Each cooler contains three fans units weighting around 6.2 kg each, being that the guard grill weights 1.5 kg; the impeller 0.7 kg and the motor approximately 4.0 kg (Johansson, personal communication, 2011). Information about material composition and fan components was obtained through email contact with the company, however did not include the electric motor. Therefore the weight distribution for different materials of the motor was based on an ABB study of an air handling unit (Legarth et al., 2000) as being 65% of carbon steel; 22% of aluminum; 11.5% of copper and 2.5% of polycarbonate.

Manufacturing processes assumed are: 'injection molding' for all plastics; 'wire drawing' for manufacturing the guard-grill (due to its wire-like profile); 'average steel, copper and aluminum product manufacturing' datasets for the electric motor (dataset descriptions available in Appendix 3: Dataset Descriptions).

1.1.3 External encasement

The external encasement is manufactured by Urshults MaskinTeknik AB which is situated close to AIA, in Urshults, Sweden. Since no response from the manufacturer was obtained and no information could be retrieved from the company's website, a qualified assumption was made regarding material composition of the external encasement. Fortunately the total weight could be retrieved through AIA's database (Rosenius, personal communication, 2011). Being so, the total weight of the external encasement is 206.7 kg and the main material composition assumed is low-alloyed steel. A special powder material is also used to cover the steel surface but this element was neglected due to lack of data.

Manufacturing process assumed is the 'average steel product manufacturing' dataset in Ecoinvent.

1.1.4 Condensation pump

No information about material composition could be retrieved from the manufacturer of the condensation pump; therefore a qualified assumption was made. Through Eckerle Industrie's website (Eckerle Industrie, 2012) the weight of the pump could be defined as being 0.73 kg; and regarding the material composition it was assumed to be 50% low-alloyed steel and 50% aluminum, based on a visual judgment.

The manufacturing processes assumed are 'average steel and aluminum product manufacturing' datasets.

1.1.5 Control unit

The SEE Cooler control unit is manufactured by Honeywell in Sweden. The company disclosed the amount of plastic material contained in one control unit (Persson, personal communication, 2011); however no electronics, such as printed circuit board (PCB) weight and composition was specified, due to confidentiality reasons according to Honeywell. The total weight of the controller is 0.5 kg and it was assumed that 80% of the controller weight is polycarbonate and 20% of PCB. The manufacturing process assumed is the 'injection molding' dataset.

After the definition of the material composition and their specific share in each component, the data finally could be inserted in SimaPro. Table 39 below exposes all Ecoinvent datasets used for each component as well as their specific amount. "Data type" regards information about how the dataset and its amount were defined (see description on the bottom of the table) and "data comment" regards the nature of the dataset, if it is a material dataset or a manufacturing process dataset.

Table 39: SEE Cooler processes as inserted in SimaPro.

SEE Cooler component	Ecoinvent material/manufacturing process dataset	Amount (kg)	Data type (dataset/amount)	Data comment
Radiator (1 unit)	Aluminum, production mix, at plant/RER S	74.2	A	Material (fins)
	Copper, at regional storage/RER S	72.6	A	Material (coils)
	Copper, at regional storage/RER S	9.0	A	Material (headers)

	Sheet rolling, aluminum/RER S	74.2	C	Manufacturing (fins)
	Aluminum product manufacturing, average metal working/RER S	74.2	C	Manufacturing (fins)
	Wire drawing, copper/RER S	72.6	C	Manufacturing (coils)
	Copper product manufacturing, average metal working/RER S	9.0	C	Manufacturing (headers)
Fan (3 units)	Steel, low-alloyed, at plant/RER S	4.5	A	Material (guard grill)
	Polypropylene, granulate, at plant/RER S	2.1	A	Material (impeller)
	Steel, low-alloyed, at plant/RER S	7.8	B	Material (electric motor)
	Copper, at regional storage/RER S	1.5	B	Material (electric motor)
	Aluminum, production mix, at plant/RER S	2.7	B	Material (electric motor)
	Polycarbonate, at plant/RER S	0.3	B	Material (electric motor)
	Injection molding/RER S	2.1	C	Manufacturing (impeller)
	Wire drawing, steel/RER S	4.5	C	Manufacturing (grill)
	Steel product manufacturing, average metal working/RER S	7.8	C	Manufacturing (el. motor)
	Copper product manufacturing, average metal working/RER S	1.0	C	Manufacturing (el. motor)
	Aluminum product manufacturing, average metal working/RER S	2.7	C	Manufacturing (el. motor)
	Injection molding/RER S	0.3	C	Manufacturing (el. motor)
External encasement (1 unit)	Steel, low-alloyed, at plant/RER S	206.7	A	Material
	Steel product manufacturing, average metal working/RER S	206.7	C	Manufacturing
Condensation pump (1 unit)	Steel, low-alloyed, at plant/RER S	0.36	C	Material
	Aluminum, production mix, at plant/RER S	0.36	C	Material
	Steel product manufacturing, average metal working/RER S	0.36	C	Manufacturing
	Aluminum product manufacturing, average metal working/RER S	0.36	C	Manufacturing
Control unit	Polycarbonate, at plant/RER S	0.4	A	Material

(1 unit)	Printed wiring board, mixed mounted, unspec., solder mix, at plant/GLO S	0.1	C	Material and manufacturing
	Injection moulding/RER S	0.4	C	Manufacturing

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

References used for modeling SEE Coolers:

Eckerle Industrie, 2012*. Electromagnetic pumps. Available from:* *http://www.eckerle.com/index.php/electromagnetic-pumps.html?file=tl_files/eckerle/files/produkte/foerdersysteme/elektromagnet-pumpen/eckerle_brochure_electromagnetic-pumps_en.pdf*. [Accessed 30 May 2012].

Johansson, H., 2011*. Personal Communication: Information about SEE Cooler fans. [Email] (Nov, 2011).*

Legarth, J.B. et al., 2000*. A Screening Level Life Cycle Assessment of the ABB EU 2000 Air Handling Unit. The International Journal of Life Cycle Assessment, 5(1), pp. 47-58. Available from:* *http://www.springerlink.com/index/10.1007/BF02978560*. [Accessed 30 May 2012].

Persson, P.-G., 2011*. Personal Communication: Information about SEE Cooler control units. [Email] (Nov, 2011).*

Rosenius, M., 2011*. Personal Communication: Discussions regarding SEE Cooler components. [Email] (Oct, 2011).*

1.2 SEE Pump Rack

The same approach used for the coolers was applied for the SEE Pump Rack data collection. In fact a visit to Pretec AB, the company responsible for assembling the racks was arranged and a similar list obtained from AIA, stating the different components and manufacturers was also provided. The contact in the company provided the following list reproduced below (Haraldsson, personal communication, 2011).

Table 40: SEE Pump Rack components

SEE Pump Rack				
Component name	**Model**	**Manufacturer**	**Amount**	**Weight (kg)/unit**
Tubes and flanges	n/a	Dahmstal AB	n/a	286.0
Heat exchanger	CB 200-150M	Alfa Laval AB	1 unit	128.0
Pump	TPE 80-110/4	Grundfos AB	2 units	84.0
Strainer	VM 6303 - DN100	Ventim AB	2 units	33.5
Butterfly valves	VM 3001 – DN100	Ventim AB	8 units	5.2
Butterfly valve	VM 3001 – DN 125	Ventim AB	1 unit	6.9
Electric actuator	VM 9282	Ventim AB	1 unit	2.4
Document cabinet	AE 1034.5	Rittal AB	1 unit	8.8

The material breakdown of one unit of the SEE Rack is shown below:

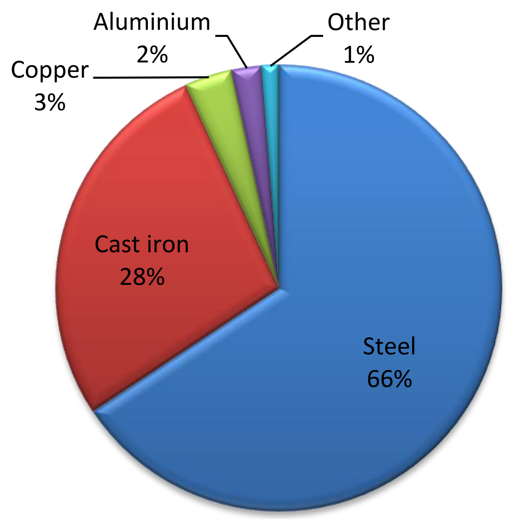

Figure 18: SEE Pump Rack material breakdown

Table 41: SEE Pump Rack material breakdown and weight contribution

Material	Weight (kg)	Contribution (%)
Steel	479.1	65.7
Cast iron	200.3	27.5
Copper	25.1	3.4
Aluminum	15.7	2.2
Other - Polycarbonate	3.5	0.4
Other - Synth. rubber	2.6	0.3
Other - ABS	1.5	0.2
Other - Brass	1.4	0.2
Other - Bronze	0.1	0.01
TOTAL	729.3	100.0

Follow bellow a description of each component found in one SEE Pump Rack unit:

1.2.1 Tubes and flanges

Information about tubes and flanges was obtained direct from Pretec AB (Haraldsson, personal communication, 2011) since the company orders 286 kg of stainless steel tubes and flanges in a variety of diameters for assembling each SEE rack. No welding material was accounted in this study due to lack of data.

Manufacturing process assumed is given by the 'average stainless steel product manufacturing' Ecoinvent dataset.

1.2.2 Heat Exchanger

The heat exchanger is a massive piece of metal weighing around 128 kg and manufactured at Alfa Laval AB in Denmark. It is available on the company's website information about the product (Alfa Laval AB, 2012; Ekonomisk Ekologi AB, 2005), from where data for material composition could be retrieved and adapted to this study as 79.8% stainless steel; 13.7% copper; 6.3% low-alloyed steel and 0.2% polycarbonate.

The manufacturing processes assumed are given by 'injection molding' dataset for plastic; as well as 'average steel product manufacturing'; 'average copper product manufacturing'; and 'average stainless steel product manufacturing' datasets. All data inserted in SimaPro representing the heat exchanger can be seen on Table 42.

1.2.3 Pump

The pumps are manufactured by Grundfos AB, also in Denmark. The material composition for the pump was found available on Grundfos' website, however for a similar product without the electric motor. This similar pump, the TP 100-120/2 weights 35.8 kg and presents the following material composition (Grundfos AB, 2001): 96% cast iron; 1% stainless steel and 3% of diverse plastic components, which in this case were assumed to be composed by 1.5% of ABS and 1.5% of polycarbonate plastic (see Table 42). These values were judged appropriate and this same material composition was applied for the pump model installed in the Green Room, the TPE 80-110/4. From (Grundfos AB, 2011b) its total weight and the model of the electric motor used in this pump could be retrieved, and from Grundfos AB (2011a) the weight of the motor was defined. Thus, subtracting one from another it was possible to determine the TPE 80-110/4's weight without the electric motor and therefore apply the material distribution explained before.

Regarding the electric motor it weighs 33 kg according to Grundfos AB (2011a). The values for its material composition were obtained from Legarth et al. (2000) and simplified in this study as being 65% carbon steel; 22% aluminum; 11.5% copper and 2.5% of polycarbonate.

The modeled manufacturing processes for the whole pump were assumed as 'injection molding' for plastics; as well as 'average steel product manufacturing'; 'average copper product manufacturing'; 'average aluminum product manufacturing'; and 'average stainless steel product manufacturing' datasets. All data inserted in SimaPro representing the pumps are available on Table 42.

1.2.4 Strainer and butterfly valves

Ventim AB provides on its website a variety of documents for their products, therefore they were the source of information about material composition for strainer and valves. The strainer weight is 33.5 kg (Ventim AB, 2010b) and its composition was adapted from Ventim AB (2010a) as 98.5% cast iron and 1.5% stainless steel. Regarding the butterfly valves, the material distribution was obtained from Ventim AB (2011a) as being 75% of its weight in cast iron; 16.5% as stainless steel; 5.3% as synthetic rubber; 3% as brass and 0.2% as bronze. In addition the respective weights for the two types of butterfly valves were obtained from (Ventim AB, 2011b).

The manufacturing processes were modeled as 'injection molding' for plastics and rubber; 'average product manufacturing' for stainless steel; and 'casting' for brass and bronze.

1.2.5 Electric actuator

Even though the electric actuator is also manufactured by Ventim AB, no information about its material composition was available on their website for this component. However its weight could be retrieved from Ventim AB (2011c) as 2.4 kg and based on a visual judgment this component was assumed to be composed of carbon steel and aluminum, in a 50% - 50% share. The manufacturing processes assumed are ‘average steel and aluminum product manufacturing’ datasets.

1.2.6 Document cabinet

Through Rittal AB’s website it was possible to define both the total weight and the manufacturing material of the document cabinet used in the SEE Rack, as being 8.8 kg and steel, respectively (Rittal AB, 2011a). Therefore when modeling this component in SimaPro, it was assumed to be composed as 100% of carbon steel (Table 42). The manufacturing process assumed was ‘average steel product manufacturing’.

1.2.7 Bolts, nuts, washers and gaskets

The small metallic parts such as bolts, nuts, washer and gaskets are assumed to have a total weight of 20 kg and were modeled as being manufactured 100% in low-alloyed steel. The manufacturing process assumed was ‘average steel product manufacturing’.

After the definition of the material composition and their specific share in each component, the data finally could be inserted in SimaPro. Table 42 below exposes all Ecoinvent datasets used for each component as well as their specific amount. “Data type” regards information about how the dataset and its amount were defined (see description on bottom of the table) and “data comment” regards the nature of the dataset, if it is a material dataset or a manufacturing process dataset.

Table 42: SEE Rack processes, as inserted in SimaPro

SEE Rack modeling	Ecoinvent material/manufacturing process	Amount (kg)	Data source	Comment
Tubes and flanges (286 kg)	Chromium steel 18/8, at plant/RER S	286.0	A	Material
	Chromium steel product manufacturing, average metal working/RER S	286.0	C	Manufacturing
Heat exchanger (1 unit)	Chromium steel 18/8, at plant/RER S	102.1	A	Material
	Copper, at regional storage/RER S	17.5	A	Material
	Steel, low-alloyed, at plant/RER S	8.0	A	Material
	Polycarbonate, at plant/RER S	0.3	A	Material
	Chromium steel product manufacturing, average metal working/RER S	102.1	C	Manufacturing
	Injection molding/RER S	0.3	C	Manufacturing
	Steel product manufacturing, average metal working/RER S	8.0	C	Manufacturing
	Copper product manufacturing, average metal working/RER S	17.5	C	Manufacturing
Pump (2 units)	Cast iron, at plant/RER S	98.0	A	Material (pump)
	Chromium steel 18/8, at plant/RER S	1.0	A	Material (pump)
	Polycarbonate, at plant/RER S	1.6	A	Material (pump)

	Acrylonitrile-butadiene-styrene copolymer, ABS, at plant/RER S	1.6	A	Material (pump)
	Aluminum, production mix, at plant/RER S	14.6	B	Material (el. motor)
	Steel, low-alloyed, at plant/RER S	43.0	B	Material (el. motor)
	Copper, at regional storage/RER S	7.6	B	Material (el. motor)
	Polycarbonate, at plant/RER S	1.6	B	Material (el. motor)
	Chromium steel product manufacturing, average metal working/RER S	1.0	C	Manufacturing (pump)
	Injection molding/RER S	3.2	C	Manufacturing (pump)
	Aluminum product manufacturing, average metal working/RER S	14.6	C	Manufacturing (el. mot.)
	Steel product manufacturing, average metal working/RER S	43.0	C	Manufacturing (el. mot.)
	Copper product manufacturing, average metal working/RER S	7.6	C	Manufacturing (el. mot.)
	Injection molding/RER S	1.6	C	Manufacturing (el. mot.)
Strainer (2 unit)	Cast iron, at plant/RER S	66.0	A	Material
	Chromium steel 18/8, at plant/RER S	1.0	A	Material
	Chromium steel product manufacturing, average metal working/RER S	1.0	C	Manufacturing
Butterfly valves (9 units)	Cast iron, at plant/RER S	36.4	A	Material
	Chromium steel 18/8, at plant/RER S	8.0	A	Material
	Synthetic rubber, at plant/RER S	2.6	A	Material
	Brass, at plant/CH S	1.5	A	Material
	Bronze, at plant/CH S	0.05	A	Material
	Casting, brass/CH S	1.5	C	Manufacturing
	Casting, brass/CH S	0.05	C	Manufacturing
	Chromium steel product manufacturing, average metal working/RER S	8.0	C	Manufacturing
	Injection molding/RER S	2.6	C	Manufacturing
Electric actuator (1 unit)	Steel, low-alloyed, at plant/RER S	1.2	C	Material
	Aluminum, production mix, at plant/RER S	1.2	C	Material
	Aluminum product manufacturing, average metal working/RER S	1.2	C	Manufacturing

	Steel product manufacturing, average metal working/RER S	1.2	C	Manufacturing
Document cabinet (1 unit)	Steel, low-alloyed, at plant/RER S	8.8	A	Material
	Steel product manufacturing, average metal working/RER S	8.8	C	Manufacturing
Small metallic parts (20 kg)	Steel, low-alloyed, at plant/RER S	20	A	Material
	Steel product manufacturing, average metal working/RER S	20	C	Manufacturing

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

References used for modeling SEE Pump Racks:

Alfa Laval AB, 2012. *CB200 / CBH200 Brazed Plate Heat Exchanger. Available from: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CFEQFjAA&url=http%3A%2F%2Fwww.alfalaval.com%2Fsolution-finder%2Fproducts%2Fcb%2FDocuments%2FCB77_PCT00121EN.pdf&ei=pVDGT8DIA4bl4QTahY3XBQ&usg=AFQjCNHYmZ5wi_qOROMubhLxPv3Ys7581w&sig2=hSXYxBJvortonNX_THTzQA*. [Accessed 30 May 2012]

Ekonomisk Ekologi AB, 2005. *Environmental Declaration Brazed Plate Heat Exchangers. Lund. Available from: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCUQFjAA&url=http%3A%2F%2Fwww.hydroset.ru%2Fuserfiles%2FBrazed%2520plate%2520heat%2520exchangers.doc&ei=kE_GT8eAJOWl4gSp4_XKBQ&usg=AFQjCNEAHj4Nxx_eYVtC3iwI5DZThJ1lVg&sig2=dD9XpC5tue1i3zVDEhRsTQ*. [Accessed 30 May 2012]

Grundfos AB, 2001. *Product Environmental Declaration. Available from: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CGAQFjAA&url=http%3A%2F%2Fwww.grundfos.se%2Fweb%2Fhomese.nsf%2FGrafikopslag%2FTP04%2F%24file%2FTP.pdf&ei=4lHGT8yeCOLk4QSw0YnsBQ&usg=AFQjCNEjJnU7zWPgvyxGorJOwUBtHuzNBQ&sig2=oW734JJK6GJWlxepPD342g*. [Accessed 30 May 2012].

Grundfos AB, 2011a. *Data Booklet MGE standard motors with built-in frequency converter. Available from: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CE4QFjAA&url=http%3A%2F%2Fwww.unopomp.com%2FResimler%2FSiteIcerik%2FMGE.pdf&ei=L1rGT-bpE-_14QSf6qXnBQ&usg=AFQjCNG4We3lnyNseh4pdVgRb-A8G9GjGg&sig2=ZQG0TNJjo82FvUTcrn0v8g*. [Accessed 30 May 2012].

Grundfos AB, 2011b. *TPE 80-110/4 A-F-A-BAQE Pump. Available from: http://net.grundfos.com/Appl/WebCAPS/custom?userid=GMA*. [Accessed 30 May 2012].

Haraldsson, S.-G., 2011. *Personal Communication: Information about SEE Rack components. [Email]. (Nov, 2011)*

Legarth, J.B. et al., 2000. *A Screening Level Life Cycle Assessment of the ABB EU 2000 Air Handling Unit. The International Journal of Life Cycle Assessment, 5(1), pp .47-58. Available from: http://www.springerlink.com/index/10.1007/BF02978560*. [Accessed 30 May 2012].

Rittal AB, 2011a. *Kompaktapparatskåp AE (1034.500)*. Available from: http://webshop.rittal.se/?opendocument&incl=1&id=2&artno=1034.500. [Accessed 30 May 2012]

Ventim AB, 2011a. *Miljödeklaration VM 3001 Vridspjällventil. Available from: http://www.ventim.se/avstangningsventiler/vridspjallventiler*. [Accessed 30 May 2012]

Ventim AB, 2010a. *Miljödeklaration VM 6303 Smutsfilter. Available from: http://www.ventim.se/?item=prod_prod-s1%2F196*. [Accessed 30 May 2012]

Ventim AB, 2011b. *VM 3001 EBRO butterfly valve, cast iron, DN 20-500, PN 16/3, wafer type. Available from: http://www.ventim.se/50.0.1.0/62/download_2486.php*. [Accessed 30 May 2012]

Ventim AB, 2010b. *VM 6303 Smutsfilter, gjutjärn, DN 15-300, PN 16/10, flänsar. Available from: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC4QFjAA&url=http%3A%2F%2Fwww.oberginnovation.se%2Fuploads%2Fpdf%2Fventims_vvs_katalog.pdf&ei=AWDGT9DrCYmF4gT9yNHEBQ&usg=AFQjCNGEAEANGkzfwiiQW2Uteaap5fcdlA&sig2=_l4wxSox2aWzlDScX0stbw*. [Accessed 30 May 2012]

Ventim AB, 2011c. *VM 9282-9289 Compact electric actuator for valves with 90 degree turning angle, 39-1960 Nm. Available from: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CFEQFjAB&url=http%3A%2F%2Fwww.ventim.se%2F50.0.1.0%2F177%2Fdownload_2550.php&ei=r3PGT9P1K4fXsgaex5QQ&usg=AFQjCNFwSBrBqZR5IGnOINs0y5C4SIn0YQ&sig2=LDAdD4bxFlluRlrL83offQ*. [Accessed 30 May 2012]

1.3 Infrastructure

Data collection for components and their respective material composition for the elements classified as Infrastructure material in this study, were mostly based on personal visits to the Green Room technical site in southeast of Stockholm. During these visits it was possible to identify in a list, the components which would be necessary to collect information about; and afterwards this same list was sent to the personnel responsible for the Green Room project at TeliaSonera, in order to provide the necessary data. In some weeks most of the searched information could be gathered through TeliaSonera's internal reports.

The components modeled under the Infrastructure tab are showed in the table below.

Table 43: Infrastructure components

Infrastructure				
Component name	**Model**	**Manufacturer**	**Amount**	**Weight (kg)/unit**
Valves	AT2310-DN50	Armatec AB	20 units	3.0
Valves	AT2310-DN125	Armatec AB	6 units	8.0
Valves	AT3610-DN50	Armatec AB	20 units	4.5
Tubes and flanges	n/a	n/a	n/a	1184.3
Electric cables	EKLK 3x1.5	n/a	n/a	65.0
Electric cables	EKEK 2x2x0.8	n/a	n/a	8.0
UPS	Powerware 9355	Eaton	1 unit	185.0
Batteries (UPS)	n/a	Eaton	2 units	510.0
Switchgear	n/a	HT Ställverk AB	1 unit	28.0[a]

Expansion tank	AT8321C50	Armatec AB	2 units	12.0
Computer	n/a	n/a	2 units	n/a
Document cabinet	AE 1280.5	Rittal AB	2 units	70.0
Roof cover	n/a	Ecophon	140 m^2	40 kg/m^3
Aluminum sheets	n/a	n/a	45 units	1.05

[a] Weight after allocation

The material breakdown of all components under Infrastructure tab is shown below:

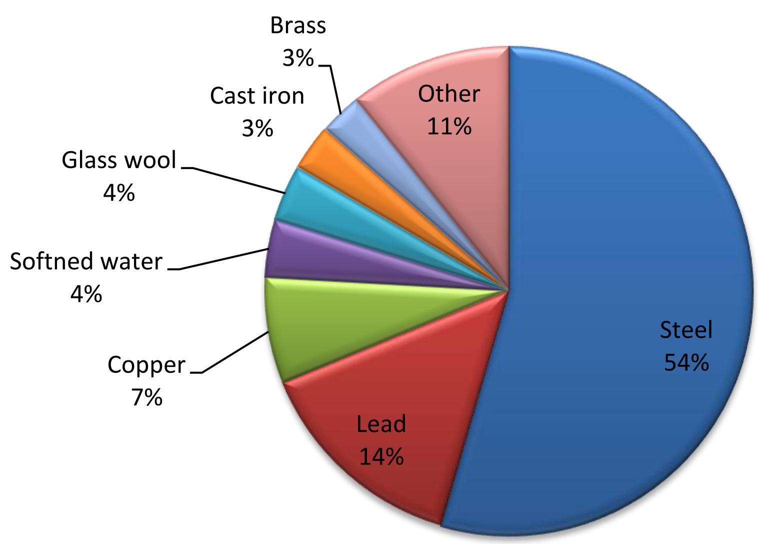

Figure 19: Material breakdown of Infrastructure components

Table 44: Infrastructure components breakdown and weight contribution

Material	Weight (kg)	Contribution (%)
Steel	1641.6	54.5
Lead	432.0	14.3
Copper	211.5	7.0
Softened water	115.2	3.8
Glass wool	112.0	3.7
Cast iron	91.5	3.0
Brass	85.5	2.8
Other – Sulph. acid	72.0	2.4
Other – Polypropylene	72.0	2.4
Other – Polycarbonate	70.1	2.3
Other – Aluminum	48.5	1.6
Other – Polyethylene	18.3	0.6
Other – Glass fiber	14.4	0.5
Other – Antimony	14.4	0.5
Other – Epoxy resin	4.9	0.2
Other – Synth. rubber	4.5	0.2

Other – Tetrafluoroethylene	1.9	0.1
Other – Bronze	1.7	0.1
TOTAL	3012.0	100.0

Follow bellow a description of each component found in the Infrastructure:

1.3.1 Valves

Forty six valves produced by Armatec AB, weighting 198 kg in total, and in different diameters are used in the Green Room. Their weight and material composition were retrieved from Armatec's website and adapted in this study as:

- Valves AT2310: 84.7% cast iron; 8.4% stainless steel; 4.2% synthetic rubber; 1.6% bronze and 1.1% low-alloyed steel (Armatec AB, 2010, 2012).
- Valves AT3610: 95.0% brass; 2.9% low-alloyed steel and 2.1% tetrafluoroethylene (Armatec AB, 2005, 2011)

The manufacturing processes assumed were 'injection molding' for plastics; 'average steel product manufacturing'; 'average stainless steel product manufacturing'; and 'casting' for bronze and brass.

1.3.2 Tubes

According to TeliaSonera (TeliaSonera internal reports, 2011c) tubes are divided in stainless steel and copper, being that stainless steel tubes comprise 1064.6 kg while the copper tubes have a total weight of 119.7 kg. No welding material is taken into account in this study due to lack of data.

Manufacturing processes assumed were 'average copper product manufacturing' and 'average stainless steel product manufacturing'. The data inserted in SimaPro can be seen on Table 45.

1.3.3 Electric cables

Still according to TeliaSonera the electric cables used in Green Room are made of copper wires enclosed in a plastic jacketing, and weight in total 73 kg (TeliaSonera internal reports, 2011a). Unfortunately no specific data for the plastic jacketing could be retrieved. Therefore this information was simplified from a study from the U.S. Environmental Protection Agency where a generic cable composition was gathered (EPA, 2008). Therefore in this study the 73 kg of cables installed were modeled as being composed of copper conductors (wires) in a 50% share of total weight; polycarbonate as jacketing material in 25% share, and polyethylene as insulation material, also in 25% share of total weight.

The manufacturing processes assumed were 'wire drawing' for copper wires and 'plastic pipes extrusion' for jacketing and insulation material.

1.3.4 Uninterruptible power system (UPS) and batteries

The UPS installed in the Green Room is manufactured by the company Eaton and is intended to support both the SEE Pump Racks and SEE Coolers in case of energy outage from the grid. Unfortunately no information about material composition for the UPS was found; however it was possible to retrieve the total weight of the equipment through the company's website, as being 185 kg without batteries (Henttonen, 2007). Therefore the material composition was defined through a visual judgment, and the main materials composing the UPS could be defined as low-alloyed steel – 40% of total weight; copper – 30% of total weight; and polyethylene as 30% of total weight.

The UPS enjoys two lead-acid (Pb-A) battery racks, weighting 510 kg each (Henttonen, 2007), from which 150 kg is the weight of the support metal frame (Henttonen, 2007). The material composition of the batteries were retrieved from Sullivan and Gaines (2010) and adapted in this work as 60% of total weight as lead (which was by its turn was divided into primary lead (30%) and secondary lead (70%)); softened water as 16% of total weight; sulfuric acid as 10%; polypropylene as 10%; glass fiber as 2%; and antimony also as 2%. Regarding the support metal frame, it was modeled as 100% low-alloyed steel, based on a visual judgment.

It is important to mention that the manufacturing processes of the batteries in this study, were not modeled according general manufacturing techniques available in the Ecoinvent database. In fact this approach was chosen since the Ecoinvent database does not provide a dataset comprising general manufacturing techniques for lead-acid batteries. This being said, the manufacturing processes were modeled as being the overall energy consumed to manufacture a lead-acid battery, according to Sullivan and Gaines (2010). The value was retrieved as 9.2 MJ/kg of manufactured battery.

The manufacturing processes inserted in SimaPro, representing the UPS were: 'injection molding' for plastics and 'average product manufacturing' for copper and steel. For the batteries, the manufacturing processes were 'average steel product manufacturing' for the support frame and 'low voltage electricity production' representing the value of 9.2 MJ consumed per kg of manufactured battery. The data inserted in SimaPro can be seen on Table 45.

1.3.5 Aluminum sheets

The aluminum sheets referred in the list are situated on the top of the SEE Coolers and server cabinets in order to avoid the mix of air from the cold and hot aisle in the datacenter room. There are 45 sheets, measuring 48 cm x 81 cm x 0.1 cm. Aluminum density was retrieved as being 2710 kg/m^3 (SImetric.co.uk, 2012), and therefore the total weight of 47.5 kg could be calculated. No data for external coating material of the sheets were taken into account in this study due to lack of data. The manufacturing process assumed was 'average aluminum product manufacturing'.

1.3.6 Roof cover

The roof cover used in Green Room is responsible for isolating both hot and cold aisles avoiding the mix of cold and hot air, therefore increasing the overall system's efficiency. The cover is produced by the company Ecophon Saint-Gobain and through a visual judgment of the product it was possible to define its composition as glass wool. The Ecoinvent database provides a dataset of glass wool production where the material studied presents a density of 40 kg /m3 (see Appendix 3: Dataset Descriptions). The cover installed in Green Room covers a surface of approximately 70 m^2 and has an average thickness of 4 cm. This being said the total weight of glass wool cover in Green Room could be retrieved as 112 kg.

1.3.7 Document cabinet

This document cabinet is also manufactured by Rittal AB, however being a heavier model, weighing 70 kg (Rittal AB, 2011b). There are 2 units installed and like the one described before (component 1.2.6) both were modeled as 100% carbon steel. The manufacturing process assumed was 'average steel product manufacturing'.

1.3.8 Computer

Two computer units used to control the pumping system are installed in the SEE Racks. Material composition for these computers was gathered through the Ecoinvent dataset for laptop computer manufacturing. A description of the dataset is available in Appendix 3: Dataset Descriptions.

1.3.9 Expansion Tank

The expansion tank is used to absorb the water volume expansion within the system due to the natural variation of the water temperature when cooling the electronic equipments in the datacenter. There are two units installed and they are manufactured by Armatec AB. Through the company's website was possible to define its total weight and main manufacturing material (Armatec AB, 2009). In this case, these 12 kg expansion tanks were modeled as being composed of 100% carbon steel. The manufacturing process assumed was 'average steel product manufacturing'.

1.3.10 Switchgear

The switchgear is used to control, protect and isolate electric equipment, ensuring reliable energy supply for them. The unit installed in the Green Room is manufactured by HT Ställverk AB in Nässjö, Sweden. It is important to state that the switchgear installed is designed to attend the demand of the Green Room cooling system plus the server racks where all telecom equipments are installed in. In other words, not just the components being considered in this study are attended by this switchgear, but also telecom equipments. Therefore it was necessary to define Green Room's share from the total environmental burden related to the life cycle of the mentioned equipment. In order to solve this, an allocation procedure based on power consumption was applied and is detailed described below.

Given that the total power of the telecom equipments cooled by Green Room is,

$Total\ Power\ IT\ equipments\ cooled\ by\ Green\ Room = 350.0\ kW$ (Izadi and El Azzi, 2012)

And that the total power consumed by Green Room system is,

$Total\ Power\ Green\ Room = Power\ MFK\ Racks + Power\ SEE\ Coolers$

Where,

$Power\ MFK\ Racks = Power\ of\ pumps = 4\ pumps * 2.2\frac{kW}{pump} = 8.8\ kW$ (Grundfos AB, 2011a)

$Power\ SEE\ Coolers = 10\ coolers * 1.2\frac{kW}{cooler} = 12.0\ kW$ (SEE Cooling AB, 2011)

Thus,

$Total\ Power\ Green\ Room = 8.8\ kW + 12.0\ kW = 20.8\ kW$

Therefore the switchgear is responsible to attend a maximum power of,

$Switchgear = Power\ IT\ equipments + Power\ Green\ Room = 350.0\ kW + 20.8\ kW = 370.8\ kW$

Which means that the Green Room share of the switchgear, according to this allocation procedure is,

$Green\ Room\ share = 20.8\ kW \div (350.0 + 20.8)\ kW * 100\% = 5.6\%$

Once defined the Green Room share on the total power that the switchgear is responsible for, the same percentage was assumed to represent the environmental burden of the switchgear extraction/manufacturing phase for which Green Room is responsible for. This being said, the total weight of the equipment could be retrieved from TeliaSonera's internal report as being 500 kg (TeliaSonera internal reports, 2011b), while its material composition was based on a similar switchgear manufactured by ABB, and adapted to this study (ABB, 2002).

Finally, the modeled switchgear on SimaPro weights 28 kg (5.6% of 500 kg) and it is composed by 19.2 kg of low-alloyed steel (68.6% share); 1.3 kg of stainless steel (4.6%); 1.6 kg of copper (5,8%); 4.9 kg of epoxy-resin (17.3%); and 1.0 kg of aluminum (3.7%). As for manufacturing processes, they were assumed as 'injection molding' for plastics and 'average product manufacturing' for low-alloyed steel, copper, stainless steel and aluminum. The data inserted in SimaPro can be seen on Table 45.

After the definition of the material composition and their specific share in each component, the data finally could be inserted in SimaPro. Table 45 below exposes all Ecoinvent datasets used for each component as well as their specific amount. "Data type" regards information about how the dataset and its amount were defined (see description on the bottom of the table) and "data comment" regards the nature of the dataset, if it is a material dataset or a manufacturing process dataset.

Table 45: Processes for Infrastructure components, as inserted in SimaPro

Infrastructure modeling	Ecoinvent material/manufacturing process	Amount (kg)	Data source	Comment
Tubes and flanges (1184.3 kg)	Chromium steel 18/8, at plant/RER S	1064.6	A	Material (Steel tubes)
	Copper, at regional storage/RER S	119.7	A	Material (Cu tubes)
	Chromium steel product manufacturing, average metal working/RER S	1064.6	C	Manufacturing (steel tubes)
	Copper product manufacturing, average metal working/RER S	119.7	C	Manufacturing (Cu tubes)
Valves (46 units)	Cast iron, at plant/RER S	91.5	A	Material (AT2310 valve)
	Chromium steel 18/8, at plant/RER S	9.1	A	Material (AT2310 valve)
	Bronze, at plant/CH S	1.7	A	Material (AT2310 valve)
	Steel, low-alloyed, at plant/RER S	1.2	A	Material (AT2310 valve)
	Synthetic rubber, at plant/RER S	4.5	A	Material (AT2310 valve)
	Brass, at plant/CH S	85.5	A	Material (AT3610 valve)
	Steel, low-alloyed, at plant/RER S	2.6	A	Material (AT3610 valve)
	Tetrafluoroethylene, at plant/RER S	1.9	A	Material (AT3610 valve)
	Chromium steel product manufacturing, average metal working/RER S	9.1	C	Manufacturing (AT2310 valve)
	Casting, bronze/CH S	1.7	C	Manufacturing (AT2310 valve)
	Steel product manufacturing, average metal working/RER S	1.2	C	Manufacturing (AT2310 valve)
	Injection molding/RER S	4.5	C	Manufacturing (AT2310 valve)
	Casting, brass/CH S	85.5	C	Manufacturing (AT3610 valve)

	Steel product manufacturing, average metal working/RER S	2.6	C	Manufacturing (AT3610 valve)
	Injection molding/RER S	1.9	C	Manufacturing (AT3610 valve)
Batteries (2 units)	Sulfuric acid, liquid, at plant/RER S	72.0	B	Material (batteries)
	Polypropylene, granulate, at plant/RER S	72.0	B	Material (batteries)
	Lead, secondary, at plant/RER S	302.4	B	Material (batteries)
	Lead, primary, at plant/GLO S	129.6	B	Material (batteries)
	Water, completely softened, at plant/RER S	115.2	B	Material (batteries)
	Antimony, at refinery/CN S	14.4	B	Material (batteries)
	Glass fiber, at plant/RER S	14.4	B	Material (batteries)
	Steel, low-alloyed, at plant/RER S	300	A	Material (support frame)
	Electricity, low voltage, production SE, at grid/SE S	6624 MJ	B	Manufacturing (batteries)
	Steel product manufacturing, average metal working/RER S	300	C	Manufacturing (support frame)
UPS (1 unit)	Copper, at regional storage/RER S	53.6	B	Material
	Steel, low-alloyed, at plant/RER S	79.6	B	Material
	Polycarbonate, at plant/RER S	51.8	B	Material
	Copper product manufacturing, average metal working/RER S	53.6	C	Manufacturing
	Steel product manufacturing, average metal working/RER S	79.6	C	Manufacturing
	Injection molding/RER S	51.8	C	Manufacturing
Electric cables (73 kg)	Copper, at regional storage/RER S	36.5	B	Material (wires)
	Polycarbonate, at plant/RER S	18.3	B	Material (jacketing)
	Polyethylene, HDPE, granulate, at plant/RER S	18.2	B	Material (insulation)
	Wire drawing, copper/RER S	36.5	C	Manufacturing (wires)
	Extrusion, plastic pipes/RER S	36.5	C	Manufacturing (jack., insul.)
Switchgear (1 unit, allocation)	Steel, low-alloyed, at plant/RER S	19.2	B	Material
	Chromium steel 18/8, at plant/RER S	1.3	B	Material
	Epoxy resin, liquid, at plant/RER S	4.9	B	Material

	Copper, at regional storage/RER S	1.6	B	Material
	Aluminum, production mix, at plant/RER S	1.0	B	Material
	Steel product manufacturing, average metal working/RER S	19.2	C	Manufacturing
	Chromium steel product manufacturing, average metal working/RER S	1.3	C	Manufacturing
	Injection molding/RER S	4.9	C	Manufacturing
	Copper product manufacturing, average metal working/RER S	1.6	C	Manufacturing
	Aluminum product manufacturing, average metal working/RER S	1.0	C	Manufacturing
Expansion tank (2 units)	Steel, low-alloyed, at plant/RER S	24	A	Material
	Steel product manufacturing, average metal working/RER S	24	C	Manufacturing
Document cabinet (2 units)	Steel, low-alloyed, at plant/RER S	140	A	Material
	Steel product manufacturing, average metal working/RER S	140	C	Manufacturing
Roof cover (140 m^2)	Glass wool mat, at plant/CH S	112.0	A	Material and manufacturing
Aluminum sheets (45 units)	Aluminum, production mix, at plant/RER S	47.5	A	Material
	Aluminum product manufacturing, average metal working/RER S	47.5	C	Manufacturing
Computer (2 units)	Laptop computer, at plant/GLO S	2 pieces	n/a	Ecoinvent dataset for material and manufacturing

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

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1.4 Cooling Production

The equipment classified as cooling production in this study refers to five chiller units which are responsible to deliver the required amount of cooled water to the whole technical site in question. Unfortunately pumps and pipes also used for this purposed could not be modeled due to lack of data. Therefore a sensitivity analysis was carried out in section 9.1 in order to verify the extension of possible impacts in the overall result.

The components modeled under the Cooling Production tab are showed in the table below.

Table 46: Cooling Production components

Cooling Production				
Component name	**Model**	**Manufacturer**	**Amount**	**Weight (kg)/unit**
Chiller	Performo SW 560	Venco	5 units	723.1[a]

[a] Allocated weight including refrigerant R134a.

The material breakdown of one chiller unit is exposed below:

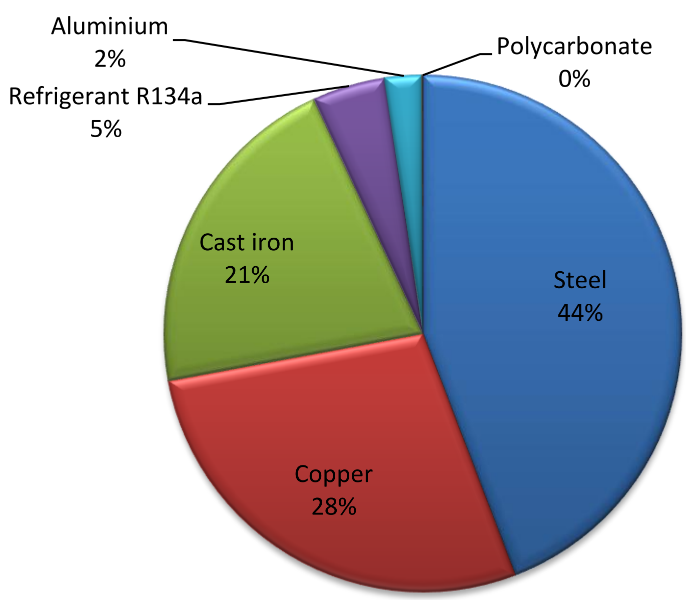

Figure 20: Material breakdown of Cooling Production components

Table 47: Cooling Production material breakdown and weight contribution

Material	Weight (kg)	Contribution (%)
Steel	319.5	44.2
Copper	201.7	27.9
Cast iron	151.8	21.0
Refrigerant R134a	33.0	4.6

Aluminum	16.8	2.3
Polycarbonate	0.3	0.0
TOTAL	723.1	100.0

1.4.1 Chiller

During some weeks of the year the utilization of a chiller is necessary in order to achieve the desired water temperature to be used as coolant in the whole technical site where Green Room is located. In fact there are 5 chiller units, produced by the Italian company Venco, each one with a maximum output of 560 KW of cooling capacity (Enlund, personal communication, 2012a).

Like the switchgear presented above (component 1.3.10), the chiller units attend the demand of the whole site, therefore a similar allocation procedure based on power consumption, was applied in order to identify Green Room's share on the environmental impacts for these equipments. The description can be seen below.

The chillers are responsible for the whole technical site, meaning that they produce cooling for IT equipments cooled by Green Room as well as all other equipments in the site which are not cooled by Green Room. According to TeliaSonera the total load of the technical site is,

$$Total\ Load\ for\ the\ whole\ site = 1190\ kW$$

From where 350 kW is cooled by Green Room and 840 kW is not cooled by Green Room (Izadi and El Azzi, 2012).

This being said, the Green Room share of the chillers, according to this allocation procedure is,

$$Green\ Room\ share = 350.0\ kW \div (350.0 + 840.0) kW * 100\% \cong 30\%$$

Through Venco's website the total weight of one unit of the chiller used in Green Room is available as being 2300 kg (TPi Klimatimport AB, 2006); however no material composition could be retrieved. This being said, this information was gathered from a similar chiller unit produced by the American company Trane (IBU, 2011), and served as model for this study.

Therefore the modeled chiller unit weights 690 kg (30% of 2300 kg) and presented the following material composition (IBU, 2011): 45% of total weight as low-alloyed steel (310.5 kg); 29% as copper (200.1 kg); 22% as cast iron (151.8 kg); 2% aluminum (13.8 kg); and 2% of its total weight refers to the electric motor (13.8 kg). In fact, as applied for other Green Room components (components 1.1.2 and 1.2.3), the electric motor by its turn, was modeled as being composed of 65% carbon steel; 22% aluminum; 11.5% copper and 2.5% of polycarbonate, based on Legarth et al. (2000).

Moreover it was also necessary to define the amount of refrigerant used in the chiller units. The refrigerant used in these units is the 1,1,1,2-tetrafluoroethane, also known as HFC-134a or R134a. Fortunately the Ecoinvent database provides a dataset containing detailed information about the raw material and manufacturing processes utilized for producing this refrigerant. As for the total refrigerant weight used in the chillers, information could be retrieved from Venco's website as being 100 kg, meaning that the amount for each chiller unit would correspond to 30 kg (30% of 100 kg). However it was also taken into consideration the surplus amount of refrigerant which is expected to leak out from the chillers, and needed to be recharged during Green Room's life cycle. The leakage rate was based on IBU (2011) as 0.5% per year. Therefore,

$$Initial\ R134a\ amount\ per\ chiller = 30.0\ kg$$

$$Leakage\ per\ chiller = \frac{0.5\%}{year} * 30.0\ kg = 0.15\ kg/year$$

In 20 years,

$$Leakage\ per\ chiller\ in\ 20\ years = 3.0\ kg$$

Therefore the total refrigerant weight modeled was given by,

$$Total\ refrigerant\ weight\ per\ chiller = 30.0\ kg + 3.0\ kg = 33.0\ kg$$

As for the manufacturing processes, they were assumed as 'injection molding' for plastics and 'average product manufacturing' for all low-alloyed steel, copper, stainless steel and aluminum present in this equipment. The data modeled in SimaPro for all 5 chillers can be seen on Table 48 below.

Table 48: Cooling Production processes, as inserted in SimaPro

Cooling production materials	Ecoinvent material/manufacturing process	Amount (kg)	Data source	Comment
Chiller (5 units)	Steel, low-alloyed, at plant/RER S	1552.5	B	Material (chiller)
	Cast iron, at plant/RER S	759.0	B	Material (chiller)
	Aluminum, production mix, at plant/RER S	69.0	B	Material (chiller)
	Copper, at regional storage/RER S	1000.5	B	Material (chiller)
	Refrigerant R134a, at plant/RER S	165.0	B	Material (refrigerant)
	Steel, low-alloyed, at plant/RER S	45.0	B	Material (el. motor)
	Aluminum, production mix, at plant/RER S	15.0	B	Material (el. motor)
	Copper, at regional storage/RER S	8.0	B	Material (el. motor)
	Polycarbonate, at plant/RER S	1.5	B	Material (el. motor)
	Steel product manufacturing, average metal working/RER S	1552.5	C	Manufacturing (chiller)
	Aluminum product manufacturing, average metal working/RER S	69.0	C	Manufacturing (chiller)
	Copper product manufacturing, average metal working/RER S	1000.5	C	Manufacturing (chiller)
	Steel product manufacturing, average metal working/RER S	45.0	C	Manufacturing (el. motor)
	Copper product manufacturing, average metal working/RER S	8.0	C	Manufacturing (el. motor)
	Aluminum product manufacturing, average metal working/RER S	15.0	C	Manufacturing (el. motor)

	Injection moulding/RER S	1.5	C	Manufacturing (el. motor)

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

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2 Transportation phase

As explained in section 7.2.2, the transportation phase was assumed to have all four main components of Green Room (SEE Coolers units, SEE Rack units, Infrastructure and Cooling Production equipment) transported through 1500 km by road, in a lorry with average load of 16 to 32 tons.

The Ecoinvent dataset selected for modeling transportation phase, take into consideration materials and energy flows, as well emissions related to the selected process (see dataset description in Appendix 3: Dataset Descriptions). Once defined the distance and vehicle, the dataset could be selected. The data modeled in SimaPro is presented below (Table 49).

Table 49: Transportation phase processes, as inserted in SimaPro

Transportation phase component	Ecoinvent process	Total weight (kg)	Distance (km)	ton*km	Data source
SEE Coolers	Transport, lorry 16-32t, EURO5/RER S	3825.0	1500	5737.5	C
SEE racks	Transport, lorry 16-32t, EURO5/RER S	1458.6	1500	2187.9	C
Infrastructure components	Transport, lorry 16-32t, EURO5/RER S	3012.0	1500	4518.0	C
Cooling Production components	Transport, lorry 16-32t, EURO5/RER S	3615.5	1500	5423.3	C

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

3 Utilization phase

As explained in section 7.2.3, the utilization phase had two components modeled: electricity consumption and R134a refrigerant leaked to the environment. On one hand, electricity consumption was modeled as 'hydropower certified electricity', since this is the type of electricity used at TeliaSonera's technical site, and it was directly selected from the database. On the other hand, it was necessary to be created a dataset on Ecoinvent in order to represent the R134a leakage. This dataset was comprised by the emission of 1 kg of '1,1,1,2-tetrafluoroethane' (R134a) to the air. The data modeled in SimaPro is presented below on Table 50, and the description of datasets used can be seen in Appendix 3: Dataset Descriptions.

Table 50: Utilization phase processes, as inserted in SimaPro

Utilization phase component	Ecoinvent process	Amount	Data source
Electricity consumption	Electricity, low voltage, certified electricity, at grid/SE U	9058.0 MWh	A
Refrigerant leakage	Green Room refrigerant R134a emissions during utilization phase	15.0 kg	B

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

4 End of Life phase

The end of life scenario considered in this study was modeled for four categories: recycling of metals; recycling of non-metals; incineration of non-metals and dummy-waste. This last category represents a small share of Green Room materials that were not considered in the end of life phase due to lack of data (a description follows further down in the text), thus presenting no impacts or mitigations during Green Room's life cycle.

As for recycling processes, it is important to state that Ecoinvent does not offer ready-available datasets representing recycling processes, however it suggests (for some materials) what should be the input material(s) during the recycling process, and what should be the avoided material(s) due to the recycling. Therefore, through Ecoinvent suggestions for some materials and through educated guesses for others (see dataset descriptions in Appendix 3: Dataset Descriptions), it was created a specific recycling dataset for each of the following materials: aluminum, steel (both low-alloyed and stainless), iron, copper, lead, polycarbonate, polyethylene, polypropylene, synthetic rubber (EPDM), ABS rubber and tetrafluoroethylene. It is important to remember that, for all non-metals the recycled amount was 50% of its total weight.

Subsequently, incineration was applied for the following materials: polycarbonate, polyethylene, polypropylene, synthetic rubber (EPDM), ABS rubber and tetrafluoroethylene. In fact differently of recycling, there are ready-available datasets concerning incineration processes on Ecoinvent (Appendix 3: Dataset Descriptions).

Finally, due to lack of data, the end of life phase for the following materials were not taken into consideration in this study: brass, bronze, refrigerant R134a, antimony, softened water, sulfuric acid, glass wool, glass fiber, epoxy resin and PCB. Actually, the total weight of materials modeled as 'dummy-waste' performs 589.3 kg, or 5% of total materials modeled, while all materials recycled or incinerated have a total weight of 11322,5 kg (95% of total).

All datasets created and data inserted in SimaPro regarding end of life modeling are exposed below.

Table 51: End of Life phase processes, as inserted in SimaPro

Dataset created	Process input	Avoided process	Data source
Recycling aluminum (1 kg)	Aluminum scrap, old, at plant/RER S (1 kg)	Aluminum, primary, at plant/RER S (0.9 kg)	C
Recycling iron (1 kg)	Iron scrap, at plant/RER S (1 kg)	Pig iron, at plant/GLO S (0.9 kg)	C
Recycling steel (1 kg)	Iron scrap, at plant/RER S (1 kg)	Pig iron, at plant/GLO S (0.9 kg)	C
Recycling copper (1 kg)	Copper, secondary, at refinery/RER S (1 kg)	Copper, primary, at refinery/RER S (0.9 kg)	C
Recycling lead (1 kg)	Lead, secondary, at plant/RER S (1 kg)	Lead, primary, at plant/GLO S (0.9 kg)	C

Recycling polycarbonate (1 kg)	Electricity, medium voltage, production SE, at grid/SE S (0.6 kWh)	Polycarbonate, at plant/RER S (1 kg)	C
Recycling polyethylene (1 kg)	Electricity, medium voltage, production SE, at grid/SE S (0.6 kWh)	Polyethylene, HDPE, granulate, at plant/RER S (1 kg)	C
Recycling polypropylene (1 kg)	Electricity, medium voltage, production SE, at grid/SE S (0.6 kWh)	Polypropylene, granulate, at plant/RER S (1 kg)	C
Recycling EPDM rubber (1 kg)	Electricity, medium voltage, production SE, at grid/SE S (0.6 kWh)	Synthetic rubber, at plant/RER S (1 kg)	C
Recycling ABS (1 kg)	Electricity, medium voltage, production SE, at grid/SE S (0.6 kWh)	Acrylonitrile-butadiene-styrene copolymer, ABS, at plant/RER S (1 kg)	C
Recycling tetrafluoroethylene (1 kg)	Electricity, medium voltage, production SE, at grid/SE S (0.6 kWh)	Tetrafluoroethylene, at plant/RER S (1 kg)	C

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

Table 52: Waste type for each dataset used, as inserted in SimaPro

End of Life phase dataset	Waste type	Percentage	Data source
Recycling aluminum	Aluminum	100%	C
Recycling iron	Ferro metals	100%	C
Recycling steel	Steel	100%	C
Recycling copper	Coppers	100%	C
Recycling lead (primary)	Lead, primary, at plant/GLO S	100%	C
Recycling lead (secondary)	Lead, secondary, at plant/RER S	100%	C
Recycling polycarbonate	Polycarbonate, at plant/RER S	50%	C
Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH S	Polycarbonate, at plant/RER S	50%	C
Recycling polyethylene	PE	50%	C
Disposal, polyethylene, 0.4% water, to municipal incineration/CH S	PE	50%	C
Recycling polypropylene	PP	50%	C
Disposal, polypropylene, 15.9% water, to municipal incineration/CH S	PP	50%	C
Recycling sinth. rubber	Synthetic rubber, at plant/RER S	50%	C
Disposal, rubber, unspecified, 0% water, to municipal incineration/CH S	Synthetic rubber, at plant/RER S	50%	C

Recycling ABS	Acrylonitrile-butadiene-styrene copolymer, ABS, at plant/RER S	50%	C
Disposal, rubber, unspecified, 0% water, to municipal incineration/CH S	Acrylonitrile-butadiene-styrene copolymer, ABS, at plant/RER S	50%	C
Recycling tetrafluoroethylene	Tetrafluoroethylene, at plant/RER S	50%	C
Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH S	Tetrafluoroethylene, at plant/RER S	50%	C

Data type: A) Manufacturer information; B) Study with similar product; C) Assumption.

Appendix 3: Dataset Descriptions

Table 53: Description of the datasets representing Extraction/Manufacturing phase in SimaPro

#	Ecoinvent process	Description
1	**Acrylonitrile-butadiene-styrene copolymer, ABS, at plant/kg/RER**	Date: 4/6/2010. Included processes: Aggregated data for all processes from raw material extraction until delivery at plant. Remark: Data are from the Eco-profiles of the European plastics industry (PlasticsEurope). Not included are the values reported for: recyclable wastes, amount of air / N2 / O2 consumed, unspecified metal emission to air and to water, mercaptan emission to air, unspecified CFC/HCFC emission to air, dioxin to water. The amount of "sulfur (bonded)" is assumed to be included into the amount of raw oil. Technology: Production by emulsion polymerization out of its three monomers.
2	**Aluminum product manufacturing, average metal working/kg/RER**	Date: 9/5/2007. Included processes: 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 aluminum input is considered for the loss during processing. Degreasing is not included and has to be added if necessary. Remark: 1 kg of this process is needed to produce 1 kg of final product. Geography: Average data from several local to global sized companies. The main focus is on Germany and Europe. Technology: The data is an average of mostly European companies and their production technologies.
3	**Aluminum, production mix, at plant/kg/RER**	Date: 6/10/2003. Included processes: Mix of primary and secondary aluminum according to their share on world-wide production. Geography: World-wide production mix as proxy for European consumption. Technology: Mix
4	**Antimony, at refinery/kg/CN**	Date: 2/4/2009. Included processes: Smelting of concentrate and disposal of wastes. Remark: The model represents Antimony production in China. China produces more than 80% of the global Antimony. CAS number: 007440-36-0; Formula: Sb; Geography: The model represents Antimony production in China. China produces more than 80% of the global Antimony. Technology: The data represent a mixture of blast furnace, rotary kiln and electro winning process. It is approximated from lead smelting.
5	**Brass, at plant/kg/CH**	Date: 6/12/2003. Included processes: copper and zinc including their melting and casting of brass ingots. Remark: Stands for brass with 70% Cu and 30% Zn. All data are calculated based on assumptions and theoretical models. Their overall quality is poor. Geography: Production data relate to the European average. Transports of inputs relate to the consumption in Switzerland. Technology: Assumed energy mix for melting. Abatement of air emissions assumed.
6	**Bronze, at plant/kg/CH**	Date: 6/12/2003. Included processes: copper and tin including their melting and casting of bronze ingots. Remark: Stands for bronze with 95% Cu and 5% Sn. All data are calculated based on assumptions and theoretical models. Their overall quality is poor. Geography: Production data relate to the European average. Transports of inputs relate to the consumption in Switzerland. Technology: Assumed energy mix for melting. Abatement of air emissions assumed.

7	**Cast iron, at plant/kg/RER**	Date: 8/13/2007. Included processes: Transports of metal and other input materials to electric arc furnace, smelting and refining process and casting. Remark: 35% scrap and 65% pig iron assumed as iron input; Geography: Data relate to plants in the EU. Technology: Electric arc furnace for melting. Energy consumption and emissions from EAF steel making.
8	**Casting, brass/kg/CH**	Date: 6/12/2003. Included processes: melting of copper and zinc and casting of brass parts. Metal input is not included. Remark: All data are calculated based on assumptions and theoretical models. Their overall quality is poor; Geography: Data relate to the European average. Technology: Assumed energy mix for melting. Abatement of air emissions assumed
9	**Casting, bronze/kg/CH**	Date: 6/12/2003. Included processes: melting of copper and tin and casting of bronze parts. Metal input is not included. Remark: All data are calculated based on assumptions and theoretical models. Their overall quality is poor; Geography: Data relate to the European average. Technology: Assumed energy mix for melting. Abatement of air emissions assumed.
10	**Chromium steel 18/8, at plant/kg/RER**	Date: 8/13/2007. Included processes: Mix of differently produced steels and hot rolling. Remark: represents Average of World and European production mix. This is assumed to correspond to the consumption mix in Europe; Geography: Data relate to plants in the EU. Technology: technology mix.
11	**Chromium steel product manufacturing, average metal working/kg/RER**	Date: 9/5/2007. Included processes: 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 chromium steel input is considered for the loss during processing. Degreasing is not included and has to be added if necessary. Remark: 1 kg of this process is needed to produce 1 kg of final product; Geography: Average data from several local to global sized companies. The main focus is on Germany and Europe. Technology: The data is an average of mostly European companies and their production technologies.
12	**Copper product manufacturing, average metal working/kg/RER**	Date: 9/5/2007. Included processes: 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 copper input is considered for the loss during processing. Degreasing is not included and has to be added if necessary. Remark: 1 kg of this process is needed to produce 1 kg of final product; Geography: Average data from several local to global sized companies. The main focus is on Germany and Europe. Technology: The data is an average of mostly European companies and their production technologies.
13	**Copper, at regional storage/kg/RER**	Date: 11/19/2007. Included processes: Transport of primary metal to Europe from the countries importing to Europe is included, as the import of concentrate, which is processed in RER. As import pattern the situation of Germany in 1994 was chosen. Remark: The module characterizes the copper used in Germany 1994 reflecting its origin and the fraction of secondary metal. It is designed for the use of the metal various technical applications such as alloys and construction material; Geography: In this module the consumption pattern of Germany is used as proxy for the situation in RER. Technology: This consumption mix represents the technology used of the countries importing to Germany in 1994 and differentiates between pyrolytical processes, hydrolytical processes and secondary copper.

14	**Electricity, low voltage, production SE, at grid/kWh/SE**	Date: 8/20/2007. Included processes: Included is the electricity production in Sweden, the transmission network as well as direct SF6-emissions to air. Electricity losses during low-voltage transmission and transformation from medium-voltage are accounted for. Remark: This dataset describes the transformation from medium to low voltage as well as the distribution of electricity at low voltage. Geography: Data apply to public and self producers. Geographical classification according to IEA. Assumptions for transmission network, losses and emissions are based on Swiss data. Technology: Average technology used to distribute electricity. Includes underground and overhead lines, as well as air- and SF6-insulated medium-to-low voltage switching stations. Electricity production according to related datasets.
15	**Epoxy resin, liquid, at plant/kg/RER**	Date: 4/6/2010. Included processes: Aggregated data for all processes from raw material extraction until delivery at plant. Remark: All data are based on Eco-profiles of the European plastics industry. Technology: Production from epichlorohydrin and bisphenol-A. CAS number: 025928-94-3; Geography: Data for 4 plants in DE, IT, NL, CH
16	**Extrusion, plastic pipes/kg/RER**	Date: 7/19/2005. Included processes: This process contains the auxiliaries and energy demand for the mentioned conversion process of plastics. The converted amount of plastics is NOT included into the dataset. Remark: 1 kg of this process equals 0.996 kg of extruded plastic pipes; Geography: information from different European and Swiss converting companies. Technology: present technologies.
17	**Glass fiber, at plant/kg/RER**	Date: 7/23/2003. Included processes: Gate to gate inventory for the production of glass fiber. Remark: Inventory based on a state of the art report for the European glass manufacturing industry. Data had to be estimated from ranges given for different parameters. CAS number: 065997-17-3; Geography: 26 furnaces operating at 12 sites in Europe. Technology: Recuperative or oxy-fuel fired furnaces.
18	**Glass wool mat, at plant/kg/CH**	Date: 4/5/2004. Included processes: Included processes: melting, fiber forming & collecting, hardening & curing and internal processes (workshop, etc.). Additionally transportation of raw materials and energy carrier for furnace, packing and infrastructure are included. For the heat needed, energy modules are used and the needed electricity is from Swiss grid. Remark: This module can be used for all different kind of glass wool mats. The density of the glass wool mat used as basis for the study is 40 kg/m3; Geography: Data are only from one company in Switzerland (Isover SA). For some exchanges DE-, RER- and GLO-modules are used as proxy. Technology: The company worked on a very high technical level but the data refer to the situation before 1995. The energy for the melting process is mainly electricity and from natural gas. The amount of waste glass used as raw material is about 65%.
19	**Injection molding/kg/RER**	Date: 6/10/2003. Included processes: This process contains the auxiliaries and energy demand for the mentioned conversion process of plastics. The converted amount of plastics is NOT included into the dataset. Remark: 1 kg of this process equals 0.994 kg of injection molded plastics; Geography: information from different European and Swiss converting companies. Technology: present technologies.

20	**Laptop computer, at plant/piece/GLO**	Date: 11/8/2007. Included processes: Describes the production of a laptop computer. Calculated per 1 produced laptop computer (1 unit). Included are the materials (mainly metals and plastics) with their respective manufacturing processes (e.g. sheet rolling, press molding). Further inventoried is the infrastructure (factory), the electricity for the assembly of the laptop computer, the water consumption and industrial waste water, the required ship, rail and road transport for input materials, the packaging, plus the disposal of the laptop. Remark: This dataset can be applied to describe the production of a typical laptop computer in the last 3 years before the reference year 2005 (Pentium 3, processor speed 600 MHz, 10 GB RAM, 128 MB memory, 12.1 inch screen, total weight with expansion base 3.15 kg; including the expansion base without speaker, switch and cables). The information is based on literature data representing a typical laptop computer of a leading producer. Laptop parts like hard disk drive, CD Rom drive, printed wiring boards (e.g. motherboard) and batteries are inventoried in individual ecoinvent datasets. ; Geography: The data is based on information by a leading international computer manufacturer. Such a laptop computer may be assembled anywhere in the world. Therefore a global dataset is justifiable. Technology: The production of a laptop computer includes the metal processing step sheet rolling and press molding of the magnesium parts. Plastic parts are blow molded or extruded into required shapes. The process technology of the parts (capacitors, resistors, microchips etc.) mounted on to the printed wiring board are described in individual datasets.
21	**Lead, primary, at plant/kg/GLO**	Date: 11/7/2007. Included processes: The module includes the production of primary lead with the sinter/blast furnace (ISP) and direct smelting process, the disposal of slag and final refining of lead. Remark: The module describes the primary production of lead in Europe. The multi-output-process "smelting, primary lead production" delivers the co-products "lead, primary, at plant" and "parkes process crust, from desilverising of lead". The flow "lead, …" is part of the respective European supply mix. The by-product "parkes process crust, …" receives part of the burden and enters the silver production chain.; Geography: This module represents the production of primary lead on a global average. Technology: A mix of 56% direct smelting and 44% sinter/blast furnace (ISP) is chosen. For emission control 56% improved and 44% limited control is chosen.
22	**Lead, secondary, at plant/kg/RER**	Date: 9/28/2007. Included processes: Collection, sorting and re-melting of the lead contained in lead acid batteries. Remark: The module describes the production of secondary lead in Europe. The feed of secondary material consists of scrap lead acid (PbA) batteries form automotives. The data refers to one big operation in Europe that operates with representative technology. CAS number: 007439-92-1; Formula: Pb; Geography: This module represents the European production based on a single major site in Belgium. Technology: The referred operation uses a shaft furnace with post combustion, which is the usual technology for secondary smelters.
23	**Polycarbonate, at plant/kg/RER**	Date: 4/6/2010. Included processes: Aggregated data for all processes from raw material extraction until delivery at plant. Remark: Data are from the Eco-profiles of the European plastics industry (PlasticsEurope). Not included are the values reported for: recyclable wastes, amount of air / N2 / O2 consumed, unspecified metal emission to air and to water, mercaptan emission to air, unspecified CFC/HCFC emission to air, dioxin to water. The amount of "sulphur (bonded)" is assumed to be included into the amount of raw oil; Geography: 3 European production sites. Technology: production by interfacial polycondesation out of phosgene and bisphenol A.

24	**Polyethylene, HDPE, granulate, at plant/kg/RER**	Date: 4/6/2010. Included processes: Aggregated data for all processes from raw material extraction until delivery at plant. Remark: Data are from the Eco-profiles of the European plastics industry (PlasticsEurope). Not included are the values reported for: recyclable wastes, amount of air / N2 / O2 consumed, unspecified metal emission to air and to water, mercaptan emission to air, unspecified CFC/HCFC emission to air, dioxin to water. The amount of "sulphur (bonded)" is assumed to be included into the amount of raw oil. CAS number: 009002-88-4; Geography: 24 European production sites. Technology: polymerization out of ethylene under normal pressure and temperature.
25	**Polypropylene, granulate, at plant/kg/RER**	Date: 4/6/2010. Included processes: Aggregated data for all processes from raw material extraction until delivery at plant. Remark: Data are from the Eco-profiles of the European plastics industry (PlasticsEurope). Not included are the values reported for: recyclable wastes, amount of air / N2 / O2 consumed, unspecified metal emission to air and to water, mercaptan emission to air, unspecified CFC/HCFC emission to air, dioxin to water. The amount of "sulphur (bonded)" is assumed to be included into the amount of raw oil. CAS number: 009003-07-0; Geography: 28 European production sites. Technology: polymerization out of propylene.
26	**Printed wiring board, mixed mounted, unspec., solder mix, at plant/kg/GLO**	Date: 9/14/2007. Included processes: This dataset represents a mix of the two mounting technologies (surface mount / through-hole mount); using for each of them a dataset representing a solder mix of Pb-containing and Pb-free solder. It includes processes of components mounting using lead and lead free solder technology. Remark: Data are based on own assumption - assuming a 50:50 mix between the two technologies (through-hole, surface mounts); Geography: Own estimation - used for the global average. Technology: Dataset represents the mix of lead and lead-free mounting of unspecified PWBs.
27	**Refrigerant R134a, at plant/kg/RER**	Date: 4/2/2004. Included processes: The module includes chemicals, energy and transport requirements for R134a production. Remark: It has been assumed that 50% of R134a is produced from trichlorethylene and 50% from tetrachloroethylene. Data based on (Frischknecht, 1999); Formula: $C_2H_2F_4$; Geography: none. Technology: none.
28	**Sheet rolling, aluminum/kg/RER**	Date: 6/17/2003. Included processes: All the process steps, which can be attributed to semi-fabrication (sawing, scalping, hot rolling, cold rolling, solution heat treatment, finishing and packaging), are included. Does not include the material being rolled; only the amount of scrap lost in waste is balanced as primary aluminum input. Includes the transport of the materials to the plant, but does not include the transport of the product to the customer. Remark: Aluminum ingots of 500-700 mm thickness and up to 25 tones weight are rolled, first hot, then cold, to a final sheet thickness ranging from 0.2 to 6 mm. The module can be applied also for section bar rolling of aluminum; Geography: Data-set is representative for European Union. Technology: Average technique for European Union. The infrastructure was assumed to be the same as for rolling steel.
29	**Steel product manufacturing, average metal working/kg/RER**	Date: 9/5/2007. Included processes: 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 processing. Degreasing is not included and has to be added if necessary. Remark: 1 kg of this process is needed to produce 1 kg of final product; Geography: Average data from several local to global sized companies. The main focus is on Germany and Europe. Technology: The data is an average of mostly European companies and their production technologies.

30	**Steel, low-alloyed, at plant/kg/RER**	Date: 8/13/2007. Included processes: Mix of differently produced steels and hot rolling. Remark: represents Average of World and European production mix. This is assumed to correspond to the consumption mix in Europe; Geography: Data relate to plants in the EU. Technology: technology mix.
31	**Sulfuric acid, liquid, at plant/kg/RER**	Date: 7/25/2003. Included processes: Inventory includes the obtainment of SO2-containing gas (by means of oxidation of the sulfur containing raw materials: elemental sulfur, pyrites, other sulfide ores or spent acids). It includes also the conversion of SO2 to SO3 and the absorption of SO3 into solution (sulfuric acid in water) to yield Sulfuric acid. Remark: Manufacturing process starting with sulfur-containing raw materials (elemental sulfur, pyrites, ores and spent acids) is considered, plus consumption of auxiliaries, energy, infrastructure and land use, as well as transportation of raw materials, auxiliaries and wastes. The generation of solid wastes and emissions into air and water and wastes. Transport and storage of the final product sulfuric acid are not included. No byproducts or co-products are considered. Transient or unstable operations are not considered, but the production during stable operation conditions. Emissions to air are considered as emanating in a high population density area. Emissions into water are assumed to be emitted into rivers. Wastes are assumed to be sent to landfill. Inventory refers to 1 kg 100% sulfuric acid, liquid, at plant. Since the sulfuric acid can be considered a as byproduct from the processing of sulfide ores (other than pyrites), for this study it is considered that the sulfuric acid produced by smelter gas burning is obtained "gratis“. As mentioned above, this process contributes with 35% to the total production. Consequently, in order to subtract the contribution of this process to the overall average, all the values for inputs and outputs presented in the report have been balanced by multiplying them by 0.65 before entering the values in the present excel files in ecoinvent database. CAS number: 007664-93-9; Formula: H2SO4; Geography: European average values. Technology: part of the sources considers the average technology used in European sulfuric acid production plants. The others consider the state-of-the-art technology in Europe.
32	**Synthetic rubber, at plant/kg/RER**	Date: 7/1/2003. Included processes: Production of EPDM-rubber, production of EPDM elastomer, extrusion and vulcanization of EPDM profiles. Also included are the transports of the raw materials to the polymerization and elastomer production plant. Remark: This module refers to the EPDM elastomer as it is used in technical products. Thus, according to DIN the name "rubber" (meaning only the un-vulcanized polymer without any fillers etc.) would actually be wrong. EPDM is one of many different rubbers and there are EPDM elastomers of many different compositions. The elastomer modeled in this data could typically be used as seals (for e.g. windows). Technology: Ziegler-Natter solution polymerization of EPDM. Internal mixing of elastomer. Salt vulcanization after extrusion.
33	**Tetrafluoroethylene, at plant/kg/RER**	Date: 7/19/2005. Included processes: Gate to gate inventory for the production, estimation for infrastructure and not including by-products. Remark: Inventory for a chemical. CAS number: 009002-84-0; Formula: C2F4; Geography: Plant e.g. in NL. Technology: Chemical processing.
34	**Water, completely softened, at plant/kg/RER**	Date: 7/4/2003. Included processes: Use of chemicals and some emissions for the treatment of water used in power plants. Remark: Rough estimation for the process; Formula: H2O; Geography: Data provided by CH company. Technology: Water treatment by ion-exchanger for the use as cooling water in power plants.

35	**Wire drawing, copper/kg/RER**	Date: 4/10/2010. Included processes: Includes the production of wire rod and the further drawing of this to wire. Does not include the material being rolled or drawn; only the amount of scrap lost in waste is balanced as primary copper input. Includes the transport of the materials to the plant, but does not include the transport of the product to the customer. Remark: Wire rod production is comparable to sheet rolling leading to another final shape. Further drawing leads to wires with cross sections ranging from 1.6 to 3.5 mm and higher.; Geography: Dataset is representative for European Union. Technology: Technique describes the average of European Union. Data are estimated basing on the data of aluminum sheet rolling, set in relation by mean of the volume of material worked.
36	**Wire drawing, steel/kg/RER**	Date: 2/7/2010. Included processes: Includes the process steps pre-treatment of the wire rod (mechanical de-scaling, pickling), dry or wet drawing (usually several drafts with decreasing die sizes), in some cases heat treatment (continuous-/discontinuous annealing, patenting, oil hardening) and Finishing. Does not include coating and the material being rolled. Remark: Wire drawing is a process in which wire rods/wires are reduced in diameter by drawing them through cone-shaped openings of a smaller cross section, so called dies. The input usually is wire rod of diameters raging from 5.5 to 16 mm obtained from hot rolling mills in form of coils. The final diameter size of dry drawn wire is between one and two millimeters, wet drawn wire has an even smaller diameter; Geography: Data-set is representative for European Union. Technology: Average technique for EU. The processes of steel and stainless steel aren't fundamentally different, thus this module covers both materials.

Table 54: Description of the dataset representing Transportation phase in SimaPro

#	Ecoinvent process	Description
37	**Transport, lorry 16-32t, EURO5/t*km/RER**	Date: 10/25/2007. Included processes: operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road. Remark: Inventory refers to the entire transport life cycle. For road infrastructure, expenditures and environmental interventions due to construction, renewal and disposal of roads have been allocated based on the Gross tone kilometer performance. Expenditures due to operation of the road infrastructure, as well as land use have been allocated based on the yearly vehicle kilometer performance. For the attribution of vehicle share to the transport performance a vehicle life time performance of 540000 vehicle*km/vehicle has been assumed. Geography: The data for vehicle operation and road infrastructure reflect Swiss conditions. Data for vehicle manufacturing and maintenance represents generic European data. Data for the vehicle disposal reflect the Swiss situation. Technology: Diesel.

Table 55: Description of the datasets representing Utilization phase in SimaPro

#	Ecoinvent process	Description
38	**Electricity, low voltage, certified electricity, at grid/kWh/SE**	Date: 2/7/2010. This dataset was created especially for the Green Room life cycle project. It is based on the Ecoinvent dataset: 'electricity, low voltage, certified electricity, at grid/kWh/CH', which represents data valid for Switzerland. Therefore in order to make this dataset suitable for Swedish conditions, the dataset 'electricity, hydropower, at power plant/CH' was substituted by the dataset 'electricity, hydropower, at power plant/SE'. Included processes: This data set includes the transmission network infrastructure and emissions from transmission at low voltage. SF6 and losses accounted for. Remark: This data set represents the electricity mix from certified sources. Electricity at low voltage. Technology: Electricity from certified sources.
39	**Green Room refrigerant R134a emissions during utilization phase**	This is a dataset created especially for the Green Room life cycle project. It is meant to represent the emission of refrigerant R134a due to natural leakage from the chiller units during their life span. 1 kg of this dataset represents the release of 1 kg of Ethane, 1,1,1,2-tetrafluoro-, HFC-134a to the air.

Table 56: Description of the datasets representing End of Life phase in SimaPro

#	Ecoinvent process	Description
40	**Disposal, plastics, mixture, 15.3% water, to municipal incineration/kg/CH**	Date: 7/15/2003. Included processes: waste-specific air and water emissions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emissions to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber sludge). Process energy demands for MSWI. Remark: Inventoried waste contains 100% Mixed various plastics. Net energy produced in MSWI: 3.48MJ/kg waste electric energy and 7.03MJ/kg waste thermal energy. Allocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI. One kg of this waste produces 0.01693 kg of slag and 0.006594 kg of residues, which are land filled. Additional solidification with 0.002638 kg of cement. Geography: Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan. Technology: average Swiss MSWI plants in 2000 with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR, 32.2% SCR-high dust, 24.6% SCR-low dust – De-NOx facilities and 13.8% without De-nox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag: 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%

41	**Disposal, polyethylene, 0.4% water, to municipal incineration/kg/CH**	Date: 7/15/2003. Included processes: waste-specific air and water emissions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emissions to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber sludge). Process energy demands for MSWI. Remark: Inventoried waste contains 100% PE. Net energy produced in MSWI: 5MJ/kg waste electric energy and 10.02MJ/kg waste thermal energy. Allocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI. One kg of this waste produces 0.01917 kg of slag and 0.005762 kg of residues, which are land filled. Additional solidification with 0.002305 kg of cement. CAS number: 009002-88-4; Formula: (CH2-CH2)n; Geography: Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan. Technology: average Swiss MSWI plants in 2000 with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag: 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%.
42	**Disposal, polypropylene, 15.9% water, to municipal incineration/kg/CH**	Date: 7/15/2003. Included processes: waste-specific air and water emissions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emissions to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber sludge). Process energy demands for MSWI. Remark: Inventoried waste contains 100% PP. Net energy produced in MSWI: 3.74MJ/kg waste electric energy and 7.54MJ/kg waste thermal energy. Allocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI. One kg of this waste produces 0.01618 kg of slag and 0.004865 kg of residues, which are land filled. Additional solidification with 0.001946 kg of cement. CAS number: 009003-07-0; Formula: (CH2-CHCH3)n; Geography: Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan. Technology: average Swiss MSWI plants in 2000 with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag: 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%.

43	**Disposal, rubber, unspecified, 0% water, to municipal incineration/kg/CH**	Date: 7/15/2003. Included processes: waste-specific air and water emissions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emissions to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber sludge). Process energy demands for MSWI. Remark: Inventoried waste contains 100% rubber. Net energy produced in MSWI: 3.02MJ/kg waste electric energy and 6.11MJ/kg waste thermal energy. Allocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI. One kg of this waste produces 0.01306 kg of slag and 0.02671 kg of residues, which are land filled. Additional solidification with 0.01068 kg of cement; Geography: Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan. Technology: average Swiss MSWI plants in 2000 with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag: 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%
44	**Recycling ABS**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kWh of 'Electricity, medium voltage, production SE, at grid/SE S' (representing the recycling process) and avoids the production of 1 kg of 'Acrylonitrile-butadiene-styrene copolymer, ABS, at plant/RER S'.
45	**Recycling aluminum**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kg of 'Aluminum scrap, old, at plant/RER S' (representing the recycling process) and avoids the production of 0.9 kg of 'Aluminum, primary, at plant/RER S'.
46	**Recycling copper**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kg of 'Copper, secondary, at refinery/RER S' (representing the recycling process) and avoids the production of 0.9 kg of 'Copper, primary, at refinery/RER S'.
47	**Recycling iron**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kg of 'Iron scrap, at plant/RER S' (representing the recycling process) and avoids the production of 0.9 kg of 'Pig iron, at plant/GLO S'.
48	**Recycling lead (primary)**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kg of 'Lead, secondary, at plant/RER S' (representing the recycling process) and avoids the production of 0.9 kg of 'Lead, primary, at plant/GLO S'.
49	**Recycling lead (secondary)**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kg of 'Lead, secondary, at plant/RER S' (representing the recycling process) and avoids the production of 0.9 kg of 'Lead, primary, at plant/GLO S'.
50	**Recycling polycarbonate**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kWh of 'Electricity, medium voltage, production SE, at grid/SE S' (representing the recycling process) and avoids the production of 1 kg of 'Lead, primary, at plant/GLO S'.
51	**Recycling polyethylene**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kWh of 'Electricity, medium voltage, production SE, at grid/SE S' (representing the recycling process) and avoids the production of 1 kg of 'Polyethylene, HDPE, granulate, at plant/RER S'.

52	**Recycling polypropylene**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kWh of 'Electricity, medium voltage, production SE, at grid/SE S' (representing the recycling process) and avoids the production of 1 kg of 'Polypropylene, granulate, at plant/RER S'.
53	**Recycling sinth. rubber**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kWh of 'Electricity, medium voltage, production SE, at grid/SE S' (representing the recycling process) and avoids the production of 1 kg of 'Synthetic rubber, at plant/RER S'.
54	**Recycling steel**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kg of 'Iron scrap, at plant/RER S' (representing the recycling process) and avoids the production of 0.9 kg of 'Pig iron, at plant/GLO S'.
55	**Recycling tetrafluoroethylene**	This dataset was created especially for the Green Room life cycle project. 1 kg of this dataset is composed by the input of 1 kWh of 'Electricity, medium voltage, production SE, at grid/SE S' (representing the recycling process) and avoids the production of 1 kg of 'Tetrafluoroethylene, at plant/RER S'.

Table 57: Description of Ecoinvent datasets applied on Sensitivity Analysis (section 9.1).

#	Ecoinvent process	Description
56	**Electricity, low voltage, production RER, at grid/kWh/RER**	Date: 8/20/2007. Included processes: Included is the electricity production in Europe (EU27 including Norway, Switzerland and the former Baltic states), the transmission network as well as direct SF6-emissions to air. Electricity losses during low-voltage transmission and transformation from medium-voltage are accounted for. Remark: This dataset describes the transformation from medium to low voltage as well as the distribution of electricity at low voltage. Geography: Data apply to public and self producers in EU27 including Norway, Switzerland and the former Baltic states. Assumptions for transmission network, losses and emissions are based on Swiss data. Technology: Average technology used to distribute electricity. Includes underground and overhead lines, as well as air- and SF6-insulated medium-to-low voltage switching stations. Electricity production according to related datasets.
57	**Electricity, low voltage, production SE, at grid/kWh/SE**	Date: 8/20/2007. Included processes: Included is the electricity production in Sweden, the transmission network as well as direct SF6-emissions to air. Electricity losses during low-voltage transmission and transformation from medium-voltage are accounted for. Remark: This dataset describes the transformation from medium to low voltage as well as the distribution of electricity at low voltage. Geography: Data apply to public and self producers. Geographical classification according to IEA. Assumptions for transmission network, losses and emissions are based on Swiss data. Technology: Average technology used to distribute electricity. Includes underground and overhead lines, as well as air- and SF6-insulated medium-to-low voltage switching stations. Electricity production according to related datasets.

58	**Electricity, production mix US/kWh/US**	Date: 9/5/2007. Included processes: It includes the shares of domestic electricity production by technology at the busbar of power plants. It does not include transformation, transport nor distribution losses. Remark: Electricity domestic net production shares are based on year 2004 data. Remark: 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 modeling characteristics), which accounted together for about 85% of US electricity production in year 2004. Other technologies are modeled using European datasets as first approximation. Geography: Data apply to utilities and self producers in the US. Technology: No technology description is provided because the dataset just describes the power plant generation portfolio of the country using current (2000 - 2005) average technology per energy carrier.
59	**Landfill/CH U**	Ecoinvent dataset represented by the landfill disposal of the following materials: 'Disposal, glass, 0% water, to inert material landfill/CH U' (for glass); 'Disposal, aluminum, 0% water, to sanitary landfill/CH U 100%' (for aluminum); 'Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U 100%' (for plastic mix); 'Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U' (for PE); 'Disposal, polypropylene, 15.9% water, to sanitary landfill/CH U' (for PP); 'Disposal, steel, 0% water, to inert material landfill/CH U' (for steel) and 'Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH U' (for all other material present in Green Room not covered by the datasets indicated above).