LIFE CYCLE ASSESSMENT OF ERICSSON'S MANAGED RURAL COVERAGE SOLUTION

BEGUM KULTUR

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KTH Industrial Engineering and Management	**Master of Science Thesis, EGI-2013-024MSC EKV941** **Life Cycle Assessment of Ericsson´s Managed Rural Coverage Solution** Begum Kultur	
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ABSTRACT

The total number of mobile subscriptions has been announced to reach 6 billion in the market, of which 4 billion are individual users. The rest of the people on earth are potential subscribers that mainly live in rural areas lacking mobile connectivity today. Many of these users do not have access to electricity and have 6 U.S. dollar per month (USD/month) of average revenue per person.

Referring to the year 2007, the telecommunication industry had a contribution of 0.6 percent of direct global carbon dioxide (CO_2) or 0.4 percent of global carbon dioxide equivalent (CO_2e). From 2007 to 2009, the number of off-grid radio base stations located in rural areas went up from 350,000 to 500,000. Nearly all of these sites use diesel generators and large amounts of fossil fuels during the operational stage. In addition the grid sites with diesel back-up were about 0.5 million in 2009. The financial and environmental consequences of the life cycle impact of the diesel fuel depleted can be significant. Adaptation of renewable energy has therefore become important for both environmental and economic reasons.

In this master thesis a Life Cycle Assessment of Ericsson's Managed Rural Coverage (MRC) solution was made. Four main life cycle stages were included: manufacturing, transportation, operation and end-of-life treatment. MRC is an off-grid site solution consisting of electronic communication equipment (radio base station, base station controller, hub, cable) photovoltaic cells, battery, antenna, and constructions part (antenna pole, tower and foundation). This study also includes the satellite connection as well as Ericsson and operator activities in the assessment. The MRC distinguishes itself from the conventional base stations, by its significant decrease of energy consumption in its operational stage as well as the business model around the offering.

The assessment in this thesis was carried out in accordance with data retrieved from an Ericsson's pilot system in Dungunab, Sudan. The ISO 1404X series of LCA standards was followed and Gabi software w used to evaluate the results.

The carbon footprint was found to be 0.3 kg CO_2e/subscriber for the pilot setup. These calculations were based on an assumption that each pilot site serviced 1000 users. The maximum number of subscribers can be about 3200, which would decrease the life cycle CO_2 emissions per user by 2/3.

According to the sensitivity analysis the maximum CO_2 emissions for a conservative MRC scenario is less than 1 kg CO_2e/subscriber. Although this figure represents a very conservative scenario, the result is low in comparison with an average GSM network which has an approximate carbon footprint of 15 kg CO_2e/subscriber. It is important to note that the MRC is not intended to replace all conventional macro RBS sites due to limitations in performance and capabilities, but is rather a complement to conventional macro radio base station sites for applicable scenarios.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Abbreviations

AC	Acidification of natural ecosystems
BSC	Base Station Controller
CAPEX	Capital Expenditure
CFC	Chlorofluorocarbon
CML	Institute of Environmental Sciences
COAX	Coaxial cable
CO	Carbon Monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents, also written as CO_2 eq. or CO_2 equiv.
C_2H_4	Ethene
DCB	Dichlorobenzene
EoL	End-of-Life
EoLT	End-of-Life Treatment
EP	Eutrophication Potential
Eq	Equivalents, for example CO_2e represents carbon dioxide equivalent
FAETP	Freshwater Aquatic Eco Toxicity Potential
GHG	Greenhouse Gases
GSM	Global System for Mobile
GWP	Global Warming Potential
GWP100	Global Warming Potential over 100 years
HTP	Human Toxicity Potential
ICT	Information and Communication Technology
ISO	International Organization for Standardization
IPCC	Intergovernmental Panel on Climate Change
kgkm	Kilogram Kilometer
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory

LCIA	Life Cycle Impact Assessment
MAETP	Marine Aquatic Eco Toxicity Potential
MJ	Mega Joules
MRC	Managed Rural Coverage
N	Nitrogen
NH_3	Ammonia
NO_X	Nitrogen Oxides
ODP	Ozone Depletion Potential
OPEX	Operating Expenditure
P	Phosphorus
pkm	Passenger Kilometer
POCP	Photochemical Ozone Creation Potential
PO_4	Phosphate
PV	Photovoltaic
RBS	Radio Base Station
Sb	Antimony
SO_2	Sulphur Dioxide
TETP	Terrestrial Eco Toxicity Potential
tkm	Ton Kilometer
USD	United States Dollar
VOC	Volatile Organic Compounds

1 INTRODUCTION

The number of base station sites was approximately 5 million in 2009 within the whole telecommunication industry and it is expanding as the demand for connectivity is growing (Ericsson internal, Lindkvist and Fager, 2009). Most of the growth is in rural areas where no electricity grid is available (off-grid) and these areas are mainly located in developing countries.

Ericsson Managed Rural Coverage (MRC)is a new offering that bundles a managed service with a cost-efficient Global System for Mobile (GSM) communication mini-site solution. The service enables profitable expansion in rural areas with no network coverage. The solution consists of a unique technology that reduces the cost for power and transmission capacity and a business model that provides incentives for subscriber growth and service maintenance for the local community, for the operator, as well as for Ericsson. This new business model is based on an operational lease; it lowers the financial and operational risks and provides a pioneering project for the operator (Ericsson internal, Ballman 2011).

Currently Ericsson has on-going projects in several African countries to deploy solar power based base station sites under the theme 'Managed Rural Coverage'. The project unites managed services with cost-efficient GSM mini-site solutions and enables profitable expansion into rural regions with no network coverage. This is a combination of unique technologies providing lower power consumption as well as transmission costs. It supports deployment of mobile telephony services for the next billion subscribers. The targeted market region is defined as small villages in countries with low penetration of mobile subscriptions.

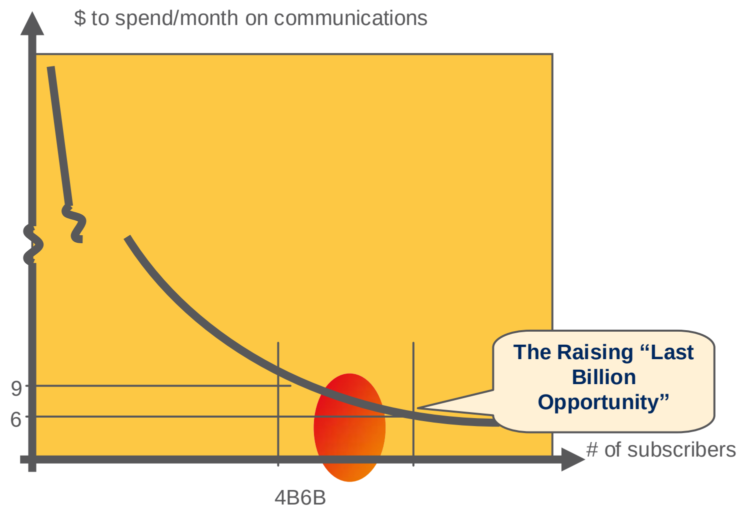

Figure 1.1. Monthly communication cost/subscriber (in USD)

The majority of the people in these villages have very low income. 80 percent of these people earn 2 United States dollars (USD) per day or less (Ericsson internal, Nabil, 2011).

The set-up of the assessed MRC solution is a stand-alone system that has maximum 4 km^2 coverage area and use lead acid batteries for back-up. The aim is to deploy this solution in rural areas at low cost, low environmental impact, lowO_2 emission and also low operational cost (OPEX) (Ericsson internal, Ghani 2011). Moreover, Ericsson continuously assess their environmental impacts of each stage of the product' life cycle by using a Life Cycle Assessment (LCA) approach which includes network and service infrastructure, end-user equipment as well as Ericsson and operators' activities. The most important outcome of this study will be to understand the contribution to the overall environmental performance of the system from each stage and part of the solution.

1.1 Background

The traditional off-grid radio base station (RBS) sites use generators and they are connected to the battery bank, which acts as a back-up system. These systems use diesel as fuel, has high operational costs and higher CO_2 emissions that grid sites. Like Ericsson, many companies have searched for solutions to adopt renewable energy usage in base station sites located in off-grid rural areas. Ericsson has e.g. developed a battery diesel hybrid power solution. In this solution, one of the diesel generators is replaced with battery bank so that the amount of diesel consumed is decreased. After this change in the system architecture, photovoltaic (PV) cells have been added to the solution. Some of the local suppliers employed wind turbines to Ericsson's base station sites as well, but currently Ericsson has not included wind power in this project (Ericsson internal, Bondesson 2010).

Figure 1.2. GSM Mini-Site Solution

The pilot system assessed in this thesis was designed for Sudan based on the MRC solution. Previously performed LCA studies for each sub-systems as well as new data collection for other products within the solution were used. The pilot system was first assembled in Kista for demonstration purposes. After the display, the site was disassembled and transported to the pilot area, Dungunab (Al Bahr Al Ahmar, Sudan), 190 km from port of Sudan.

The MRC solution is providing cost efficient GSM coverage in rural areas with low capital cost (CAPEX) and the lowest OPEX possible by the most optimized use of solar satellite connectivity. The main sub-systems, assessed in this study and shown in the figure 1.2, were; Mini-site Pico base station RBS2409, base station controller, antenna, complete solar system with PV cells and solar batteries, mini-site pole with tower, antenna pole and foundation. Remote site, hub side equipment and spare parts for satellite communication were not included in the system.

1.2 Life cycle assessment design approach

LCA has become the most common method to map the total environmental footprint of products or services from their whole life-cycle; from extraction and processing of raw materials, to manufacturing, transportation, distribution, maintenance, reuse and recycling. The International Organization for Standardization (ISO) defines the life cycle of a product as including “raw material extraction (the cradle) and acquisition, through energy and material production and manufacturing (the gate), to use and end of life treatment and final disposal (the grave)” (ISO 14040:2006). LCA includes inflows and outflows throughout the life-cycle stages. Inflows include the resources needed to make and transport the product, while outflows include the emissions and waste the product creates throughout its life (Baumann and Tillman, 2004).

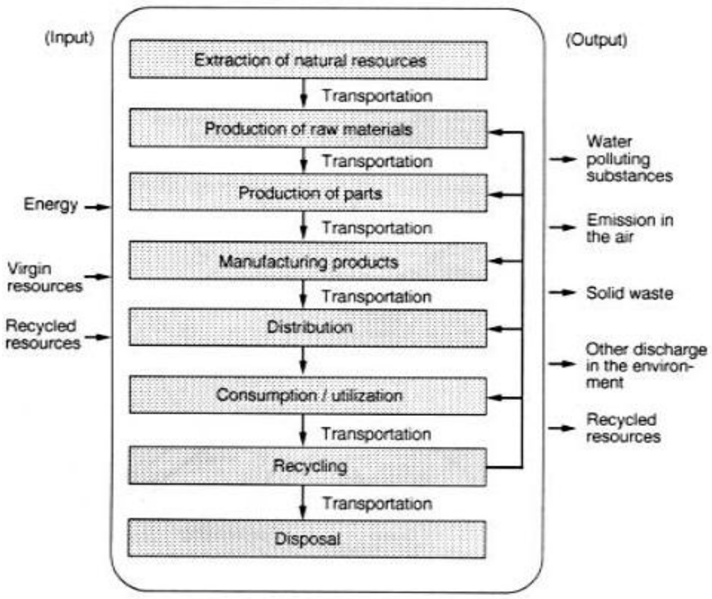

Figure 1.3. Typical Product System used in a LCA

LCA includes four phases; goal and scope, inventory analysis, impact assessment and interpretation, where the results from the other three phases are summarized and evaluated (ISO 14040:2006).

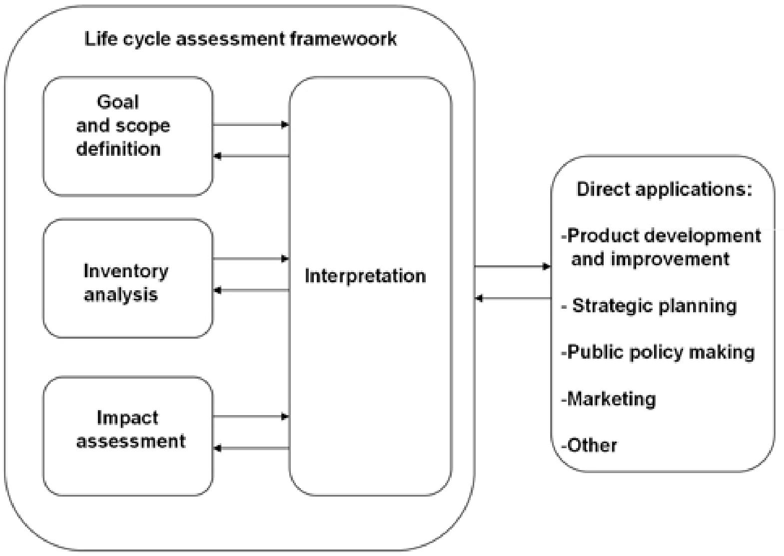

Figure 1.4. Life Cycle Assessment According to ISO 14040 Standards

1.2.1 Goal and scope definition

In the first phase of an LCA, goal and scope should be defined in order to emphasize the purpose of the study. This phase includes intended application and audience as well as the main reasons that the results of the LCA will be used. The scope of the study includes system description, system boundary setting and also choice of functional unit for the studied product.

To start an LCA study, a detailed flow chart consisting of the technical system for the studied system is made. This is really important in order not to make each step too complex or out of system boundary. Technical system includes set of process units, intermediary product flows linking them together and input/output flows in connection to the natural system. System boundary also should be drawn clearly in order to define which parts and processes will be included in the system and which will be excluded (Cavallaro et al., 2006). Moreover the chosen environmental impact category (Global Warming Potential, Acidification etc.) and chosen inventory data (CO_2 and SO_2 emissions etc.) should be defined within the goal and scope setting as well as the functional unit.

1.2.2 Life cycle inventory analysis

This phase collects and analyzes data on the inputs of the system like energy and materials and outputs of the system like emissions and wastes within the whole life cycle stages of the studied product. Life cycle inventory (LCI) methodology is an engineering mass balance accounting of energy and materials for a defined system. This system wide approach also identifies comprises, media shifts and conflicting trade-offs within a product life-cycle (Owens et al., 1996). The unit process is the smallest process for the input output data. Flows for resource or release to air, water and soil should be considered. Finally in this stage according to the assumptions made, the calculations should be the bridge between the inventory data and functional unit.

1.2.3 Life cycle impact assessment

This phase of LCA is an evaluation step of potential human health and environmental impacts of the environmental resources and released emissions that are identified during the previous phase which is LCI. Life cycle impact assessment (LCIA) should underline ecological and human health effects as well as resource depletion. It should behave as a bridge between the product or process and its potential environmental impacts. For instance the questions to be answered in this phase are; 'What are the impacts of 5,000 tons of carbon dioxide (CO_2) released to the atmosphere?' or 'What is the potential impacts of this amount of CO_2 on global warming?' or it should compare the two released emissions and answer the questions like 'Has this amount of methane or this amount of carbon dioxide more impacts on environment in global warming perspective?' etc. (EPA online report). 'Stressor' is a key concept in LCIA and refers to a set of conditions that may lead to an impact. For instance the emitted greenhouse gases (GHG) by any process will make an increment in GHG in the atmosphere and will contribute to global warming.
LCIA systematically classifies and characterizes the environmental effects. The main reason to conduct an LCIA is that it provides the basis to compare the potential impacts of the released emissions or impacts. The results of LCIA can determine which product or process causes more impacts for each kind of impact categories. There are 7 key steps in this phase (Bare, 2009).

1. Selection and Definition of Impact Categories – to identify relevant environmental impact category/categories for the study (e.g. global warming).
2. Classification – to assign LCI results to the chosen impact category (e.g. classifying CO_2 to global warming).
3. Characterization – to model LCI impacts within impact categories
4. Normalization – to express potential impacts in ways that can be compared.
5. Grouping – to sort or rank the indicators (e.g. by location; local, regional or global).
6. Weighting – to emphasizing the most important potential impacts.
7. Evaluating and Reporting LCIA Results

1.2.4 Life cycle interpretation

In this phase of LCA, the results from the LCI and the LCIA are analyzed from the defined goal and scope point of view. The main purpose is to come up with conclusions and recommendations in accordance with the goal, scope definition, made assumption and data quality. Also sensitivity and uncertainty analysis take place in this phase to reach more qualified results and conclusions for the study. The results of the LCA should be related to the defined goals and if it is not fulfilled, the LCA should be improved or the defined goal should be redefined according to the results.

1.2.5 Delimitations of LCA methodology

In LCA the accurate results depend on availability of data and also the assumptions and approximations that are made during the analysis. These are the critical points for LCA methodology. To decrease uncertainties general and standardized methodologies have to be used to make LCA studies comparable and to get a more reliable approach.
There are many ongoing studies and also methodology work (e.g. standardization) that addresses delimitations of LCA methodology

1.3 Methodology and report structure

An LCA methodology according to Baumann and Tillman and ISO standards was used.

The thesis project was divided into three steps;

In step one, a literature study was performed and a deep analysis of the different parts of the solution was made in order to evaluate in the LCA process. The detailed literature review and data collectionwere performed with a data quality goal appropriate for an LCA based on the GaBi tool. Internal Ericsson documentation provided information on the different parts of the solution like; pico base station, antenna, solar system, mini-site pole, foundation, remote sites equipment for satellite, hub side equipment, spare parts for satellite communication and base station controller. Also an external literature study was made in order to collect information about the LCA procedure, and also another external literature (based on web searches) was made to find previously made LCA studies of different parts of this solution. The goal and scope of the project was clearly defined. The main reason of running this project was underlined.

In step two, by use of appropriate LCA methodology, an LCA was performed based on the received information of each part of the solution. Data was collected in accordance with the GaBi software so that the modeling and evaluation could be performed in GaBi as parts of the Inventory Analysis. One way of collecting data was to use average data from previous studies. Collection of primary data for all processes within the system boundary would be more accurate but would take more time since there are many different parts of system.

In step three, the LCA results were exported from GaBi and summarized into a simplified environmental evaluation tool. The results were then evaluated according to the defined goal of the project.

2 GOAL AND SCOPE

2.1 Goal of the study

LCA is a method which evaluates the potential environmental impact of a product throughout its entire life cycle by quantifying the use of resources (inputs: energy, raw materials, water etc.) and environmental emissions (outputs: to air, water or soil) associated with the system that is being evaluated. The goal of this study was to evaluate the environmental impacts of a managed rural coverage that is designed for rural areas. The assessed solution includes a solar system with solar batteries and panels, antenna, foundation and also solar power satellite including side equipment of each segment.

This study was conducted for the goal of answering certain questions which were identified at the starting point of the project. These questions form the framework and design of the LCA study. The questions were; ‘In which *life cycle stage* and for which *components* of the solution does the major impact occur?’ and ‘What are the relative contributions of the different stages in the life cycle of this product to total emissions?’

The role of LCA in this study was to understand the solution in terms of its environmental impact. Moreover LCA helped to analyze the solution from a system-wide, functional unit point of view in order to guide choices of raw materials and product innovation. It identified which parameters are most likely to be significant in order to monitor and control and underline the opportunities for improving overall system performance.

2.1.1 Target audience and intended application

In general the intended application of this study is to understand the environmental profile of the solution throughout its entire lifetime.

In addition, this study will guide decision making in Ericsson Research EMF Safety and Sustainability department. The results from this study will be used internally in the department to help the further studies that will take place in Ericsson, to prioritize different measures that can be taken to improve the environmental performance and also as a marketing information source. It will also guide the potential users, i.e. which are operators’ working to provide coverage to rural areas. It will give an environmental and economic view to the potential users and help researchers to in forthcoming studies.

2.2 Scope

2.2.1 System definition

The MRC site will behave like a traditional base station and will carry around maximum 3500 subscriber at the same time (based on an Ericsson internal project description from 2010). It consists of base station site, satellite link, satellite hub, base station controller (BSC). The base station site consists of RBS2409 (Pico base-station), antenna, PV module, solar battery, mini-site pole (tower and antenna pole) and foundation which will be explained in detail in the next chapter.

2.2.2 Functional unit

The functional unit is *one pilot system in operation for one year time*. This pilot system is based on a system that was assembled in Dungunab, Sudan. The pilot system in Sudan included only 4 base station sites connected via satellite link to a satellite hub and a BSC. A more mature system deployment with 50 sites connected to a satellite hub and a BSC was also evaluated. The number of sites and the number of subscribers (mobile users) were addressed in the sensitivity analysis.

2.2.3 System boundaries

System boundaries of the site can be seen in figure 2.1.

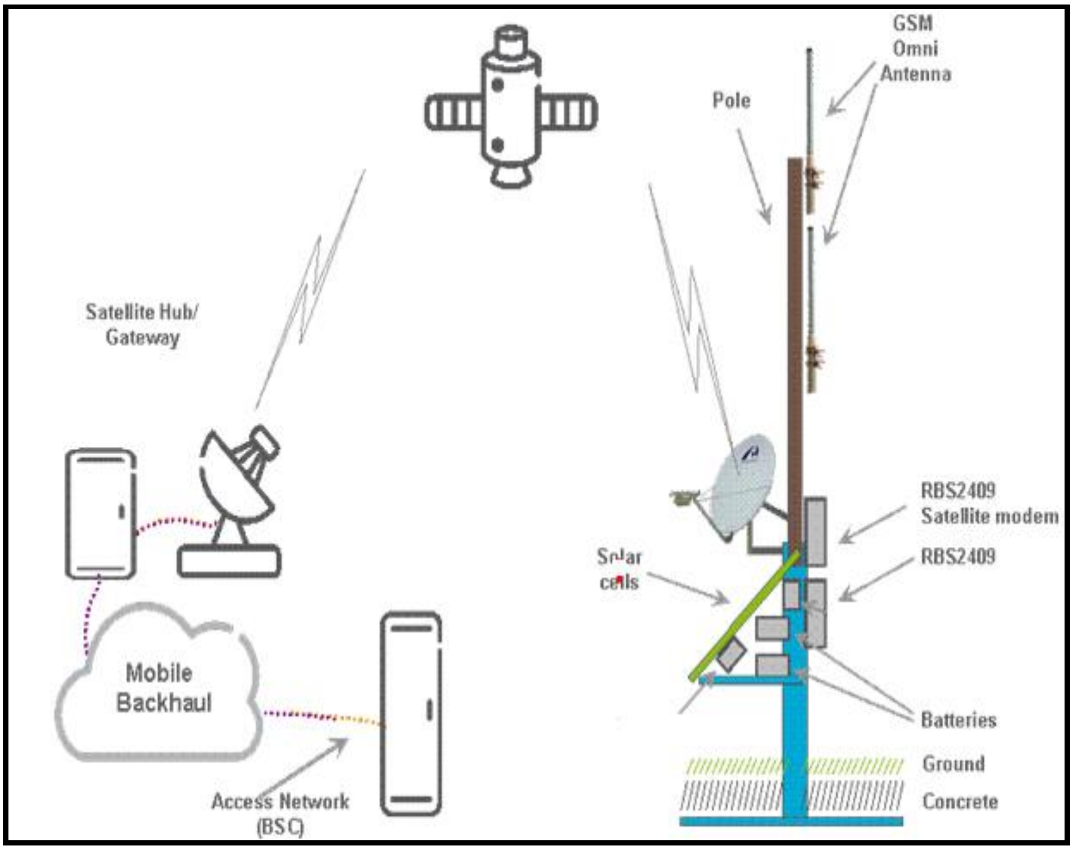

Figure 2.1.System Boundary of the Pilot System

2.2.3.1 Definition of life cycles

This study was done under cradle to grave approach and therefore cradle and grave of this study are defined as nature. The boundary between nature (cradle) and technical system which are the activities under human control begins with the raw material extraction. The grave is emissions from the system in the sense that waste is released to the nature through the whole life cycle of the site

2.2.3.2 Boundaries within the life cycles

The following steps within the life cycle of the site were evaluated from the environmental performance point of view;

- Manufacturing data (cradle to gate)
- Transportation data (from production place to the defined site)
- Operation stage data (behavior of end-user and operator)
- End-of-life treatment data (recycling, re-use, landfill etc.)

The construction parts which are foundation, mini-site pole (tower and antenna pole) were included in the study and assumed to be manufactured in Stockholm and transported to the site from Kista.

Ericsson activities such as business travel, use of offices (power consumption) and computers were also included. Other consultant companies that works within this site were not included.

More detailed explanation will be added at the end of the study.

2.2.3.3 Geographical boundaries

Geography of the studied system and sub-systems matters since the impact of each life cycle stage varies according to the used data within different regions. The assessed site was a pilot system and each part of the system was first used in Kista in order to present the site to the market. The whole system was then transported to Port Sudan (Al Bahr Al Ahmar, Sudan) and further on to the real site which is Dungunab, (Al Bahr Al Ahmar, Sudan-190 km).

In the sensitivity analysis the initial transportation between Sudan and Kista, which related to the special conditions of the pilot system, was tested by applying a local transport scenario which more reflects a mature system deployment.

For the manufacturing stage, the electricity production mix was applied in accordance with the production place. For the construction parts and RBS manufacturing, a Swedish electricity mix was used. The use stage took place in Africa, Sudan so African average data was used. For the end-of-life treatment the world average data was used.

2.2.3.4 Boundaries in time

The following lifetimes were used for each sub-system, can be seen in table 2.1;

SUB-SYSTEM	LIFE TIME
PV	20 years
BATTERY	5 years
ANTENNA	20 years
POLE	20 years
TOWER	20 years
RBS	10 years
FOUNDATION	20 years
SATELLITE	15 years

Table 2.1. Lifetimes of each sub-system

2.2.4 Methods for inventory analysis

2.2.4.1 Cut-off criteria for Inventory

Data were collected from product manufacturers for some parts of the system. For some parts of the site, assumptions were assessed according to previous studies and some data have been allocated according to the total weights of the products.

At least 90 percent of weight, cost and energy consumption was included in the LCI model which means; up to 10 percent of the data that represents some small parts or small inflows or outflows were excluded from LCI model.

2.2.4.2 General allocation principle

Input/output data (e.g. average production data) which was reused from previous studies has been scaled based on weight and area to be applicable to the products and conditions of this study.

2.2.4.3 LCA database and software

The following software was used:

- GaBi 4, PE International experts in sustainability. GaBi 4.4 version numbers; Compilation: 4.4.131.1, DB version: 4.131
- Microsoft Office Excel, 2003. Microsoft Corporation.
- LCA++v1.12 - FOCUS LCA 2011

2.2.5 Data requirements and data quality

The data that has been used has many different sources in this study. These sources differ within the products. For the whole site input from Ericsson employees who were working on this site since the beginning of the project was used, and a visit to the real site when displayed in Kista before transfer to Sudan helped a lot in the data collection phase. During the literature survey other LCA studies, published reports, and databases provided guidance for collecting data and also supplier contacts provided real data and product specifications for some of the products. Finally Ericsson internal documents, especially previous LCA studies that assessed the same parts as the studied site, were the basic guide in order to build the methodology.

Primary data was used when possible but, as the available time was limited, secondary data was used when needed. Further details are provided in 3.2.
In some parts technological resemblances between two different products helped in inventory stage where the real data could not be obtained.

During the inventory analysis impact from data gaps and data of insufficient quality, was investigated by sensitivity analysis in order to understand the uncertainties and their effects to the system. Further a trial and error approach was used to have the best results for the study. In sensitivity analysis, the procedure was to vary the studied input parameter and to revise the results for the new value when all the other parameters were kept constant.

In general for the whole analysis, it can be said that to determine the region of the processes plays a large role in LCI as the energy usage should be modeled depending on the region and its electricity mixture. However it is really difficult to find the applicable region for each process. Moreover, for raw materials proxy data based on similar materials was used when data for a specific material was not available (Malmodin, 2009). All these circumstances created some data gaps and the necessity of less qualified data to be used rather than real data.

When interpreting the results of this study for instance for the manufacturing scenario it should be understood that if it is moved from one region to another or if another raw material choice was made it would give completely different results.

2.2.6 Assumptions, simplifications and limitations

The following assumptions, simplifications and limitations were made:

- Manufacturing power consumption was based on assumptions from previous studies.
- Raw material transportation and extraction power requirement were based on software database and partly included.
- The technical solution and system configuration of RBS2409 was modeled based on an RBS6000 Low Power Node and the data was scaled based on weight.
- The hub and base station controller were based on similar systems and modeled based on the control and core network of a previous Ericsson internal LTE study.
- The network was assumed to be dimensioned for 50 sites, each representing an average of 1000 subscribers. These numbers will most probably change in a scenario where the product is introduced more widely to the market.
- Final assembly for the whole site was assumed to include energy and packaging of the sub-systems.

- The packaging that was included in the transportation stage was assumed to be 20 percent of the total weight of the product
- Electricity mixes according to project conditions were applied unless differently specified.
- The transportation modes were assumed to be 2000 km by air, 10200 km road and 800 km by sea and the route of transportation was based on information from Google Maps.
- End-of-life treatment stage consists of a representative scenario and the transportation was divided into three parts. One was used for Ericsson products, the other for the products that their suppliers took care of and the final one represented the transports that took place in the area closest to the pilot system region Dungunab, Sudan.
- In the operation stage the annual electricity consumption of the site was assumed to be 1500 MJ and the operator activities included the local transports of 800 km and 330 tkm respectively and the replacement of parts. Further one person from Ericsson, Stockholm was assumed to travel once a year via air transport of 10000 pkm.
- The cable mixture was based on real data but was assumed to be 50 kg for the site.
- The construction part of the system assumed manufacturing in Sweden for the pilot system but for the extended system manufacturing in Africa was assumed.

3 LIFE CYCLE INVENTORY (LCI)

3.1 Methods for inventory analysis

First of all for each sub-system and as a whole system itself, a detailed knowledge is required in order to reach a system understanding. In the goal and scope definition the requirements for this study were underlined and this stage of the study was done in accordance with these requirements. First the flowchart of the system that shows the activities that were included was drawn. The assessed life cycle stages were manufacturing, transportation, operation and end-of-life treatment. All these stages were connected and energy usage for each stage was included as well. In the second part data for all processes that are mentioned above were included. All input and output data were collected from suppliers or reused from previous studies and adapted to the conditions of this study. In the last part of inventory analysis, resource use and emissions to air, soil and water amounts were calculated and evaluated in accordance with the chosen functional unit.

So in general the inventory analysis followed the path of Bauman and Tillman (2004) methodology. The first detailed flow charts for each sub-system were drawn in order to fit into the software process. Then data collection was performed according to the system definition and functional unit. The data was documented and also resource use and emissions were calculated in accordance with the functional unit and the goal of the study. For each sub-system three stages (manufacturing, transportation and end-of-life treatment) were modeled separately. In contrast the operation stage and Ericsson activities were combined in one model for the whole system

3.2 Collection process

For the Ericsson products the data was collected within Ericsson. For other parts previous studies, database documentation, real data from suppliers and site-specific data was used.

The descriptive data for the model of technological system and numerical data for GaBi model was collected in an iterative process based on a free translation method suggested by Bauman and Tillman (2004).

The data collection period took place from 22nd of August 2011 to 31st of December 2011.

LCA stage	LCI models	Source/reference
Raw material	PV	Alsema et al., 2005; Kim and Fthenakis, 2010; Krauter and Ruther, 2003
	BATTERY	Bergmark et al., 2001; Sulivan and Gaines, 2010
	ANTENNA	Ahrens, 2011
	POLE	Hedlund, 2011; Ahrsjö, 2011a
	TOWER	Hedlund, 2011; Ahrsjö, 2011a
	RBS2409	Bondesson, 2011
	FOUNDATION	Hedlund, 2011; Ahrsjö, 2011a
	CABLE	Guldbrandsson, 2011
	SATELLITE	Nakano and Asakura, 2011
Manufacturing	Mechanics, cables, construction parts, components with minor influence of the life cycle. Manufacturing processes considered accurate for the time, geography, etc. compared to previous network LCA studies.	Previous network LCA studies updated with new EcoInvent electricity models. Site-specific data, suppliers.
Ericsson activities	In-house office and travel activities.	Ahrsjö, 2011b
Operation	Operator activities.	Ahrsjö, 2011b
	Power consumption of network components	Previous network study and EARTH Ericsson internal project
End-of-life treatment	All network components	Panikker and Sjöblom, 2011
Transportation	All network system components	EcoInvent transportation models (from Gabi database)

Table 3.1. LCI models and sources of the life cycle stages

3.3 Description of the System

The assessed pilot system consisted of four parts:

- Base station site
- Satellite link
- Satellite Hub
- BSC

The base station site included all equipment needed to provide coverage up to 4 km^2 such as; RBS2409, antenna, PV cell, solar battery, mini-site pole (tower and antenna pole) and foundation as seen in the Figure 3.1.

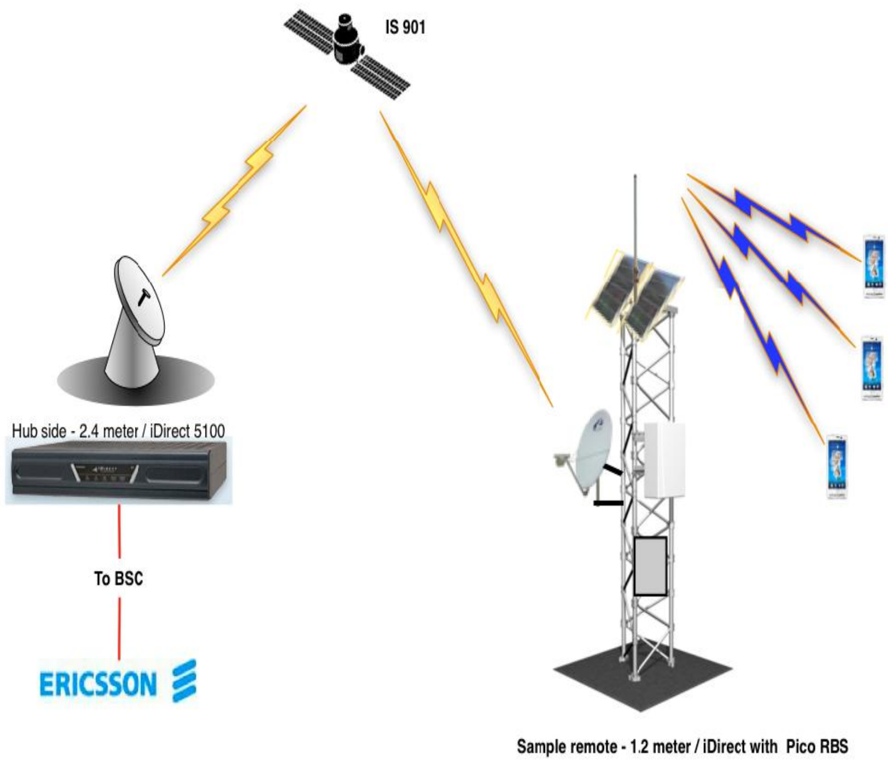

Figure 3.1. Model of the Managed Rural Coverage Site Solution

There are two Omni antennas placed at the top of a 4 meter antenna pole. They are placed on top of each other with a separation of 0.3meter. Each antenna is connected directly to respective RBS2409.

A detailed full system description has been filed as an Ericsson Internal report which is classified as “Ericsson Internal” since it contains sensitive technical and commercial information.

3.4 Description of core unit operations and LCI sub models

The life cycle model was designed as shown in figure 3.9.

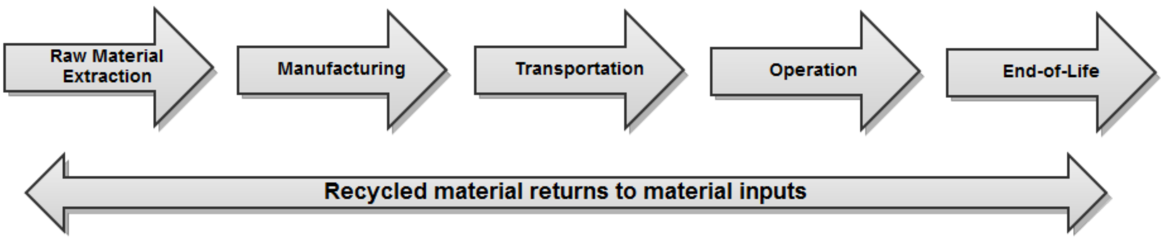

Figure 3.2. Life cycle stages of managed rural coverage site

A detailed breakdown of the included raw materials is documented in the internal Ericsson report which is classified as “Ericsson Internal” since it contains sensitive technical and commercial information.

3.4.1 Manufacturing

This part of the study accounts for the energy used in processing the raw materials into the mechanical parts for the systems. Several different sub-models were built in order to model the manufacturing stage of each sub-system. Each sub-system was modeled separately as each system represents different physical and structural properties.

3.4.2 Transportation

Because of the use of fossil fuels in transportations, this stage has an effect on global warming and also on acidification and eutrophication of lakes. For the heavy traffic areas ground level ozone is also a problem within this life cycle stage of the system.

The transportation models of the pilot system includes vehicle fuel production and burning of fuel. Manufacturing transportation was partly included in the scenario but road systems (roads, lights, etc.), service of vehicles; fuel handling and airports were not included. Transport models for airplane, truck and boat were covered within the transportation system. The database consists of different types, size, age, etc. of vehicles for each mode of transport. The railway mode of transport was not used for this study. In a more realistic scenario than the pilot one, boat transports are often used as the main mode of transport since according to the previous studies within telecommunication industry, this mode of transportation has a low impact on environment.

The same transport models and data are used for all transportation. The data refer to ton kilometer (tkm) and kilogram kilometer (kgkm) according to the used transportation mode, which means 1 ton transported 1 km and 1 kg transported 1 km respectively.

In this study the transportation model was designed with focus on the main contributors which were the truck and ship transportation. Air transports were assumed for personal transfer and also for the parts that was first transported to Kista before relocating the site to the pilot region.

3.4.3 Operation

This stage of life cycle is the stage that differs most in impact compared to traditional base station sites; since the operation does not include diesel use it operates with solar energy, and also the site is off-grid. The model also included the operator activities, part replacement and one employee’s travel once a year from Ericsson, Sweden.

The operator within Sudan travels 1000 km per year which was modeled as local transportation by car.

Some parts of the system were assumed to be replaced during the life-time of the site which was set to be 20 years. For instance battery life-time was assumed to be 5 years and batteries would need to be replaced 4 times during the assumed life-time of the site of 20 years. From the transportation point of view this was modeled as 350 tkm via truck transport within GaBi software. The annual transportation of the Ericsson employee was modeled as 10000 passenger kilometer (pkm) which corresponds to 1 passenger travels 10000 km via air travel.

Finally some parts of the site need electricity to operate and the annual electricity usage was assumed to be 1650 mega joule (MJ) within the operation model.

Based on the above assumptions the operation stage was found to give a low impact compared to traditional sites.

3.4.4 End-of-life treatment

For this stage a representative end-of-life treatment process was modeled in the software for each sub-system.

Specifically for the transportations, four different scenarios were created depending on the product and the closest recycling facility (in Dubai) was considered to be the most representative destination for the transport scenario. Since Ericsson has a take-back service in place for its products (Ericsson internal; Emma Karlsson, 2010), the electronics part of the site, i.e. base station controller, the hub, RBS2409 and the cables, will be collected at end of life and sent for processing in Dubai. This means 400 km of sea transport and 2000 km of road transport.

The antenna, the antenna pole and the tower was processed in Jeddah which is 400 km of sea transport from Sudan. The battery was processed in Morocco via 3000 km of sea transport and 300 km of road transport. The photovoltaic was processed in Dubai which means 400 km of sea and 2000 km of road transport. The satellite and foundation were not included in this stage.

4 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The main purpose of this assessment was to understand the environmental impact of the managed rural coverage solution based on the inventory analysis. This stage consisted of converting environmental load into environmental impacts through the inventory analysis. The reason for this conversion is to make the results clearly understandable thus more relevant and applicable in terms of environmental understanding. Hence this stage makes it more clear how the studied product impacts the environment.

In this part of the report the environmental impact categories corresponding to the resources and emissions are described. This assessment is based on the Institute of Environmental Sciences (CML) database problem oriented approach and the CML defined impact categories, category indicators and characterization model.

4.1 General allocation procedure

An allocation problem arises when classifying impact parameters if they are assigned to more than one impact category there should be allocation between the substance flows that effects more than one impact (Baumann and Tillman, 2004); e.g. nitrogen oxides cause both acidification, eutrophication and photo-oxidant formation and sulphur dioxide cause human health effects and acidification. If the impacts are independent there is no need for allocation to impact categories.

In this study there is no need for allocation between the impact categories because of the serial character or minor allocation problem within the impact categories.

4.2 Definition of impact categories and characterization factors

In this study, according to the previous LCA studies on mobile communication systems, the related and most important impact categories outlined below were chosen. Manufacturing stage, with 60 percent contribution to the total life cycle carbon dioxide equivalents (CO_2e) emissions of the pilot system, was the main contributor to the total impact.

The chosen categories were:

- Abiotic resource depletion
- Global warming
- Acidification of natural ecosystems (AC)
- Eutrophication
- Eco toxicity potential to freshwater, land and seawater
- Photochemical ozone creation potential
- Ozone depletion potential (ODP)

- Human toxicity potential (HTP)
- Primary energy and electricity requirements

The description of each impact category can be found in Appendix C.

5 LIFE CYCLE IMPACT ASSESSMENT RESULTS

The results are given for each life cycle and the functional unit is kg CO_2e per site per year. The results are based on CML 2001 – Dec 07 database. For each life cycle stage and each sub-system the results is shown in Appendix A.

For the pilot system in figure 5.1, the manufacturing stage represents around 60 percent of the total CO_2e emissions; the pilot system transportation represents around 23 percent, operation 13 percent and end of life treatment 4 percent. Looking into the sub-systems' contributions to the total site impact, the tower represents 32 percent and the battery 24 percent. The contributions from the life cycle stages and also from the sub-systems are shown in Appendix B.

The results for the 12 impact categories are shown for each sub-system. In order to get a better understanding and to provide a better guide for future studies on this system's environmental impact, it has been decided to focus on the sub-system rather than the life cycle stages (manufacturing, transportation, operation and end-of-life). Still impacts for the different life cycle stages can be seen in the Appendix in order to facilitate comparisons with traditional base station sites.

In figure 5.1 the annual CO_2e contribution of each sub-system is shown in absolute annual kg CO_2e as well as percentage of total. Ericsson and operator activities are related to a mature (Ericsson average) business also for this pilot system. The satellite HUB and BSC setup are shared by the initial four pilot sites. The total CO_2e is 437 kg/year which corresponds to 8.7 tons for 20 years life time.

The main contributors to the site in terms of CO_2e are tower, PV and battery. The tower is made of 600 kg of steel and the other two has the mixture of raw materials that have more environmental impacts than the other sub-systems of the site.

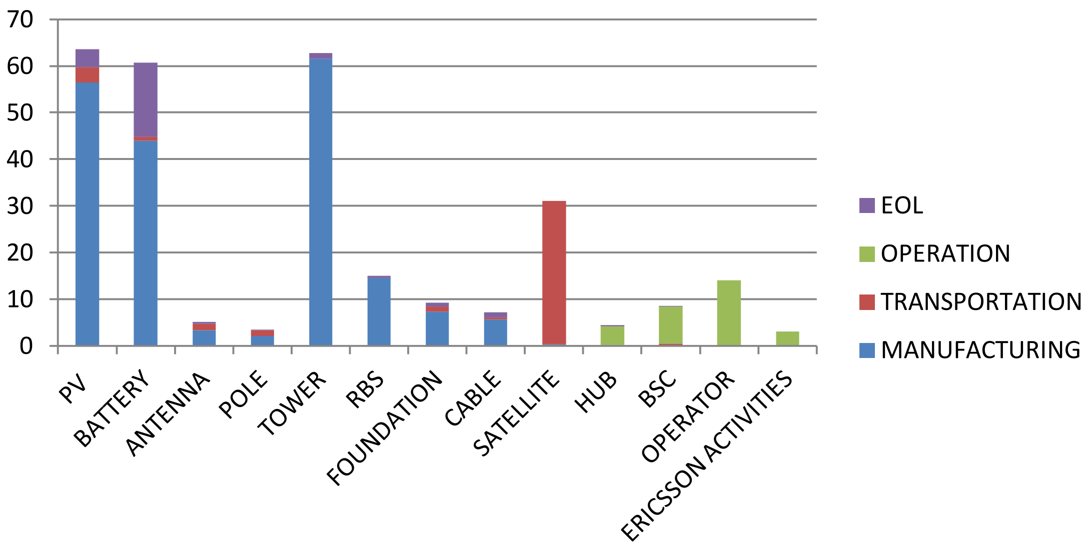

Figure 5.1. Transport from Kista of 4 sites, kg CO_2e contribution of sub-systems per year with % contribution

The difference between figure 5.1 and 5.2 is that 5.1 allocates the Hub and the BSC's impact between only 4 sites whereas 5.2allocates them between 50 sites which is more representative for a mature system. The pilot system is designed for 4 pilot sites but in reality there will for sure be for more sites in the area. Figure 5.2 results in 321 kg of CO_2e/year which corresponds to 6.4 tons of CO_2e during 20 years.

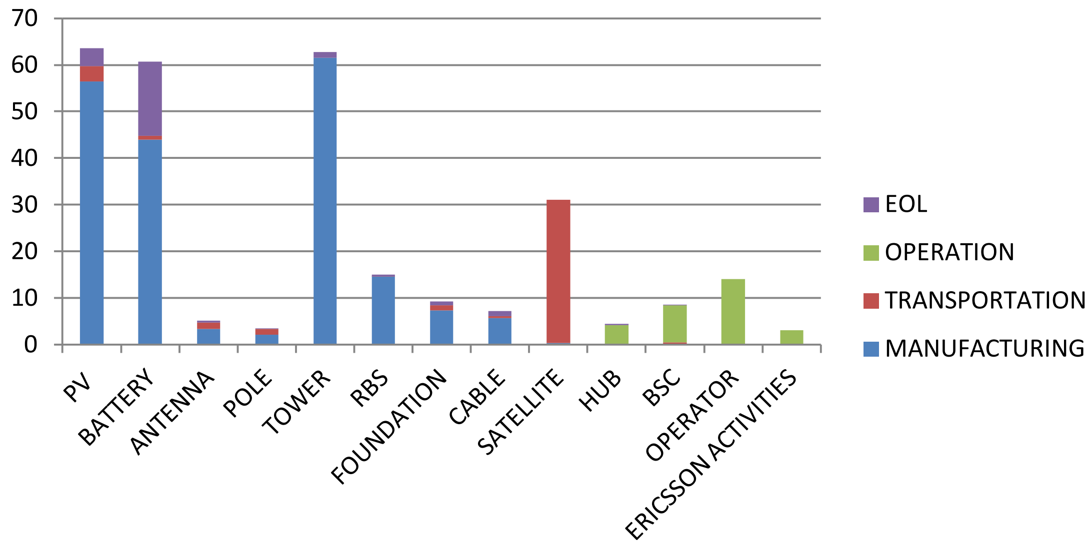

Figure 5.2. Transport from Kista of 50 sites, kg CO_2e contribution of sub-systems per year with % contribution

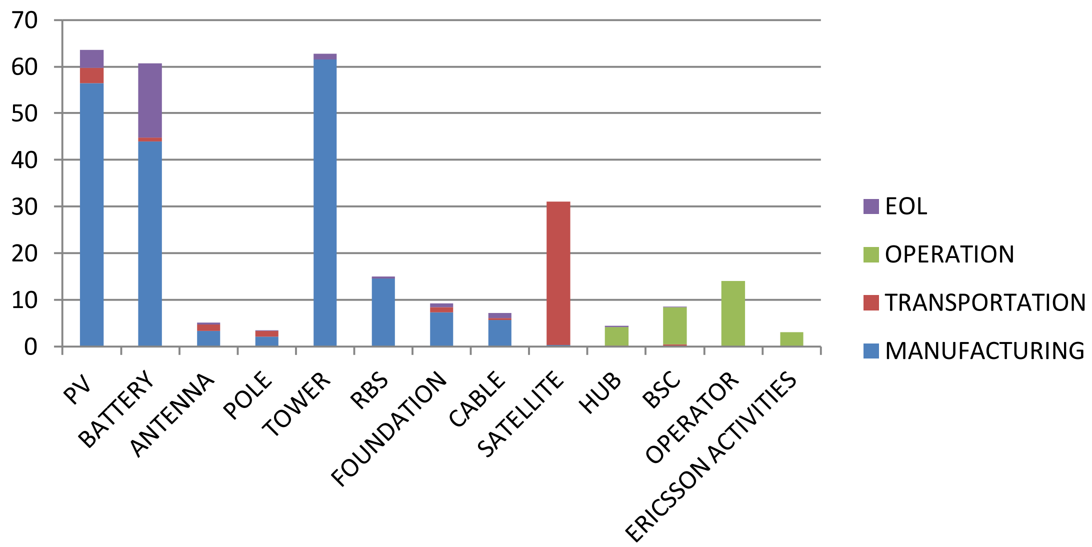

Figure 5.3. Pilot based transport, kg CO_2e contribution of sub-systems per year with % contribution

Figure 5.3 considers 50 sites when making the calculations for the Hub and BSC, and further the transport from Kista to the pilot site which is Dungunab, Sudan is excluded. Thus this last figure can be thought as the most representative for a real scenario for a mature system and gives a better guide for future studies, since tower foundation transport has changed to a more local transport scenario. The results for CO_2e are 286 kg/year and for the life time (20 years) it corresponds to 5.7 tons of CO_2e.

In figure 5.4 the LCA results for all the studied impact categories of the MRC solution are shown and the relative distribution between each sub-system is indicated for the chosen environmental impact categories.

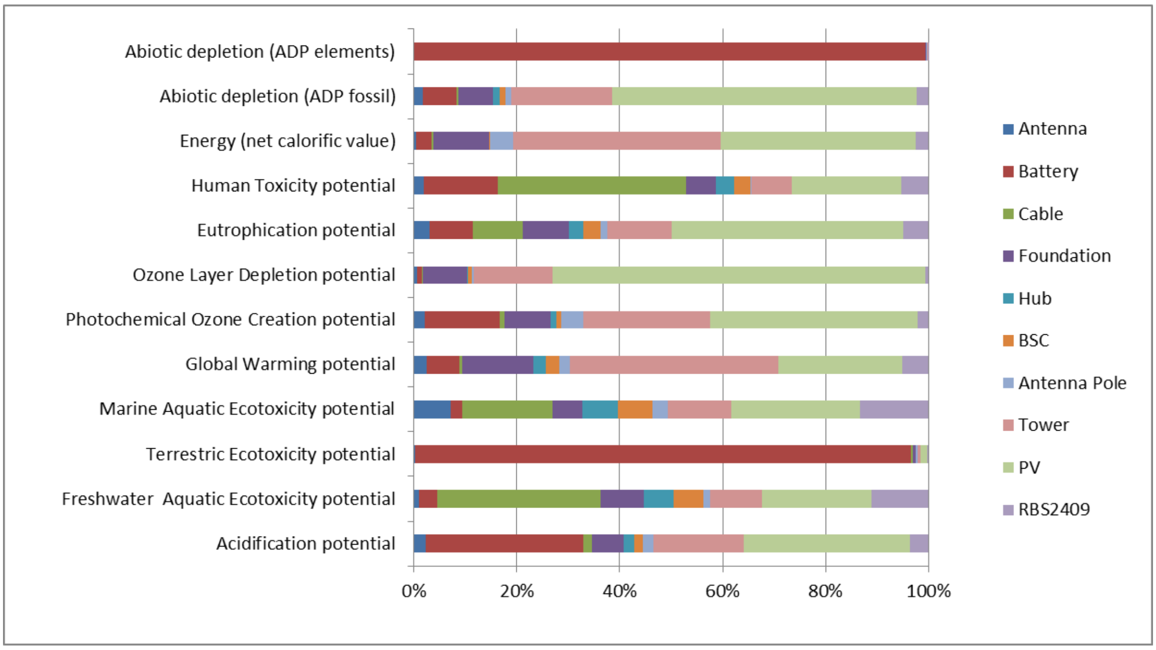

Figure 5.4. Relative environmental impacts for the different sub-systems of the site

1 Material resource depletion is defined to only happen when materials are lost at end-of-life treatment (EoLT). All materials is allocated to the end-of-life treatment stage even if it is coming from manufacturing waste.

2 For global warming the largest impact in absolute and relative terms comes from energy consumption. So as it is seen in the graph manufacturing stage has the most contribution since within the whole life cycle of the site energy consumption is mostly coming from manufacturing. And also fossil fuels from transportation are the second most important contributors. Seven out of twelve impacts categories are proportional to the energy consumption

3 Human and eco-system toxicity impacts are mostly coming from manufacturing and end-of-life stage. In end-of-life (EoL) stage an average scenario has been used.

4 The stratospheric ozone depletion emissions come mainly from the PV manufacturing.

5 In other impact categories the results to a large extent similar to GWP and fossil fuel incineration.

In figure 5.5 CO_2e results for subscribers per pilot system and year is shown as a function of number of subscribers per site. All results are for one pilot system as defined in the functional unit section. This is a very conservative case compared to an assumed typical system deployment since the sub-systems like the hub and BSC can be used for around 100 sites.

In the results below the overhead results (Satellite hub, BSC, etc.) has been allocated to just four pilot sites instead of the maximum 100 sites.

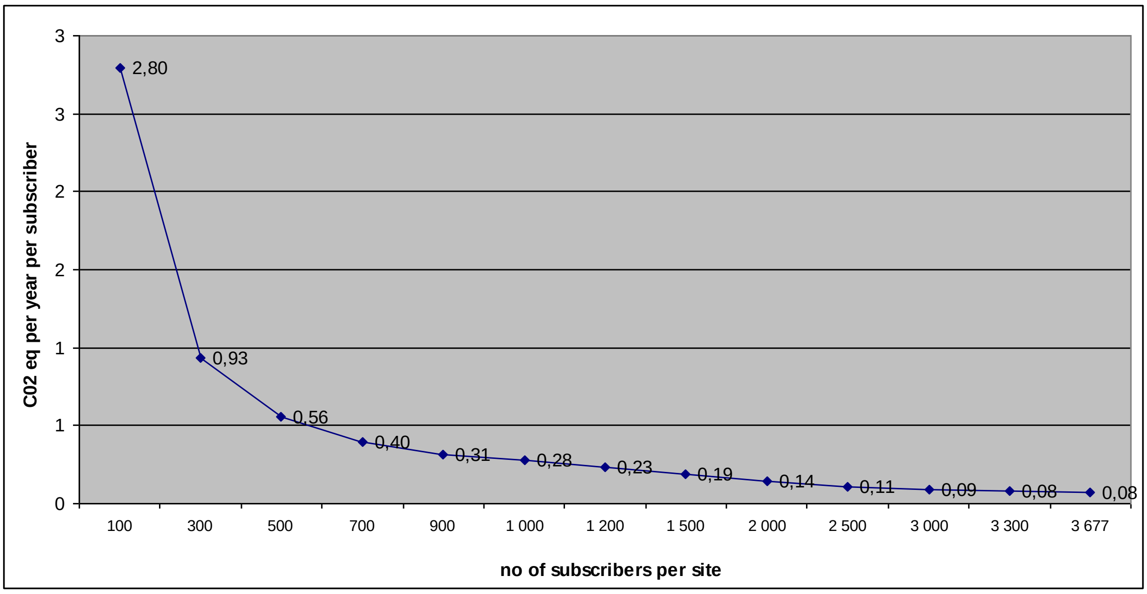

Figure 5.5. CO_2e per year and per subscriber and per site

6 LIFE CYCLE INTERPRETATION

6.1 Comparison of the sub-systems

The managed rural coverage solution consists of several sub-systems that contribute to the total environmental impact of the system. The contribution of each sub-system of the site was studied to find their impacts on environment. The results may be used to mitigate the site's total environmental impact.

Net calorific energy consumption variations determine the impact potentials and shows similar environmental profiles as the impact results. The reason for this is that many impact categories mainly depend on electricity consumption. The main electricity consumers are large contributors to these impact categories as well. Toxicity impacts can be different since they depend more on raw material processing and production processes than the other impact potentials.

Manufacturing of the tower is the most important contributor to all impact potentials both through high electricity requirements but also through production process emissions.

The second most important contributors are the manufacturing of PV and battery sub-systems.

Looking at the combined impact from all life cycle stages PV, tower, battery and antenna are the most important contributors to the main impact potentials. When looking into each category the most important contributors are as follows:

- Abiotic depletion (elements): Battery
- Abiotic depletion (fossil): PV followed by Tower
- Energy: Tower
- Human toxicity: Cable
- Eutrophication: PV
- Ozone depletion: PV
- Photochemical ozone creation: PV
- Global warming: Tower
- Marine aquatic eco toxicity: PV
- Terrestric eco toxicity: Battery
- Freshwater aquatic eco toxicity: Cable
- Acidification: PV and Battery

The importance of the different life cycles stages differs between the system components. The tower, PV and the battery cause more impact in the production than in the other stages. In the transportation stage foundation and tower has the highest contribution. However, the selected scenario is only applicable to the pilot scenario as foundations are normally not transported over such distances. In end-of-life stage battery, PV, tower, and cable mixture gives the most significant contributions respectively. Total impact results for each sub-system can be seen in Appendix A.

6.2 Sensitivity analysis

In LCA studies, the most important method to find out how uncertainties have affected the system and in which ways is the sensitivity analysis. In each assessment there are some data gaps and some data that has not reach the intended quality. In sensitivity analysis these data should be checked and recalculated according to the general procedure. In this way all the other input parameters should be constant to have the results over the whole system just for the studied parameter.

6.2.1 Results of the sensitivity analysis for CO_2 equivalents

6.2.1.1 Transportation

Transportation of the pilot system emerged from collection of the sub-systems on site in Kista, Stockholm first. The reason for that was that Ericsson had decided to present four pilot sites to the employees in Sweden before using it in Sudan. As this study made an assessment of the pilot set-up this path of transportation was included in the assessment. In order to help further studies, a sensitivity analysis of transportation for a more realistic scenario was done and the differences in contribution of each transportation can be seen in the below graphs. In the pilot system case the contribution of the transportation is 26 percent but when the transportation to Kista is excluded the contribution of transportation is 12 percent. Thus it can be said that almost half of the impact from transportation can be decreased by the recalculation of this transport. The comparison can be seen in the figure 6.1 and 6.2.

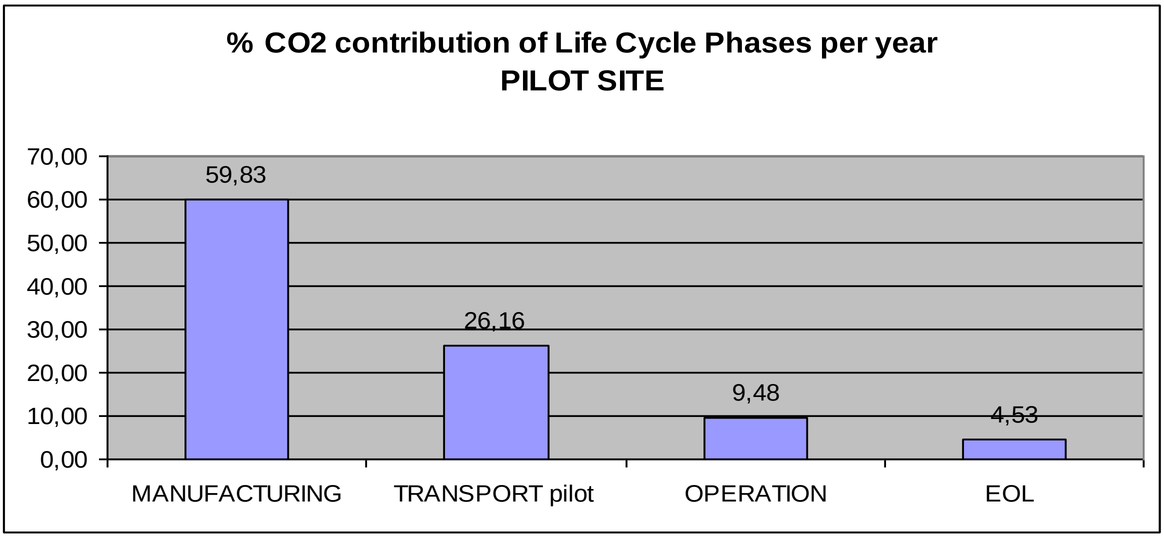

Figure 6.1. % CO_2e contribution of life cycle stages per year for the Pilot system

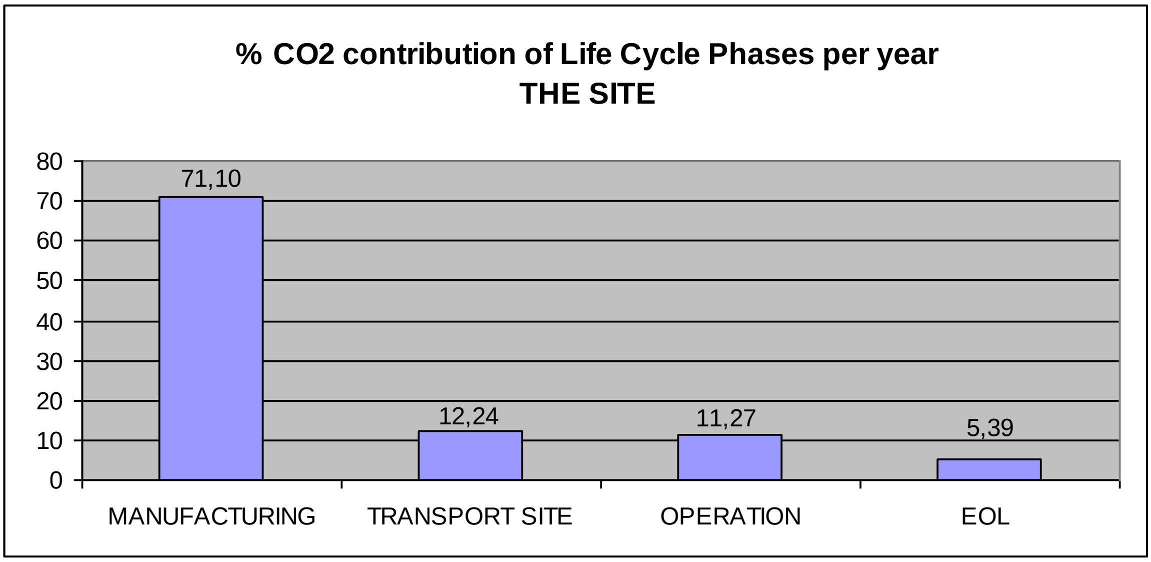

Figure 6.2. % CO_2*e contribution of life cycle stages per year for the normal system*

6.2.1.2 <u>The satellite</u>

The CO_2e contribution of the satellite to the whole site is about 10 percent. In this calculation there are many data gaps and also the data quality is too low. In this sensitivity analysis it is better to investigate the results excluding the satellite results. The results with and without satellite can be seen in the below graphs by comparing figure 6.3 and 6.4.

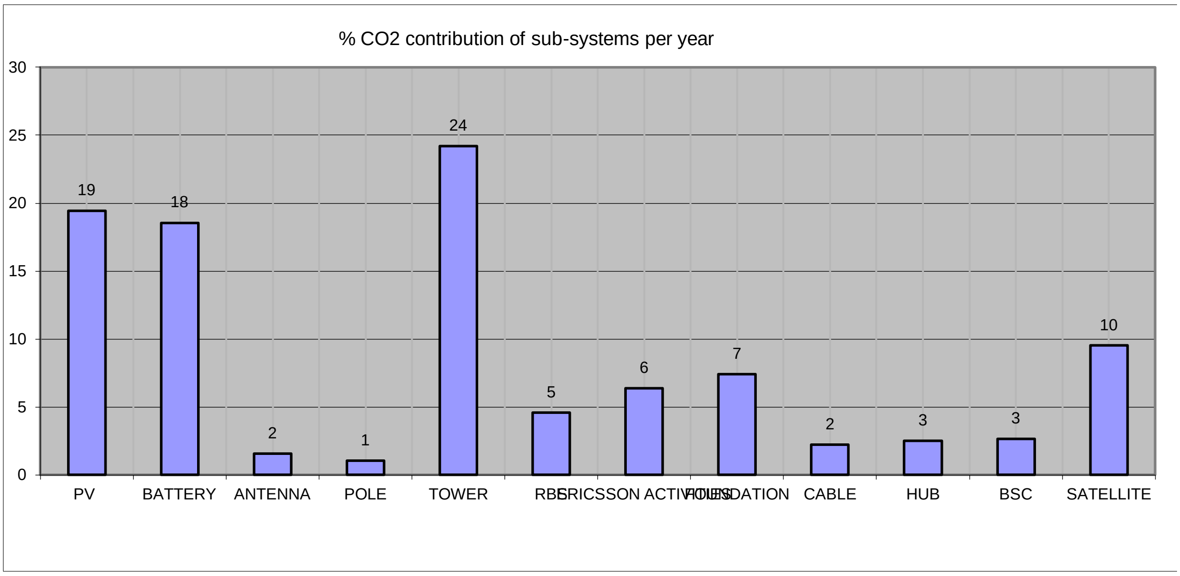

Figure 6.3.% CO_2*e contribution of sub-systems per year for the Pilot system*

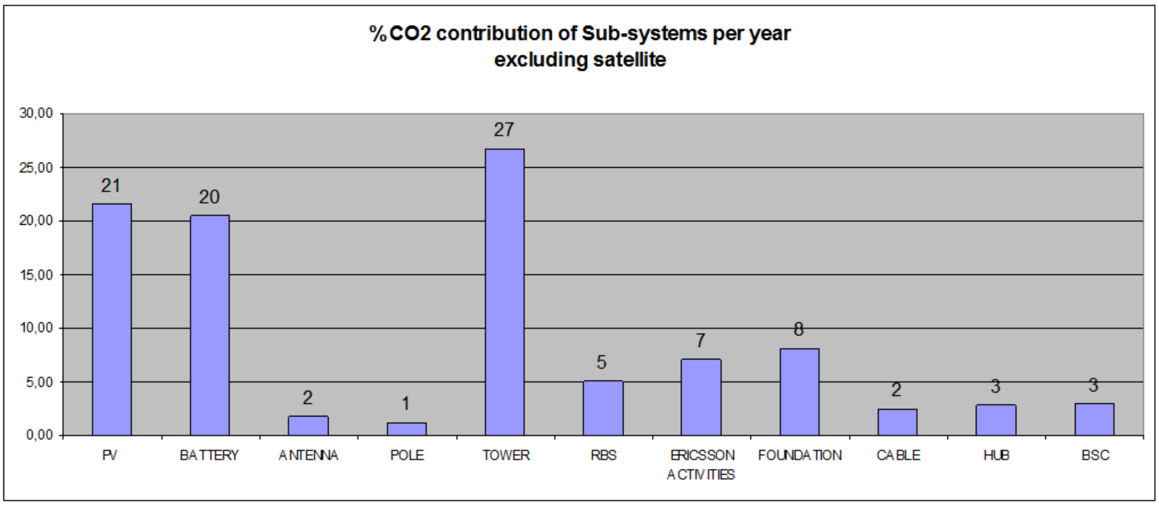

Figure 6.4. % CO_2*e contribution of sub-systems except satellite per year for the Pilot system*

6.2.1.3 Total site number

This sensitivity analysis is done for 50 sites instead of 4 as in the pilot scenario. For a more state-of-the-art BSC much higher numbers apply. In order to see the impact of these figures, the sensitivity analysis also investigates how results changes if 200 sites are taken into account and the results for CO_2e emissions can be seen in the below graphs. In this calculation the hub and the base station controller data have been changed since the number of sites impacts the share of those sub-systems that is to be considered. Also the satellite impact is allocated based on number of sites but that has been neglected in this sensitivity analysis. The results can be compared by looking at figure 6.5 and 6.6. The results differ only slightly since the hub and BSC give low impacts to the whole site. Still it is clear that the impact of the two sub-systems has been decreased when increasing the number of sites.

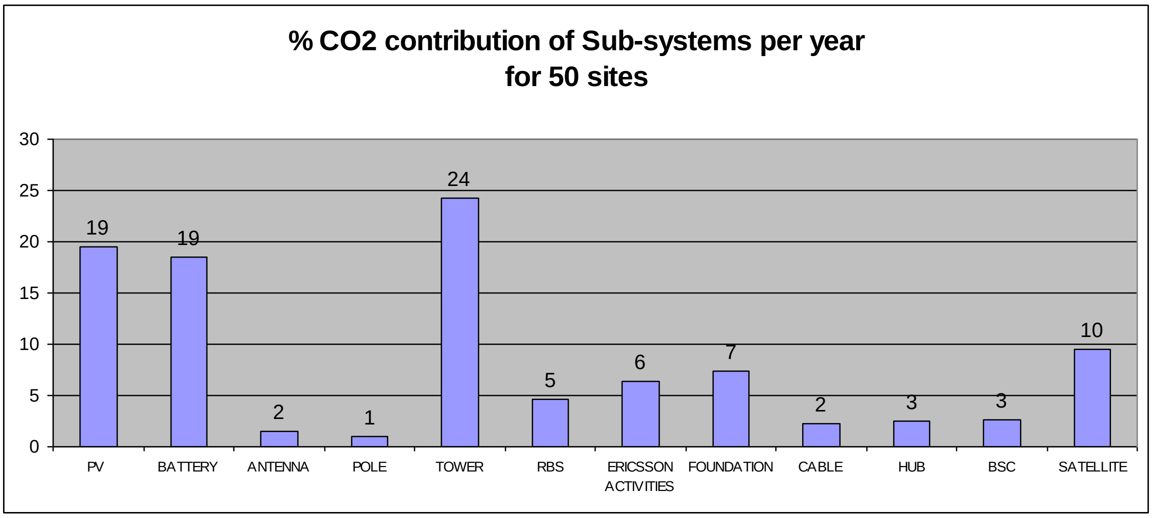

Figure 6.5. % CO_2*e contribution of sub-systems per year for 50 sites*

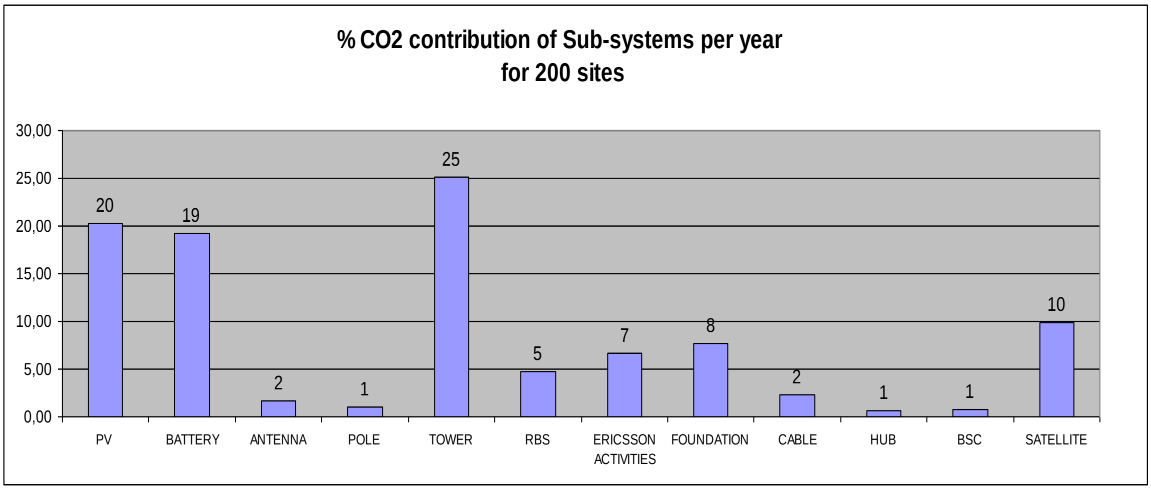

Figure 6.6. % CO_2e contribution of sub-systems per year for 200 sites

6.2.1.4 Photovoltaic

Photovoltaic (PV) is one of the major contributors to the whole site in kg CO_2e values. In order to see how important the PV model is to the overall result, it is studied how the results are affected when PV weight doubled. The contribution of tower and battery is still high but not higher than PV which is increased from 19 percent as it is seen in figure 6.3 to 33 percent. The results can be seen in the figure 6.7.

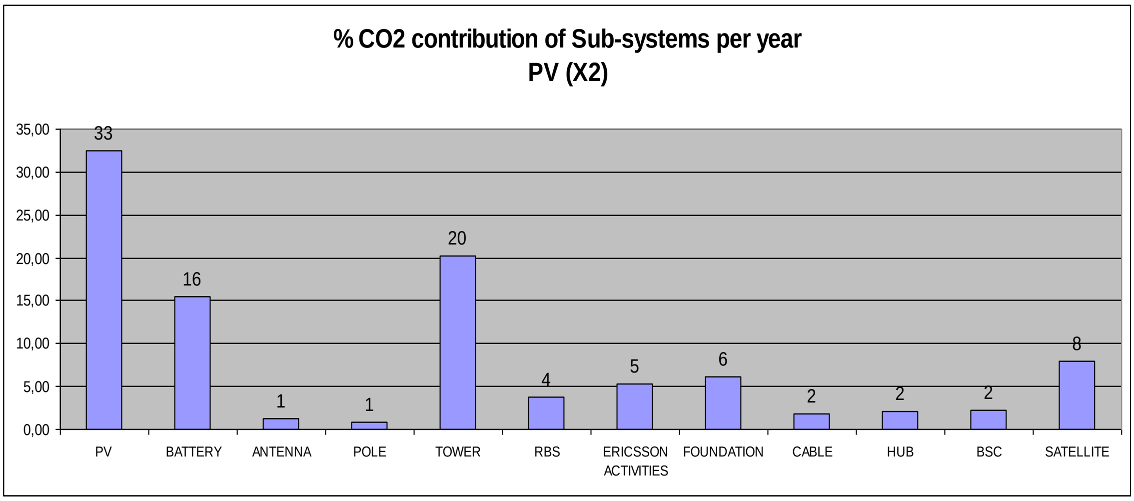

Figure 6.7. % CO_2e contribution of sub-systems per year when PV double weighted

6.2.1.5 Battery

Battery is another major contributor in CO_2e values. When the weight of the battery is doubled, it becomes the most important contributor. The tower and PV together have still higher contribution but battery's contribution has increased from 19 percent to 31 percent. The results can be seen in the figure 5.8.

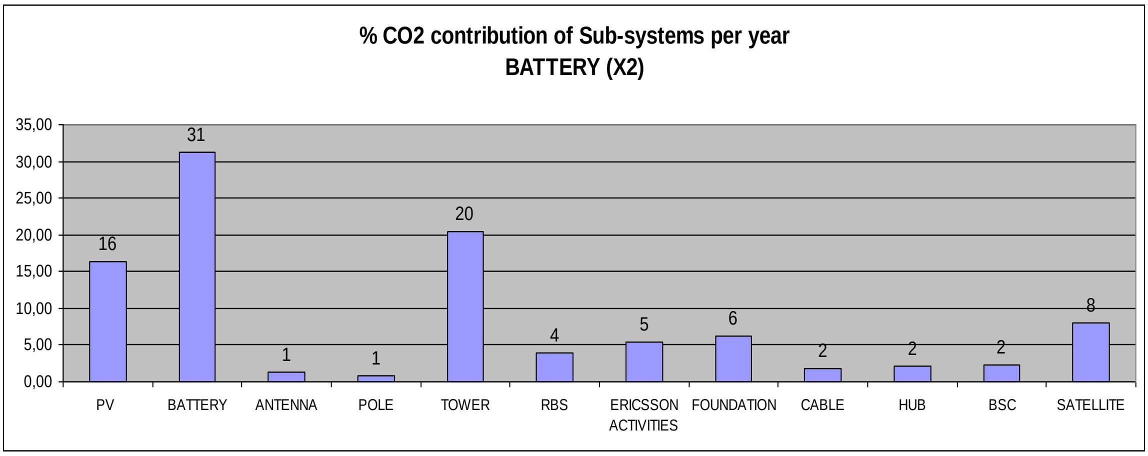

Figure 6.8. % CO_2*e contribution of sub-systems per year when battery double weighted*

6.2.1.6 Antenna tower

The antenna tower is the most important contributor to CO_2e since its material is steel and weighs around 600 kg. So when the weight of it is assumed to be four times larger in weight than in the pilot scenario, the whole system contribution will change in large amounts and the tower contribution increases from 24 percent to 56 percent. The results can be seen in the figure 6.9.

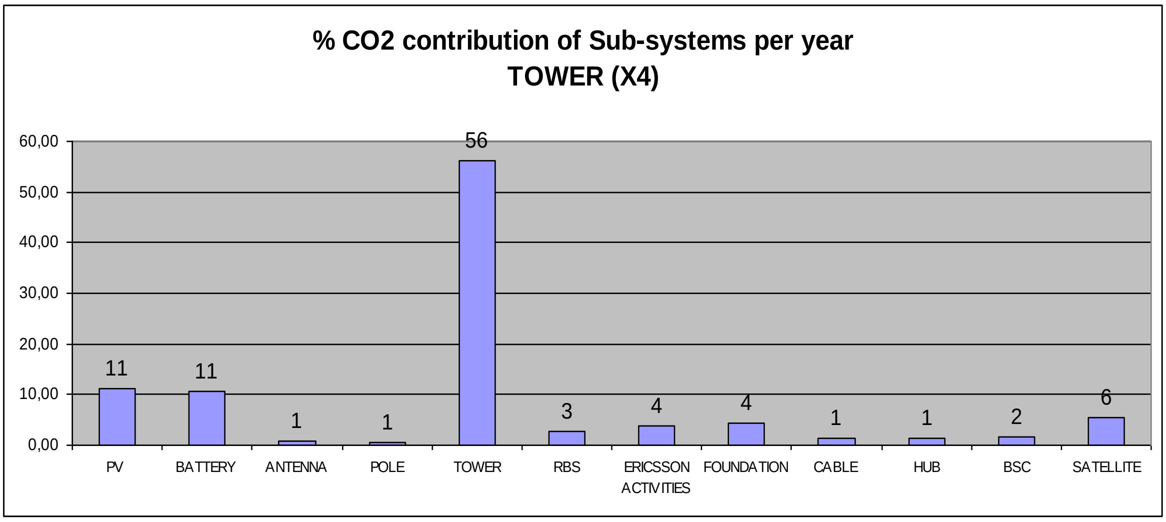

Figure 6.9. % CO_2*e contribution of sub-systems per year when tower four times weighted*

7 DISCUSSION

Like in all LCA studies, this study includes many sources of uncertainties and variations that create variations in the results. The reasons behind this are that the site has many complex sub-systems and the collected data involves many uncertainties. There are three different uncertainties associated with this study. These are parameter uncertainty (within input-data), scenario uncertainty (related to choices) and model uncertainty (related to insufficient knowledge of the studied system). It is worthy to keep in mind that the results of an LCA study should be regarded as an estimation that includes information on relative impacts. In addition, it should act as a comparison parameter for other system life cycles and/or different system components.

The assessed site is designed for off-grid rural regions that do not have access to mobile communication. It is known that there are around 1 billion people who are affected by this issue. Therefore, in the light of the results, impact per subscriber data should be used as a key parameter in order to compare the site with traditional sites. It is important to point out that this solution differs greatly from traditionally used systems. Even though there is a great difference between the two technologies, it was reported that the carbon footprint per average mobile subscription was 30 kg CO_2e (Malmodin et.al, 2011). The difference in energy consumption is caused by the decreased consumption of energy in operational stage of the proposed system. This shows that the operational stage of the solution can be considered as a success for its intended applications. It is important to mention that the assessed base station's carbon footprint per average mobile subscription is less than 10 kg CO_2e, which is nearly one third of a traditional site (Malmodin et.al, 2011). For the intended applications of this solutions the results seems encouraging but it should be noted that this kind of solutions could not in general replace traditional macro base stations due to limitations in capabilities.

In this study, electronics part like RBS2409, BSC, hub and the cable mixture have been modeled based on previous studies and the data has been scaled according to the weights of each product. It is assumed that this will not lead to a large difference from the actual system, because the electronic parts of each stage do not have a considerable impact on the total site results.

Considering the satellite data, which could have been more accurate, the results might have been different in terms of total impacts. It is assumed that if the end of life stage of satellite had been added to the results, it would also change the result and could decrease the total impact of the satellite if it would be recycled.

The manufacturing stage in general has the highest impact. In some studies the impact from Information and Communication Technology (ICT) and PV is too high due to use of old data and could be shown to be lower if more up-to-date data is used. However, in this study the main impacts come from concrete and steel and therefore no such reduction in emission levels could be expected.

The transportation stage results were evaluated for the pilot system and sensitivity analysis was done according to more realistic scenarios. This showed that the results for the realistic scenario was decreased compared to the pilot scenario.

It can be expected that in a commercial roll-out of the solution, the impact results would decrease accordingly, especially, when considering that the total number of sites would increase from 50. Therefore, this study provides a brief summary of how impacts would be decreased in the future in a commercial set-up.

8 CONCLUSIONS

This LCA study of a newly designed solar powered base station includes sub-systems and life cycle stages that affect the environmental impacts. The analysis of the impact results is mainly focused on the global warming potential. Thus, the most important results are;

- Annual CO_2e emissions compared with average mobile subscriptions are very low. In general the GSM network average emission is about 30 kg per subscriber and year (Malmodin et.al, 2011). In this study, the CO_2e emissions are lower than 10 kg per subscriber and year. It could be decreased in near future with the use of raw materials that have less environmental impact and also with using different structural design. However it is important to keep in mind that traditional macro base station sites differ in capabilities compared to the assessed coverage sites and that the figures are not directly comparable. Still the results are encouraging for the intended applications which need to be based on low cost RBSs with low power consumption to enable the use of solar based power supply.
- The manufacturing stage is the most important life cycle stage for several impact categories environmental impact potentials. To be more precise, main contributors to these impact categories are manufacturing of the steel tower and PV cells.
- The site's energy consumption is not the most important individual parameter for the results of the LCA studies as in traditional sites. The reason is that it uses PV and battery instead of diesel and also that it is off-grid. Therefore, the energy consumption is not the most important parameter in this study.
- Electricity production is one of the most important underlying processes, since around 70 percent of all primary energy associated with the mobile networks is used to produce the electricity used for manufacturing of sub-systems and (slightly) for office usage (Ericsson activities). The remaining part of primary energy is used for fuels in raw materials and transportation stage.

8.1 Future improvements and use of the model

Future improvements from LCA point of view would be;

- To update the satellite LCI model: A change in this model will not change the results but marginally as the satellite gives only a low contribution to the overall results. Still the model could be updated in a more detailed way with up-to-date data.
- To update transportation and operation scenario: The operation and transportation scenarios were created based on assumptions. More detailed investigation could be performed based on a commercial set-up. To update these scenarios accordingly.
- To detail the end-of-life stage processes: This would be better for the results in order to show the positive environmental effects of the sub-systems.

- The results for human eco toxicity (dominated by the antenna pole) and energy (antenna) are not in accordance with expectations and should be further studied.

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10 APPENDIX

APPENDIX A: LCIA Results for each sub-system with their life-cycle stages

ANTENNA					
Impact category	**Manufacturing per life-time**	**Transportation per life-time**	**End-of-life per life-time**	**Total per siteyear**	**Unit**
Acidification potential	0,34	0,21	0,02	0,03	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	2,88	0,11	0,52	0,18	kg DCB eq.
Terrestric Ecotoxicity potential	0,16	0,03	0,14	0,02	kg DCB eq.
Marine Aquatic Ecotoxicity potential	109000,00	985,00	917,00	5545,10	kg DCB eq.
Global Warming potential	63,70	34,32	7,49	5,28	kg CO_2e
Photochemical Ozone Creation potential	0,03	0,02	0,00	0,00	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,04	0,03	0,10	0,01	kg PO_4 eq.
Human Toxicity potential	17,60	1,33	0,76	0,98	kg DCB eq.
Energy (net calorific value)	496,00	26,10	41,90	28,20	MJ
Abiotic depletion (ADP fossil)	0,32	0,36	0,19	0,04	kg Sb eq.
Abiotic depletion (ADP elements)	0,02	0,00	0,00	0,00	kg Sb eq.

BATTERY					
Impact category	**Manufacturing per life-time**	**Transportation per life-time**	**End-of-life per life-time**	**Total per siteyear**	**Unit**
Acidification potential	4,06	0,03	5,51	0,48	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	1,33	0,02	14,40	0,79	kg DCB eq.
Terrestric Ecotoxicity potential	0,70	0,01	292,00	14,64	kg DCB eq.
Marine Aquatic Ecotoxicity potential	37000,00	141,00	15700,00	2642,05	kg DCB eq.
Global Warming potential	246,26	5,09	145,36	19,84	kg CO_2e
Photochemical Ozone Creation potential	0,24	0,00	0,30	0,03	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,08	0,01	0,45	0,03	kg PO_4 eq.
Human Toxicity potential	56,40	0,20	123,00	8,98	kg DCB eq.
Energy (net calorific value)	4514,00	3463,77	11,76	399,48	MJ
Abiotic depletion (ADP fossil)	1,51	0,05	2,41	0,20	kg Sb eq.
Abiotic depletion (ADP elements)	0,49	0,00	32,60	1,65	kg Sb eq.

CABLE					
Impact category	**Manufacturing per life-time**	**Transportation per life-time**	**End-of-life per life-time**	**Total per siteyear**	**Unit**
Acidification potential	0,39	0,01	0,00	0,02	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	130,00	0,01	0,00	6,50	kg DCB eq.
Terrestric Ecotoxicity potential	1,33	0,00	0,00	0,07	kg DCB eq.
Marine Aquatic Ecotoxicity potential	269000,00	81,80	3,91	13454,29	kg DCB eq.
Global Warming potential	15,58	1,72	0,02	0,87	kg CO_2e
Photochemical Ozone Creation potential	0,03	0,00	0,00	0,00	kg C_2H_4 eq.

Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,56	0,00	0,00	0,03	kg PO_4 eq.
Human Toxicity potential	384,00	0,08	0,01	19,20	kg DCB eq.
Energy (net calorific value)	445,00	65,54	0,24	25,54	MJ
Abiotic depletion (ADP fossil)	0,11	0,03	0,00	0,01	kg Sb eq.
Abiotic depletion (ADP elements)	0,02	0,00	0,00	0,00	kg Sb eq.

FOUNDATION

Impact category	Manufacturing per life-time	Transportation per life-time	End-of-life per life-time	Total per siteyear	Unit
Acidification potential	0,04	1,51	0,02	0,08	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	0,03	34,50	0,01	1,73	kg DCB eq.
Terrestric Ecotoxicity potential	0,27	1,25	0,06	0,08	kg DCB eq.
Marine Aquatic Ecotoxicity potential	726,00	89600,00	389,00	4535,75	kg DCB eq.
Global Warming potential	106,04	443,41	44,70	29,71	kg CO_2e
Photochemical Ozone Creation potential	0,00	0,24	0,01	0,01	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,00	0,44	0,08	0,03	kg PO_4 eq.
Human Toxicity potential	0,29	60,00	0,11	3,02	kg DCB eq.
Energy (net calorific value)	6694,20	13350,00	99,70	1007,20	MJ
Abiotic depletion (ADP fossil)	0,23	3,08	0,02	0,17	kg Sb eq.
Abiotic depletion (ADP elements)	0,00	0,00	0,00	0,00	kg Sb eq.

HUB

Impact category	Manufacturing per life-time	Transportation per life-time	End-of-life per life-time	Total per siteyear	Unit
Acidification potential	0,47	0,01	0,00	0,02	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	24,00	0,00	0,02	1,20	kg DCB eq.
Terrestric Ecotoxicity potential	0,18	0,00	0,00	0,01	kg DCB eq.
Marine Aquatic Ecotoxicity potential	105000,00	56,00	66,40	5256,12	kg DCB eq.
Global Warming potential	102,52	1,82	0,60	5,25	kg CO_2e
Photochemical Ozone Creation potential	0,03	0,00	0,00	0,00	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,16	0,00	0,00	0,01	kg PO_4 eq.
Human Toxicity potential	37,50	0,08	0,09	1,88	kg DCB eq.
Energy (net calorific value)	184,09	0,06	29,67	10,69	MJ
Abiotic depletion (ADP fossil)	0,60	0,02	0,01	0,03	kg Sb eq.
Abiotic depletion (ADP elements)	0,00	0,00	0,00	0,00	kg Sb eq.

ANTENNA POLE

Impact category	Manufacturing per life-time	Transportation per life-time	End-of-life per life-time	Total per siteyear	Unit
Acidification potential	0,30	0,20	0,01	0,03	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	4,79	0,07	-0,03	0,24	kg DCB eq.
Terrestric Ecotoxicity potential	0,80	0,02	0,01	0,04	kg DCB eq.
Marine Aquatic Ecotoxicity potential	43610,00	503,00	125,00	2211,90	kg DCB eq.
Global Warming potential	64,45	25,71	2,67	4,64	kg CO_2e

Photochemical Ozone Creation potential	0,10	0,01	0,00	0,01	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,04	0,04	0,00	0,00	kg PO_4 eq.
Human Toxicity potential	0,922	0,90	0,08	0,09	kg DCB eq.
Energy (net calorific value)	4535,00	0,63	3726,58	413,11	MJ
Abiotic depletion (ADP fossil)	0,37	0,18	-0,05	0,02	kg Sb eq.
Abiotic depletion (ADP elements)	0,10	0,00	0,00	0,00	kg Sb eq.

TOWER

Impact category	Manufacturing per life-time	Transportation per life-time	End-of-life per life-time	Total per siteyear	Unit
Acidification potential	3,08	1,18	0,07	0,22	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	2,21	26,90	12,90	2,10	kg DCB eq.
Terrestric Ecotoxicity potential	0,59	0,98	0,08	0,08	kg DCB eq.
Marine Aquatic Ecotoxicity potential	117000,00	70100,00	3560,00	9533,00	kg DCB eq.
Global Warming potential	1323,60	347,10	54,83	86,28	kg CO_2e
Photochemical Ozone Creation potential	0,50	0,19	0,02	0,04	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,28	0,34	0,10	0,04	kg PO_4 eq.
Human Toxicity potential	35,20	46,90	0,65	4,14	kg DCB eq.
Energy (net calorific value)	59180,00	10470,00	5224,40	3743,72	MJ
Abiotic depletion (ADP fossil)	7,12	2,43	0,20	0,49	kg Sb eq.
Abiotic depletion (ADP elements)	0,05	0,00	0,00	0,00	kg Sb eq.

PV

Impact category	Manufacturing per life-time	Transportation per life-time	End-of-life per life-time	Total per siteyear	Unit
Acidification potential	1,40	6,56	0,01	0,40	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	1,70	84,60	0,18	4,35	kg DCB eq.
Terrestric Ecotoxicity potential	0,19	4,05	0,01	0,21	kg DCB eq.
Marine Aquatic Ecotoxicity potential	94400,00	291000,00	228,00	19315,60	kg DCB eq.
Global Warming potential	382,60	618,26	8,58	51,76	kg CO_2e
Photochemical Ozone Creation potential	0,17	0,98	0,00	0,06	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,09	2,46	0,01	0,13	kg PO_4 eq..
Human Toxicity potential	21,40	202,00	0,11	11,19	kg DCB eq.
Energy (net calorific value)	70300,00	138,16	0,46	3522,00	MJ
Abiotic depletion (ADP fossil)	1,48	27,50	0,04	1,46	kg Sb eq.
Abiotic depletion (ADP elements)	0,01	0,00	0,00	0,00	kg Sb eq.

RBS2409

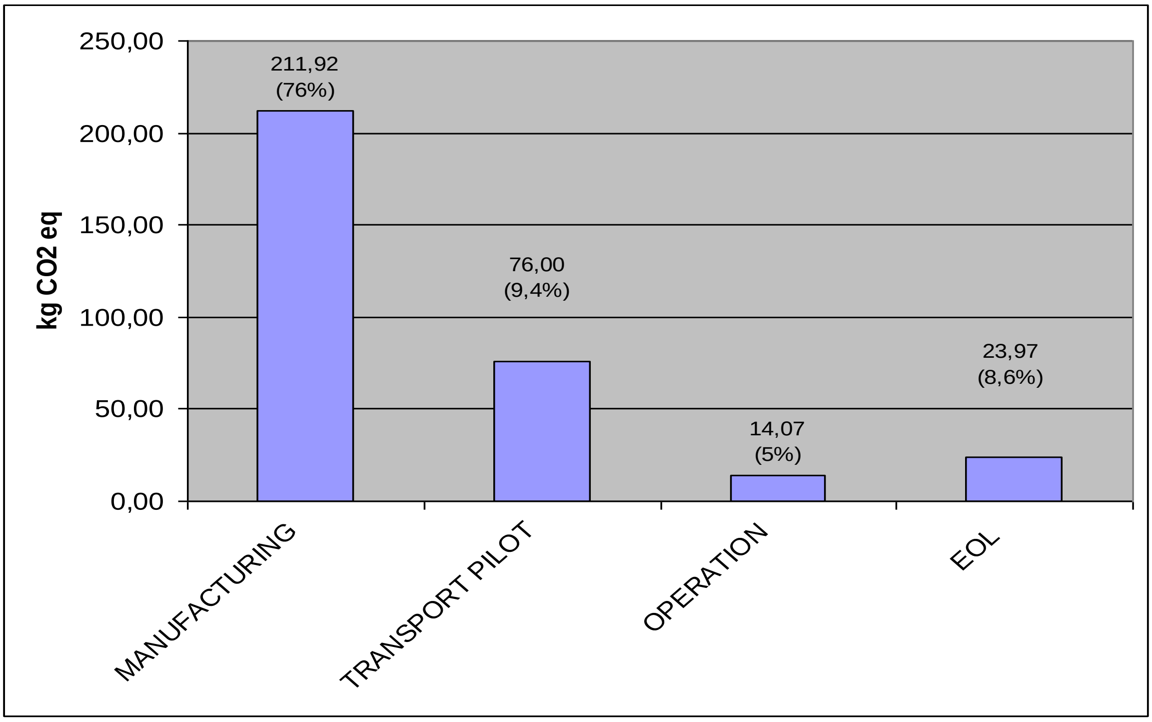
Impact category	Manufacturing per life-time	Transportation per life-time	End-of-life per life-time	Total per siteyear	Unit
Acidification potential	0,44	0,00	0,00	0,04	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	22,70	0,00	0,09	2,27	kg DCB eq.
Terrestric Ecotoxicity potential	0,18	0,00	0,01	0,02	kg DCB eq.
Marine Aquatic Ecotoxicity potential	102000,00	4,66	321,00	10216,28	kg DCB eq.
Global Warming potential	105,40	0,15	2,85	10,69	kg CO_2e

Photochemical Ozone Creation potential	0,03	0,00	0,00	0,00	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,00	0,00	0,00	kg R11 eq.
Eutrophication potential	0,14	0,00	0,00	0,01	kg PO_4 eq..
Human Toxicity potential	27,10	0,01	0,49	2,73	kg DCB eq.
Energy (net calorific value)	2264,00	3,70	141,20	233,65	MJ
Abiotic depletion (ADP fossil)	0,54	0,00	0,03	0,06	kg Sb eq.
Abiotic depletion (ADP elements)	0,00	0,00	0,00	0,00	kg Sb eq.

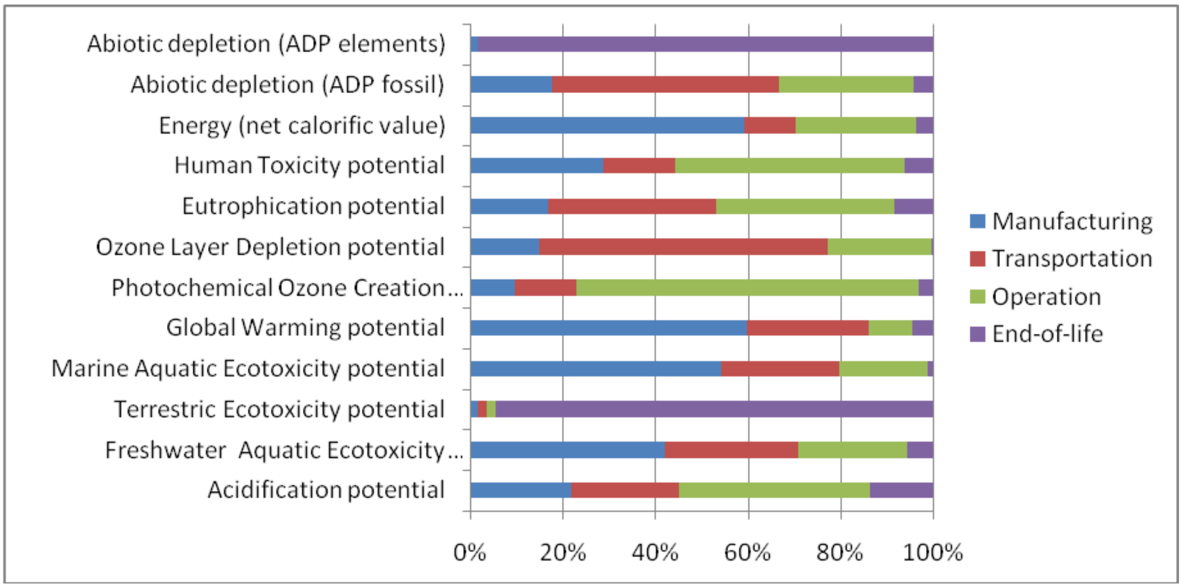
SATELLITE					
Impact category	**Manufacturing per life-time**	**Transportation per life-time**	**End-of-life per life-time**	**Total per satelliteyear**	**Unit**
Acidification potential	178,70	4160,00	?	0,87	kg SO_2 eq.
Freshwater Aquatic Ecotoxicity potential	1759,00	2990,00	?	0,95	kg DCB eq.
Terrestric Ecotoxicity potential	73,70	2360,00	?	0,49	kg DCB eq.
Marine Aquatic Ecotoxicity potential	28210000,00	23100000,00	?	10262,00	kg DCB eq.
Global Warming potential	56500,00	6190000,00	?	1249,30	kg CO_2e
Photochemical Ozone Creation potential	23,00	612,00	?	0,13	kg C_2H_4 eq.
Ozone Layer Depletion potential	0,00	0,02	?	0,00	kg R11 eq.
Eutrophication potential	20,67	462,00	?	0,10	kg PO_4 eq.
Human Toxicity potential	6050,00	16200,00	?	4,45	kg DCB eq.
Energy (net calorific value)	1012900,00	114870000,00	?	23176,58	MJ
Abiotic depletion (ADP fossil)	364,00	53500,00	?	10,77	kg Sb eq.
Abiotic depletion (ADP elements)	2,80	1,59	?	0,00	kg Sb eq.

APPENDIX B: Life cycle stage distributions in CO_2e and LCIA results of life cycle stages for the chosen impact categories

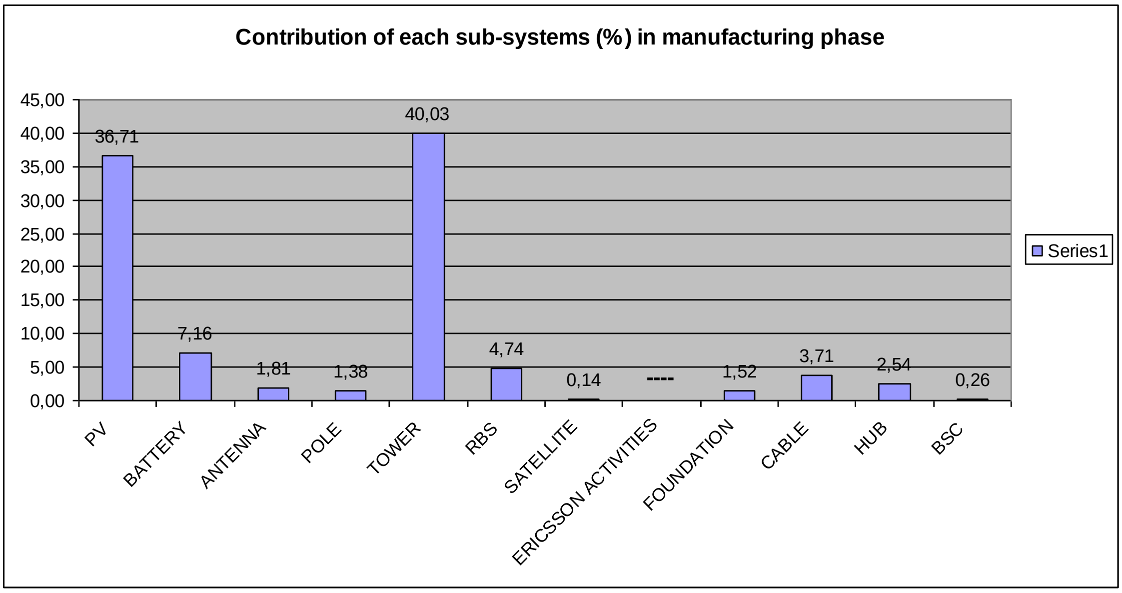
In the below figure kg CO_2e and % contribution of life cycle stages per year are shown.

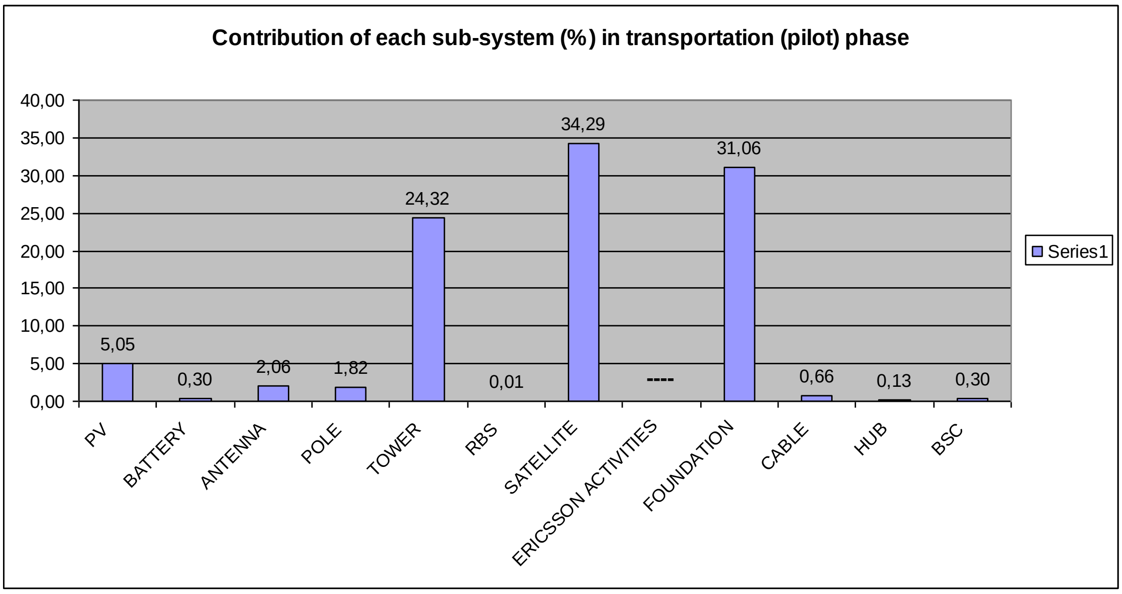


In the below figure the LCA results for assessed site are shown. The relative distribution between each life-cycle stages are indicated for the chosen environmental impact categories.

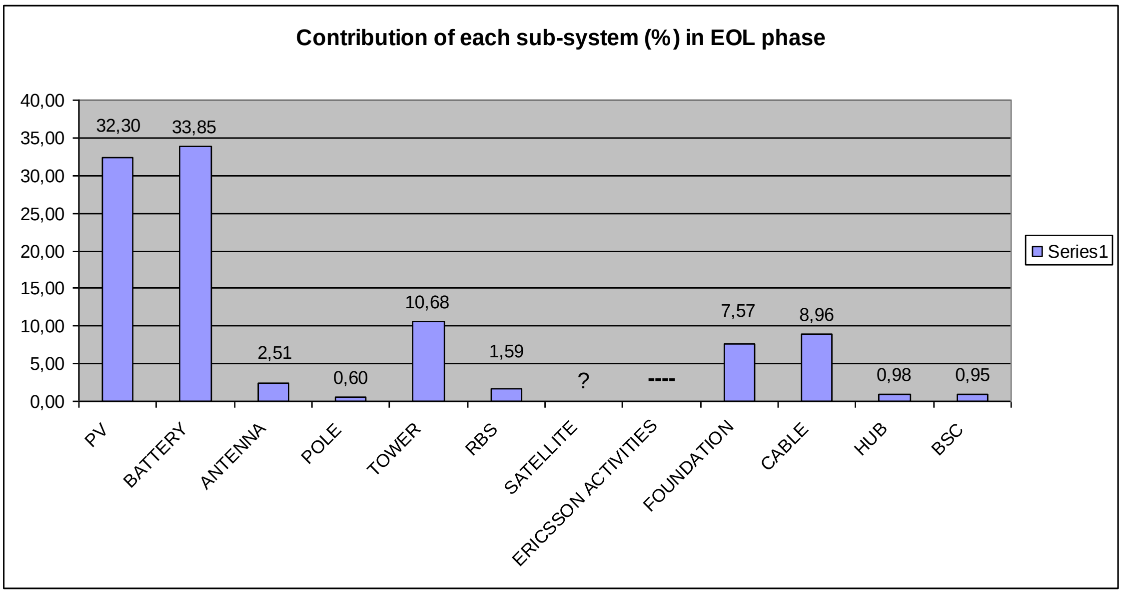


In the following 3 figures percentage contribution of CO_2e of each sub-system for each phase (manufacturing, transportation and end-of-life) is shown.




Contribution of each sub-system (%) in transportation (pilot) phase
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
5,05
0,30
2,06
1,82
24,32
0,01
34,29

31,06
0,66
0,13
0,30
PV
BATTERY
ANTENNA
POLE
TOWER
RBS
SATELLITE
ERICSSON ACTIVITIES
FOUNDATION
CABLE
HUB
BSC
Series1


Contribution of each sub-system (%) in EOL phase
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
32,30
33,85
2,51
0,60
10,68
1,59
?

7,57
8,96
0,98
0,95
PV
BATTERY
ANTENNA
POLE
TOWER
RBS
SATELLITE
ERICSSON ACTIVITIES
FOUNDATION
CABLE
HUB
BSC
Series1

APPENDIX C: Description of impact categories

Abiotic resource depletion

Fuels and metals are the non-renewable resources that the world contains. Van Oers et al. (2002) describe the depletion of resources; 'abiotic resource depletion is the decrease of availability of the total reserve of potential functions of resources, due to the use beyond their rate of replacement'. This category of impact assessment has discussed both renewable and non-renewable resources. Depletion of minerals and fossil fuels are non-renewable and extraction of water, wind and wood are renewable resources. Abiotic resource depletion considers non-living resources. Antimony (Sb) metal depletion is a reference unit to make a comparison with the extraction rate and remaining reserves kilogram antimony equivalent (kg Sb eq.).

Global warming

Climate change has number of environmental mechanisms that affect both human health and natural environment. Its models make assessment in the future impact on climate from varying scenarios. Man-made climate change is caused by the emissions of greenhouse gases (GHG). These gases have the ability to absorb infrared radiation from the earth. This is called radiative forcing. The Bern model has been developed by the Intergovernmental Panel on Climate Change (IPCC) and it calculates the radiative forcing of all GHGs and branded them Global Warming Potential (GWP) over 100 years (GWP100). The emissions that are coming from GHG s to air is measured with the carbon dioxide equivalency factor (kg CO_2e)(Ericsson internal: Jens Malmodin, 2011).

Acidification of natural ecosystems

This category of impact assessment considers the impacts from acidification by the emission of airborne acidifying chemicals. In physical description, it can be said that the acidity of water and soil increase by hydrogen ion concentration. It is caused by atmospheric deposition of acidifying substances generated largely from emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ammonia (NH_3), the latter contributing to acidification after it is nitrified (in the soil). The reference unit of this category is kilogram sulphur dioxide equivalent (kg SO_2 eq.).

Eutrophication

This category considers the impacts from nitrogen (N) and phosphorus (P) in bio-available forms on aquatic and terrestrial ecosystems. The eutrophication potential for all related emissions to air, water and soil is measured by a phosphate equivalent (kg PO_4 eq.).

Ecotoxicity potential to freshwater, land and seawater

This category considers emissions of toxic substances that have effect on ecosystem. Freshwater aquatic ecotoxicity potential (FAETP) relates to the impact on freshwater aquatic ecosystems, marine aquatic ecotoxicity potential (MAETP) relates to marine aquatic ecosystems and terrestrial ecotoxicity potential (TETP)

relate to land-based ecosystems. The reference unit of kilograms of 1,4-dichlorobenzene equivalents (kg 1,4DCB eq.) (Guinee et al, 2002).
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Photochemical ozone creation potential

Photochemical generated pollutants have reactive nature and this makes them to oxidize organic molecules. This feature of pollutants has negative impacts on humans and vegetation. Photochemical ozone creation potential (POCP) is a concept that models the impact category within the effect of emissions like carbon monoxide (CO) and volatile organic compounds (VOCs) and the reference unit is kilograms of ethylene equivalents (kg C_2H_4 eq.).

Ozone depletion potential

Ozone is formed and destroyed by sunlight and chemical reactions in stratosphere and the depletion of ozone exists when the rate of ozone destruction is increased. The ozone depletion potential (ODP) considers human health and ecosystem effects caused by ozone depletion and the reference unit of this category is kilograms of chloroflurocarbon-11 equivalents (kg R-11 eq.).

Human toxicity potential

LCA characterization models and factors for toxic effects should be in the same path as models that consider chemical’s state in environment, human exposure and differences in toxicological response. The human toxicity potential (HTP) of substances that are emitted to air, water and soil is compared with the reference unit of 1,4dichlorobenzene equivalents (kg 1,4 DCB eq.)(Guinee et al, 2002).

Primary energy and electricity requirements

The manufacturing stage requires energy both in raw material extraction and in processing session of the stage. So the primary energy consumption is used as the energy usage and it is measured in net calorific value (MJ). It is used as possible relation with the other impact categories and electricity incentive activities.

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