Quantifying the life cycle assessment uncertainty in the information and communication technology sector

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Abstract Conducting a Life Cycle Assessment (LCA) study of Information and Communication Technology (ICT) products and systems is a challenging task. Dealing with complex products and a significant amount of data involves many sources of uncertainty that will affect the accuracy of the results. In this paper identified parameter uncertainties significant for the calculations of the total Ericsson carbon footprint in 2010 are studied. Uncertainties have been estimated on an aggregated level for activities included in the carbon footprint and classical rules of error propagation have been applied to obtain the uncertainty of the total carbon footprint. The parameter uncertainty estimations of Ericsson's life-cycle carbon footprint for the included life-cycle stages indicate a combined uncertainty from around +/-6 percent for Ericsson activities to +/-30 percent for the supply chain with a level of confidence of approximately 95 percent. In addition different scenario and model uncertainties are discussed, uncertainty related to lifetime of the product being a major source of scenario uncertainty.

1 Introduction

In recent years, the methodology for estimating a company's total Greenhouse Gas (GHG) emissions, i.e. total carbon footprint, has expanded to include the whole life-cycle, i.e. including also the corporate value chain (so-called scope 3 emissions) [1]. Ericsson has used Life Cycle Assessment (LCA) as a methodology to investigate and evaluate the environmental impact of mobile products and systems over the whole life-cycle for more than 15 years and has reported its total carbon footprint in a life-cycle perspective since the year 2007. This is done by separately calculating emissions from the supply chain, Ericsson´s in-house activities such as product transport, facility activities, business travels and commuting, as well as product operation and End-of-Life Treatment (EoLT) [2].

Conducting LCAs of ICT products and systems is challenging, dealing with complex products and a significant amount of processes and data. In addition LCA is a model-based methodology and as such associated with large uncertainties. Uncertainty is an important aspect to take into consideration when communicating and using the results as decision support.

1.1 Uncertainty in life-cycle assessments

Three categories of uncertainties related to LCA can be distinguished in the literature [3-5]: parameter uncertainty (related to input data), scenario uncertainty (related to choices) and model uncertainty (related to set relations).
Parameter uncertainty includes uncertainties in data collected for the inventory analysis and uncertainties when translating inventory flows into environmental impact potentials. The influence of parameter uncertainty on the final result can be assessed analytically or by simulation. The *scenario uncertainty* represents variation of results depending on methodological choices, e.g. modeling principles, allocation procedures and cut-off decisions. The scenario uncertainty can be quantified through sensitivity analysis varying single or combinations of parameters. *Model uncertainty* arises from insufficient knowledge of the studied system, leading to omission of data or incorrect assumptions. Model uncertainty is difficult to quantify.

2 Study scope and method

In this paper the uncertainty of the total Ericsson carbon footprint in 2010 is studied. To calculate the carbon footprint for Ericsson, results from a number of high-quality LCAs for important activities have been used to estimate all included activities. Due to the large number of data within each of the LCA models and virtually non-existing uncertainty data, it was not possible to assess the uncertainty for each individual data parameter. Therefore the method has been to estimate the uncertainty on an aggregated level for typical parameters within each of the categories i.e. the supply chain, Ericsson´s in-house activities, and product operation, based on practitioners LCA experience and knowledge of background LCA data, and then apply classical rules of error propagation [6] to obtain the uncertainty of the total carbon footprint of each category. Examples of such input parameters are reported transport distances, emission factors for average air travel, reported electricity consumption from facility management or reported global

CO2 emissions used for estimating uncertainty in global electricity production. When no references or benchmarking were available for the uncertainty estimation, variations of results between different data sources have been used. Within this assessment the term uncertainty therefore refers both to uncertainties and maximum and minimum variations. When neither benchmarking nor data on variations were available starting point assumptions were made to be refined in future work on uncertainties. The uncertainties for input parameters, see Table 1-3, are provided as the standard uncertainty for normal probability distributions (N) and as total span for triangular distributions (T).

The standard uncertainties for individual parameters e.g. for energy consumption or emission factors were considered as stochastic variables with a specific mean and standard deviation. The standard uncertainties for parameters were combined into uncertainties for the categories included in the carbon footprint i.e. the supply chain, Ericsson´s in-house activities, and product operation by using (1), where f, xi and u(xi) denote the function describing the process, a specific influence quantity (see Table 1-3), and the associated standard uncertainty, respectively [6]. Equation (1) includes partial derivatives corresponding to the sensitivity coefficients describing how the output estimate varies with changes in the input parameters.

$$u_c^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) \qquad (1)$$

The combined standard uncertainty has been expanded and scaled with a coverage factor of k=2 to give a level of confidence of approximately 95 percent. This means that all resulting category uncertainties are presented with 95 percent confidence, i.e. the interval which the true value is expected to be found with a predefined certainty.

In this study the EoLT has been left out for the reason that this category has a very small contribution to the overall carbon footprint result for Ericsson.

3 Results - uncertainty in Ericsson´s total carbon footprint

The parameter uncertainties for the different categories included in Ericsson´s carbon footprint are presented below. In section 3.5 the summarized parameter uncertainty is presented.

3.1 Supply chain

The supply chain includes estimated emissions from the cradle-to-gate manufacturing of Ericsson equipment e.g. Radio Base Stations (RBSs), power and telecom cables and packaging. In addition, the supply chains of electricity production, fuels and other types of energy having large influence on CO2 emissions related to Ericsson activities are reported.

Ericsson is manufacturing about 1 million products per year, including about a billion sub-parts and components. It is practically impossible to collect product specific data. Instead high-quality models of generic product models are used to calculate emissions from the different product groups. The CO2 emission for each product group are calculated by multiplying the product group weight with an product group specific emission factor, given as kg CO2/kg product based on detailed cradle-to-gate LCAs.

The uncertainty for each of the product groups were estimated based on uncertainties of the total weight and applied emission factor, see Table 1. These estimated uncertainties leads to a combined parameter uncertainty in Ericsson supply chain of about +/-30 percent.

Table 1: Uncertainty for the weight and emission factor for each product group considered for the supply chain and related Ericsson activities.

Input parameter (xi), uncertainty	Source/type of data and motivation for estimation of uncertainty
Product groups (several)	
Weight, +/-10% (T)	Measurements from Ericsson facilities and distribution service providers. Main uncertainty sources include 1) the allocation between product and packaging weight, 2) inherent uncertainties from measurements and reporting.
Emission factor, from +/-32% (N) for ICT network products to +/-50% (T) for cables and packaging	Internal and external LCAs with high technology and geography correlation. Main uncertainty sources include 1) low sample sizes from a large supplier base with high market variations, 2) use of old data that leads to overestimated results, 3) data gaps for e.g. some supplier activities leading to underestimated results. Combined uncertainty for materials (+/-80%), major components (e.g. integrated circuits) with electricity mixes based on location of suppliers (+/-40%) and use of LCA results to represent similar products (+/-50%). Cables and packaging with a small influence on the total result have been estimated to have a 50% (T) uncertainty based on LCA data for materials.

Ericsson activities related to the supply chain	
Buildings supply chain, +/-30% (T)	Internal and external [7-8] LCAs on buildings. Lower uncertainty than ICT equipment because construction materials such as concrete and steel are well studied.
Jet fuel supply chain, +/-20% (T)	Internal and external [9] LCAs on jet fuel supply chain. Well studied system in the LCA literature. The estimated uncertainty is based on variation between studies.
Electricity production supply chain, +/-25% (N)	Internal LCAs based mainly on [10]. Combined uncertainty of fugitive methane (CH4) and CO2 emissions, CO2e gas and oil supply and additional CO2e emissions based on LCA studies including SF6, see Table 3.
All other fuels supply chain, +/-20% (T)	Internal LCAs and [9] on fuels supply chain. Well studied system in the LCA literature. The estimated uncertainty is based on variation between studies.
Computer hardware, paper, hotel nights, +/-18% (N)	LCA studies on paper and computer hardware [10], and reported data from the hotel chains. Combined uncertainty of computer hardware (+/-30%), paper (+/-20%) and hotel nights (+/-14%) are based on variation between the individual studies, with triangular distribution.

3.2 Ericsson´s in-house activities

The total carbon footprint of Ericsson activities is the sum of transports, use of facilities, business travels and commuting. For all these activities parts of the collected data, for example on distances and energy consumption at facilities, are reported, remaining data have been estimated based on costs, number of employees or square meters of facility. To estimate the CO2 emissions connected to these activities different emission factors are used, depending on for instance transportation mode and location or electricity consumption.

The uncertainties for each of the activities are based on the assumption that reported data have a semi span of 10 percent and estimated data a semi span of 30 percent with a triangular probability distribution for the distance or facility use, in combination with the uncertainty of the applied emission factor. The influence of the probability distribution should be noted. The estimated uncertainties, according to Table 2, lead to a combined parameter uncertainty for the total of Ericsson activities of about +/-6 percent.

Table 2: Uncertainty for activities included in Ericsson activities.

Input parameter (xi), uncertainty	Source/type of data and motivation for estimation of uncertainty
Air transports	
Distance, +/-8% (N)	Reported total distance 346 Million ton km (Mtonkm), from distribution service providers (DSPs) and Ericsson´s logistic management. 95% is reported data and 5% is estimated based on transported weight.
Emission factor, +/-10% (T)	Average emission factor 0.59 kg CO2e/tonkm. Internal air transport investigation by Ericsson and distribution service providers (DSP).
Road transport	
Distance, +/-19% (N)	Total distance 300 Mtonkm. Same data source as air transports. 23% is reported data and 77% is estimated based on transported weight.
Emission factor, +/-30% (T)	Average emission factor 0.08 kg CO2e/tonkm. Internal Ericsson road transport investigation, based on [1]. Large uncertainty is estimated due to uncertainty of load factors and spread in vehicle emissions.
Shipping	
Distance, +/-8% (N)	Total distance 58 Mpkm. Same data source as air transports. 90% is reported data and 10% is estimated based on transported weight.
Emission factor, +/-30% (T)	Average emission factor 0.017 kg CO2e/tonkm. Internal Ericsson shipping investigation, based on [11]. Large uncertainty is estimated due to uncertainty of load factors and spread in vehicle emissions.
Air travel	
Distance, +/-9% (N)	Total distance 1,250 Mpkm. Reported data from travel agencies and Ericsson travel management. 70% is reported data and 30% is estimated based on cost.
Emission factor, +/-10% (T)	Average emission factor 0.12 kg CO2e/pkm. Based on [12-13]. Estimated uncertainties based on variation between regional and long-distance flights and reported average emissions from several air line companies.
Car travel and commuting	
Distance, +/-30% (T)	Total distance 390 Mpkm. Based on previous internal car travel and commuting investigations. 100% is estimated based on previous car travel and commuting investigations. Large

	uncertainty is estimated due to age of data and spread in vehicle emissions.
Emission factor, +/-30% (T)	Average emission factor 0.16 kg CO2e/pkm. Based on average emissions in EU.
Swedish electricity	
Electricity, +/-10% (T)	Total electricity 224 GWh. Reported data from facility management. 100% is reported data.
Emission factor, +/-20% (T)	Average emission factor 0.003 kg CO2e/kWh. Based on reported emissions from specific electricity suppliers in Sweden. The higher uncertainty estimated for Swedish electricity is due to the higher share of renewable energy, especially biofuels.
Swedish district heating	
District heating, +/-10% (T)	Total district heating 58 GWh. Reported data from facility management. 100% is reported data.
Emission factor, +/-20% (T)	Average emission factor 0.07 kg CO2e/kWh. Based on average district heating emissions in Sweden. Estimated according to Swedish electricity.
World average electricity	
Electricity, +/-14% (N)	Total electricity 427 GWh, Reported data from facility management. 46% is reported data and 54% is estimated based on site floor area.
Emission factor, +/-4% (N)	Combined uncertainty of reported global emissions for electricity production, see Table 3.
World average district heating	
District heating, **+/-** 17% (N)	Total district heating 37 GWh. Reported data from facility management. 47% is reported data and 53% is estimated based on site floor area. No uncertainty is reported for the input parameters, a basic uncertainty of +/-10% for reported and +/-30% for estimated data has been used.
Emission factor, +/-20% (T)	Average emission factor 0.2 kg CO2e/kWh. Based on older data for average emissions in Sweden, modified for global electricity.
Total other energy (fuels)	
Energy, +/- 13% (N)	Total energy 97 GWh. 47% is reported data and 53% is estimated based on site floor area. No uncertainty is reported for the input parameters, A basic uncertainty of +/-10% for reported and +/-30% for estimated data has been used.
Emission factor,. +/-4% (N)	A low uncertainty is estimated based on the results of the combined uncertainty of reported global emissions for (fossil fuel based) electricity production, see Table 3.

3.3 Operator activities

Emissions from operator activities included in Ericsson´s carbon footprint are based on reported data from environmental/CR/CSR reports, answers given to the Carbon Disclosure Project [14] and operator's homepages. The data represent about 40 percent of the entire subscriber base world wide [10].
The uncertainty in the emissions for operator activities is assumed to be about +/- 20 percent. This assumption is based on variations of reported figures from operators with relatively high data quality, i.e. including facilities, travel and vehicle fleet; and uncertainty in the model used by Ericsson to estimate the lifetime impact from the operator activities, not considering continuous improvements.

3.4 Product operation

The carbon footprint from product operation for 2010 includes the lifetime operation for all products manufactured and sold during 2010. Over 100 energy consumption models based on average traffic in field are used to calculate the yearly consumption. To calculate the carbon footprint of product operation the yearly energy consumption is multiplied with a global average emission factor of 0.6 kg CO2e/kWh and applied product lifetime.
A study of the average global electricity model including total CO2e emissions [10] are presented in Table 3 together with corresponding uncertainty estimations applied in this study. If these uncertainties are combined the uncertainty of the average global electricity mix will be about +/-4 percent. When also considering uncertainties in the amount of electricity consumed, according to Table 3, the product operation has a combined parameter uncertainty of about +/-10 percent.

Table 3: Results from the global electricity study in [10] and estimated uncertainty, and uncertainty in the electricity consumption of product operation.

Input parameter (xi), uncertainty	Source/type of data and motivation for estimation of uncertainty
Global electricity model	
Direct CO2 emissions, +/-3% (T)	Total 9340 Mtonnes [10]. Measured and governed in most countries around the world.
All Methane (CH4) and fugitive CO2 emissions,	Total 710 Mtonnes [10]. The uncertainty of CH4 emissions described in CO2e is about +/-35 percent alone [15].

+/-50% (T)	
CO2e gas and oil supply, +/-20% (T)	Total 400 Mtonnes [10]. CO2e from supply chain is derived from different LCAs and supply chain data. Extraction, production and distribution of fossil fuels have been examined thoroughly over the years.
Additional CO2e emissions +/-50% (T)	Total 400 Mtonnes. Based on LCA studies including SF6 [10]. Review of different LCA studies and how the global average was calculated is described in [10]. The combined uncertainty for all these CO2e emissions is estimated to be about +/-50 percent.
Electricity consumption	
Energy consumption from different products, +/-15% (N)	Total GWh/year. More than 100 models for typical products. Uncertainty estimations from Ericsson´s product management has been applied here. The reported energy consumption and the estimated uncertainty have been found to be well aligned with operator survey´s [10].

Emissions from electricity production vary with region depending on the fossil fuel intensity of the electricity production. The average emission factors for electricity production for Ericsson's nine biggest markets in 2009, assumed to be representative for the year 2010, and the estimated average for the remaining markets has been investigated using data from year 2007 presented by Carbon Monitoring for Action (CARMA) [16]. This results in a global average emission factor of about 0.59 kg CO2e/kWh, corresponding to less than 2 percent difference from the global emission factor applied by Ericsson.

3.5 Combined uncertainty for Ericsson´s carbon footprint

The parameter uncertainty estimations of Ericsson's life-cycle carbon footprint for the included life-cycle stages indicate a combined uncertainty from around +/-6 percent for Ericsson activities to +/-30 percent for the supply chain with a level of confidence of approximately 95 percent see Fig. 1.

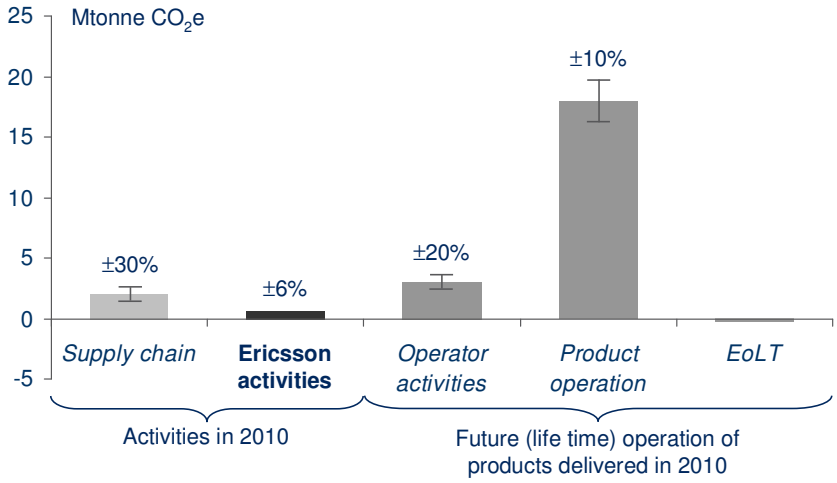

Fig.1: Ericsson´s life-cycle assessment carbon footprint 2010 including parameter uncertainty. The minor contribution from EoLT was not possible to illustrate in this graph.

4 Discussion

The different uncertainties connected to parameters, scenarios and modeling all have potential to influence the result. Within this study the parameter uncertainty for the input data has been analyzed in detail. The main scenario and modeling uncertainties are briefly discussed below.

Two important sources of scenario uncertainties for the carbon footprint are allocation of inventory data and assumed lifetime of products. Within this study uncertainties related to allocation of inventory data have not been evaluated separately, but have to some extent been included as part of the parameter uncertainty. The lifetime used for calculating Ericsson´s carbon footprint is 10 years for e.g. the RBSs and 15 years for other product groups, based on observations of products currently in operation and limited data on age of products taken out of service. The uncertainty connected to lifetime should be combined with the uncertainty of the life-cycle stages. This could be done in different ways, either with a lifetime or with an annual perspective. With a lifetime perspective, the lifetime uncertainty should be combined with the uncertainty of annual product operation and operator activities. With an annual operation perspective, the lifetime uncertainty should be combined with the uncertainty of supply chain and Ericsson activities. By presenting the results on an annual basis instead of

from a lifetime perspective the influence of the lifetime uncertainties will decrease.
A source of model uncertainty is the possible inclusion of emissions from infrastructure and supply chain for travel and transportation activities proposed in [9]. In addition there is an ongoing debate on whether to include CO2e emissions from aviation. Omitting selected emissions or insufficient knowledge on their influence on the final result will result in model uncertainties. As an example, CO2 emissions from aircrafts can be multiplied by a factor of 2-5 to include additional potential effects from nitrous oxides, water vapor, cloud formation etc. [17-18]. For the calculations of the total carbon footprint, Ericsson includes indirect emissions from electricity production, i.e. the extraction of primary energy, building of power plants, production and distribution, installation and maintenance of the grid and waste treatment. However, for the time being Ericsson does not include infrastructure in general and additional aviation effects. There are also some model uncertainties related to product operation that cannot be quantified at this stage including the use of diesel or renewable energies for electricity generation at off-grid sites, changes in data traffic and new power saving features implemented in the operating software.

5 Conclusions

Uncertainties are usually ignored when LCA results and carbon footprints are communicated. In this study, a methodology to estimate the main uncertainties related to Ericsson´s life-cycle carbon footprint has been described.
The parameter uncertainty estimations of Ericsson's life-cycle carbon footprint for the included life-cycle stages indicate a combined uncertainty at around +/-6 percent for Ericsson activities and +/-30 percent for the supply chain with a level of confidence of approximately 95 percent. The influence of different scenario and model uncertainties are not included in these values.

6 References

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