SUPPORTING INFORMATION FOR:

Malmodin, J., D. Lundén, Å. Moberg, G. Andersson, and M. Nilsson. 2014. Life cycle assessment of ICT: Carbon footprint and operational electricity use from the operator, national, and subscriber perspective in Sweden.

Summary

This supporting information provides additional information regarding inventory data based on previous LCA studies (appendix S1), user equipment data (appendix S2), ICT network description (appendix S3), ICT network data for TeliaSonera and Sweden (appendix S4), data traffic model for Sweden (appendix S5), detailed results for different primary subscription services (appendix S6), abbreviations and terminology used (appendix S7), and additional references.

Appendix S1: Inventory data based on previous LCA studies

TeliaSonera and Ericsson have performed LCA studies since 1995. This study is based on specific data as well as on data from a number of earlier performed LCA studies by Ericsson and TeliaSonera. The main reports which have given vital information to the present study, especially for manufacturing, deployment of network equipment and physical infrastructure, are presented in table S1.1 below.

Table S1.1. List of previous LCA studies performed by TeliaSonera and Ericsson providing vital input to the current study.

LCA study of	Reference, year	Key results
Greenhouse gas emissions and operational electricity use in the ICT and entertainment & media sector	Malmodin et al (2010a)	Average embedded carbon footprints for different user equipment categories 0.6 kg CO_2-eq/kWh for global average electricity production
Data transmission and IP core network	Malmodin et al (2012)	64 g CO_2-eq/GB or 0.006 g CO_2-eq/GBkm
Mobile telephone	Bergelin (2008) Externally verified (2010)	Manufacturing: 22 kg CO_2-eq/mobile phone Use: 2 kWh /year

PSTN switching (local, LX)	Lindroth (1999b) Externally verified (2010)	Average, Sweden: 2 kg CO_2-eq/line*year
Radio base station site(s)	Ericsson internal reports (2002, 2010) Externally verified (2001 and 2010)	3.5 kg CO_2-eq/sub*year, average site infrastructure: antenna towers, housings, batteries etc. (for current Swedish average subs/site = 430, 1.5 kg CO_2-eq/sub*year for 1000 subs/site)
Radio link vs. cable	Lindroth (1999a)	Radio link incl. site: 0.2 and 15.5 kg CO_2-eq/connection and year (site to site) including all site material and infrastructure (Variations due to reused infrastructure, estimated life span etc. Radio link (equipment + operation): 0.2 and 1.2 kg CO_2-eq/connection and year.
Operator activities	Malmodin et al (2010b)	Fixed operator activities: 4.8 kg CO_2-eq/sub year Mobile operator activities: 2.6 kg CO_2-eq/sub year. These figures have been updated based on updated energy reporting and divided per operation based on number of employees.
Submarine optical fiber cable	Donovan (2009)	44 g CO_2-eq/GB over 7300 km, or 0.006 g CO_2-eq/GBkm, including operation. Most of the carbon footprint origins from ship operations.
Telephony subscription (PSTN line) deployment	Lindroth (1999b)	Construction of an average PSTN subscriber line (no use or phone/switch equipment included): Apartment, city: 1.6 kg CO_2-eq/line*year Apartment, urban: 3.1 kg CO_2-eq/line*year House, urban: 5.3 kg CO_2-eq/line*year House, rural: 16 kg CO_2-eq/line*year Average, Sweden (used in study): 5.3 kg CO_2-eq/line*year
Telecommunication land cable vs. telephone poles	Tingstorp (1998)	Average for Stockholm – Gothenburg (600 km): Construction: 5 ton CO_2-eq/km

Appendix S2: User equipment data

Sale statistics have been used to determine the amount of new products that are manufactured. About 1.7-2.0 million PCs were sold in Sweden per year 2005-2011 and in total about 11 million PCs were sold in 6 years. The number of PCs in active use is estimated to about 8.5 million. This value is based on the number of PCs in Swedish homes (Zimmerman 2009) and estimates made for this study regarding PCs in non-residential use, 2.1 million, which is based on estimates of number of workplace PCs in Sweden, 1.7 million (Malmodin et al 2010a), and other use of PCs, e.g. shared PCs used in the service sector (education, health care, stores etc.).

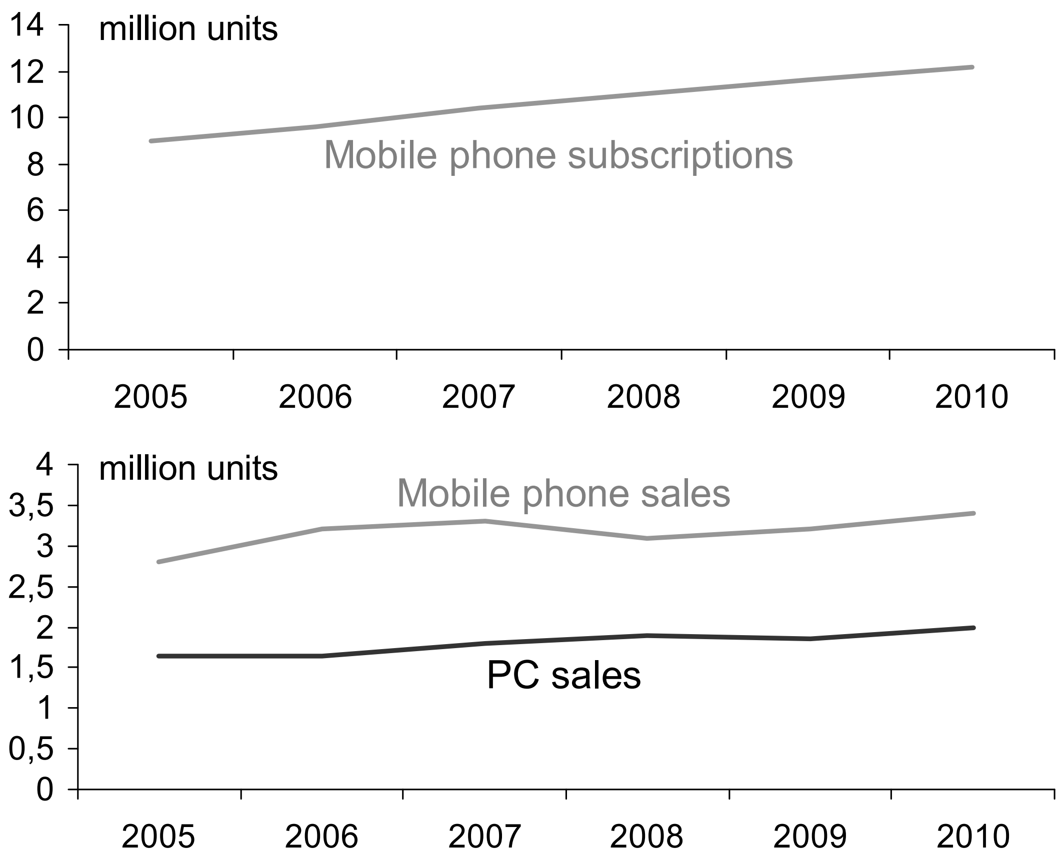

Figure S2.1. Mobile subscriptions (excl. M2M subs, about 2 million in 2010), mobile phone sales and PC sales in Sweden 2005 - 2010. Market data comes from (PTS 2006-2011) and industry analysts IT Research (does not exist today) and recently from Gartner.

Both the mobile phone market and PC market show a moderate growth in Sweden since about 2005. Estimates of the average life time based on the ratio new units / all units in use have become less uncertain. The average life time of mobile phones can be estimated to about 3 years and the average life time of PCs to about 4 years, which is split on 3.5 years for office PCs and 4.25 years for residential PCs.

One key challenge in this study was to find representative figures for the energy use and the embodied carbon footprint of a number of user equipment categories.

Figure S2.2 and table S2.1 and S2.2 describes background data and an estimated average reflecting the current use of ICT user equipment in Sweden for different user equipment categories.

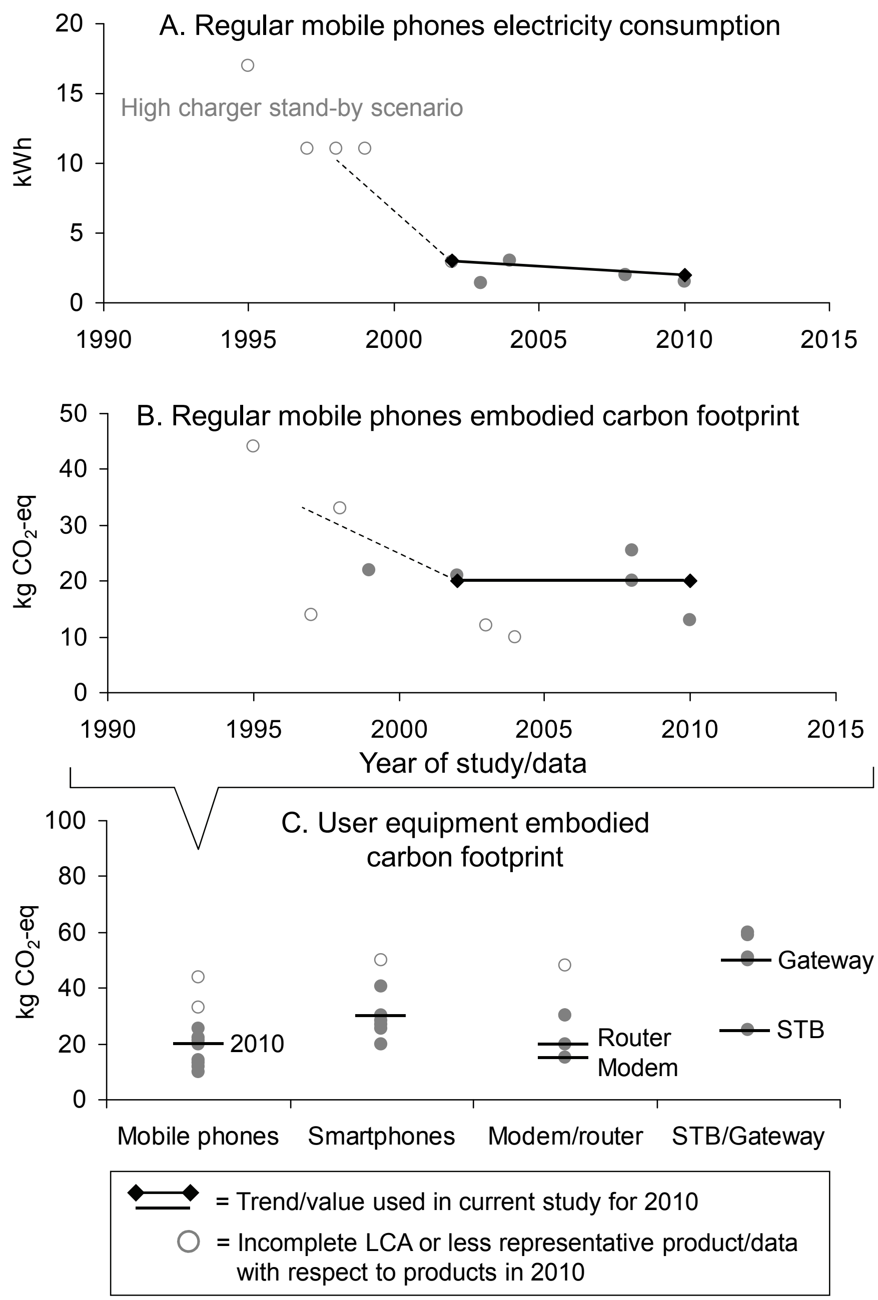

Figure S2.2. Values for electricity consumption (a) and embodied carbon footprint (b) of mobile phones based on a number of previous studies. Smartphones and fixed broadband CPE are also shown in summary graph (c). Selected relevant values used in the present study are indicated. In diagram (b), 2010 is included to visualize the variations in reported LCA results in that year and to highlight the average figure used in this study. For references to all studies, see table S2.1 and table S2.2.

Table S2.1. Regular or average mobile phone LCA or AEC studies
AEC = Annual electricity consumption, CF = Carbon Footprint

Reference	Year	CF kg CO_2-eq	AEC kWh	Notes
Ericsson	1995	44	17	
Nokia	1997	14	11	Charger, packaging and documentation is not included in any of Nokia's LCA
Ericsson / Telia	1998	33	11	
Motorola	1999	22	11	Referenced in Nokia (2005)
Ericsson 2002	2002	21	2.9	Includes also comparisons to data and results from earlier LCA studies
Nokia 2005	2004	10	3	Includes also comparisons to data and results from earlier LCA studies
Ericsson (Bergelin 2008)	2008	20-24	2	
Ericsson 2010	2008	17	2	Low-end model based on data from Bergelin (2008)
Hermann 2008	2008	25,5	2	A more advanced mobile phone
Nokia 2011	2010	16	1.5	

Mobile phone average used in the study: 21 kg CO_2-eq, 2 kWh

Table S2.2. Smartphone LCA or AEC studies
AEC = Annual electricity consumption, CF = Carbon Footprint
[A] Apple high use scenario, at least every day charging

Reference	Year	CF kg CO_2-eq	AEC kWh	Notes
Hermann	2008	25.5	2	A more advanced mobile phone
Apple [A]	2009	27	10 [A]	iPhone 3GS
Ericsson	2010	28.5	6	Every day charging scenario
Apple [A]	2010	30	8 [A]	iPhone4
Nokia	2010	20	4	N8
Apple [A]	2011	40	8 [A]	New results for iPhone4S
Apple	2012		3	New user study

Smart phone average used in the study: 30 kg CO_2-eq, 4 kWh

Figure S2.3 and table S2.3 and S2.4 describes background data and an estimated average reflecting the current use of PCs in Sweden.

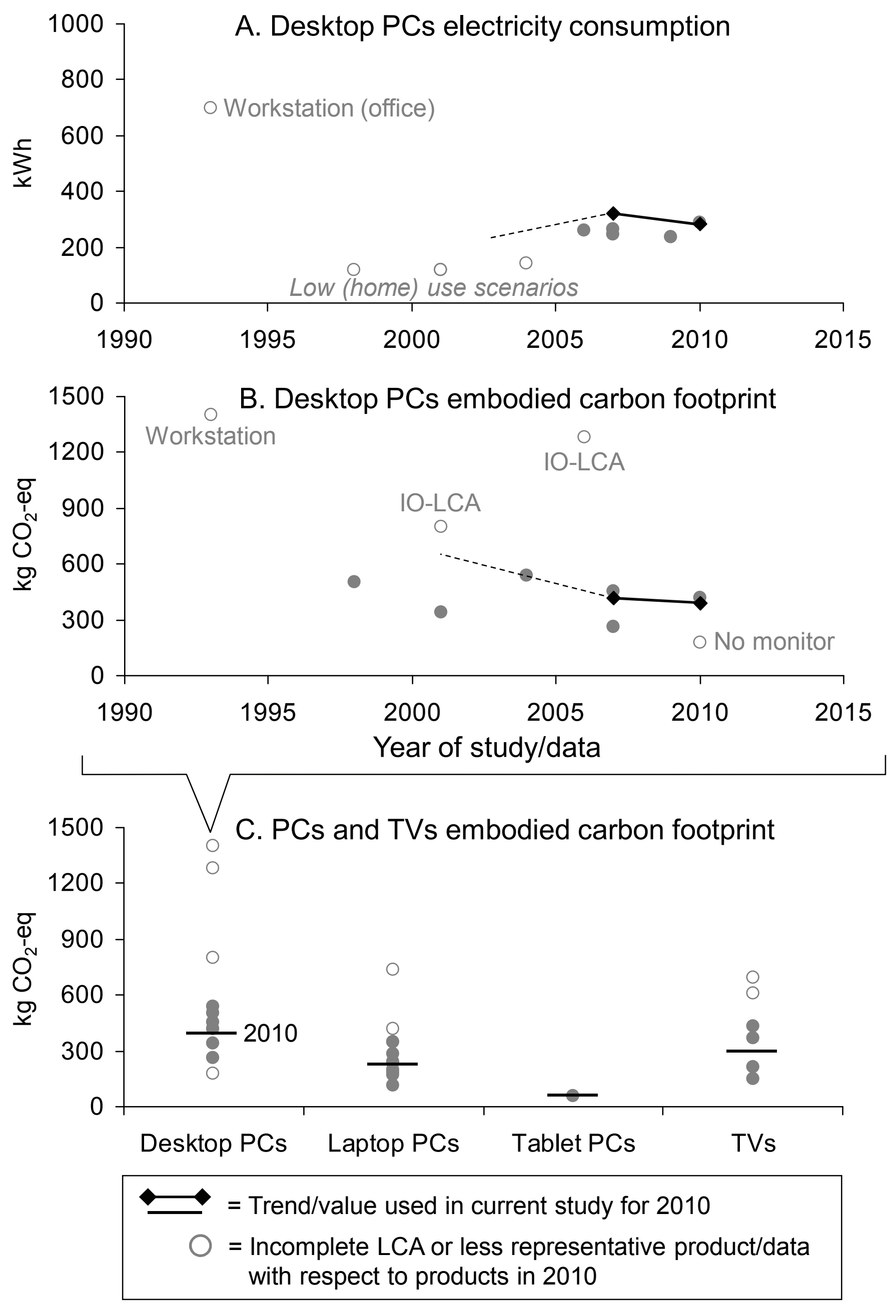

Figure S2.3. Values for electricity consumption (a) and embodied carbon footprint (b) of desktop PCs based on a number of previous studies. Laptops, tablets and TVs are also shown in summary graph (c). Selected relevant values used in the present study are indicated. In diagram (b), 2010 is included to visualize the variations in reported LCA results in that year and to highlight the average figure used in this study. For references to all studies, see table S2.3 and table S2.4. This figure also appears in the main article as figure 2.

Table S2.3. Desktop PC LCAs or AEC studies (monitor included if not stated otherwise)
AEC = Annual electricity consumption, CF = Carbon Footprint

Reference	Year	CF kg CO_2-eq	AEC kWh	Notes
MCC	1993	1400	700	Workstation, CF estimated based on 2300 kWh embodied energy
Atlantic consulting	1998	250	120	CF estimated based on 963 kWh embodied energy
Della Croce and Jolliet	2001	540	120	IOLCA, not including monitor
Della Croce and Jolliet	2001	340	120	
Williams	2004	535	140	CF estimated based on 2056 kWh embodied energy, IOLCA
Loerincik	2006	1280	258	IOLCA
IVF (EU EuP)	2007	265	266	EU project
EcoInvent	2007	450-620		
Roth and McKenney	2007		246	About 1/3 in assessment was laptops
Zimmermann	2009		234	400 households measured for 1 year, small amount of laptops included
Dell (Dell 2010a)	2010	180		Not including monitor, basic model
Malmodin et al (2010a)	2010	420	290	2007 average desktop + monitor

Table S2.4. Laptop PC LCAs or AEC studies
AEC = Annual electricity consumption, CF = Carbon Footprint

Reference	Year	CF kg CO_2-eq	AEC kWh	Notes
Tekawa	1999	350	67	
Loerincik	2006	735	74	IOLCA
EcoInvent	2007	220		
Roth and McKenney	2007		72	
IVF (EU EuP)	2007	110		
Hermann	2008	170		Small basic laptop
Apple	2009	184		MacBook Air
Apple	2009	281	70	MacBook Pro 13
Apple	2009	347		MacBook Pro 15
Apple	2009	415		MacBook Pro 17
Dell (Dell 2010b)	2009	200	70	Office use, basic model, no extra monitor or docking station included
Malmodin et al (2010a)	2010	240	55/75	Home/Office use, no extra monitor or docking station included

Table S2.5. LCD Monitors and TVs, tablet and CPE equipment LCA or AEC studies
AEC = Annual electricity consumption, CF = Carbon Footprint

Reference	Year	CF kg CO_2-eq	AEC kWh	Notes
Modem (NTT 2003)	2003	48	125	
Modem (Roth and McKenney 2007)	2005		53	
Modem (Inge 2009)	2009		79	
Modem (Malmodin et al 2010a)	2007	15	79	
Router (GeSI 2008)	2007	30	20	
Router (Inge 2009)	2009		79	
Router (Malmodin et al 2010a)	2007	20	79	
Gateway (FTTH 2008)	2008	30		
Gateway (ALU 2008)	2008	51	96	
Gateway (CESC 2011)		59		
STB (Roth and McKenney 2007)	2005		131	Based on older US satellite STBs
STB (GeSI 2008)	2007	60	49	
STB (Inge 2009)	2009		61	
STB (CESC 2011)	2010		61	
TV (Taeko 2003)	2003	250-470		From CRT to PDP
TV (Socolof et al 2005)		420		17” high-end PC monitor
TV (Fraunhofer IZM and PE Europe 2007)		211-365		From 29” CRT to 42” PDP
TV (Roth and McKenny 2007)			222	
TV (Apple 2008)		430		24 LED high-end monitor
TV (Zimmerman 2009)			200	400 households measured for 1 year
TV (Malmodin et al 2010a)		300	200	2007 average TV
TV (Hisher 2010)		400		42” PDP

Table S2.6. Server LCA or AEC studies
AEC = Annual electricity consumption, CF = Carbon Footprint

Reference	Year	CF kg CO_2-eq	AEC kWh	Notes
Della Croce and Jolliet	2001	1080	2190	Estimate based on 2 * Desktop PC
Hermann	2008	550		
IBM, Weber (2010a)	2011	380	2000	
Google [A]	2011	600	1450	5 year life time assumed

[A] The Google power/energy data also includes storage/network and other data center overheads (e.g. cooling, power), and the manufacturing CF also includes construction of the data centers and Google business operations (offices, travel)

Table S2.7. Embodied carbon footprint and electricity consumption for different types of PCs, the year 2008 has been chosen to best represent the average PC in use and manufactured for the Swedish market in the study

	2007	**2008**	2009	2010	2011
Desktop PCs, office use [kWh/year]	350	**340**	330	320	310
Desktop PCs, home use [kWh/year]	290	**282,5**	275	268	260
Desktop PCs, manufacturing [kg CO_2-eq]	420	**410**	400	390	380
Laptop PCs, office use [kWh/year]	75	**72,5**	70	68	65
Laptop PCs, home use [kWh/year]	55	**53.5**	52.5	51	50
Laptop PCs, manufacturing [kg CO_2-eq]	240	**232,5**	225	213	210
Extra monitor, office use [kWh/year]	100	**97,5**	95	93	90
Extra monitor, manufacturing [kg CO_2-eq]	150	**150**	150	150	150
Tablet PC, use [kWh/year]	20	**20**	20	20	20
Tablet PC, manufacturing [kg CO_2-eq]	60	**60**	60	60	60

Table 1 and 2 in the main article lists the average electricity consumption and embodied carbon footprint used in the study which have been based on all the user equipment annual electricity consumption studies and LCA studies described here in Supporting Information Appendix S2. The data for PCs is are averages based on the data presented in table S2.7 above which in turn is based on data from table S2.3 and table S2.4. The data for mobile phone is also an average based on data presented here in table S2.1 and S2.2.

Appendix S3: ICT network description

This chapter attempts to structure and pedagogically describe the different networks parts studied. The ICT network is a complex "technology body", (see figure S3.1) both related to operation as well as actual usage of the network itself. In addition the ICT services origins from different sciences and traditions such as telecommunication and data communication and this causes sometimes confusions due to that used acronyms is used differently and might have slightly different interpretations by different peoples. Most of the network devices that have been identified in the work and calculated are described below. For additional explanations and abbreviations please see Supporting Information Appendix S5.

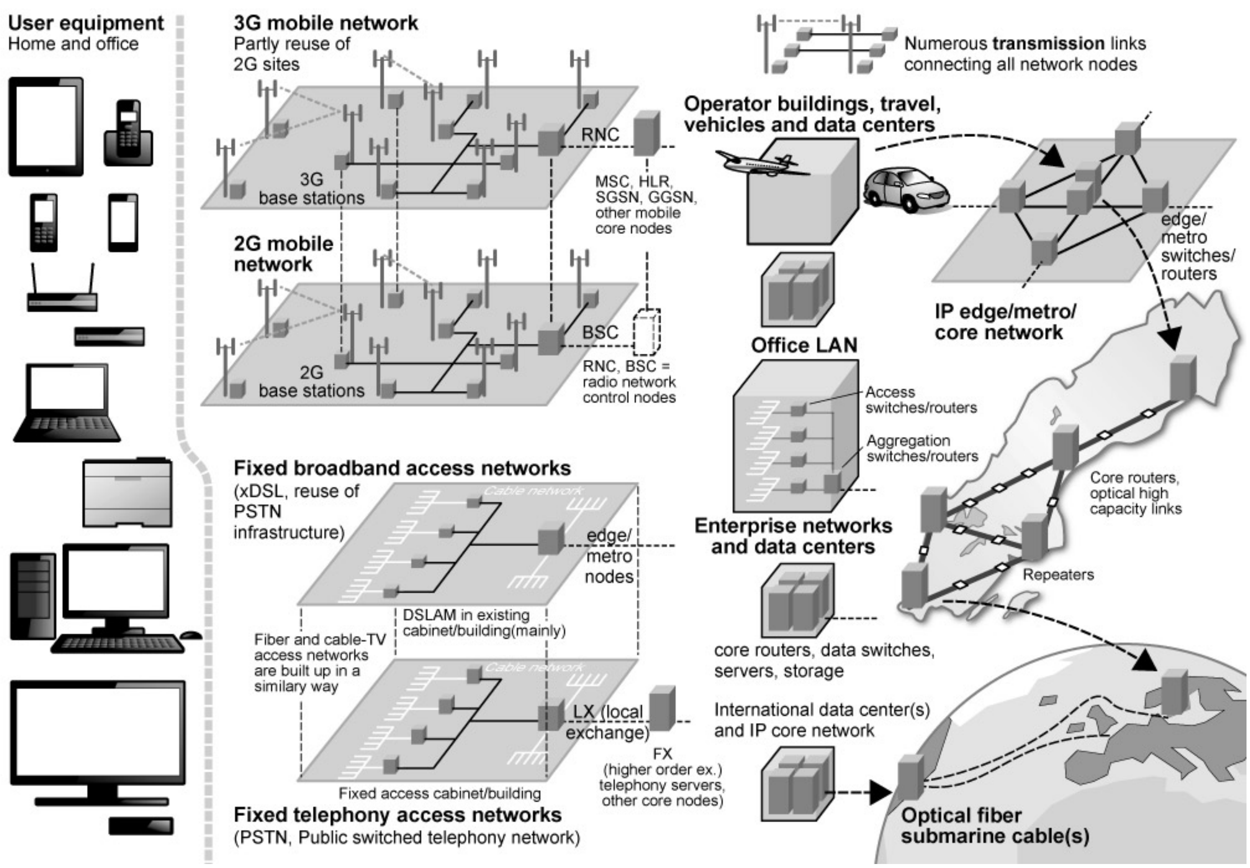

Figure S3.1. A visualization of the ICT network including everything from end user equipment via core network to international fiber connections and external data centers for e.g. search motors and social network.

The description is structured as follows:

- From user into the core network - or in another wording from crust to core and
- From local to international level since the network is spread globally not on but several rounds around the globe connecting individuals as well as operations seamlessly.

S3.1: User equipment

The terminal or end user equipment has many names and abbreviations e.g. the concept "Customer premises equipment" (CPE) is used in some parts of the world. In short the function can be described as the way an end user is accessing the shared resources available on the internet. The access forms can be either fixed or wireless. It can also be automatic without any previous human interaction or require user activities in some form. The following widely adopted terminal types have been included in the study:

- Mobile phones, smartphones, fixed (cordless) phones, PCs/terminals, office equipment, TVs used together with IPTV subscriptions. Additional equipment like personal data storage and audio peripherals are excluded, as they are defined as entertainment and media products (Malmodin et al. 2010a)
- Home network equipment or customer premises equipment (CPE), e.g. modems, routers and gateways, and set-top-boxes (STBs) used together with IPTV

S3.2: Access network + control and core nodes

Access network is the part of the telecom operator's network that is interfacing and is located closest to the terminal / end user equipment but "on the other side of the wire". The wire can be either physical such as optical fiber or copper or wireless such as mobile communication as presented below:

- 2G and 3G mobile radio access, public switched telephone network (PSTN), digital subscriber line (xDSL), cable TV (CATV), fiber to the home/curb (FTTx), etc.

The additional required control and core nodes (for the actual services) has been included in the Access network part despite the fact that these systems (normally very few with limited impact) often is located in Data centers. However since the main function is to control and steer the access network the impact has been allocated to the Access network for the following services:

- PSTN voice
- 2G and 3G mobile voice and data and
- voice over IP (VoIP)

S3.3: Transmission and IP core network

The transmission and IP core network is the "backbone" of al communication. It connects data streams between different access nodes as well as data centers and "internet". It consists of active parts as well as optical fiber and high capacity radio link point to point communication. The Transmission and IP core network is shared by all users whether they use Mobile or Fixed communication. However since there's a difference in data capacity usage a larger share of the total capacity is allocated to Fixed communications. The following services have in this study been allocated to the Transmission and IP core network:

- A large number of different transmission link equipment (copper, optical fibers, radio links etc.), IP switches and (core) routers including supporting infrastructure for cooling, power, etc.

S3.4: Operator Data center

The operator data center sites including data storage are used by telecom operators for administrative purposes e.g. to keep track of all technical sites including a huge number of ICT devices and data servers and where the electricity consumption, cooling demand and where need for backup power supply is significant. It's worth noticing that devices belonging to Transmission and IP core network are often in many studies partly located in "data centers". However in the study a distinction is made between the traditional Transmission and IP core network on one hand and data server operations on the other hand to more clearly indicate how the environmental load is distributed between different functional parts of the network. The number of actual servers in a data center varies quite much but the main criteria for labeling a telecom site as "data center" is important. Of all 11 000 sites in TeliaSonera Swedish ICT network only 7 are labeled data center. The following devices can normally be found in a data center:

- Servers, storage, routers and switches in data centers including all supporting infrastructure for cooling, rectifiers and back-up systems

S3.5: Third party enterprise networks and third party data centers

Dedicated enterprise networks including data centers are connected to the Swedish ICT network and by that accessible for selected users in Sweden as well as globally. All these connections are normally based on optical fiber or broadband communication via SDH links. The following "devices" have been added for this part:

- Third party enterprise networks and data centers in Sweden:
    - Enterprise networks (LAN) with access and aggregation switches and routers
    - Servers, storage, routers and switches in data centers including all supporting infrastructure for cooling, rectifiers and back-up systems

S3.6: Internet Global

The ICT network in Sweden operated by TeliaSonera is connected via different nodes to the ICT network in Europe. The European ICT network is then connected to other continents via underwater fiber cables to America, Asia and further, often referred to as the global ICT backbone network. Each continental backbone network is then divided equal to the European network. All these connections are nowadays based on optical fiber communication via SDH links.

Global public server data providers such as social networks and search engines are connected to the local ICT provider where their Data centers are located, and further connected and accessible via the Transmission and IP core network in each country and further.

Public data centers in combination with national Transmission and IP core networks, continental back bone network, cross linking submarine optical fiber networks etc. is better known as "the Internet".

- International data transport, IP core networks and data centers, routers and optical fiber links and submarine optical fiber cable systems for data traffic outside Sweden/EU, etc.
- International third party enterprise networks and data centers accessible also for Swedish users:
    - Enterprise networks (LAN) with access and aggregation switches and routers
    - Servers, storage, routers and switches in data centers including all supporting infrastructure for cooling, rectifiers and back-up systems

S3.7: Operator activities

For a telecom operator there is a significant impact not only from the actual network but also from other parts of the operations; personnel is traveling, offices needs to be heated, contracting work etc. And all these must also be included into a comprehensive assessment. The following operator aspects have been included in the study:

- Offices and stores (energy), business travel, service vehicles (own and third party services), as well as activities required for operation and maintenance of the ICT networks and to serve the subscribers, etc.

S3.8: Summary

The network studied contained all functions that can be expected from an operator that aims to offer all modern ICT services for both the private sector and business customers, including machine to machine services and seamless cloud functionalities for fixed and mobile operations. All parts of the TeliaSonera ICT network physically located in Sweden were included also core network interfaces towards the international backbone network. Impacts outside of Sweden related to international traffic to and from Sweden were included and shared between originating and terminating networks. Equipment of TeliaSonera installed at other operators' premises was included, and other operators' equipment installed at TeliaSonera premises was excluded, by use of site and equipment specific information. The Home/CPE network includes modems, routers and gateways (combination products) which can be fixed and/or wireless equipment inside the home (LAN/WLAN), see figure S3.8.1.

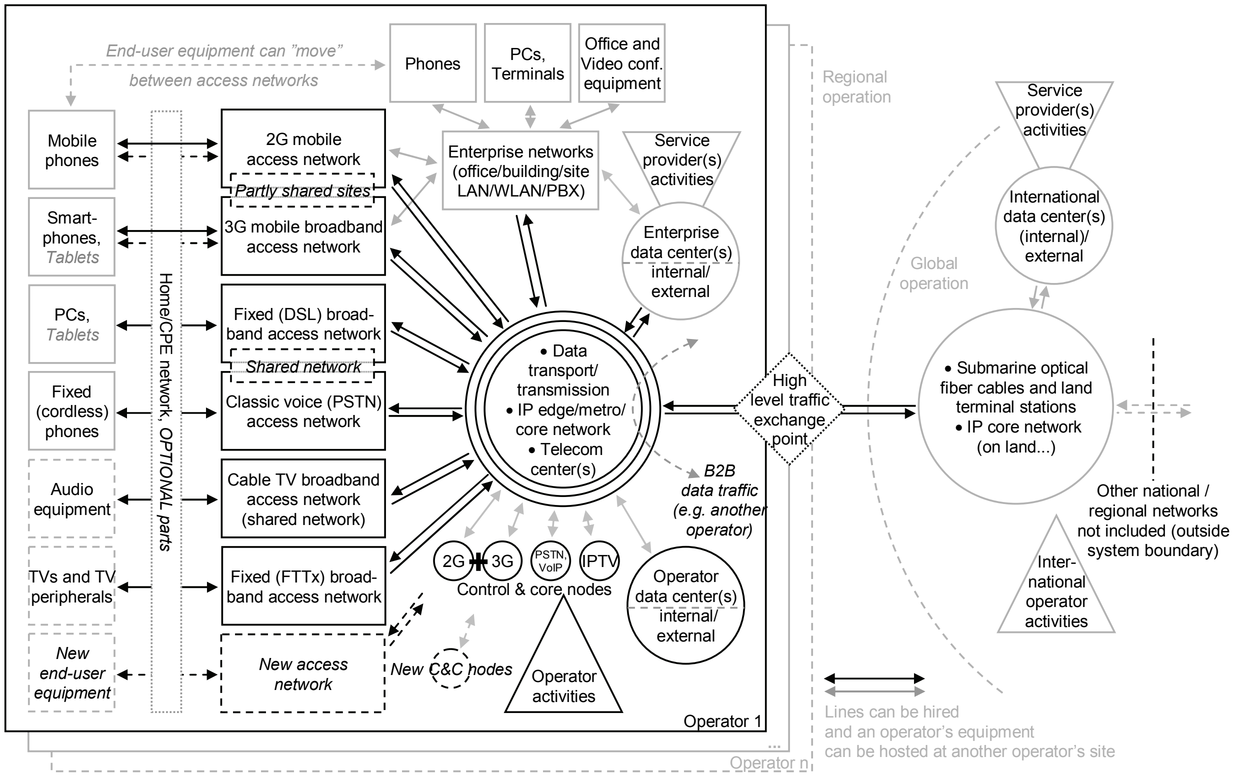

Figure S3.8.1. A logic visualization of parts in the ICT network included in this study - from end user equipment to international shared data centers.

The Home/CPE network includes modems, routers and gateways (combination products) which can be fixed and/or wireless equipment inside the home (LAN/WLAN). The network studied contained all functions that can be expected from an operator that aims to offer all modern ICT services for both the private sector and business customers, including machine to machine services and seamless cloud functionalities for fixed and mobile operations. All parts of the TeliaSonera ICT network physically located in Sweden were included also core network interfaces towards the international backbone network. Impacts outside of Sweden related to international traffic to and from Sweden were included and shared between originating and terminating networks. Equipment of TeliaSonera installed at other operators' premises was included, and other operators' equipment installed at TeliaSonera premises was excluded, by use of site and equipment specific information.

An important part of the study was to include all network infrastructures such as cables, antenna towers, site housings and related civil work. Most of the materials used for an ICT network is actually steel, concrete and gravel. In this study a relevant share of their life cycle impact was included. Other activities, such as business travel, office heating and use of service vehicles, by service providers such as Google and Facebook, has not been included in the study.

S.3.9: Additional information

S.3.9.1: Back ground data on TeliaSonera's network

TeliaSonera is the 5th largest telecom operator in Europe with a focus on Nordic, Baltic and Eurasia (a total of 17 countries). In addition TeliaSonera is also the 3th largest global internet backbone provider covering almost 80 countries. In Sweden TeliaSonera operates one of three national wide GSM networks and has the largest geographical coverage. The operator is also the shared owner (50%) of one of tree national wide 3G networks. It is worth noticing that 4G/LTE was not included in the study since this technology was launched in December 2009. TeliaSonera is also the national wide operator of the PSTN network in Sweden and maintains the fixed access network for other operators. In addition TeliaSonera is one of 4 national wide fixed broadband operators (xDSL). The operator is also the major national ICT core network provider in Sweden both in relation to fiber lengths as well as data transmission. Finally TeliaSonera is one of several suppliers of collocated data services and is also the third largest backbone provider for international traffic globally.

Appendix S4: ICT network data for TeliaSonera and Sweden

The results of the network analysis as well as results of the investigation of TeliaSonera's operator activities are shown in table S4.1. The operator activities are described in more detail in Malmodin et al. (2010b) but new electricity consumption data for offices, stores and internal data centers based on the current study have been used in this study. Data transmission and IP core network is based on the average model developed for Sweden which has been described in more detail in Malmodin et al (2012), see also Supporting Information Appendix S5.
The extrapolation to Sweden is done using subscription data or other quantifying data described in table S4.1.

A summary of the estimations of 3rd part enterprise networks and data centers described in chapter 3.5 of the article is also included in table S4.1. These parts have been estimated based on statistics on the national level. The allocation to TeliaSonera (50%) is based on the average share of other subscribers (40%) and the share of the IP core network (~2/3 of fiber length). The 3rd part enterprise network and data centers are not related to a specific operator in the same way as a PSTN/mobile/broadband subscriber.

Table S4.1. ICT networks data for TeliaSonera and Sweden (scaled TeliaSonera data)

Network part	TeliaSonera Description	Electricity GWh	Total Sweden Description	Electricity GWh
Access networks	**Including control & core and dedicated transmission)**	**264**		**541**
PSTN and broadband telephony (VoIP = Voice over IP)	4,2 M active lines (7,4 M lines built), 8 400 sites[1]	131	4,7 M active lines + 0,7 M VoIP subs	145
2G (GSM) mobile communication	1 national network, approx. 6 000 sites[1], 2,7 M subs (PTS, 2011)	64	3 national networks, approx. 17 000 sites, 5,7 M subs (PTS, 2011)	172
3G (WCDMA) mobile broadband	50% share of 1 national network, approx. 3 000 sites[1], 2,8 M subs (PTS 2011)	35	2 national networks (4 operators), approx. 12 000 sites, 6.4 M subs (PTS, 2011)	134
Fixed xDSL broadband	1,1 M active lines (1,8 M lines deployed), approx. 10 000 cabinets (at existing sites)	34	1,7 M active lines	56
Fixed cable-TV (CATV) and fiber (FTTx) broadband	Few lines, more planed		1,1 M active lines, estimate based on xDSL	34
Operator activities		**66**		**143**
Offices and stores	15 larger offices, 58 stores	29	Extrapolation based on TeliaSonera	73
Data centers	7 larger data centers	37	Estimate based on TeliaSonera	70
Other energy (estimate, note that this is primary energy not directly comparable to secondary electric energy)	*Heating in offices and stores, business travel, car fleet, own and 3rd part services*	*(~125)*	*Estimate based on TeliaSonera*	*(~250)*
Data transmission and IP core network	**Approx. 4 100 switches/routers/high-capacity optical links, approx. 64 000 other link elements**	**84**	**TeliaSonera has about 2/3 of total fiber length in Sweden's core network**	**126**
3rd part enterprise networks and data centers	**Estimated based on total figures for Sweden**	**657**	**2,1 M active PCs and 330 000 active servers**	**1 314**
Enterprise networks	50% of enterprise networks and data centers related to TeliaSonera's networks	37		74
Office equipment		55		110
Data centers/rooms used internally (Intranet) by the company/organization		283	50% of all servers	565
Data centers/rooms open		283	50% of all servers	565

1. The total number of actual physical sites is less than the summarised volume of all PSTN, 2G and 3G sites. This due to that some sites are shared.

Appendix S5: Data traffic model for Sweden

A data traffic model has been created for Sweden. It's partly based on Malmodin et al. (2012) which have been extended with estimates for share of open/closed (external/internal or Internet/Intranet) data centers and international data traffic, see figure S5.1 below.

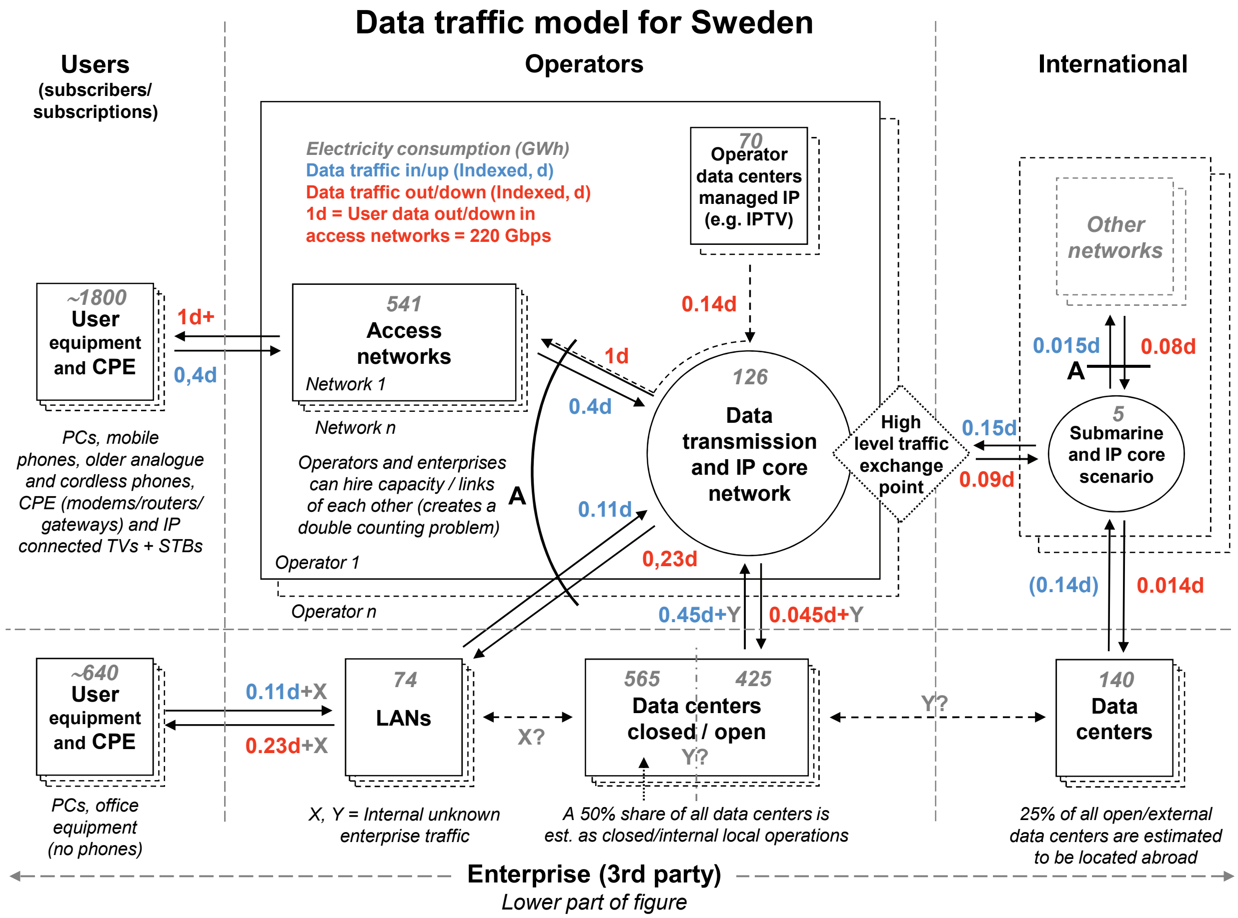

Figure S5.1 Data traffic model for Sweden in 2010 (figures are rounded). Data traffic is shown in relation to the data traffic out/down from the core network to the access network nodes (= 1d = 220 Gbps on average in 2010, not including LANs). Note that the data traffic model and volumes are just an estimate built on many different nonpublic sources.

Two major estimates have been made in the study:

- The share of servers or data rooms/centers that is used by enterprises in a closed/internal environment is set to 50% based on internal data on enterprise networks, e.g. servers to PCs ratios (1:10) of internal operations and similar information. An enterprise server or part of a server network also serves off-site usage and this is seen as open/external traffic and was taken into account in the estimate (large uncertainty).
- The share of international data traffic and traffic exchange with data centers located abroad is assumed to be about 25%, based on IP core and international data capacity. Therefore, open/external data centers electricity consumption is estimated to 420 GWh in Sweden and 140 Gwh in data centers abroad (140 GWh of 565 GWh total data center electricity consumption in Sweden is at the same time allocated to be used abroad).

The total amount of data traffic increased by about +30% per year and the mobile data traffic by about 100% per year during the period 2006-2010 and this needs to be taken into account when energy/data figures are re-used in future studies.

The total data traffic between access networks including LANs (interfaces marked with an A in figure S5.1) and the core network is estimated to about 1.6 million TB in 2010 (about 400 Gbps on average) and the traffic share is shown in table S5.1. As for data centers a smaller part has been allocated to international core networks (Part of the Swedish core network is at the same time allocated to use abroad). The electricity consumption per amount of data is estimated to be 0.08 kWh/GB.

The share of data traffic in table S5.1 has been used to allocate the data transmission and IP core network to the different types of primary subscription services (see Supporting Information Appendix S6). Data center related data traffic is not included in this figure which is explained further below but the main reason is that this traffic is very efficient and would lead to a too low figure for the data traffic related to access networks.

Table S5.1. Data traffic between access networks and the core network in Sweden 2010.

Data traffic generated by:	**Traffic in %**
Fixed broadband (including IPTV)	75%
Business IP WAN and B2B	20%
Mobile broadband	3.4%
Fixed voice[1] and dial-up modems	0.7%
Mobile voice[1]	0.2%

[1] Voice converted to data according to: fixed voice = 30 kbps*2, Mobile voice = 10 kbps*2.
Voice does not share IP core equipment but can share data transmission links.

An additional estimate of 180 Gbps for all data center (including operators own data centers and managed IP, mainly IPTV) and international high-level data traffic can be added. The internal data traffic in LAN's and data centers and between these in a private enterprise network environment (marked with X and Y in figure S5.1) is not included in this estimate. However, it's assumed that all energy consumption of related equipment to this internal data traffic have been captured when LAN's and data centers have been studied at e.g. TeliaSonera and Ericsson.

The average data traffic out/down from access network nodes to CPE and user equipment are even higher than between access nodes and the core network due to increased use of broadcast techniques and smart routers and servers in the network. IPTV is an example where the actual end user traffic is higher than the traffic generated in the IP core network. This is the reason the amount of data traffic is stated as "1d+" in figure S5.1.

The total electricity consumption in open/external data centers related to their user data traffic from access networks through the IP core network is about 1 kWh/GB. This figure can be interpreted as the total amount of electricity that a data center in general consume in relation to user data traffic of which most is sent to the user.

Note that the difference between different data services can be very large. High quality video streaming can be 100x more energy efficient (0.01 kWh/GB) while on the other hand low amounts of user data related to a service can require substantial resources in a data center. The utilization of servers is in general rather low which can be addressed by sharing data center resources more efficiently e.g. with cloud based solutions. Newly designed data centers and modernization of existing ones improves in general the overall efficiency.

Table S5.2 below shows energy per amount of data figures for fixed broadband data flows presented in this study compared to some other studies that present similar figures.

Table S5.2. Comparison of energy per amount of data figures for fixed broadband data flows for various parts of the network.

Network part:	**Weber (2010b)**	**Baliga[1] (2009)**	**Coroama (2013)**	**This study**
Year of data:	2010[1]	?[2]	2009	2010
CPE (average modem/router/gateway setup in this study)	~1.2 kWh/GB[1]	0,11 kWh/GB (5 W modem)	*Not included*	0,3 kWh/GB
Access network (xDSL/DSLAM in this study)		0,06 kWh/GB	*DSLAM not included*	0,08 kWh/GB
Data transmission and IP core network			0,2 kWh/GB	0,08 kWh/GB
International submarine cable system (share)[3]	? (small impact)			0,02 kWh/GB (only 12.5% of data center traffic share)
Open ("Internet") enterprise data centers share[3]	~2.3 kWh/GB[1]	*Not included*	*Not included*	1 kWh/GB (<50% of access data traffic)[3]
Total:	~3.5 kWh/GB[1]	0,17 kWh/GB	0,2 kWh/GB	1,5 kWh/GB

[1] Extrapolated from results for 2008 which in turn was extrapolated from data for 2006.
[2] Can be considered to be more "state-of-the-art new all IP all optical network" but with similar average traffic as in Sweden 2010. 100 kbps (approx. 400 GB/year) and oversubscription ratio = 25 assumed for the presented figure of 0.17 kWh/GB (75 μJ/bit) for typical low access rates (matches current deployed networks best).
[3] Note that slightly more than half of all access data traffic do not go to an enterprise data center as it is p2p or go to the operator's telecom / data center e.g. managed IP services (e.g. IPTV).

In this study, the term data center have been used for all types of server deployments or server networks in various scales and in various types of buildings. All servers and related infrastructure is included in the study under the term data center, from a single server to large enterprise data centers. The total operational energy use for data centers in Sweden was based on Koomey (2011) due to lack of server sale statistics for Sweden. The number of active servers was estimated based on the global ratio between estimated active servers and PCs and the number of PCs in Sweden. About the same ratio was found between global DNS (Domain Name System) registrations globally and in Sweden, same ratio also for data traffic volumes and data center count. Investigations of energy consumptions of PCs and data centers/rooms in offices and other service buildings in Sweden added to the picture but were incomplete and uncertain estimates for industry classified buildings had to be added. The different data sources and estimates ended up close to each other but it was decided to use the estimates by (Koomey 2011) and PCs to server ratios.

Ericsson and TeliaSonera operates a few of the largest data centers in Sweden or has hosted equipment in other large co-location data centers and all together this information have been used to build a data model for Sweden. The average PUE-factor (1.8) was found to be close to the average used by (Koomey 2011). At the moment Facebook are building a mega data center in the north of Sweden which in terms of energy will add an estimated 20%-30% in full operation to the total electricity consumption of data centers in Sweden.

The share of p2p (peer-to-peer) data traffic was still rather high in Sweden in 2010 and as much as about 50% of the data traffic between access networks and the core network was p2p. When looking at all data traffic including data centers about 1/3 was p2p. This is slowly changing and more and more videos will come from data centers in the future. Video will still be the dominating type of traffic but the source is slowly changing.

To be noted: The data traffic model and amounts of data traffic is just an estimate built from many different nonpublic sources. In the end it’s almost impossible to measure the total data traffic with high accuracy in a large region due to the many operators and enterprises that operates parts of the total network.

Appendix S6: Detailed results

Detailed results are presented for all different primary subscription services and their subparts, e.g. user equipment, access network and operator activities. The manufacturing or embodied carbon footprint and operational electricity consumption for user equipment is described more in detail in S2. The results are for an average subscription with average user equipment and average ICT network usage. The electricity consumption for each network subpart (total Sweden) is taken from table S4.1 in Supporting Information Appendix S4 divided by number of subscriptions in Sweden. Each subpart is described short followed by energy and embodied carbon footprint data and a short result summary including a graph with results for both Sweden and the global scenario.

S6.1: Detailed results for PSTN subscription

According to PTS (2010) there were about 4.7 million active PSTN subscription/lines in Sweden on average in 2009 (mid year average).

User (phone) equipment: 1 analog and 1 basic cordless phone is assumed to be used per average PSTN line in Sweden. No investigation of cordless phones in active use has been carried out. Data for electricity consumption and manufacturing are based on Malmodin et al (2010a). No PCs connected to PSTN (have usually an internal PSTN data modem) or older answering machines or number presenters are included in this study as very few are still in use. PSTN data subscriptions have decreased from 1.1 million in 2006 to 0.34 million in 2009 with a further decrease to 0.24 million in 2010, a reduction of nearly 80% since 2006 (PTS 2008-2011).

PSTN access line (and PSTN access site): Manufacturing and construction data for the cable infrastructure is from Lindroth (1999b) which was based on an average PSTN line deployed in Sweden prior to 2000. About 1.7 million physical PSTN lines are shared with xDSL broadband lines but no share of the embodied footprint has been subtracted (allocated to broadband) and therefore a whole line (100%) is allocated to a PSTN subscription.

Exchanges & core nodes: Manufacturing data is from Lindroth (1999b) and is based on the average PSTN exchange & core nodes equipment installed in Sweden prior to 2000. Electricity consumption and the manufacturing CF would be considerably lower if new PSTN equipment was studied (also valid for the PSTN access line equipment described above).

Operator activities: Based on TeliaSonera's operator activities (offices, stores, own cars, business travel) per average fixed subscription, including third party services and their car travel, see further Supporting Information Appendix S4. No manufacturing of buildings or vehicles or other infrastructure is included.

Transmission and IP core network: Based on the average transmission and IP core network and data traffic model developed for Sweden (Malmodin et al 2012), and the average data traffic (only including voice) generated by an average PSTN subscription, about 1.5 GB/year. Both operation of equipment and construction of the cable infrastructure are included. PSTN is separated from the IP core network but the fiber network is shared. Dedicated transmission links between the PSTN access sites and the network (also the network counter part) is included here and not together with the PSTN access line equipment. The dedicated transmission's share of the electricity consumption and CF for transmission and IP core network is nearly 100%.

There are fewer PSTN lines in active use today (4.7 million) compared to all deployed lines (over 7 million) and lines in active use in 2000 (over 6 million) when the PSTN line LCA study was carried out. The carbon footprint related to manufacturing and construction of the physical line infrastructure itself has not been allocated on the fewer lines in active use today. The same data and results as in the original study have been used (Lindroth 1999b).

Table S6.1.1. User (phone) equipment data for an average PSTN subscription

	Analog phone	Cordless phone	User (phone) Equipment
Quantity	1 phone	1 phone	2 phones
Typical power	0 W [A]	3 W	3 W
Annual electricity consumption	-	27 kWh	27 kWh
Annual operation CF…			
…Swedish electricity (0.06 kg CO_2-eq /kWh)	-	1.6 kg CO_2-eq	1.6 kg CO_2-eq
…Global electricity (0.6 kg CO_2-eq /kWh)	-	16 kg CO_2-eq	16 kg CO_2-eq
Manufacturing CF	5 kg CO_2-eq	15 kg CO_2-eq	(20 kg CO_2-eq)
Life time	10 years	5 years	7.5 years
Annual manufacturing CF	0.5 kg CO_2-eq	3 kg CO_2-eq	3.5 kg CO_2-eq

[A] Analog phone powered via operator access network.

Table S6.1.2. Network data for an average PSTN subscription

	PSTN access line	Exchanges & core nodes	Operator activities	Transmission and core network[1]
Typical power	2.1 W	0.6 W	0.4 W	0.5 W
Annual electricity consumption	18.3 kWh	5.3 kWh	3.3 kWh	4 kWh
Annual operation CF…				
…Sweden electricity (0.06 kg CO_2-eq /kWh)	1.1 kg CO_2-eq	0.32 kg CO_2-eq	0.2 kg CO_2-eq	0.25 kg CO_2-eq
…Global electricity (0.6 kg CO_2-eq /kWh)	11 kg CO_2-eq	3,2 kg CO_2-eq	2 kg CO_2-eq	2.5 kg CO_2-eq
…Other energy			4.8 kg CO_2-eq	
Manufacturing CF				
Life time	10-40 years	10-40 years	Annually	10-40 years
Annual manufacturing CF	5.3 kg CO_2-eq	2 kg CO_2-eq	Not included	0.3 kg CO_2-eq

[1] Includes also dedicated transmission links between the fixed access nodes and the higher order transmission network. Nearly all electricity consumption and manufacturing carbon footprint is related to this dedicated transmission and not to the core network.

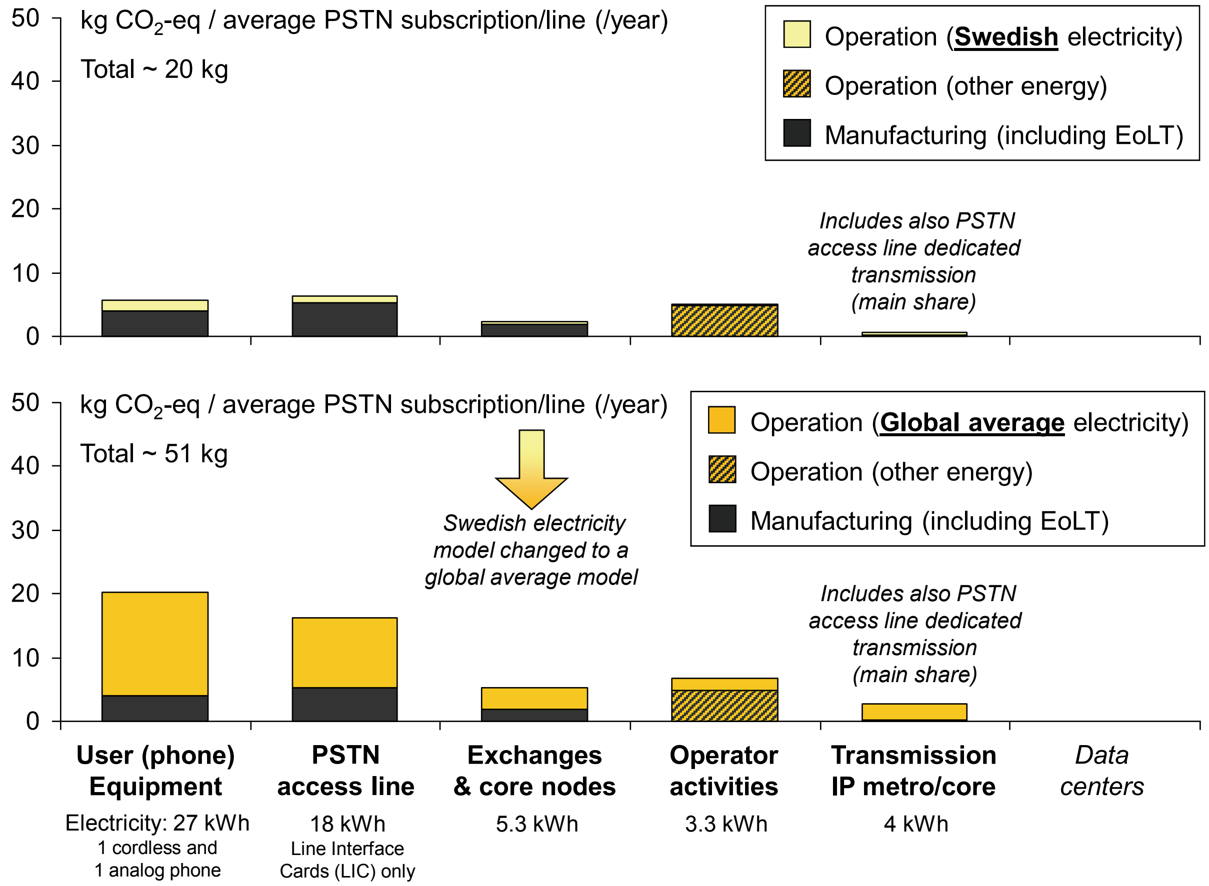

Figure S6.1.1. Detailed carbon footprint per average PSTN subscription in Sweden and in a global scenario, including figures for operational electricity use at the bottom.

Results summary (based on the global scenario with global average electricity):

- Largest contribution to the total carbon footprint comes from: User (phone) equipment operation and PSTN access line operation, then smaller contributions come from manufacturing and construction of the physical line infrastructure and exchanges, and then from operator activities.
- The total carbon footprint per average PSTN subscription/line is about 20 kg in Sweden and about 51 kg in the global scenario.

Two improvement areas have been identified:

- The basic cordless phone setup model used in the study consists of a handset and a base station (charges also the handset) with an AC/DC adapter that draws power more or less constantly. New cordless phones use better power management and more efficient components and the electricity consumption can be reduced substantially.
- The annual electricity consumption of the PSTN access line, exchanges and dedicated transmission is together about 27 kWh/line. New equipment could lower the electricity consumption substantially but investments in new PSTN equipment is questionable as newer technologies like mobile and VoIP are probably preferred in the future.

S6.2: Detailed results for VoIP subscription

According to PTS (2010) there were about 0.7 million active VoIP subscriptions in Sweden on average in 2009 (mid year average).

User (phone) equipment: The same analog phone and basic cordless phone setup as for an average PSTN subscription is used, see table S6.1.1 in S6.1.

CPE & xDSL access line: The CPE and xDSL access line data is the same as used for an average 3-play subscription (see S6.6). The components in the gateway dedicated for VoIP is estimated to consume about 1 W (EU 2011) and this part is allocated to VoIP. The other gateway parts share allocated to VoIP is based on average time of use. If amount of data would be used, the share would have been nearly 10 times larger but still only about 1/5 of the dedicated components fully allocated to VoIP.

Control & core nodes: Manufacturing data is from Lindroth (1999b) and is based on the average PSTN exchange & core nodes equipment installed in Sweden prior to 2000. The electricity consumption is based on TeliaSonera's operation of VoIP node equipment in 2009 that served about 70k subscriptions. This subscription service was under development at the time of the study and it is believed that a more mature service with more subscriptions will reduce the electricity consumption and equipment needed per subscription in the future.

Operator activities: Based on TeliaSonera's operator activities (offices, stores, own cars, business travel) per average fixed subscription, including third party services, maintenance etc., see further Supporting Information Appendix S4. Manufacturing of buildings, vehicles and other infrastructure is not included.

Transmission and IP core network: Based on the average data traffic model developed for Sweden (Malmodin et al 2012) and the average data traffic generated by an average VoIP subscription, about 1.5 GB/year.

The results are for private residential VoIP subscriptions which make up more than 90% of all VoIP subscriptions in Sweden in 2009 (PTS 2010).

The same analog phone and basic cordless phone setup as for an average PSTN subscription is used, see table S6.1.1 in S6.1.

Table S6.2.1. Network data for an average VoIP subscription

	CPE and xDSL access line[1]	Control & core nodes	Operator activities	Transmission and IP core network
Allocation (share of)	1.5% (based on use time)			
Typical power	1.2 W	0.6 W	0.4 W	0.02 W
Annual electricity consumption	10.5 kWh	21 kWh	3.3 kWh	0.2 kWh
Annual operation CF…				
…Sweden electricity (0.06 kg CO_2-eq/kWh)	0.6 kg CO_2-eq	1.6 kg CO_2-eq	0.2 kg CO_2-eq	0.01 kg CO_2-eq
…Global electricity (0.6 kg CO_2-eq/kWh)	6.3 kg CO_2-eq	16 kg CO_2-eq	2 kg CO_2-eq	0.1 kg CO_2-eq
…Other energy			4.8 kg CO_2-eq	
Manufacturing CF				
Life time	10-40 years	10-40 years	Annually	10-40 years
Annual manufacturing CF	0.1 kg CO_2-eq	2 kg CO_2-eq	Not included	0.03 kg CO_2-eq

[1] The CPE and xDSL access line data is the same as used for an average 3-play subscription, see S6.6. The components in the CPE (gateway) that is dedicated to PSTN is allocated fully to VoiP, the other part is allocated based on share of data traffic (only about 1.5% allocated to VoIP).

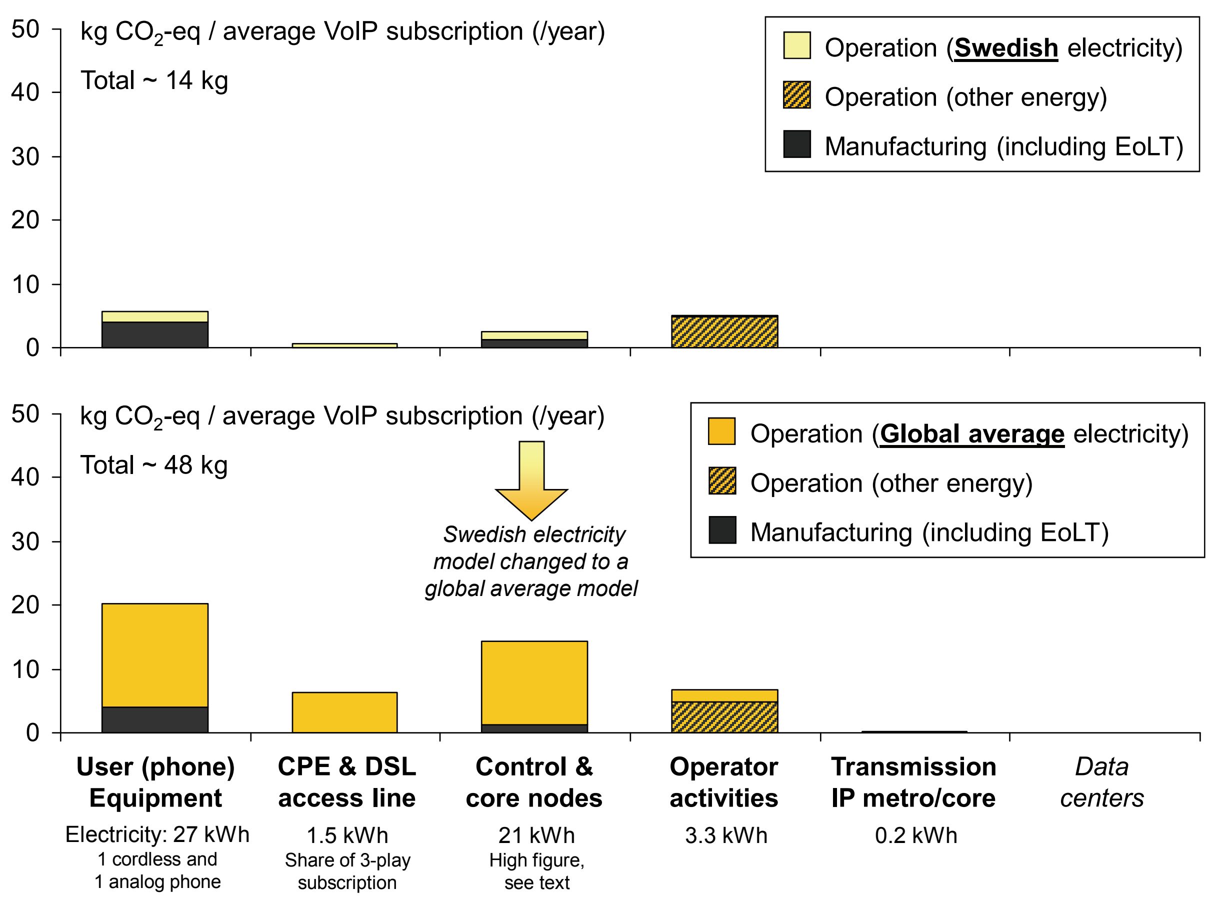

Figure S6.2.1. Detailed carbon footprint per average VoIP subscription in Sweden and in a global scenario, including figures for operational electricity use at the bottom.

Results summary (based on the global scenario with global average electricity):

- Largest contribution to the total carbon footprint comes from: User (phone) equipment operation and control & core nodes operation, and then from operator activities. The control & core nodes and operator activities carbon footprint are expected to be smaller per subscription/line in the future when the service is more mature and more subscriptions are served.
- The total carbon footprint per average VoIP subscription/line is about 14 kg in Sweden and about 48 kg in the global scenario.

Two improvement areas have been identified:

- The same basic cordless phone setup as for an average PSTN subscription is used for VoIP with the same identified improvement potential, see PSTN S6.1.
- Operation of control & core nodes and operator activities can be reduced substantially in the future which has been described in the subpart list and the results summary.

S6.3: Detailed results for 2G (GSM) subscription

According to PTS (2011) there were about 5.7 million active 2G subscriptions in Sweden on average in 2010 (midyear average). However, 3G subscribers can also use the older 2G network for voice but also for data when no 3G coverage exist.

User (mobile phone) equipment: Based on an average mobile phone specified in table S6.4.1 in S6.4. Supporting Information Appendix S2 describes how quantities and type of user equipment was estimated and how average manufacturing and electricity consumption data for user equipment have been estimated based on other studies, e.g. LCA studies. Ericsson has performed a number of LCAs of mobile phones over the years of which the latest published is Bergelin (2008).

Base station sites: 3G subscribers (subscriptions) as defined by PTS can also access older 2G base stations for voice but also for data when no 3G coverage exist, therefore the average electricity consumption for base stations uses the combined 2G and 3G base station average, 23 kWh/subscription. This average also better describes . The electricity consumption for 2G base stations divided by 2G subscriptions is about 27 kWh/subscription. Manufacturing data is from Ericsson (2010) and is based on the average base station site installed in Sweden prior to 2005. Electricity consumption and the manufacturing CF could be considerably lower if new base station equipment was used and studied.

Control & core nodes: Core nodes shared by 2G and 3G have been allocated to each network based on internal experts at TeliaSonera. Manufacturing data is from Ericsson (2010) and is based on the average control and core node site installed in Sweden prior to 2005.

Operator activities: Based on TeliaSonera's operator activities (offices, stores, own cars, business travel) per average mobile subscription, including third party services and their car travel, see further Supporting Information Appendix S4. No manufacturing of buildings or vehicles or other infrastructure is included.

Transmission and IP core network: Based on the average transmission and IP core network and data traffic model developed for Sweden (Malmodin et al 2012), and the average data traffic (including voice) generated by an average 2G subscription, about 0.7 GB/year. Dedicated transmission between the base station and the network (e.g. radio links) is included here (also the network counter part) and not together with the base station site equipment. The dedicated transmission's share of the CF for transmission and IP core network is about 2/3.

Data centers: See description in next section about an average 3G (WCDMA) subscription, same principle is used for GSM but the amount of data traffic per subscription is much lower for GSM.

The average mobile phone using GSM is based on the average mobile phone specified in table S6.4.1 in S6.4.

Table S6.3.1. Network data for an average 2G (GSM) subscription

	Base station sites	Control & core nodes	Operator activities	Transmission and IP core network[1]	3rd part Data centers
Typical power	2.1 W	0.1 W	0.3 W	0.2 W	0.04 W
Annual electricity consumption	23 kWh	1 kWh	2.5 kWh	2.3 kWh	0.4 kWh
Annual operation CF…					
…w. Swedish electricity (0.06 kg CO_2-eq /kWh)	1.4 kg CO_2-eq	0.06 kg CO_2-eq	0.2 kg CO_2-eq	0.14 kg CO_2-eq	0.024 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq /kWh)	14 kg CO_2-eq	0.6 kg CO_2-eq	2 kg CO_2-eq	1.4 kg CO_2-eq	0.24 kg CO_2-eq
…Other energy CF			4.8 kg CO_2-eq		
Manufacturing CF					
Life time	10-20 years	10-40 years	Annually	10-40 years	5-10 years
Annual manufacturing CF	3.5 kg CO_2-eq	0.1 kg CO_2-eq	Not included	0.27 kg CO_2-eq	0.034 kg CO_2-eq

[1] Includes also dedicated transmission links between the base station sites and the higher order transmission network. About 2/3 of the electricity consumption and manufacturing carbon footprint is related to this dedicated transmission and not to the core network.

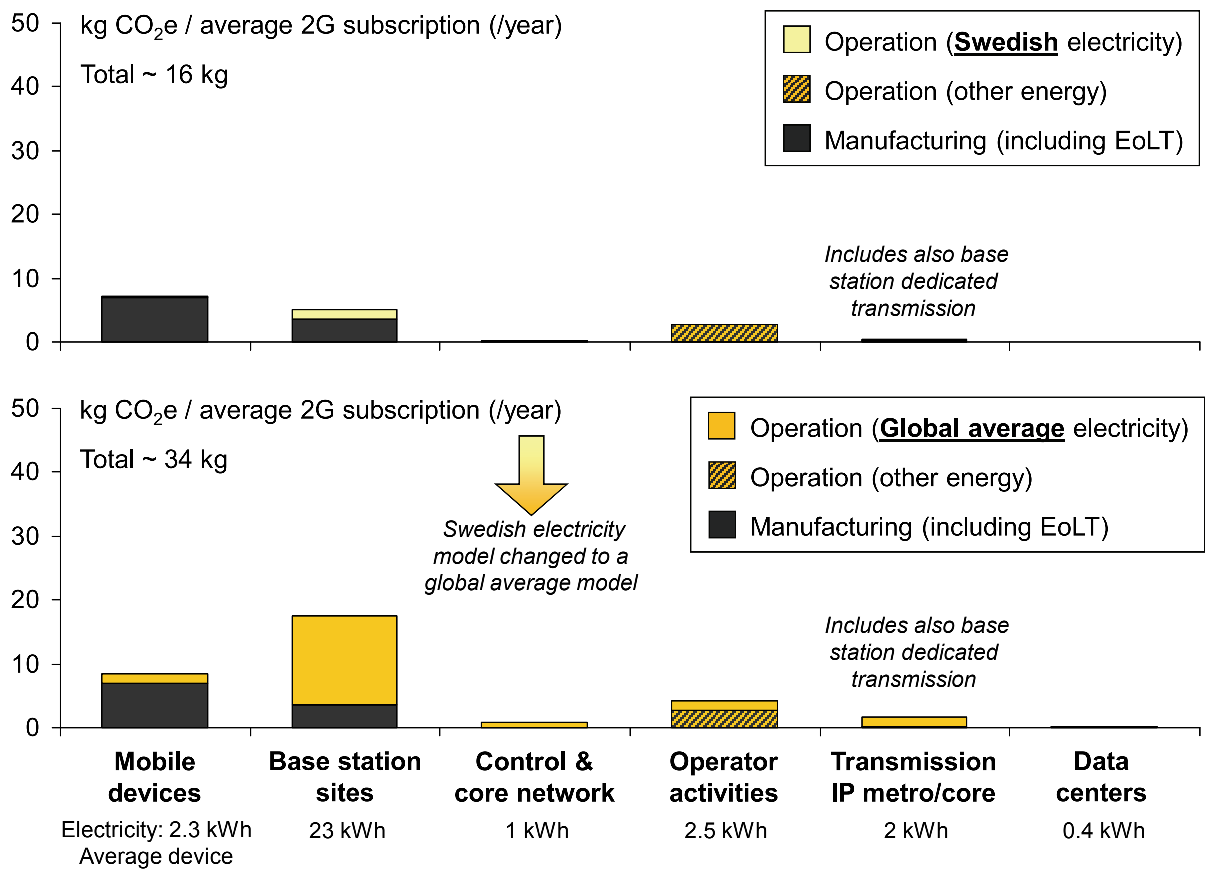

Figure S6.3.1. Detailed carbon footprint per average 2G (GSM) subscription in Sweden and in a global scenario, including figures for operational electricity use at the bottom.

Results summary (based on the global scenario with global average electricity):

- Largest contribution to the total carbon footprint comes from: Operation of base station sites and manufacturing of mobile phones, and then from operator activities.
- The total carbon footprint per average 2G (GSM) subscription/line is about 16 kg in Sweden and about 34 kg in the global scenario.

Two larger areas where improvements have been or can be made have been identified:

- The increase in mobile subscriptions and 3G subscriptions in particular have led to a reduction per subscription as base stations and other network parts is shared by more subscriptions.
- Operation of base station sites. The energy consumption have been reduced significantly for new GSM base stations since the first base station sites were built in Sweden in the early 90’s. There are still many older sites in operation that can be modernized.

S6.4: Detailed results for 3G (WCDMA) subscription

According to PTS (2011) definitions there were about 6.4 million active 3G subscriptions in Sweden in 2010 with average data traffic of about 8.5 GB.

User (mobile device) equipment: Based on an average mobile device specified in table S6.4.1. Supporting Information Appendix S2 describes how quantities and type of user equipment was estimated and how average manufacturing and electricity consumption data for user equipment have been estimated based on other studies, e.g. LCA studies. Ericsson has performed a number of LCAs of mobile phones over the years of which the latest published is Bergelin (2008).

Base station sites: 3G subscribers (subscriptions) as defined by PTS can also access older 2G base stations for voice but also for data when no 3G coverage exist, therefore the average electricity consumption for base stations uses the combined 2G and 3G base station average, 23 kWh/subscription. The electricity consumption for 3G base stations divided by 3G subscriptions is about 19 kWh/subscription. Manufacturing data is from Ericsson (2010) and is based on an average base station site installed in Sweden prior to 2005.

Control & core nodes: Core nodes shared by 2G and 3G have been allocated to each network based on internal experts at TeliaSonera. Manufacturing data is from Ericsson (2010) and is based on the average control and core node site installed in Sweden prior to 2005.

Operator activities: Based on TeliaSonera's operator activities (offices, stores, own cars, business travel) per average mobile subscription, including third party services and their car travel, see further Supporting Information Appendix S4. No manufacturing of buildings or vehicles or other infrastructure is included.

Transmission and IP core network: Electricity consumption and manufacturing is based on the average transmission and IP core network and data traffic model developed for Sweden (Malmodin et al 2012), and the average data traffic (including voice) generated by an average 3G subscription, about 8.5 GB/year. Dedicated transmission between the base station and the network (e.g. radio links) is included here (also the network counter part) and not together with the base station site equipment. The dedicated transmission's share of the CF for transmission and IP core network is about half of the total footprint.

Data centers: Based on the external/open or "Internet" part of all data centers in Sweden (50% of all servers estimated). About 25% of all data center locations and data traffic is estimated to be international which is accounted for by using global average electricity emissions for this part, even when studying Sweden only. See also Supporting Information Appendix S4.

Table S6.4.1. User (mobile devices) equipment data for an average 3G subscription

	Average phone	Smartphone	Laptop[1]	Desktop[1]	Average
Share of all mobile devices	55%	28%	12%	5%	1 average mobile device
Share allocated to 3G (allocated results shown below)	100%	100%	50%[1]	50%[1]	92%
Annual data traffic	4 GB (including voice)		30 GB		8.5 GB
Typical power	0.2 W	0.4 W	3 W	15 W	1.5 W
Annual electricity consumption	2 kWh	4 kWh	25.5 kWh	134 kWh	12.8 kWh
Annual operation CF…					
…Swedish electricity (0.06 kg CO_2-eq/kWh)	0.12 kg CO_2-eq	0.24 kg CO_2-eq	1.5 kg CO_2-eq	8 kg CO_2-eq	0.77 kg CO_2-eq
…Global electricity (0.6 kg CO_2-eq/kWh)	1.2 kg CO_2-eq	2.4 kg CO_2-eq	15 kg CO_2-eq	80 kg CO_2-eq	7.7 kg CO_2-eq
Manufacturing CF	21 kg CO_2-eq	36 kg CO_2-eq	106 kg CO_2-eq	195 kg CO_2-eq	46 kg CO_2-eq
Life time	3 years	3 years	4 years	4 years	3.2 years
Annual manufacturing CF	7 kg CO_2-eq	12 kg CO_2-eq	27 kg CO_2-eq	47 kg CO_2-eq	14.5 kg CO_2-eq

[1] Laptop and desktop PCs connected to 3G via data only subscriptions is allocated 50% to 3G and allocated results are shown in this table (50% of actual manufacturing and use). At the time of the study, number of tablet PCs with 3G was limited and not included in the study.

Table S6.4.2. Network data per subscription for an average 3G (WCDMA) subscription

	Base station sites	Control & core nodes	Operator activities[1]	Trans. And IP core network[2]	3rd part Data centers
Annual electricity consumption	23 kWh	1.3 kWh	Buildings: 2.2 kWh Data centers: 0.3 kWh	Dedicated: 2 kWh IP: 0.7 kWh	Sweden: 3 kWh +Global: 1 kWh
Average power	2.1 W	0.1 W	0.3 W	0.2 W	0.4 W
Annual operation CF…					
…w. Swedish electricity (0.06 kg CO_2-eq/kWh)	1.4 kg CO_2-eq	0.08 kg CO_2-eq	0.2 kg CO_2-eq	0.18 kg CO_2-eq	Swe.: 0.8 kg CO_2-eq +Global: 0.6 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq/kWh)	14 kg CO_2-eq	0.8 kg CO_2-eq	2 kg CO_2-eq	1.8 kg CO_2-eq	2.4 kg CO_2-eq
…Other energy CF			2.6 kg CO_2-eq		
Manufacturing CF					
Life time	7-20 years	5-20 years	Annually	5-40 years	5-20 years
Annual manufacturing CF	3.5 kg CO_2-eq	0.1 kg CO_2-eq	Not included	0.24 kg CO_2-eq	0.34 kg CO_2-eq

[1] TeliaSonera's own data centers (excluding hosted equipment) are included in operator's activities.
[2] Includes also dedicated transmission links between the base station sites and the higher order transmission network. About 2/3 of the electricity consumption and manufacturing carbon footprint is related to this dedicated transmission and not to the core network.

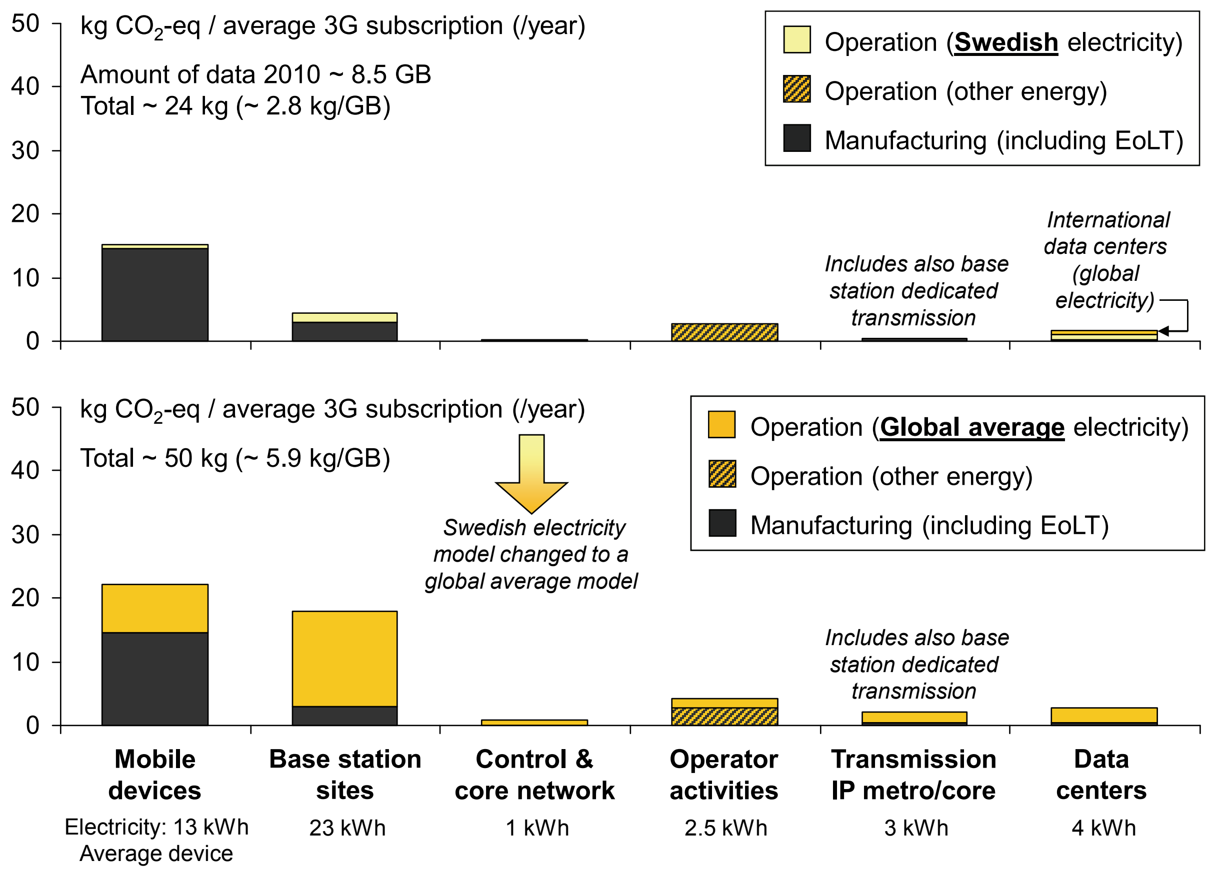

Figure S6.4.1. Detailed carbon footprint per average 3G (WCDMA) subscription in Sweden and in a global scenario, including figures for operational electricity use at the bottom. This figure also appears in the main article as figure 6.

Results summary (based on the global scenario with global average electricity):

- Largest contribution to the total carbon footprint comes from: Manufacturing of mobile devices (including PCs) and operation of base station sites, and then from operation of mobile devices (including PCs).
- The total carbon footprint (CO_2-eq) per average 3G (WCDMA) subscription/line is about 24 kg in Sweden and about 50 kg in the global scenario.
- Total CO_2-eq/GB is about 2.8 kg in Sweden and 5.9 kg in the global scenario. Note that data traffic is from 2010 and that it grows by about 100% per year.

Three larger areas where improvements have been or can be made have been identified:

- The increase in mobile subscriptions and 3G subscriptions in particular have led to a reduction per subscription as base stations and other network parts is shared by more subscriptions.
- Operation of base station sites. The energy consumption have been reduced significantly for new 3G base stations since the first base station sites were built in Sweden in 2001. There are still many older sites in operation that can be modernized.
- Manufacturing of mobile devices. The carbon footprint of mobile devices has increased compared to former studies due to more advanced smartphones and PCs with 3G data subscriptions, see data in S2.

S6.5: Detailed results for xDSL subscription

According to PTS (2010) there were about 1.7 million active xDSL subscriptions in Sweden on average in 2009 (mid year average).

User PCs: Based on an average PC used in homes specified in table 7. Supporting Information Appendix S2 describes how quantities and type of user equipment was estimated and how average manufacturing and electricity consumption data for user equipment have been estimated based on other studies, e.g. LCA studies. According to Zimmerman (2009) about 1.5 PCs is in active use in an average Swedish household. The estimated life time is estimated to 4.25 years, slightly higher than the average 4 year life time for PCs in Sweden as home PCs is used longer than office PCs.

CPE: Based on an average home modem and router setup with 1 modem and 0.5 routers. Both devices are estimated to consume about 80 kWh per year (9 W continuously), see further S2. 1 modem for 1 PC or 1 modem + 1 router for 2 PCs give the same average electricity consumption per PC. Manufacturing data for home modems and routers are taken from Malmodin et al (2010a).

Access network (xDSL access line): The copper cable infrastructure is shared with a PSTN subscription, see description in S6.1. About 1.7 million physical PSTN lines are shared with xDSL broadband lines but no share of the embodied footprint has been subtracted (allocated to PSTN) and therefore a whole line (100%) is allocated to a xDSL broadband subscription. If this allocation would have been based on data, nearly 100% would in fact be allocated to xDSL broadband.

Operator activities: Based on TeliaSonera's operator activities (offices, stores, own cars, business travel) per average fixed subscription, including third party services and their car travel, see further Supporting Information Appendix S4. No manufacturing of buildings or vehicles or other infrastructure is included.

Transmission and IP core network: Based on the average transmission and IP core network and data traffic model developed for Sweden (Malmodin et al 2012), and the average data traffic generated by an average xDSL subscription without IPTV, about 360 GB/year for an average broadband in Sweden excluding IPTV. Both operation of equipment and construction of the cable infrastructure are included.

Data centers: Based on the estimated external/open or "Internet" part of all data centers in Sweden and abroad, and the data traffic amount described above. About 25% of all data center locations and data traffic is estimated to be international which is accounted for by using global average electricity emissions for this part, even when studying ICT in Sweden only. See also Supporting Information Appendix S4.

Other user equipment besides PCs, first of all mobile devices, can use the xDSL subscription through WiFi access. This has not been accounted for in the study and the xDSL subscription has been fully allocated to PC use.

According to (PTS 2010) there were about 1.1 million active cable-TV (CATV) and FTTx subscriptions in Sweden on average in 2009 (mid year average). The results per xDSL subscription presented here can be assumed to be very similar for a home connected via CATV or FTTx (fiber to the x, x = e.g. home, curb, building) to the Internet. A similar CPE setup is used and the access network has similar electricity consumption per subscriber on average.

Table S6.5.1. User (PC) equipment data for the average home PC

	Desktop	Laptop, no extra monitor	User PC (average PC)	User PC (1.5 average PCs)
Quantity	2/3 (66%)	1/3 (33%)	1	1.5
	Figures below are for 1 PC:			
Typical power	32 W	6 W	23.5 W	35 W
Annual electricity consumption	282.5 kWh	53.5 kWh	206 kWh	309 kWh
Annual operation CF…				
…w. Swedish electricity (0.06 kg CO_2-eq/kWh)	17 kg CO_2-eq	3.2 kg CO_2-eq	12.4 kg CO_2-eq	18.6 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq/kWh)	170 kg CO_2-eq	32 kg CO_2-eq	124 kg CO_2-eq	186 kg CO_2-eq
Manufacturing CF	410 kg CO_2-eq	233 kg CO_2-eq	351 kg CO_2-eq	527 kg CO_2-eq
Life time	4.5 years	4.5 years	4.5 years	4.5 years
Annual manufacturing CF	91 kg CO_2-eq	52 kg CO_2-eq	78 kg CO_2-eq	117 kg CO_2-eq

Table S6.5.2. Network data per subscription for an average xDSL subscription

	CPE	Access network	Operator activities[1]	Trans. And IP core network[2]	3rd part Data centers
Annual electricity consumption	118 kWh	31 kWh	Buildings: 3.3 kWh Data centers: 1.5 kWh	29 kWh	Sweden (SWE): 137 kWh +Global: 46 kWh
Average power	13.5 W	3.5 W	0.5 W	3.2 W	21 W
Annual operation CF…					
…w. Swedish electricity (0.06 kg CO_2-eq/kWh)	7.1 kg CO_2-eq	1.9 kg CO_2-eq	0.3 kg CO_2-eq	1.7 kg CO_2-eq	Sweden: 8 kg CO_2-eq +Global: 28 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq /kWh)	71 kg CO_2-eq	19 kg CO_2-eq	2.9 kg CO_2-eq	17 kg CO_2-eq	110 kg CO_2-eq
…Other energy CF			4.8 kg CO_2-eq		
Manufacturing CF	35 kg CO_2-eq				
Life time	5 years		Annually		5 - 20 years
Annual manufacturing CF	5 kg CO_2-eq	6.4 kg CO_2-eq	Not included	3 kg CO_2-eq	15 kg CO_2-eq

[1] TeliaSonera's own data centers (excluding hosted equipment) are included in operator's activities.

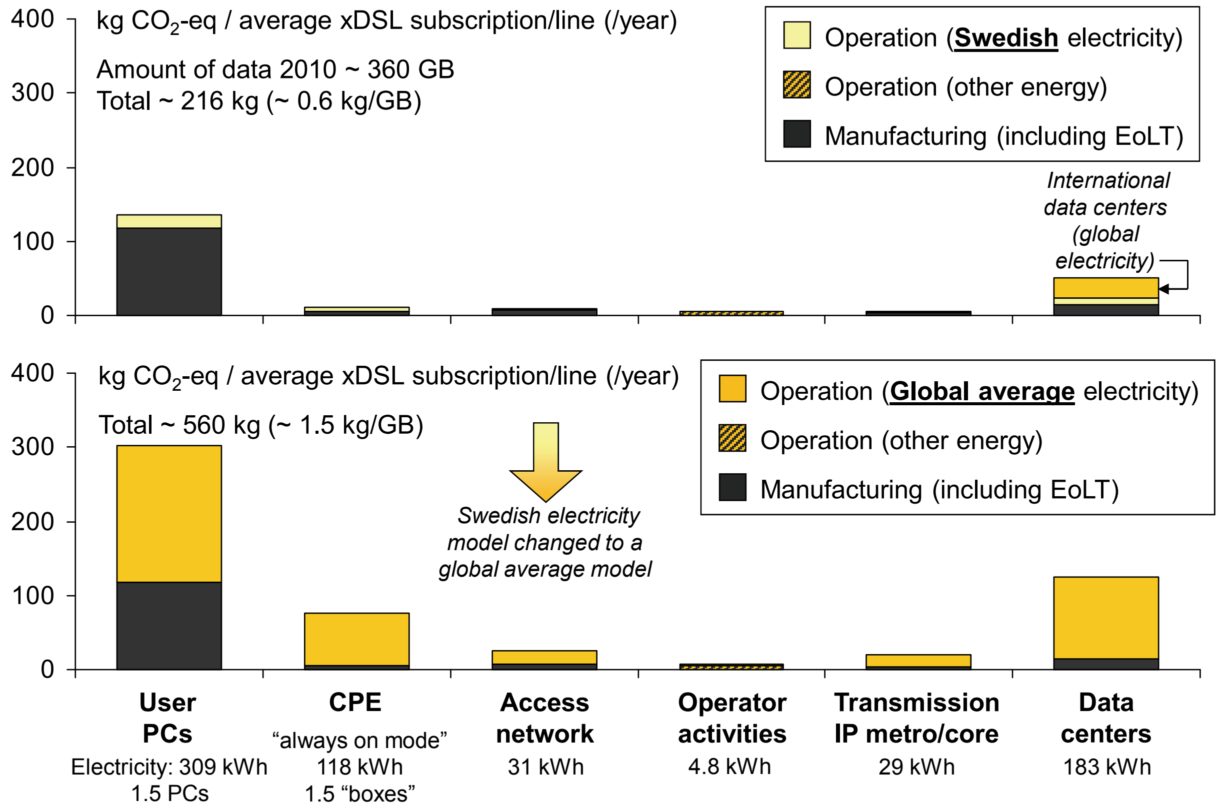

Figure S6.5.1. Detailed carbon footprint per average xDSL subscription in Sweden and in a global scenario, including figures for operational electricity use at the bottom. This figure also appears in the main article as figure 7.

Results summary (based on the global scenario with global average electricity):

- Largest contribution to the total carbon footprint comes from: User (PCs) equipment operation and manufacturing, data centers operation and then CPE operation.
- The total carbon footprint per average xDSL subscription is about 216 kg in Sweden and about 560 kg in the global scenario.
- Total CO_2-eq/GB is about 0.6 kg in Sweden and 1.5 kg in the global scenario. Note that data traffic is from 2010 and that it grows by about 30% per year (gives about 20% lower emissions per GB per year).

Three larger areas where improvements have been or can be made have been identified:

- The carbon footprint related to operation and manufacturing of PCs have been decreasing and can be expected to continue to decrease due to: the shift from CRTs to LCDs, the shift from desktops to laptops, the decrease in size, the advancements in semiconductor technology and power efficiency (e.g. longer battery life times for laptops). The average selling price (ASP) for PCs has decreased from over 2000$ in the mid 90's to about 1000$ in the mid 2000's (Apple 2009). ASP for a PC is a good proxy for the embodied carbon footprint of a PC.
- The CPE operation is an area identified for future improvements. Sleep modes could reduce the electricity consumption when no device is on and sends/receives user data. To share one gateway in e.g. a 3-play subscription lower the CPE per individual service (Internet, VoIP and IPTV).

- Data centers that host all different ICT data services are increasing its footprint but the growth is expected to slow down due to the many electricity reduction projects going on as a result of the increased focus on the electricity consumption of data centers, see Koomey (2011).

S6.6: Detailed results for 3-play subscription

According to PTS (2010) there were about 0.35 million active 3-play subscriptions in Sweden on average in 2009 (mid year average).

User equipment: The phones used are the same as described in S6.2 and the 2 PCs (assumption in the study) used together with a 3-play subscription is based on 1 desktop and 1 laptop described in S6.5. An average TV and STB is used in the study. It could be argued it's the primary TV (with a larger screen and used more frequently) that's used in a household together with a 3-play subscription. But it could also be argued that some of the use is related to non-IP use e.g. based on optical disc media (gaming, movies etc.). No usage study was done to support an allocation and the average TV model was used unchanged. Supporting Information Appendix S2 describes how quantities and type of user equipment was estimated and how average manufacturing and electricity consumption data for user equipment have been estimated based on other studies, e.g. LCA studies.

CPE: Based on a new 3-play gateway that consumes about 11 W on average (96 kWh annually). See S2 for further information about the gateway data.

Access network (xDSL access line): The copper cable infrastructure is shared with a PSTN subscription, see description in S6.1. About 1.7 million physical PSTN lines are shared with xDSL broadband lines but no share of the embodied footprint related to the line itself has been subtracted (allocated to PSTN) and a whole line is allocated to a broadband subscription. If this allocation would be based on data, nearly 100% would in fact be allocated to broadband.

Operator activities: Based on TeliaSonera's operator activities (offices, stores, own cars, business travel) per average fixed subscription, including third party services and their car travel, see further Supporting Information Appendix S4. No manufacturing of buildings or vehicles or other infrastructure is included. A 3-play subscription is estimated to require 2 times the resources compared to an ordinary xDSL or PSTN subscription.

Transmission and IP core network: Based on the average transmission and IP core network and data traffic model developed for Sweden (Malmodin et al 2012), and the average data traffic generated by an average 3-play subscription including IPTV, about 800 GB/year. Both operation of equipment and construction of the cable infrastructure are included.

Data centers: Based on the estimated external/open or "Internet" part of all data centers in Sweden and abroad, and the data traffic amount excluding IPTV (about 500 GB) described above. All network nodes and data centers serving IPTV is included in TeliaSonera's internal IP core network and data centers. About 25% of all data center locations and data traffic is estimated to be international which is accounted for by using global average electricity emissions for this part, even when studying ICT in Sweden only. See also Supporting Information Appendix S4.

Table S6.6.1. User (PC) equipment data for the average home PC

	User (phone) Equipment	User PC (2 average PCs)	TV	STB
Quantity	1 analog, 1 cordless	1 desktop, 1 laptop	1 large primary	1
Typical power	3 W	47 W	32 W	7 W
Annual electricity consumption	27 kWh	412 kWh	200 kWh	61 kWh
Annual operation CF…				
…w. Swedish electricity (0.06 kg CO_2-eq/kWh)	1.6 kg CO_2-eq	25 kg CO_2-eq	12 kg CO_2-eq	3.7 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq /kWh)	16 kg CO_2-eq	248 kg CO_2-eq	120 kg CO_2-eq	37 kg CO_2-eq
Manufacturing CF	(20 kg CO_2-eq)	702 kg CO_2-eq	300 kg CO_2-eq	25 kg CO_2-eq
Life time	7.5 years	4.5 years	7 years	5 years
Annual manufacturing CF	3.5 kg CO_2-eq	156 kg CO_2-eq	43 kg CO_2-eq	5 kg CO_2-eq

Table S6.6.2. Network data per subscription for an average 3-play subscription

	CPE, 3-play gateway	Access network	Operator activities[1]	Trans. And IP core network[2]	3rd part Data centers
Annual electricity consumption	96 kWh	31 kWh	Buildings: 6.6 kWh Data centers: 3 kWh	74 kWh	Sweden: 180 kWh +Global: 64 kWh
Average power	11 W	3.5 W	0.5 W	3.2 W	29 W
Annual operation CF…					
…w. Swedish electricity (0.06 kg CO_2-eq /kWh)	5.8 kg CO_2-eq	1.9 kg CO_2-eq	0.6 kg CO_2-eq	4.4 kg CO_2-eq	Sweden: 12 kg CO_2-eq +Global: 38 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq /kWh)	58 kg CO_2-eq	19 kg CO_2-eq	5.8 kg CO_2-eq	44 kg CO_2-eq	153 kg CO_2-eq
…Other energy CF			9.6 kg CO_2-eq		
Manufacturing CF	50 kg CO_2-eq				
Life time	5 years		Annually		5 - 20 years
Annual manufacturing CF	10 kg CO_2-eq	6.4 kg CO_2-eq	Not included	7.7 kg CO_2-eq	21 kg CO_2-eq

[1] TeliaSonera's own data centers (excluding hosted equipment) are included in operator's activities.

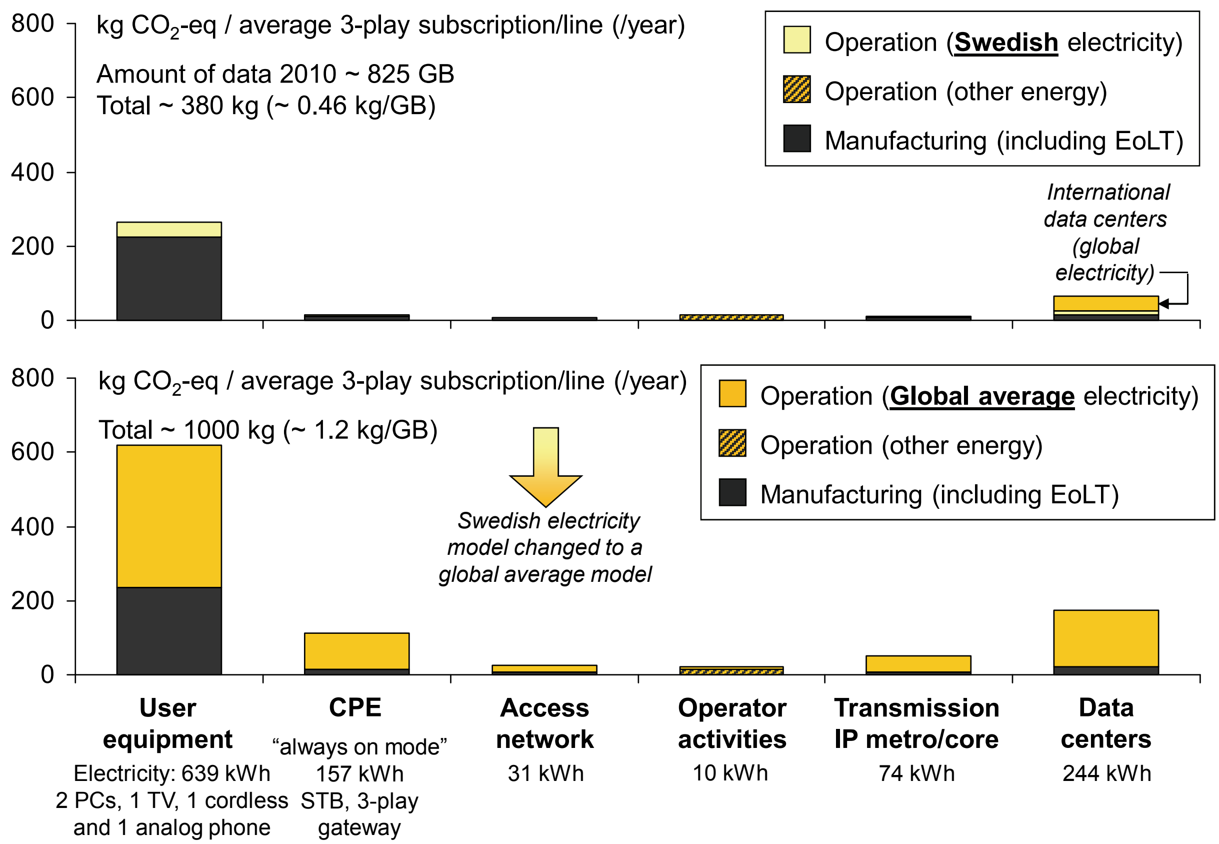

Figure S6.6.1. Detailed carbon footprint per average 3-play subscription in Sweden and in a global scenario, including figures for operational electricity use at the bottom. This figure also appears in the main article as figure 8.

Results summary (based on the global scenario with global average electricity):

- Largest contribution to the total carbon footprint comes from: User equipment operation and manufacturing, data centers operation and then CPE operation.
- The total carbon footprint per average 3-play subscription is about 380 kg in Sweden and about 1000 kg in the global scenario.
- Total CO_2-eq/GB is about 0.46 kg in Sweden and 1.2 kg in the global scenario. Note that data traffic is from 2010 and that it grows by about 30% per year.

Three larger areas where improvements have been or can be made have been identified:

- The same reduction of the embodied footprint and electricity consumption of PCs described in S6.6 also applies here. TVs show similar trends but efficiency improvements are somewhat countered by larger and larger screen sizes.
- The CPE operation is an area identified for future improvements. Sleep modes could reduce the electricity consumption when no device is on and sends/receives user data. To share one gateway in e.g. a 3-play subscription lower the CPE per individual service (Internet, VoIP and IPTV).
- Data centers that host all different ICT data services are increasing its footprint but the growth is expected to slow down due to the many electricity reduction projects going on as a result of the increased focus on the electricity consumption of data centers, see Koomey (2011).

S6.7: Detailed results for workplace PC

Number of workplace PCs have been estimated to about 2.1 million in Sweden in 2010.

Workplace PCs: The average workplace PC is based on desktops (50%) and laptops (50%) including extra monitors and docking stations. The share of laptops is increasing and about 2/3 of all PCs sold in Sweden in 2010 was laptops. The estimated life time is estimated to 3.5 years, a bit lower than the average 4 year life time for PCs in Sweden as office PCs is used shorter than home PCs.

CPE: The term CPE is usually used for residential equipment but here used for office equipment and includes printers and copiers (largest share of CPE electricity consumption), projectors and video- and teleconference equipment. Based on internal studies at TeliaSonera and Ericsson, the electricity consumption of workplace CPE has been reduced substantially and is today only about 1/3 per workplace PC compared to about 10 years ago.

LAN: LAN equipment includes all access switches/routers and aggregation switches/routers and all network cables. Total electricity consumption of all equipment per active workplace PC is based on internal studies at TeliaSonera and Ericsson.

Service provider activities: Can be both in-house or sourced from a third party (more common today) but they are not included in this study.

Transmission and IP core network: Based on the average transmission and IP core network and data traffic model developed for Sweden (Malmodin et al 2012), and the average data traffic generated by an average LAN or workplace PC on the external IP core network, about 100 GB/year. Both operation of equipment and construction of the cable infrastructure are included. All internal LAN data traffic is included in the LAN part above (third bullet).

Data centers: Based also on the estimated external/open or “Internet” part of all data centers in Sweden and abroad, and the WAN data traffic amount (100 GB) described above. About 25% of all data center locations and data traffic is estimated to be international which is accounted for by using global average electricity emissions for this part, even when studying ICT in Sweden only. See also Supporting Information Appendix S4.

Table S6.7.1. User (PC) equipment data for the average workplace PC

	Desktop	Laptop, extra monitor, docking station	User PC (average)
Quantity	50%	50%	100% (1)
	Figures below are for 1 PC:		
Typical power	39 W	19 W	29 W
Annual electricity consumption	340 kWh	170 kWh	255 kWh
Annual operation CF…			
…w. Swedish electricity (0.06 kg CO_2-eq /kWh)	20.4 kg CO_2-eq	10.2 kg CO_2-eq	15.3 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq /kWh)	204 kg CO_2-eq	102 kg CO_2-eq	153 kg CO_2-eq
Manufacturing CF	410 kg CO_2-eq	382 kg CO_2-eq	396 kg CO_2-eq
Life time	3.75 years	3.75 years	3.75 years
Annual manufacturing CF	109 kg CO_2-eq	102 CO_2-eq	106 CO_2-eq

Table S6.7.2. LAN network data per workplace PC

	CPE (office equipment)	LAN	Trans. And IP core network[2]	3rd part Data centers
Annual electricity consumption	52 kWh	35 kWh	8 kWh	Sweden: 258 kWh +Global: 13 kWh
Average power	6 W	4 W	0.9 W	31 W
Annual operation CF…				
…w. Swedish electricity (0.06 kg CO_2-eq /kWh)	3.1 kg CO_2-eq	2.1 kg CO_2-eq	0.5 kg CO_2-eq	Sweden: 15 kg CO_2-eq +Global: 8 kg CO_2-eq
…w. Global electricity (0.6 kg CO_2-eq /kWh)	31 kg CO_2-eq	21 kg CO_2-eq	5 kg CO_2-eq	163 kg CO_2-eq
…Other energy CF				
Manufacturing CF				
Life time				5 - 20 years
Annual manufacturing CF	3 kg CO_2-eq	5 kg CO_2-eq	1.4 kg CO_2-eq	23 kg CO_2-eq

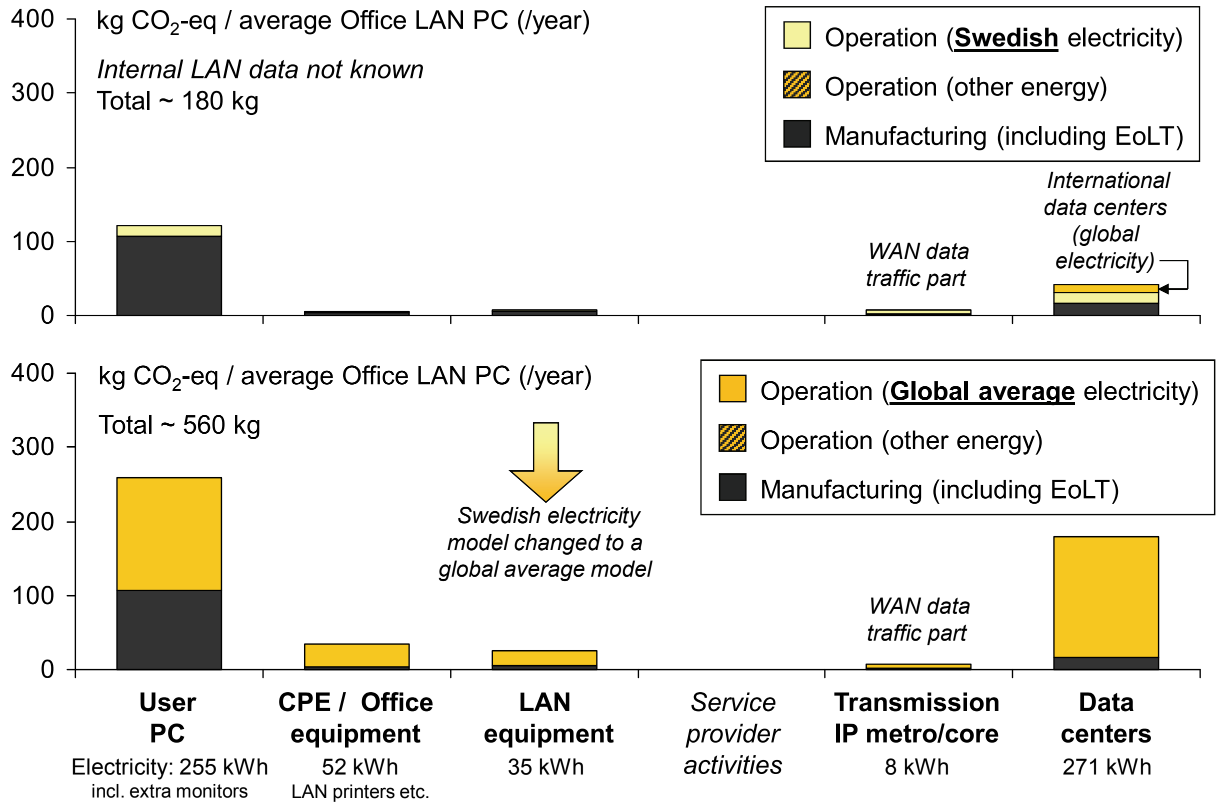

Figure S6.7.1. Detailed carbon footprint per average workplace PC in Sweden and in a global scenario, including figures for operational electricity use at the bottom.

Results summary:

- Largest contribution to the total carbon footprint comes from: Data centers operation, workplace PCs operation and then workplace PCs manufacturing.
- Data centers carbon footprint is here more than twice as large as the data centers carbon footprint per average home xDSL subscription.
- The total carbon footprint per average workplace PC is about 180 kg in Sweden and about 560 kg in the global scenario.
- Internal LAN data traffic is not known and total CO_2-eq/GB cannot be presented.

Three larger areas where improvements have been made or can be made are identified:

- Many enterprises/organizations, especially small and medium sized ones, use servers and storage less efficient (low utilization). More centralized IT solutions ("cloud services") could reduce the electricity consumption for data centers/rooms substantially, with as much as >90% for small enterprises that have their IT systems on-premise locally (Accenture 2010).
- Continue to replace desktop PCs and old CRT monitors still in use with new energy efficient laptops and LCD monitors. Older less efficient LCD monitors and docking stations may also be replaced.
- The electricity consumption including stand-by for office equipment has been reduced significantly over the years, especially for printers and copiers.

Appendix S7: Abbreviations and Terminology used

The following list presents an overall description of the most common abbreviations used in the article and supporting information. If there is a request for additional description and or functionality some online information is available at the following sites:

- http://webapp.etsi.org/Teddi/
- http://www.itu.int/SearchCenter/Pages/default.aspx

S7.1 Abbreviations and explanations

Name or abbreviation	Full name	Explanation
2G	Global System for Mobile Communications (GSM).	Standard for Mobile Communication
3G	Universal Mobile Telecommunications System (UMTS) or Wideband CDMA (WCDMA).	Standard for Mobile Communication
ADSL	Asymmetrical Digital Subscriber Line	See xDSL
AEC	Annual Electricity Consumption	
AXE	-	Automatic PSTN exchange.
B2B	Business to Business	
BSC	Base Station Controller	
BSS	Business Support Centre	System located in data centers used by telephone operators to run internal and business operations linked to support the need for end to end user services.
CATV	Cable Television	
CF	Carbon Footprint	
CPE	Customer Premises Equipment	Communication devices to facilitate data communication between Internet and within
DECT	Digital Enhanced Cordless Telecommunication	Cordless fixed phone
Disc boxes		Part of Data center storage system of large quantities of data such as back up and operational data.
DSLAM	Digital Subscriber Line Access Multiplexer	
DWDM	Dense WDM	Special case of WDM.
EoLT	End Of Life Treatment	
FTTx	Fiber To The (x = Cab Cabinet, x = C Curb, x = B Building, x = H Home)	

FX	Remote Exchange	
GHG	Green House Gas	
GRI	Global Reporting Initiative	
GGSN	Gateway GPRS Support Node	
GSM	Global System for Mobile Communication	
GPRS	General Packet Radio Service	
HLR	Home Location Register	
ICT	Information Communication Technology	
IO LCA	Input-Output Life Cycle Assessment	
IP	Internet Protocol	
IP Core	IP Core network	
IP Metro	IP Metro Network	
IPTV	Internet Protocol TeleVision	
IT	Information Technology	
LAN	Local Area Network	
LCI	Life Cycle Inventory data	
LIC	Line Interface Card	The LIC terminates the physical PSTN subscription line from the end user
LX	Local Exchange	
M2M	Machine to machine	
MSC	Mobile Switching Center	
OSS	Operator Support System	System located in data centers used by telephone operators to run internal and business operations linked to support the need for end to end user services.
P2P	Peer to Peer	
PBX	Private Board eXchange	
PDH	Plesiochronous Digital Hierarchy	
PSTN	Public Switch Telecommunication Network	
PTS	The Swedish Post and Telecom Agency	
PUE	Power Usage Effectiveness	
Radio link		Fixed point to point radio based communication
RGW	Gateway and Residential Gateway (RGW)	Communication devices to facilitate data communication between Internet and within LAN. Includes modem and switch/router functionality and may also include VoIP functionality.
Router		Active and smart devices that facilitate data communication/steering to and from as well as within LAN. A router can be small and used in a home or big used in the core network. Two special cases worth highlighting: • Core router: Operates in the Internet

		backbone/core network. It transfer and sort large volumes of IP packages (Gigabit/second) with minimal delay's via many different interfaces at full speed. • Edge router: Equal to the core router with the distinction that an edge router is located at the edge of a backbone network, not in the network it selves.
SAN array	Storage Area Network	Part of Data center storage system of large quantities of data such as back up and operational data.
SDH	Synchronous Digital Hierarchy	
SGSN	Serving GPRS Support Node	
STB	Set Top Box	
Storage robot		Older Data center solution for data storage under phase out.
Switch		Active but "dumb" device that facilitate data communication within LAN. A switch that enables signals in optical fibers, integrated optical circuits or copper cables to be selectively switched from one circuit to another. On core network level the majority of switching is performed on optical fibers.
UPS	Uninterrupted Power Source	Backup power
WAN switch		Part of Data center storage system of large quantities of data such as back up and operational data.
VCR	Video Conference System	
VDSL	Very high bit-rate Digital Subscriber Line	See xDSL
VoIP	Voice over IP	
WCDMA	Wide band Code Division Multiple Access	See 3G
WDM	Wavelength Division Multiplexing	In optic communications used to combine a number of optical carrier signals into one single optical fiber by using different wavelengths. This makes it possible to communicate both ways on a single fiber as well as multiplies capacity without the need of installing new optical fiber cables
WiFi	Wireless Fidelity	IEEE 802.11 family of standards
xDSL	Digital Subscriber Line (ADSL or VDSL)	See ADSL and VDSL

References in Supporting Information

Accenture. 2010. Cloud Computing and Sustainability: The Environmental Benefits of Moving to the Cloud.

Alcatel, 2008. Life cycle assessment of GPON and DSL technologies for broadband access, RDC environment report, September 2008.

Apple. 2008-2012. LCA studies of PCs, monitors and mobile phones verified by The Fraunhofer Institute, Germany. http://www.apple.com/environment/resources/environmentalperformance.html.

Apple. 2009. Mac sales projected to grow 26% in 2010, outpacing PC market. Apple Insider: http://appleinsider.com/articles/09/12/03/mac_sales_projected_to_grow_26_in_2010_outpacing_pc_market

Atlantic consulting and IPU. 1998. LCA study of the product group personal computers in the EU ecolabel scheme.

Baliga et al 2009, Energy Consumption in Optical IP Networks. IEEE. Journal of Lightwave Technology. Volume 27, issue 13: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4815495&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F50%2F5133707%2F04815495.pdf%3Farnumber%3D4815495

Bergelin, F. 2008. Life cycle assessment of a mobile phone - a model on manufacturing, using and recycling. MSc thesis, Ericsson Research and Uppsala University. ISSN: 14-5773, UPTEC Q08014. 2008

Coroama, V., L. Hilty, E. Heiri, F. Horn. 2013. The direct Energy Demand of Internet Data Flows. *Journal of Industrial Ecology* 17(5):680-688.

Dell. 2010a. Carbon Footprint of a Typical Business Laptop From Dell http://i.dell.com/sites/content/corporate/corp-comm/en/Documents/dell-laptop-carbon-footprint-whitepaper.pdf. Accessed in September 2010

Dell. 2010b. Carbon Footprint of a Typical Business Desktop From Dell: http://i.dell.com/sites/doccontent/corporate/corp-comm/en/Documents/dell-desktop-carbon-footprint-whitepaper.pdf. Accessed in September 2010

Della Croce F. and O. Jolliet. 2001. Energy consumption and environmental impacts of the Internet in the US. Ecole polytechnique federale de Lausanne.

Donovan, C. 2009. Twenty tousend leagues under the sea: A Life cycle assessment of fibre optic submarine cable systems. MSc Thesis. Degree project SoM Ex 2009:40. Department of urban planning and environment, Royal institute of technology, Stockholm.

Duan H., M. Eugster, R. Hischier, M. Streicher-Porte, J. Li. 2009. Life cycle assessment study of a Chinese desktop personal computer. Science of the total environment. 407:1755-1764.

Ecoinvent Centre, Extension database to GaBi 4 Professional or stand-alone with GaBi 4 software. Copyright, Ecoinvent EMPA Ueberlandstrasse 129 CH-8600 Duebendorf, Switzerland, www.ecoinvent.org.

Ericsson. 2002. Life cycle assessment of a 3G system (final report), Ericsson technical report, 2002. Externally verified (ISO 14 04x). Includes LCA data and results from earlier LCA studies (-2002).

Ericsson. 2010. Life cycle assessment of Ericsson mobile communication systems. Ericsson technical report, 2010. Externally verified (ISO 14 04x). Includes LCA data and results from earlier LCA studies (2005-2010).

EU. 2011. EU Code of Conduct on energy consumption of Broadband Equipment. Version 4. Also available at: http://iet.jrc.ec.europa.eu/energyefficiency/ict-codes-conduct/energy-consumption-broadband-communication-equipment

Fraunhofer IZM and PE Europe. 2007. EuP Preparatory Studies “Televisions” (Lot 5). Final Report on Task 5 “Definition of Base Cases”. Report for Tender No. TREN/D1/40 lot 5-2005. Berlin

FTTH, 2008. Developing a generic approach for FTTH solutions using LCA methodology. [Report prepared for FTTH Council] February 2008 e.d. Ecobilan S.A.

GeSI. 2008. Smart 2020: Enabling the low carbon economy in the information age. A report by The Climate Group on behalf of the Global eSustainability Initiative (GeSI)

Google. 2011. Google carbon footprint 2010 available at: http://www.google.com/green/the-big-picture.html

Hermann. C. 2008. Environmental Footprint of ICT Equipment in Manufacture, Use and End of Life. Presentation made at ECOC in Brussels 23rd September 2008.

Hishier and Baudin, 2010. LCA study of plasma television device. International Journal of Life Cycle Assessment. Volume 15, Number 5. Page 428-438.

Hochschorner E., György D., Moberg Å. 2011. LCA of movie distribution, using Internet a screening study. Presentation at the 3rd NorLCA symposium in Helsinki 15-16 September 2011.

Inge M. 2009. “De 10 värsta strömtjuvarna” (In Swedish, measurements of consumer electronics power consumption over time with professional equipment) M3 Digital, August 2009.

IVF. 2007. Lot 3. Personal Computers (desktops and laptops) and Computer Monitors. Final Report (Task 1-8). IVF Report 07004. ISSN 1404-191X.

Koomey. J.2011. Growth in Data center electricity use 2005 to2010. Oakland, CA: Analytics Press. August 1. Also available at: http://www.analyticspress.com/datacenters.html

Lange et al, Energy Consumption of Telecommunication Network and Related Improvement Options. IEEE Journal of selected topics in quantum Electronics. Vol 17 no 2. March/April 2011

Lindroth, M. 1999a. Life cycle assessment of radio relay systems. MSc Thesis. TRITA-KET-IM 1999:30, ISSN 1402-7615. Industrial Ecology, Royal institute of technology, Stockholm.

Lindroth, M. 1999b. Livscykelanalys av telefoniabonnemang (In English: Life cycle assessment of fixed telephone subscription services). TeliaSonera internal report, externally verified by IVL 2000. Stockholm.

Loerincik, Y. 2006. Environmental impacts and benefits of information and communication technology infrastructure and services, using process and input-output life cycle assessment. These no 3540. École Polytechnique Fédérale de Lausanne (EPFL).

Malmodin et al. 2010a. Greenhouse gas emissions and operational electricity use in the ICT and entertainment & media sector. Journal of Industrial Ecology 14, 770-790.

Malmodin, J., D. Lundén, and N. Lövehagen. 2010b. Methodology for life cycle based assessments of the CO_2 reduction potential of ICT services. IEEE International Symposium on Sustainable Systems and Technology (ISSST). Washington May 16-19 2010. Available at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5507738.

Malmodin et al. 2012. LCA of data transmission and IP core networks. Conference paper. Electronics Goes Green 2012+ (EGG). Also available at: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6360437&contentType=Conference+Publications&sortType%3Dasc_p_Sequence%26filter%3DAND%28p_IS_Number%3A6360408%29%26rowsPerPage%3D75

MCC. 1993. Environmental consciousness: A strategic competitiveness issue for the electronic and computer industry. Austin, TX: Microelectronics and Computer Technology Corporation.

Nokia. 2005. Integrated Product Policy Pilot Project. Stage I Report. Part of European Commission's Integrated Product Policy (IPP) project.

NTT. 2003. Dynamic model for analysing environmental impacts caused by the ICT infrastructure in Japan. Presented by NTT at the conference Environmental Assessment in the Information Society, 3-4 Dec 2003, Lausanne, Switzerland

PTS. 2008. The Swedish Post and Telecom Agency. The Swedish Telecommunications Market 2007 - PTS-ER-2008:15. Also available at http://www.statistics.pts.se/start_en/

PTS. 2009. The Swedish Post and Telecom Agency. The Swedish Telecommunications Market 2008 - PTS-ER-2009:21. Also available at http://www.statistics.pts.se/start_en/

PTS. 2010. The Swedish Post and Telecom Agency. The Swedish Telecommunications Market 2009 - PTS-ER-2010:13. Also available at http://www.statistics.pts.se/start_en/

PTS. 2011. The Swedish Post and Telecom Agency. The Swedish Telecommunications Market 2010 - PTS-ER-2011:15. Also available at http://www.statistics.pts.se/start_en/

Roth, K.W. and K. McKenney. 2007. Energy consumption by Consumer Electronics in U.S. Residences. TIAX LLC

Socolof, M. L., J.G. Overlay and J.R Geibig. 2005. Environmental life-cycle impacts of CRT and LCD desktop computer displays. Journal of Cleaner Production 13(13-14):1281-1294

Taeko, A., T. Michiyasu, Y. Matsuoka and N. Shikata. 2003. Case Study for Calculation of Factor X (Eco-Efficiency) – Comparing CRT TV, PDP TV and LCD TV. In Proceedings of EcoDesign2003: Third International Symposium on Environmentally Conscious Design and Inverse Manufacturing, Tokyo, Japan, December 8-11, 2003.

Tekawa, M. 1999. NEC Environmental report 1999. NEC corporation.

Tingstorp, S. 1998 (Reviewed by Lindroth, M. 1999). Livscykelanalys för anläggning av telekabel. (In English: Life cycle assessment of construction and excavation for telephone cable services). MSc Thesis. 1998:280 CIV, ISSN:1402-1617, ISRN:LTU-EX-98/280-SE. Institutionen för Samhällsbyggnadsteknik, Luleå tekniska Universitet. Luleå.

Weber, C. 2010a. Uncertainty and Variability in Carbon Footprinting for Electronics - Case Study of an IBM Rack-mount Server. Executive Summary. Carnegie Mellon University 2010.

Weber et al. 2010b. The Energy and Climate Change Impacts of Different Music Delivery Methods. The Journal of Industrial Ecology. vol. 14, no. 5. October. pp. 754–769. Available at: http://dx.doi.org/10.1111/j.1530-9290.2010.00269.x

Williams, E. 2004. Energy intensity of computer manufacturing: hybrid analysis combining process and economic input-output methods. Environmental Science and Technology 38(22): 6166-6174.

Zimmermann, J. P. 2009. End-use metering campaign in 400 households in Sweden. Assessment of the potential of electricity savings. Enertech. Eskilstuna: Swedish Energy Agency.