Methodology for Life Cycle Based Assessments of the CO_2 Reduction Potential of ICT Services

Jens Malmodin, Dag Lundén, and Nina Lövehagen

***Abstract*— The presented LCA-based method can be used when assessing the potential CO_2e emission reduction from introducing an ICT-based service. The method was used to analyze the CO_2e emissions from the communication networks in Sweden as well as on the effects of introducing smart work solutions at TeliaSonera. For TeliaSonera the CO_2e reductions resulting from smart work sum up to about 40% per employee, or over 2.8 ton CO_2e per employee and year. The total reduction potential due to smart work in the world was estimated to be 2 % - 4% of global CO_2e emissions, if reductions of 20% - 40% can be achieved per employee in a 10 – 20 year timeframe.**

***Index Terms*— carbon dioxide, ICT, life cycle assessment, smart work**

I. INTRODUCTION

CLIMATE change is one of the major challenges of our time. Scientific consensus points to a need to reduce the emissions of greenhouse gases (GHG) to prevent climate change from having a severe impact on the planet. The information and communications technology (ICT) sector can provide solutions to help reduce the GHG emissions.

There are currently several methods and approaches used to analyze the reduction of CO_2 emissions from introducing ICT solutions e.g. [1]. These methods are seldom based on life cycle assessments (LCA), and they typically only include the end-user equipment. However, recent work has shown that the environmental impacts from the infrastructure are important to include, [2]-[3].

Ericsson has developed a method for how to assess the environmental impact reduction potential from the use of ICT services [4]. The method can be used for various environmental impact categories, but here only global warming potential, measured in CO_2e (CO_2 equivalents), is described.

In this collaborative project between Ericsson and TeliaSonera, this method has been used to estimate the CO_2e emissions of ICT services in Sweden. ICT is here defined as fixed and mobile communications, including all end-user equipment such as mobile phones and PCs, the networks, the operators and service providers and data centers. As a second part, a case study of the implementation of smart work solutions and CO_2e emission reductions at TeliaSonera has been performed, also scaled up to a nationwide implementation in Sweden.

II. METHODOLOGY FOR MAKING LCA ON SERVICES

To be able to quantify the potential CO_2e reductions of ICT applications and services, environmental impacts of both the ICT based system and the so called conventional system, i.e. the solution the ICT based service is replacing, need to be assessed from a life cycle perspective. Figure 1 gives an overview of the developed methodological framework.

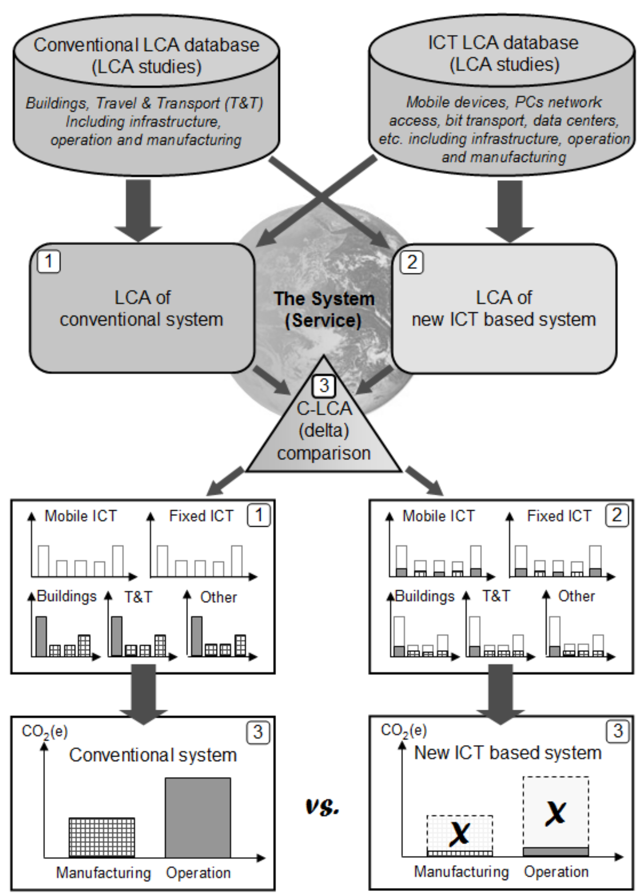

Fig.1. Overview of the developed methodological framework

An LCA provides a systematic approach to the impacts,

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from resource extraction, through the design, manufacturing, distribution, use phase and end-of-life treatment.

The methodology is based on the LCA methodology specified in the ISO 14040 series [5]-[6].

To assess the potential CO_2e reductions, a number of steps need to be followed, both for the ICT based system and for the system it replaces:

a) **Define the processes and boundaries** of the ICT based service and the conventional system, (e.g. travel and building use that might be influenced of the introduction of the new service).
b) **Collect data** for both the ICT based system and the conventional system.
c) **Assess CO_2e impacts** based on LCA methodology and compare the collected baseline data of emissions from the conventional system with the emissions obtained when ICT solutions are introduced.

The scope of the presented method includes a wide perspective, covering the life cycle aspects of the infrastructure, see Fig. 2. This means that for ICT systems, infrastructure parts like towers, cables and data centers need to be included, and for conventional sectors data for road and building infrastructure, etc. should be compiled.

A. Conventional services

An important part of an LCA on a service is to also include indirect emissions over time that can be related to both ICT systems and all conventional activities.

Table I shows the emission factors and the factor used to include total indirect emissions, such as infrastructure, that have been applied for Sweden and when scaling the results to the world. The manufacturing of cars, roads and other supporting infrastructure are by that included in car travel. Likewise, the construction of buildings and supporting infrastructure like the electricity grid are included in buildings, airports and aircrafts as well as travel to and from the airport.

TABLE I
CO_2 EMISSION FACTORS

Activity	Direct Travel or Operation		Factor to Include Total Indirect Emissions	
	Sweden	World average	Sweden	World average
Car travel	0.18 kg/pkm	0.18 kg/pkm	1.8	1.9
Air travel	0.12 kg/pkm	0.12 kg/pkm	2.4	2.4
Building operation	21 kg/m^2	74 kg/m^2	2	1.65

kg = kilogram, pkm = personal kilometer, m^2 = square meter

To be able to use the methodology for a specific service the environmental impacts from the total system needs to be allocated to all different services provided. This is done by considering equipment type, life time, use time and data traffic.

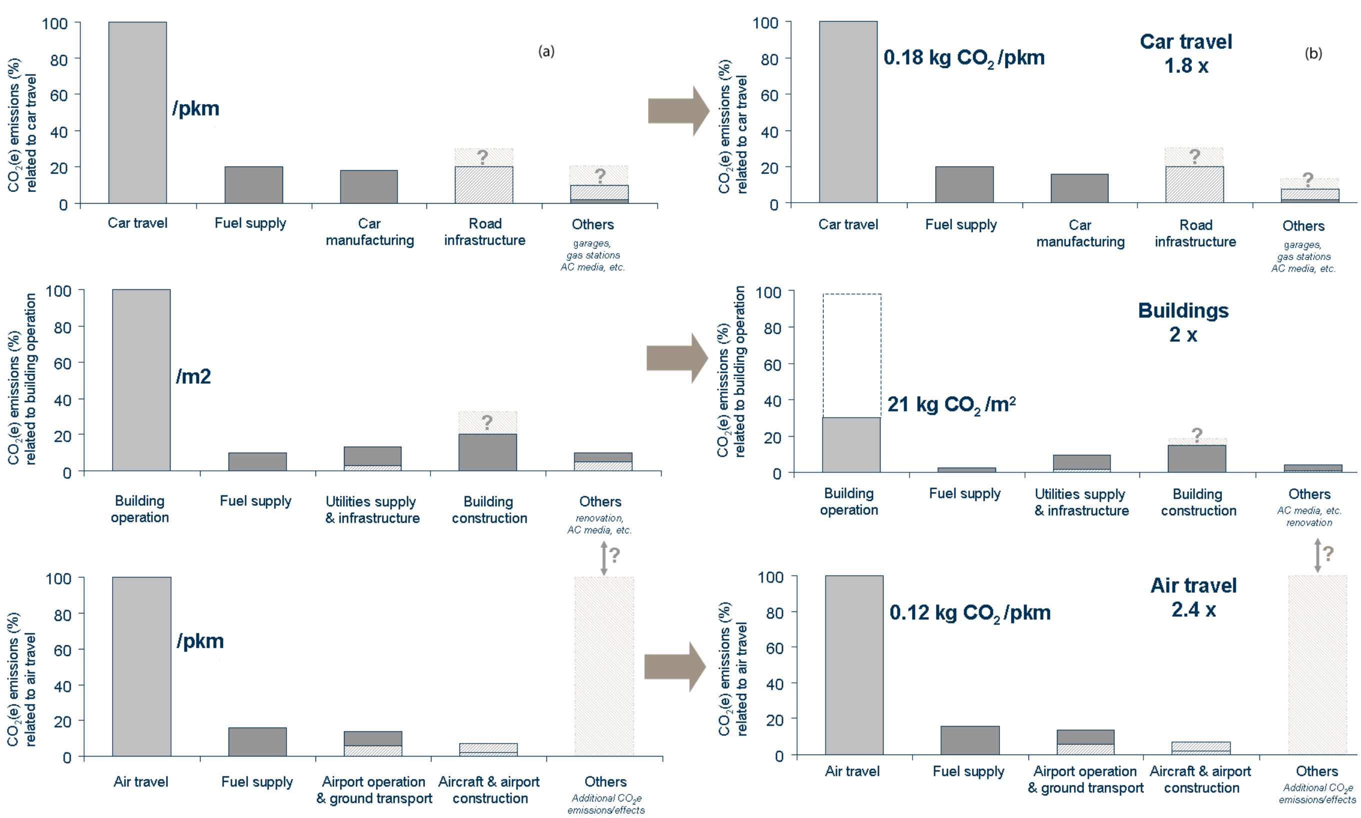

Fig. 2. CO_2e emissions for car and air travel and building operation based on LCA results, global averages (a) and adjusted for Sweden (b).

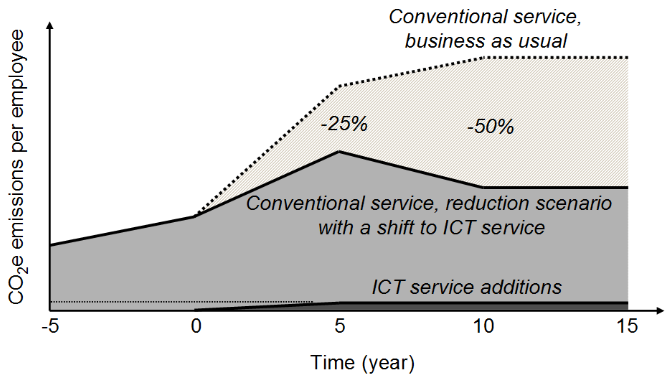

Fig. 3. Example of how to present results from a comparative LCA on services.

Figure 3 shows how the results from a comparative LCA on a service can be presented. In the TeliaSonera case study, the CO_2e emissions is a function of the number of employees and the reduction per employee in percentage is used as the primary metric.

B. *CO_2e emissions from the ICT system in Sweden*

TeliaSonera and Ericsson have studied the ICT systems in Sweden. One result is that the CO_2e emissions associated with an average mobile broadband (3G) subscriber in Sweden is about 25 kg/year, including the whole life cycle of equipment, networks and supporting infrastructures, see Fig. 4a. The corresponding figure for an average PC user with fixed broadband is about 200 kg/year. The average emissions per subscriber/user are higher globally than in Sweden due to the fact that electricity production in Sweden origins from sources with low CO_2e per kWh such as hydro and nuclear. To adjust for this fact, the additions are indicated in Fig. 4a.

The total CO_2e emission for the ICT system in Sweden is about 2 Mton, or about 2% of Sweden's total annual emissions using a life cycle perspective [7]. As much as 70% of the ICT related emissions (1.4% of the 2%) is so called imported embodied CO_2e, mainly from end-user equipment manufactured outside of the country, hence, emissions not taking place in Sweden. Imported and exported emissions associated with international data traffic and data centers are also included in the method and in the study of Sweden.

The study of the Swedish ICT systems might also provide a general platform for any studies of ICT services globally. Figure 4b shows mobile broadband services (3G) on average per subscription and an example of a specific mobile broadband service quantified by use time and data traffic. The reductions enabled by ICT services can be estimated based on LCAs of conventional activities that are part of the methodological framework and included in the smart work case study.

Figure 4a shows also estimated emissions from additional infrastructure like factory and road construction. Such emissions are very seldom included in any LCA study and are therefore shown separately in the figure.

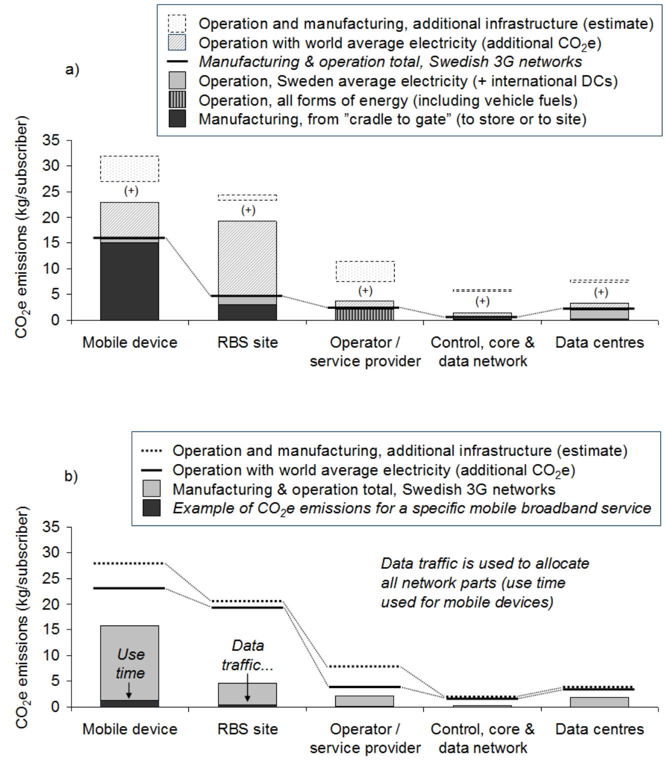

Fig. 4. (a) CO_2e emissions for an average mobile broadband (3G) subscriber in Sweden 2008. (b) Example of CO_2e emissions for a specific mobile broadband service

III. Smart Work Background and Potential

Smart work is a concept covering many activities like virtual meetings and working from home. Smart work can be defined as activities that contribute to the reduction of the overall carbon footprint, or energy consumption and costs, for typical office work, usually measured per employee. Smart work is in this study defined as a number of ICT activities that are listed and explained in Table II. Other ICT activities like e-commerce, e-learning and dematerialization as part of the regular office activities has not been studied in detail in the TeliaSonera smart work case study.

TABLE II
Smart Work Activities

1. Teleworking *Tele-commuting, Flexi-working*	Teleworking can reduce the annual commuting distance and also reduce the traffic congestion at peak traffic hours, and thereby also reduce the need to build out road infrastructure. Reductions can also be made to public transportation.
2. Smart meeting *Virtual or tele-presence / meeting / conference*	Virtual meeting facilities for teleworking and telemeetings can reduce business-related travel. The number of hotel nights may also be reduced.
3. Virtual office *Flexi-office*	Teleworking and smart meetings can reduce the need for office space like workplace meeting space, storage space and storage of furniture. Paper consumption may also be reduced.

Commuting to and from work is the single most important reason why traveling by car. As an average, about half of all car travel is for commuting, [8]-[9]. According to the World Resource Institute (WRI), about 6% of total CO_2e emissions are related to car travel in the world, making it the single most important travel or transport category [10].

Air travel is another large source of CO_2e emissions, especially if including all infrastructure and effects from high altitude flights. The aviation sector is responsible for about 5% of global CO_2e emissions in a life cycle perspective, also including airports, ground travel, etc. Business travel by air is the single most important reason to travel by air, standing for about 60% of all air travel [11].

Buildings are the largest source of CO_2e emissions in the world in a life cycle perspective [12]. Including building construction, all utility infrastructure, land use, etc., buildings are responsible for about one third of the global CO_2e emissions. Besides residential buildings, which make up about 60% of the total CO_2e emissions related to buildings, offices are the second most important building type [13]. Non-residential buildings make up about 50% of the total energy consumption in US, Japan and Sweden, while their share of the total building space is less than 40% [12], [14].

The potential to reduce the overall global carbon footprint by working smarter is large and about 10% of total global direct and indirect CO_2e emissions are estimated to be related to typical office work. This estimation is based on the data sources discussed above.

Another study that tried to quantify the potential energy reductions from the use of ICT concluded that the potential energy reductions in offices and in commuting were large [15]. The total potential energy reductions in society due to teleworking were estimated to 0.8-2.1% in two scenarios in US and Japan.

ETNO/WWF estimate the reduction potential for a number of activities through the use of ICT services to 50 Mton CO_2 annually [16]. The Smart 2020 report estimates that about 340 Mton, or 0.7%, compared to emissions in a business as usual scenario, can be reduced by teleworking and video conference systems globally in the year 2020 [17]. WWF together with HP and EcoFys estimate in a similar way that from 270 Mton (0.7%, low scenario) to 2 230 Mton CO_2 (5.6%, high scenario) can be reduced by teleworking, video conference systems, e-commerce and dematerialization in the year 2030. The CO_2 reduction per employee was estimated to about 0.25 ton in Smart 2020 [17] and to about 0.35 ton by ETNO/WWF [16]. The different studies of teleworking from [18] resulted in estimated annual reductions per office employee of about 10%-20% or 0.5-1 ton CO_2 in Japan and estimated savings of about 1-3 ton CO_2 per employee and year in the US.

IV. TeliaSonera Smart Work Case Study

A. Smart Work concept at TeliaSonera in Sweden

TeliaSonera in Sweden started to implement a smarter way of working already in the 1990's and the implementation was intensified in 2000-2001. New meeting policies including travel restrictions were established. The three main goals were to reduce business travel by air; car travel, both by company cars, rental cars, taxis and the usage of private cars for business purposes; and to reduce office space. Besides the goals on cost savings and productivity increase, there also existed an ambition to become a good show-case of what could be achieved with ICT services.

Year 2001 has been chosen as the baseline year and 2007 as the target year. The reason is that measurements and calculations of CO_2 emissions based on various emission factors before 2001 were more uncertain. The time before 2001 was also a transition time for TeliaSonera from a government-owned monopoly business to an operator on a deregulated telecom market.

The scope of this case study was wide, both in terms of what to include and the time perspective. The aim was to catch all possible reductions over a longer time period through the use of ICT services. No direct assessment of how the internal ICT environment at TeliaSonera has changed has been carried out. The energy consumption due to ICT equipment (or system) used by TeliaSonera internally was assumed not to have increased over the studied period. The latest survey at TeliaSonera shows that the electricity consumption due to ICT at offices decreases per employee. This has to do with the shift to laptops and LCD monitors, more energy efficient printers/copiers, centralization and virtualization of servers and data storage networks. There are probably more projectors and teleconference equipment installed but the lower electricity consumption indicate that they have no major impact. A large investigation of offices by the Swedish Energy Agency also shows that energy consumption in offices decreases slightly per square meter [19].

TeliaSonera has made large improvements of their energy supply, both for their networks but also for their buildings. However, the effects from these changes were excluded from the smart work assessment as was the reduction of the operation and maintenance vehicles' total mileage, as neither are part of the smart work concept. Figure 5 shows the CO_2e emissions for TeliaSonera and the emissions that can be related to smart work.

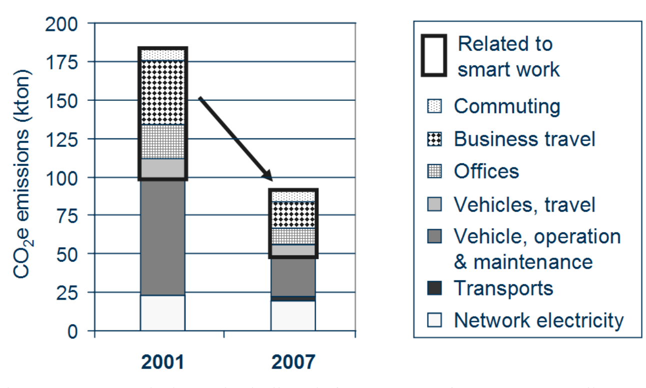

Fig. 5. CO_2e emissions, including infrastructure, for operator TeliaSonera 2001 and 2007, and reductions related to smart work activities marked.

There might be some extra equipment at employee's homes who are teleworking more frequently. Examples of extra equipment are ranging from extra AC/DC adapters and docking stations to larger workplaces at home including extra monitors and office chairs. This has not been taken into account in this study, due to lack of data. Moreover, teleworking is not as much exploited as other smart work activities at TeliaSonera.

One reason for the reduction is the lower emission factor for the purchased "green" electricity in 2007. Part of the improvements is also due to the fact that TeliaSonera has concentrated their activities to fewer locations, which also has a reduction effect on the overall travel. However, these concentrations are likely to increase commuting distances to and from work and then also increase the potential reductions that can be achieved by teleworking.

B. *Reductions per Employee*

The CO_2e reductions resulting from smart work, hence excluding vehicles used for operation and maintenance, outsourced businesses, transports, network electricity or a shift of energy source, sum up to about 40% per employee, or over 2.8 ton CO_2e per employee and year. In absolute terms, the emissions per employee, including infrastructure, was about 6.8 ton CO_2e in 2001, and it has decreased to about 4 ton in 2007. The direct CO_2 emissions excluding infrastructure have been reduced from about 3.2 ton to 1.9 ton per employee.

The energy consumption per employee has decreased, mainly as a result of the decreased office space per employee. Apart from a limited reduction in the number of employees, during the period 2001-2007, the total office space per employee has been halved and different travel categories reduced between 20% and 75% per employee. Figure 6 shows the CO_2e emissions per employee at TeliaSonera and the corresponding total CO_2e emissions per capita in Sweden. The direct CO_2 emissions, not taking infrastructure into account, are also indicated in the graph.

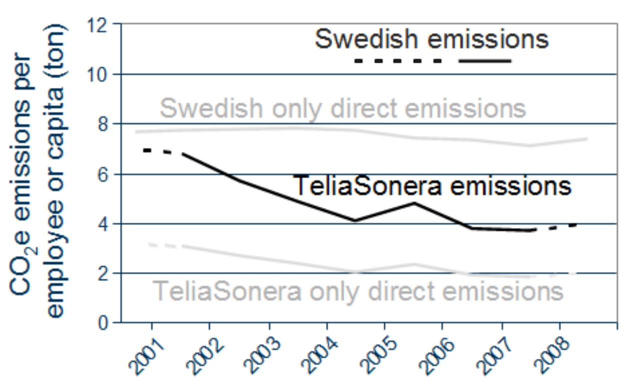

Fig. 6. CO_2e emissions per employee for TeliaSonera and corresponding Swedish emissions per capita. The grey lines indicate the direct CO_2 emissions not including infrastructure.

Since the changes in TeliaSonera's business activities have taken place over a period of many years, a number of factors and trends have been investigated, leading to the following results:

- The average emissions per kilometer of the rolling stock of cars have been nearly constant. New cars began to have noticeable emission reductions in 2006 [20]
- The number of air passengers has increased, especially for long distance flights [21]
- The average office has been nearly constant in terms of energy consumption per square meter and in total floor space [22].

It can be concluded that no trends in Sweden in the time period studied has had any larger impact on the results which the Swedish trends per capita indicated in Fig. 6.

C. *Scaling the Results to Swedish Level*

The presented LCA method has been used to assess the ICT system in Sweden and to build a platform for further assessments of ICT based services. TeliaSonera's smart work concept has been used to verify the methodology for ICT services.

The easiest approach to scale the TeliaSonera results per employee to the national level of Sweden is to just multiply TeliaSonera's reductions per employee with the total number of employees with similar work places in Sweden. The total number of workers in similar work environments is estimated to 1.7 million of the total Swedish workforce of 4.5 million (only counting active workers). The Swedish figure is based on statistics for Sweden from ILO [23] compared to statistics for US and Japan and the more detailed office work investigation in [19]. Of the ILO classes 1-4, 70% are assumed to be straight office workers.

In a short to medium timeframe, similar work places in Sweden are assumed to be able to achieve half of the reductions made by TeliaSonera. Resulting in a reduction of about 1.2 Mton CO_2e, by multiplying the 50% of the reductions per employee at TeliaSonera with the total number of employees with similar work places in Sweden.

The total potential reductions of smart work in Sweden can also be estimated by a top-down approach. Based on [22], [24]-[26], the following emissions can be associated with office work:

- Car commuting by office workers: 3 Mton CO_2
- Business related air travel: 1.3 Mton CO_2
- Offices share of all non-residential buildings: 1 Mton CO_2

It can be estimated that about 20% can be reduced fairly easy in a medium time perspective (about 10 years or in 2020). A 20% reduction translates to about 1.1 Mton or 0.65 ton/employee which is very similar to the 1.2 Mton estimated from the bottom-up approach based on 50% of all direct reductions per employee in TeliaSonera.

If TeliaSonera's smart work concept could be adopted fully (100%) by all similar companies and organizations, the reductions from just smart work would be larger than the impact of ICT itself, both operation and manufacturing, in Sweden. Hence, the reductions enabled by this ICT use cancel out the impact of ICT itself. The total CO_2e emission in Sweden in 2007 was about 65 Mton, excluding land use change. The total trade balance in terms of CO_2e for Sweden has been estimated to about +30 Mton [7], which can be added to the 65 Mton above to also include the so called embodied CO_2e, which includes manufacturing, forestry and agriculture activities.

This means that the total reduction of CO_2e emissions (carbon footprint), also including indirect (infrastructure) emissions in Sweden is 2% - 4.2% if reductions of 20% - 40% can be achieved per employee in a 10 - 20 year timeframe.

D. Scaling the Results to Global Level

When scaling the TeliaSonera results to a global level, the same factors has to be considered as when scaling the results to the national level of Sweden.

The largest difference is that the office space reductions could be much larger in the world on average as the electricity and district heating in Sweden are associated with low emissions per produced unit of energy. On the other hand, the office space in Sweden is likely larger per employee as [27] and [24] indicate.

The number of office workers in the EU, US and Japan in 2007 is estimated to 160 million, based on [18]. That corresponds to about 40% of the total workforce in those countries and 70% of ILO classes 1-4 [23]. It is estimated that only about 20% of the remaining workforce works in an office environment, resulting in an estimate of about 800 million office workers globally in 2007. Consideration has been taken to that about 30% of the total workforce globally is unemployed or underemployed. The figure 800 million is a bit lower than the 1 billion office workers estimated by [28].

The estimated total CO_2e reduction potential due to smart work in the world is in the same order of magnitude as the reductions in Sweden. Thus, smart work could potentially reduce the global footprint by 2% to 4% of global CO_2e emissions, if reductions of 20% - 40% can be achieved per employee in a 10 – 20 year timeframe, including indirect emissions (infrastructure).

V. Conclusion

The presented LCA method has been used to assess the ICT system in Sweden and to build a platform for further assessments of ICT based services. TeliaSonera's smart work concept has been used to verify the methodology for ICT services.

The result shows that if TeliaSonera's smart work concept was adopted by all similar companies and organizations in Sweden, the CO_2e emission reductions achieved in a total life cycle perspective could be in the same order as the total CO_2e emissions from the ICT system itself.

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