Considerations for macro-level studies of ICT´s enabling potential

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***Abstract*—This paper explores how companies and other stakeholders could assess the macro-level enabling potential of Information and Communication Technologies (ICT), in other words, the ability of ICT to reduce the negative sustainability impact of other industry sectors at a society level, and identifies some important considerations for such assessments including impact trends, addressable emissions, boundary setting and ICT solution categories of particular interest. To illustrate the complexity of performing macro-level estimates of ICT's enabling potential, this paper also discusses the 2020 enabling potential proposed by GeSI in their SMARTer2020 report. In addition, it investigates how organizations present GHG emissions reductions in different sectors where such reductions have already been achieved and finds that the claimed GHG emission reductions and energy savings would often need more details on calculations, methodology and background data.**

***Index Terms*—ICT, ICT solution, networked society, enabling potential, macro-level, GHG emissions reductions**

I. Introduction

The European Commission [1], the United Nations, OECD [2] and the Intergovernmental Panel on Climate Change (IPCC) [3] have all shown interest in the potential of Information and Communication Technologies (ICT)[1] to enable significant GHG emission reductions now and in the future and some studies have been made to investigate this potential (See section VIII).

The potential number of ICT solutions and their application are countless, offering the possibility to broadly impact society. However, there are few identified macro-level studies targeting the enabling potential of ICT. On the solution level, the ICT industry is presenting figures and/or case studies showing the reductions in greenhouse gas (GHG) emissions enabled by ICT solutions, but reductions are often not presented together with details regarding methodology and data, and a life cycle perspective is often not mentioned (See section III). The current situation thus indicates a need to further assess both the macro-level sustainability impact of a networked society[2] and the impacts of specific ICT solutions, though this paper focus on the macro-level evaluation.

For assessments of GHG emissions of specific ICT solutions at a society level, the International Telecommunication Union (ITU) has methodological work under way. For a more generalized assessment of ICT´s enabling potential, less methodological work has been performed by the industry. This paper therefore tries to understand what companies and other stakeholders need to consider when assessing the enabling potential of ICT at a macro-level, in order to gain insights regarding some important considerations including impact trends, addressable emissions, boundary setting and ICT solution categorization. To illustrate the complexity of making macro-level estimates of ICT's enabling potential, this paper also discusses the 2020 enabling potential proposed in the SMARTer2020 report [4]. In addition, this paper investigates how organizations present the reductions in GHG emissions in different sectors achieved by ICT solutions today.

II. Method

To identify consideration areas for macro-level studies of ICT´s enabling potential, internal workshops were held. Previous experiences taken into account include life cycle assessments, assessment methodology development for impact from specific ICT solutions in cities and impact assessment case studies of ICT solutions [5-7].

Next, background information was collected including: 1. ICT solutions with an enabling potential applied in society today – to understand the baseline (Section III); 2. A brief historical overview of environmental and socioeconomic development mainly focusing on greenhouse gas (GHG) emissions – to understand current trends (Section IV); 3. Boundary setting effects of applying a consumption or a production perspective – to understand its impact on results (Section V); and 4. ICT solutions that could increase the sustainability of the future networked society – to understand

1 By the term ICT, this paper refers to the communication networks with related user equipment and data centers as well as the operator activities for operation and maintenance of those. This scope is close to that of GeSI (2012), with the difference that GeSI also include printers. The scope is further detailed in (Malmodin et al. 2014) and (Malmodin et al. 2013) which also discusses its relationship to the OECD definition of ICT.

[2] A networked society refers to a society with ubiquitous communication and everything connected.

where to focus (Section VI). Based on the background information, the different consideration areas were detailed and the insights gained were taken into account when analyzing the ICT enabling potential estimated in SMARTer 2020 [4]. To investigate how the potential of ICT solutions are presented today, an internet search was performed as further outlined in section III.

III. Applied ICT solutions with an enabling potential

During 2013 Ericsson performed an internet search including more than 200 companies and organizations from various industry sectors, among them the world´s 100 largest companies according to Fortune Magazine [8] ranked by total revenues, to better understand if actual GHG emission reductions due to ICT were achieved or, at least, how they were presented. The ICT solutions taken into account were all checked against a number of criteria including: 1. a use case applicable for a networked society; 2. a stated GHG emission reduction compared to a reference situation without the ICT solution applied; 3. a reduction based on actual measurements; 4. a reduction achieved thanks to ICT (ICT not only in a monitoring or other supportive role); and 5. a positive impact on GHG emissions without significant negative economic and social effects.

The results indicate that companies in different sectors and society areas are using ICT solutions with some sustainability potential. The ICT sector itself was found to be the most active one in presenting its ICT solutions and their impact. The two most common sectors among the search items were the financial sector and the sector of oil and gas production, but most solutions were found in the ICT sector. In total, 20 ICT solutions which claimed actual reductions in GHG emissions were identified in various sectors as well as 14 solutions with estimated enabling potential. In addition, another 26 ICT solutions with non-quantified possible enabling potential were identified, as well as 13 ongoing projects which may be interesting to keep track of as data may be presented at a later stage. One or more ICT solutions which claimed GHG emissions reductions were identified in the following areas: electricity supply, transport infrastructure, transports, work, travel, building management, waste management, and media distribution.

Among the investigated items, the most commonly adopted ICT solutions with an enabling potential were videoconferencing, followed by transport route optimization and smart metering, with claims exemplified in [9-11]. The outcome of the study indicates that ICT solutions that reduce GHG emissions are applied already today, and that many stakeholders seem to have experienced actual energy savings and GHG emission reductions. However, according to this study, the claimed GHG emission reductions and energy savings are seldom presented with a level of detail regarding calculations, methodology and background data that allows for a deeper understanding of the figures presented. Furthermore, any references to the use of a life cycle perspective were rare and the negative impact of the ICT solution itself was usually not mentioned. Another key finding is that although ICT solutions are used beyond the ICT sector, other sectors seem not to be monitoring their ICT related gains or at least do not appear to report them.

IV. Environmental and socioeconomic development

Future growth expectancies and population development need to be understood, and it may prove helpful to also consider the historical environmental, socioeconomic and economic trends and their interactions when modelling both future scenarios for the use of ICT in different societal areas and the business-as-usual scenario.

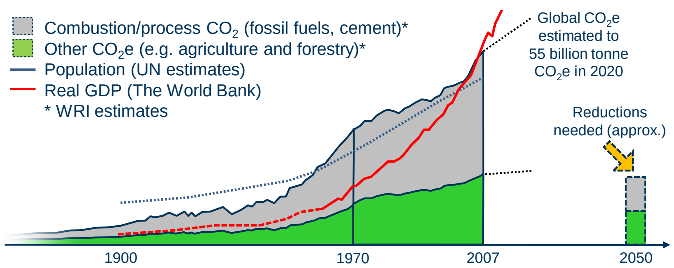

Figure 1 Trends in global population, real GDP, GHG emissions since about 1900 based on data from [12-17].

The most common way to measure economic productivity is GDP (Gross Domestic Product), and GDP per capita is often used to compare regions and to follow changes over time. GDP per capita is also considered to be an indicator of a country's standard of living or welfare.

Already 45 years ago, Paul R. Erlich [18] came up with the following simple relationship between environmental impact and human activity which could be used as a starting point when considering future scenarios:

Impact = Population × Affluence factor × Technology factor

Impact (I) usually refers to environmental impact including impact on natural resources. As an example, Impact could be impacts related to climate change (kg carbon dioxide equivalents (CO_2e)). Population (P) is the number of inhabitants. The Affluence factor (A) represents the economic prosperity which is then measured as GDP per capita (US$/capita), and the Technology factor (T) which represents the environmental impact at a certain technology level, by GHG emissions/GDP (measured as kg CO_2e/US$).

If the Population and/or the Affluence factors increase, the environmental impact increases unless technological advancements, represented by the Technology factor, can compensate for this increase. However, if, for instance, the growth in Population is partly offset by a technological development which leads to reductions in negative impact, the technology development may simultaneously increase the economic prosperity (thus the Affluence factor), which leads to increased impacts (so called rebound effect) so that the overall impact increases in spite of the technology development.

Specifically, for the Technology factor when looking at GHG emissions, an important part of it, not least when considering ICT, is related to energy. This part can be expressed as (Energy / GDP) * (GHG emissions / Energy) to show the importance of both the energy efficiency and the energy mix [19]. Another impact to consider is non-energy related GHG emissions, such as emissions related to chemicals with high GHG emissions, and the impacts related to agriculture and forestry, whereas technological development and transformation through the use of ICT, can lower energy consumption per unit of GDP as well as the GHG emissions per unit of energy. Globally today, energy generation remains, to a large extent, based on the incineration of fossil fuels and not only climate change, but also many other impact categories are to a varying extent related to these processes. Such impact categories include depletion of natural energy resources, terrestrial acidification, dust/particles/smog and ground-level ozone. This means also that other environmental indicators could be impacted favorably if ICT enables the reduced use of fossil fuels.

Erlich´s formula [18] may not give immediate guidance on how to handle complexities such as the relationship between social and economic development, which could substantially impact the scenario-setting. Jackson [20] states that social and economic development are closely related to each other, especially up to a certain level of GDP per capita, which is about 10 000 US$ per capita (1995 US$). Jackson [20] also finds that most welfare indicators like, life expectancy, education and employment ratio and other more subjective so called happiness indicators, show a fast increase to this level of GDP per capita but then flatten out quite rapidly, and more GDP per capita has only limited further impact. Particularly, Jackson sees that above 15 000 US$ per capita (1995 US$) the impact becomes very small.

In summary, when modelling the future scenarios for the use of ICT in different societal areas, it seems relevant to consider the historical environmental, socioeconomic and economic trends and their interactions. Erlich´s formula [18] could give a starting point for such considerations although it may not sufficiently capture all complexities involved.

The main focus of this paper is on ICT´s environmental impact, particularly on GHG emissions. 2011the ICT sector was responsible for about 1.5 percent of the global GHG emissions measured in CO_2e, and it is only expected to grow to about 2 percent in 2020, in spite of the substantial expansion of the sector, see [21]. A comparison between the enabling potential of ICT and ICT's own footprint, as forecasted by GeSI [4], indicates that ICT has the potential to be a relatively efficient sector from a GHG emissions perspective. Looking at the Technology factor (in terms of CO_2e/US$), the ICT sector has a relatively low value - about four times lower than the global economy on average [22]. Also, mobile technology seems to be more than two times lower than the whole ICT sector and up to 10 times lower than the global economy on average [22]. Therefore, the potential enabling potential of ICT based technology development is considered substantial, particularly for mobile technology.

V. Understanding the Impact of System Boundaries

Both for ICT itself, and for the sectors using its solutions in a non-global scenario, results will differ between a study applying a production perspective, i.e. including only the emissions generated within the assessed geopolitical area or one applying a consumption perspective, i.e. a study which consider the life cycle impact of activities taking place within its geopolitical boundaries.

To understand the importance of such boundary setting on the results of any study, with respect to the difference between applying a consumption and a production perspective, the city of Stockholm and country of Sweden were used as a reference, due to good availability of data and high ICT maturity. Particularly, a consumption perspective means that impacts related to manufacturing of products and services need to be included in the assessment. Simultaneously, impacts related to exports of products and services are excluded.

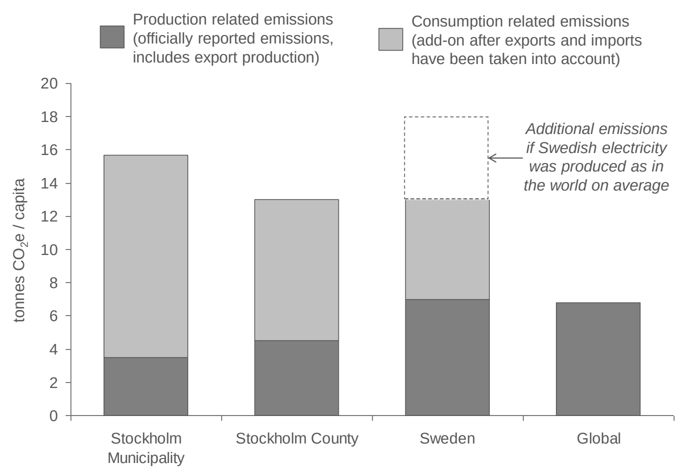

Figure 2 GHG emissions per capita for different geopolitical areas based on [23]

Note! Land use change effects are included for the global bar, but not for Stockholm and Sweden (Land use would decrease the total levels by about 2 tonnes CO_2e/capita – a negative value as Sweden's forest has a net growth and acts as a sink for emissions).
Note! For the global bar the distinction between a production and consumption perspective is not relevant as the total volumes of both production and consumption are included.

Figure 2 indicates that the different perspectives lead to a substantial difference in results. The GHG emissions in Sweden become nearly two times larger if a consumption perspective is applied compared to the officially reported figures, and that GHG emissions of Stockholm become about three times higher [23]. Figure 2 also shows the importance of the geopolitical boundary setting (see difference between Stockholm Municipality, Stockholm County and Sweden) and that its impact on the results also varies depending on the chosen perspective. As Stockholm and its surroundings have fewer large industries, forestry and agriculture areas compared to Sweden on average, the impact appears lower for Stockholm if a production perspective is applied. Additionally, the results show that, when a consumption perspective is applied, the per capita impact related to a city can actually be similar to, or even higher than, the emissions of the country [23]. From a life cycle perspective, a consumption perspective seems reasonable as it considers both the use of products and services and their supply chain. However, the high uncertainties and practical difficulties related to such an approach need to be considered. In many cases a production perspective is the only possibility based on data availability. When looking into ICT the results both for ICT´s own footprint and for its impact in other sectors varies with the chosen perspective.

VI. Enabling ICT Solutions

A. Which ICT solutions are relevant to consider?

Most activities of the modern society make use of ICT in one way or another and ICT solutions include a wide range of technical solutions. In this paper a distinction is made between ICT solutions and other electronic systems, like embedded microprocessor systems (e.g. a motor optimization system), which are not considered as ICT systems.

Further, a distinction is made between solutions that are mainly based on ICT, and solutions that are only supported by ICT. For many ICT solutions like teleworking, videoconferencing and e-commerce, the ICT usage in itself enables the potential reduction in physical travel or transports. For solutions where ICT is mainly used as a tool for administration or design, and is not impacting the performance of the associated activity, e.g. a building design process. It seems better to apply a more conservative boundary setting by excluding them when estimating the macro-level enabling potential of ICT. Thus; this paper proposes to consider only solutions where the use of ICT is a prerequisite for the enabling, not only a tool for administering it or designing it.

B. ICT solutions with anticipated enabling potential

The potential ICT solutions are countless and it is not possible to capture the full potential of ICT – in analogy with the difficulties in deriving the full impact from the use of roads. Thus, it is necessary to identify the solutions that are of main interest in order to set the scope for a macro-level analysis. Kramers et al. [24] attempt to make a framework for identifying areas where ICT solutions will have the greatest impact on reducing energy usage. So called household functions, hence, all society activities, seen from an individual´s perspective, that require energy, are mapped towards the ICT opportunities presented by Mitchell [25]. The authors use the concept “ICT opportunities” to denote the main mechanisms leading to the enabling. The ICT opportunities intelligent operation and soft transformation, which represents transformation of existing physical infrastructure, in combination with the household functions of transport and heating of buildings, are seen as the areas with the largest enabling potential. The result correlates with Erdmann et al. [26] which concluded that the main potentials for ICT to decrease energy consumption lie in making use of ICT to shift from material goods to services, installing intelligent heating systems, and using ICT for production process control and supply chain management.

Looking into SMARTer 2020 [4], the largest reduction potentials enabled by ICT are expected to occur in energy and buildings, and transport and travel. Wireless access plays an important role for these two areas. Many of the macro-level studies listed in Table I also estimate high potentials for the energy and transport sectors.

Smart meters which allow users to manage their electricity consumption by using remote control and monitoring areas, are of special interest. ICT also enable small-scale efficient renewable energy production (e.g. solar panels) and feedback into the grid. Introducing large renewable energy sources into the grid demands that ICT is used for dynamic monitoring and control, but the enabling as such is not due to the ICT solution, but to the change in energy source. This paper defines the integration of small-scale renewable energy production as part of the ICT enabling potential, while the introduction of large renewable energy sources is excluded.

In the travel and transport sector mobile technology can play an important role in route planning, fleet management, traffic management, more efficient public transports and ride sharing, etc. It should, however, be observed that this is an area where ICT solutions have been used for quite some time and part of the potential may already have been realized. Potential reductions through the use of online media and online meetings/conferences, have traditionally been associated with fixed telecom, but are also enabled by mobile broadband.

The manufacturing sector includes some reduction potentials that are more related to local IT and microprocessor solutions which cannot be labeled as ICT, e.g. control of electric motors used at manufacturing sites. On the other hand, by using ICT solutions, the use of buildings, vehicles and other products and services can be made more efficient which indirectly reduces the need to manufacture these products in the first place. As the emissions at the same time are large for the manufacturing sector this hidden potential can be large as suggested by Erdmann et al. [26]. It can be much more efficient to rent or share products as a service, and ICT can play a large role in this transition and enable future smart services that use products more efficiently.

The agriculture and forestry sector is another sector where wireless access can play an important role, e.g. in monitoring assets and helping to plan activities depending on different sources of information such as weather, demand, etc. This sector may have a large future potential, especially in developing countries, but more development is needed. Consumer services are another area where there is significant enabling potential. Here, e-commerce can play a large role. Studies by NTT in Japan [27-29] estimate a high potential for e-commerce. However, rebound effects may counter potential reductions as discussed in [26].

For many societal services like health and education, the focus is not so much on environmental sustainability, but rather on improving the socio-economic sustainability, not least, in emerging markets where ICT based solutions can be a more cost-efficient way to provide societal services.

VII. Considerations for Assessing the macro-level impact of ICT solutions

A possible and practical approach for a macro-level analysis of ICT´s enabling potential is to combine a top-down approach for addressable emissions, looking at the overall emissions of different societal activities/sectors for the assessed geopolitical area, and a bottom-up approach for the assessment of specific ICT solutions which could then be scaled as appropriate. A macro-level study of this kind needs to consider estimated or measured enabling potentials of different ICT solutions, together with data regarding total and addressable impacts for different sectors to calculate a reasonable total enabling potential. While sections IV and V focused on setting the scenario particularly for the addressable emissions, section VI concentrated on the ICT solutions to consider and related input data. To estimate the enabling potential of ICT solutions, it is necessary to understand how environmental impacts are distributed between different parts of society to identify the addressable impacts.. For example, an ICT solution with a relatively small enabling potential per user may have a quite substantial impact if applied widely in society, while a solution with high impact per user may give a relatively low reduction overall if the potential users are few. Further, interaction between solutions should be considered, and, to the extent possible, also indirect effects such as drivers and barriers, and the rebound effects, at least qualitatively.

For the considered ICT solutions the methodology framework previously proposed for society level assessments of one or more ICT solutions is applicable [5-6]. That methodology is, to a large extent, aligned with the LCA standards from ETSI [30] and ITU [31] and recommends that a life cycle perspective is applied as far as possible. Also the White Paper Quantifying Emissions Right [7] describes how the enabling potential of individual ICT solutions could be assessed. To understand the impact of a certain scenario both the usage scenario and the technical system need to be known, as well as the impact in other sectors. Regarding input data for ICT solutions, specific considerations are identified: the number of actual users (sample size), the time period during which emissions are followed, the exclusion of other factors that could have led to the enabling, the representativeness to other users before extrapolation of results. Particularly, users starting from a very high emission level before the enabling is taking place, would form a poor basis for an average user. Another factor to consider is if the enabling is actual or estimated.

VIII. Macro-level studies of ICT solution impacts

The two reports commissioned by GeSI, Smart 2020 [32] and SMARTer 2020 [4] may be the two most well-known studies that estimate the future enabling potential of ICT solutions on a global societal level. Other comprehensive studies are the research by Buttazoni [33] and Erdmann et al. [26]. These studies together with other macro-level studies are listed in Table I.

TABLE I. Overview of macro-level studies of ICT solutions

Study	**ICT solutions**	**Region, year, total business-as-usual emissions and estimated change (scenario)**
Korean GHG reductions by ICTs [34]	Smart grid, tele- presence, e-commerce, e-civil service, e-logistics, real-time navigation, e-government, home energy management system, smart motor, digital contents, e-learning, bus information system, e-health care	Korea 2007: 610 Mt CO_2e -10 Mt CO_2e Korea 2020: 813 Mt CO_2e -118 Mt CO_2e (14.5% or 5.8 times ICT sector footprint)
SMARTer 2020 [4]	Smart consumer and service, smart manufacturing, smart transports, smart buildings, smart power, smart agriculture	World 2020: 55 Gt CO_2e -9.1 Gt CO_2e (-16.5%)
Yankee/GeSI/ACEEE study [35]	Telecommuting, digital photos, online shopping, online banking, 4 other minor activities	US & EU 2012: 75 billion barrels of oil -370 million barrels of oil (-2%)
Macroeconomic impact of ICT [36]	10 earlier macro-level studies assessed, 11 ICT application domains studied	EU15 2020 (vs. 2000): +35% to -29% (total) +1.6% to -19%
Smart 2020 [32]	Dematerialization, smart motor systems, smart logistics, efficient vehicles, private transport optimizations, smart buildings, smart grids, efficient power	World 2020: 53 Gt CO_2e -7.7 Gt CO_2e (-15%)
WWF/HP/ EcoFys [33]	Dematerialization, e-commerce, flexi-working, virtual presence, smart production, smart transports, smart cities, smart buildings, smart grids	World 2030: 40 Gt CO_2 (Note only CO_2) -1.2 to 8.7 Gt CO_2e (-3% to -22%)
Telstra study Climate Risk [37]	Smart grid, telework, e-commerce, e-meeting	Australia 2015: 560 Mt CO_2e -27 Mt CO_2e (-4.9%)
NTT studies [27-29]	e-commerce, telework, e-meeting	Japan 2006-2010: about 1.2 Gt CO_2e -1.9% 2006 -3.9% 2010
@ the speed of light, ETNO / WWF [38]	Telework, e-meetings	EU25 2010: 4 Gt CO_2e -50 Mt CO_2e (-1.3%)
The future impact of ICT [26]	Dematerialization, Intelligent transports, facility management and production processes	EU25 2010 (vs. 2000): +32% to -29% Up to -16%
Telework potential in the US and Japan [39]	Telework, low / high scenario	US & Japan 2003: 7 Gt CO_2e -60 to -160 Mt CO_2e (-0.8% to -2.1%)

The study by Erdmann and Hilty [36] assess earlier macro-level studies (most of the studies listed in Table I dated before 2010) and provides an update of the results from their earlier macro-level study of the ICT enabling potential in the EU in 2020, as compared to 2000 (Erdmann et al. [26]). The study by Erdmann et al. [26] is of particular interest as rebound effects have been taken into account and because baseline emissions vary between different future scenarios due to non-ICT effects.

The studies by the Japanese telecom operator NTT [27-29] are also of particular interest as the impact assessment of ICT solutions in Japan is based on input/output analysis. NTT estimates for the assessed period that the reduction in other sectors due to ICT solutions is up to two times as large as ICTs own footprint. The same concept has been adopted by Fuhr and Pociask, [40] and Laitner and Ehrhardt-Martinez [41] in the US and the enabling for the studied period is estimated to equal ICTs own impact.

IX. Complexities of macro-level estimates of the ICT enabling potential – the SMARTer2020 case

A. Identification of discussion topics

GeSI, in its report SMARTer 2020 [4][3], estimates that the global GHG emissions will reach 55 Gtonnes CO_2e in 2020 based on IEA data [42], to be compared with 48 Gtonnes in 2011 based on WRI data [17]. SMARTer 2020 then break down of emissions between different societal activities and forecasts the 2020 enabling potential from ICT solutions to be 9.1 Gtonnes CO_2e, which corresponds to about 16.5% of global emissions in a business-as-usual emissions scenario for 2020[4]. The background data has not been published, but is available from GeSI at request.

The SMARTer 2020 report is well-known within the ICT sector and among its stakeholders, including policy makers, though it might not be familiar to a wider audience. The reason for choosing to focus on the SMARTer 2020 report in this paper is due to the role it seems to play in putting the future potential of ICT on the agenda, and the fact that it is frequently quoted in various publications. The SMARTer 2020 applies a bottom-up method that is based on results from a limited number of case studies - results from one or a few small-scale studies related to a limited geographical area are scaled to represent the global potential for a certain ICT solution category. A significant part of the estimated enabling potential is based on older estimates, several of these from the Smart 2020 study [32], and not on new case studies. Both case study results and other estimates include substantial uncertainties and many assumptions. Potential rebound effects are not considered. As part of a continuous effort to better understand the uncertainties related to studies of ICT´s own emissions and the enabling potential, this paper uses the SMARTer2020 report to illustrate the complexity of macro-level estimates of the ICT enabling potential. This paper is not intending to debate the results of SMARTer 2020, rather to take the thinking a step further in order to show the complexity of performing and understanding macro-level ICT enabling potential forecasts. The topics that are looked into include the selection of ICT solutions, the impact of interactions and the importance of providing background data among other things. In this work the studies listed in section VIII are considered.

The first observation refers to the selection of ICT solutions which contributes to the enabling potential. The SMARTer 2020 study includes mainly solutions with a clear enabling potential, such as videoconferencing, where the purpose of the ICT solution is to replace physical services by virtual ones. However, in some cases, it includes solutions which are only using ICT for monitoring or administrative purposes, i.e. solutions for which ICT in itself does not give any GHG reductions. As an example, building design is included. In some cases, SMARTer 2020 also include general electronic solutions, like embedded microprocessor solutions, which this paper does not consider as ICT solutions. Thus, there are parts of the enabling potential claimed by GeSI [4] which does not seem relevant to include with the stricter boundary setting proposed in section VI.A. On the other hand, other ICT solutions with enabling potential may be underestimated or missing in the estimate of the identified enabling potential.

The next observation is that SMARTer 2020 calculated the enabling potential of the different ICT solution categories without considering the interactions between them, i.e. how the existence of two solutions, targeting the same emissions, impacts the addressable emissions per solution. Another observation related to the SMARTer 2020 assessment deals with how data is presented, identifying particularly two areas where the lack of detailed information prevents a deep understanding of results: Limited information regarding distribution between industry sectors and life cycle stages. Among basic production activities, the use of electricity is presented separately but not fuel and materials supply. Also for electricity, it is not clear how the electricity figures relate to the end-use sectors which are the main consumers of this electricity and effects of potential double counting cannot be fully analyzed. It could also be noted that industry sector emissions are seen as homogenous entities and that proposed reduction factors for specific solutions are applied to overall sectors which is then a simplification.

TABLE II. SMARTer 2020´s global ICT reduction potential in 2020 (all figures in Gtonnes CO_2e)

ICT solution category	Total CO2e emissions and reduction factor				
	A/B+	*C+*	*D*	*E*	*Notes*
1 Smart power	**11.80**		**2.02**	**-**	
a Demand management	0.24	4%	0.01	-	
b Time-of-day pricing	15.6	1%	0.21	-	Dev.¤ ***
c Power-load balancing	0.24	60%	0.38	-	Dev.¤
d Power grid optimization	1.1	30%	0.33	-	
e Integration of renewables	3.4	25%	1.05	-1.05	
f Virtual power plant	0.14	26%	0.04	-	
2 Smart buildings	**n.a.***		**1.58**	**-**	

[3] The SMARTer 2020 report is a consultancy report, not a scientific paper.
[4] Ericsson, as a member of GeSI, participated in the SMARTer 2020 study together with other GeSI members.

ICT solution category	Total CO2e emissions and reduction factor				
	A/B+	*C+*	*D*	*E*	*Notes*
a Building design			0.45	-0.45	(2008)**
b Building management system			0.39	-	(2008)
c Integration of renewables	17.1	3%	0.50	-	Dev.¤
d Voltage optimization			0.24	-	(2008)
3 Smart transports (including travel)	**7.90**		**1.94**	**-**	
a Eco-driving			0.25	-0.25	(2008)
b Real-time traffic alerts	11.4	0.7%	0.07	-	Dev.¤ 0.08
c Apps for public transports	7.4	1%	0.07	-	
d Asset sharing	7.4	2%	0.14	-	Dev.¤ 0.15
e Videoconferencing / Telecommuting			0.34	0.3	(2008)
f Optimization of logistics	4		0.76	-	Dev.¤ 0.79
g Integration of EVs	11.4	2.1%	0.2	-0.2	
h Intelligent traffic management	11.4	0.4%	0.03	-	Dev.¤ 0.04
i Fleet management and telematics	4	2%	0.08	-	
4 Smart manufacturing	**17.40**		**1.25**	**-**	
a Automation of industrial processes	14.3	5%	0.72	-0.72	
b Optimization of motor systems	2.92	18%	0.53	-0.53	
5 Smart agriculture	**12.40**		**1.60**	**-**	
a Livestock management	9.93	7%	0.70	-	
b Smart farming	12.4	2%	0.25	-	
c Smart water	0.13	25%	0.03	-	
d Soil monitoring / Weather forecasting	12.4	5%	0.62	-	
6 Smart consumer and service	**5.70**		**0.73**	**-**	
a e-commerce, e-paper	1.27		0.15	-	Dev.¤
b Minimization of packaging			0.22	-	(2008)
c Online media			0.02	0.05	(2008)
d Public safety/disaster management	0.12	25%	0.03	-	Dev.¤
e Reduction in inventory			0.18	1	
f Smart water	0.52	25%	0.13	-	(2008)

Note! Some SMARTer2020 categories that are similar have been added together to make the list shorter.
Note! The ICT solution categories are referred to as sub-levers in SMARTer 2020.

A = Total CO2e emissions (in bold), B = Emissions addressable by ICT, C = reduction factor, D = Estimated reductions, E = Ericsson adjustment

Figure in brackets are considered as more uncertain than others
+) The figures in this column were never published but are made available by GeSI at request.
¤)"Dev." means that there are deviations between the background information in SMARTer 2020 and the figure used in the actual report. In these cases the published information was used.
*) Building-related emissions included in other sectors, mainly electricity (smart power)
**) Values reused by SMARTer 2020 from [32]
***) Values reused by SMARTer 2020 from [4] but with a small adjustment.

Note! Several lines in column B address the same emissions and the values could not be added together.
Note! An addressable emission in column B is marked red if it is larger than the corresponding total ICT solution category emission value in column A. Both A and B consist of data from SMARTer 2020 [4] and the handling of this discrepancy in the present study is described in the body text.

Some data discrepancies are identified in Table II: First, in some cases the addressable emissions (e.g. time-of-day pricing in column A/B+ row 1b) are larger than the estimated total emissions for its ICT solution category (e.g. Smart power in column A/B+ row 1). The same goes for 2c, 3b, 3g and 3h. Total emissions (bold values in column A/B+) is better aligned with other sources, e.g. WRI [16-17], but the non-bold values in column A/B+ are used in our analysis of the SMARTer2020 results due to lack of alternative detailed data. Consequently the resulting enabling potential may be slightly too high. The reason may be that the estimated addressable emissions include fuel supply emissions, while the estimated total emissions may not. As all background data is not available, this could not be fully investigated.

Next, as several ICT solutions address the same impact, the different lines in column D should not be added together without considering interactions between them, as that also leads to double counting and a too high resulting enabling potential value.

B. Evaluation of the SMARTer 2020 enabling potential

To analyze the enabling potential presented in the SMARTer 2020 report, its original data (column B & C II) was analyzed with respect to interactions between ICT solutions and modified to remove double counting effects, which resulted in a reduction of 0.92 Gtonnes CO_2e.

The resulting enabling potential was then reduced according to Table II column E, by removing the ICT solution categories for which ICT in itself is only a support function. In total, these adjustments reduced the estimated enabling potential by 2.25 Gtonnes CO_2e by removing the ICT solution categories, which are not networked ICT solutions[5], and by another 1.17 Gtonnes CO_2e corresponding to ICT solution categories where ICT does not enable any savings but rather is used for administrative purposes and monitoring, etc.[6].

The next adjustment was to increase potentials that seemed underestimated based on other sources (Erdmann et al. [26]; NTT [27-29]; Weber et al. [43]; Williams and Matthews [39]). Among those the dematerialization area, which is seen by other papers as a major opportunity (see section VI.B), is worth mentioning separately and represents an adjustment of 1 Gtonnes CO_2e based on (Erdmann et al. [26]). Subsequently, the enabling potential was further adjusted to include the missing enabling potential related to the supply chain of non-used fuel and energy as derived by [5].

As SMARTer2020 did not study to what extent the enabling potential had already been implemented, a reduction in enabling potential was made based on other sources to find the remaining enabling potential (Table III).

Finally, an additional potential coarsely addressing the potential reductions in GHG emissions related to infrastructure, i.e. lower GHG emissions due to reduced need

[5] Table II , line 1e, 2a, 4b and 6b
[6] Table II, line 3a,3g and 4a

for new roads and road maintenance when transports are replaced by ICT, was estimated based on [5].

Table III summarizes the stepwise modification of the SMARTer2020´s estimate of ICT´s enabling potential described above. The intention is not to make a separate estimate of the ICT enabling potential, but rather to illustrate how the different discussion areas impact the results of a macro-level study and add to the uncertainties of enabling potential values.

TABLE III. ANALYSIS OF SMARTER 2020´S ENABLING POTENTIAL

Step-by-step analysis	**Gt CO_2e**	**Graphical representation**
Original SMARTer 2020 enabling potential	9.12[a]	
Reduction due to interaction between ICT solutions (-0,92)	8.2	
Subtraction of end-use activities that are not considered relevant for ICT (-2,25)*0.9[1]	6.2	
Subtraction of end-use activities where ICT does not have an enabling role (-1,17)*0,9[1]	5.1	
Addition of ICT solutions considered as underestimated or missing (+0,55)	5.7	
Additional potential added for dematerialization “from products to services” (+1)	6.7	
Fuel and energy supply chain impacts added[2] (*1,2)	up to 8	
Subtraction of reductions already implemented in society[3] (-1,27- -2,54)	5.5 – 6.8	
Resulting estimate (summary)	**5.5 – 7**	
Infrastructure and all life cycle impacts added (based on Ericsson analysis[1]) (*1,2 - *1,4)	up to 9.5	

1. This factor is needed to compensate for the interaction factor added in the previous step
2. The estimates for fuel supply, infrastructure and all life cycle impacts (also including embodied impacts) have been based on [5].
3. The high estimate based on [27-29], the low is based on (Fuhr and Pociask [40]) and (Laitner and Ehrhardt-Martinez [41])

The overall result from a complex macro-level study can be discussed and modified in many ways, as the above analysis of SMARTer 2020 illustrates. With the modifications made in this analysis the enabling potential becomes 5.5 - 7 Gtonnes. However, if life cycle impacts of vehicles, buildings and related infrastructure (e.g. roads and land use) are considered the estimated enabling potential (incidentally) ends up in the same range as the SMARTer 2020 – by applying wider system boundaries than in SMARTer 2020 in general[7]. Furthermore, due to the uncertainties and methodological problems involved, LCAs of ICT applications generally do not include the life cycle impacts of vehicles, buildings and related infrastructure. Especially, inclusions of potential reduction in emissions related to the infrastructure, comes with considerable uncertainties which may provide for a conservative approach.

Figure 3 show the distribution of emissions and reductions after the modifications of the SMARTer 2020 enabling potential. As the SMARTer 2020 report includes data and results for only two years, 2008 (baseline) and 2020 (future scenario), the data for year 2000 are based on WRI [15] and is added to show trends more clearly.

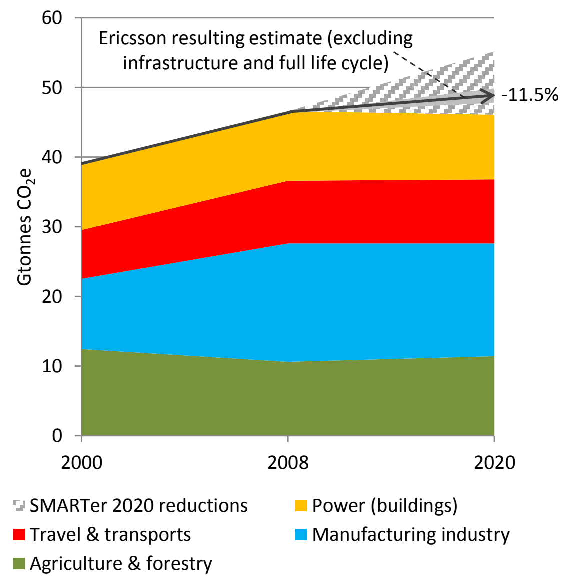

Figure 3 Estimated GHG emissions per ICT solution category, SMARTer 2020 reduction scenario and Ericsson resulting estimate.

The uncertainties of a macro-level study of this kind are high due to the many assumptions, and it is important to understand the input data and assumptions made to interpret the results. The step-wise modifications made in Table III due to our analysis illustrate how results, even when the same input data is used, vary with system boundaries and assumptions. In this case, from the lowest estimate of about 5 Gtonnes CO_2e to the highest estimate of nearly 9.5 Gtonnes CO_2e.

X. DISCUSSION

Future work regarding ICT´s enabling potential should include assessments for different scenarios taking into account the methodological consideration points identified in this paper and relevant and comprehensive case studies. When evolving and applying the macro-level analysis in the future, available case studies, as well as detailed knowledge about the distribution of impacts between sectors, and impact trends will provide important input and enable more robust predictions. Also other environmental and socioeconomic impact categories are of interest for future studies.

Looking into how ICT solutions are presented today, it seems clear that other sectors do not often mention GHG reductions due to ICT. One reason may be that ICT solutions

[7] However, some of the case studies used as input data may have taken infrastructure into account.

are seen as integrated parts of larger projects, another that they have no incentives to talk about ICT specifically. ICT solutions may also be applied due to other advantages and incentives may be missing to look into their environmental impact.

For scenario setting, both on societal and individual level, the importance of driver´s and barrier´s for the uptake of different ICT solutions needs careful consideration. As an example, when setting the macro-level scenario for ICT enabling, it is important to understand how people will change their actions (social practices) as a response to the ICT solutions. Another important area, when considering impacts of ICT at a societal level, is the rebound effect [26] for which a qualitative approach may be used in a first step.

XI. Conclusions

The purpose of this paper was to explore how companies and other stakeholders could assess the macro-level enabling potential of ICT, particularly for a future scenario, and to identify some important considerations for such assessments. A number of such considerations were identified and discussed, including future and historical trends in environmental, socioeconomic and economic development, system boundaries, and distribution of addressable emissions. Also highlighted were the importance of understanding the interactions between ICT solutions and the addressable impacts to make realistic estimates of future potentials. A consumption perspective, i.e. considering the life cycle impacts related to products consumed within the geopolitical boundaries, but manufactured elsewhere, is indicated to have a significant impact in case of non-global assessments, but may be hard to apply in practice.

A number of existing macro-level studies of ICT´s enabling potential were identified and, to illustrate the complexities of making macro-level studies of ICT´s enabling potential and the uncertainties of their results, the 2020 GHG emission reduction potential enabled by ICT was analyzed based on SMARTer 2020 data. The analysis indicates how results, when the same input data is used, vary with system boundaries and other assumptions, in this case from the lowest estimate of about 5 Gtonnes CO_2e to the highest estimate of nearly 9.5 Gtonnes CO_2e – to be compared with the 9.1 Gtonnes proposed by GeSI [4] based on the same data. The intention of presenting these results is not to debate the enabling potential proposed by GeSI [4] – rather to build on the GeSI study and take the thinking one step further in order to show the complexity of calculating and interpreting macro-level studies and the importance of critically analyzing their results. Though ending with a somewhat different result, our analysis supports the conclusion made by GeSI that ICT has a substantial enabling potential, well out-weighting its own footprint.

Future studies applying more visionary future scenarios based on more rigorous methods and more comprehensive case studies may identify a higher enabling potential than the ones mentioned here. An internet search of 200 companies and organizations indicates that ICT solutions that reduce GHG emissions are applied today, and that many stakeholders claim actual energy savings and GHG emission reductions. In total, 20 ICT solutions with claimed and quantified GHG emission reductions were identified in various sectors, as well as 14 solutions with estimated enabling potential. The most common enabling ICT solutions identified were videoconferencing, followed by (transport) route optimization and smart metering. However, further studies are needed, especially since existing case studies have generally not published sufficient information regarding background-data, assumptions and method and often seem to lack a life cycle perspective. Also, although ICT solutions are used in all sectors, other sectors rarely publish their ICT related sustainability gains.

Looking into the main areas for ICT´s enabling potential, previous studies finds the main enabling opportunities in the areas of energy supply, buildings, transport, travel and products as services through the mechanisms of intelligent operation and ICT transformation. Also, agriculture and forestry are seen as areas of opportunity in the literature.

Acknowledgment

We like to acknowledge our speaking partners at the Centre for Sustainable Communications (CESC) at the KTH Royal Institute of Technology in Stockholm, financed by the Swedish Governmental Agency for Innovation Systems (VINNOVA).

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