KTH Centre for Sustainable Communications

The electricity consumption and operational carbon emissions of ICT network operators 2010-2015

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The electricity consumption and operational carbon emissions of ICT network operators 2010-2015

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Summary

This report is built on a large primary data set for operational energy consumption and carbon footprint, collected from telecom operators in different countries, and complemented by publicly available data from other operators. The purpose of the study is to estimate the current magnitude and trends for the electricity consumption and operational carbon emissions of telecom operators globally, and the primary data was collected with the support of the Global e-Sustainability Initiative (GeSI) and the European Telecommunications Network Operators' Association (ETNO).

In this report, the electricity consumption and operational carbon emissions of telecom operators are investigated, to calculate the ICT network (i.e. fixed and mobile telecom networks) operations´ share of the Information and Communication Technology (ICT) sector impact globally, historically (2010 and 2013) as well as currently (2015). The study covers the ICT networks, defined as fixed and mobile telcom networks, and related operator activities, but excludes enterprise networks, data centers and end-user equipment. The study draws from a similar study of ICT in Sweden 2015 [1] and uses measured and collected data. End-user equipment is outside the scope of this study.

Several other studies in the past predicted that the ICT sector, in particular the ICT networks, would increase its electricity consumption and operational carbon emissions in line with the growth in data traffic which was discussed in the previous study [1].

In the present study telecom operator data representing approximately 15% of the global fixed subscriptions, 40% of global mobile subscriptions and more than 35 countries in all regions except Oceania have been collected as input data. This represents a significant statistical foundation for further assessments and for extrapolation to the overall ICT networks. Approximately data for 10% of the global fixed and mobile subscriptions have been collected directly from operators, the remaining dataset is based on publicly reported data by some of the world's largest telecom operators.

The keyfindings of this study are:

- **The total annual operational electricity consumption of the overall ICT networks globally is estimated to 242 TWh for 2015 including both grid (215 TWh) and on-site generated electricity (27 TWh). The total corresponds to 1.15% of the total electricity grid supply.**
- **The total annual operational carbon emissions of the ICT networks are estimated to 169 Mtonnes CO_2e for 2015. This corresponds to 0.53% of the global carbon emissions related to energy (about 32 Gtonnes), or 0.34% of all carbon emissions (about 50 Gtonnes).**
- **Between 2010 and 2015 the electricity consumption of the ICT networks grew by 31% from a level of 185 TWh which corresponded to 0.97% of the total electricity grid supply. During the same period the operational carbon emissions grew by 17%. This could be compared to the increase in number of subscriptions from 6.7B to 9.0B during the same period.**
- **Per subscription, the average annual operational electricity consumption, including on-site generation, has decreased slightly from 27.6 kWh to 27 kWh per subscription between 2010 and 2015. For the operational carbon emissions, the emissions per user have reduced from 21,5 kg CO_2e to 19 kg CO_2e. The annual emissions per subscriber of 19 kg CO_2e corresponds to driving about 100 km on the highway including the fuel supply chain emissions.**
- **Seen in the light of earlier estimates this study shows a result which is 24% lower than the operational carbon emissions estimated by the Smarter 2020 report for 2020.**

The result shows an approximately linear increase trend in annual electricity consumption and operational carbon emission. The fixed and broadband part is almost unchanged over time, so the increase is mainly associated with the expansion of mobile networks. Still the data traffic increase is in magnitude many times higher compared to the electricity consumption and operational carbon emission increase and the impact per subscription is actually decreasing in most cases.

To understand the total ICT sector´s electricity consumption and operational carbon emissions, including all user equipment and the full life cycle, further studies are needed. However, this study brings a unique data set and insights regarding one of the key components – the operations of the network part of ICT.

Keywords—ICT, ICT sector, ICT networks, telecom operators, ICT network operations, energy, electricity, operational carbon emissions

I. INTRODUCTION, BACKGROUND AND SCOPE

For a number of years, it has been alleged that the global ICT sector has been increasing its electricity consumption and operational carbon emissions. For instance, it is obvious that the increased internet traffic and usage of services such as YouTube, Netflix, Google and Facebook drives data traffic. But while the data usage is increasing at a pace similar to Moore's law, as reported for instance in Cisco's data traffic report [3], the growth of the number of subscriptions is slowing down as most of the population in the world are already subscribers, see International Telecommunication Union (ITU) Key ICT data [4]. A key question is if the electricity consumption and operational carbon emission is growing as quickly as data usage or more slowly as is the number of subscriptions?

This study is an attempt to present the actual electricity consumption and operational carbon emission for the global telecom operators in the world, based on an extensive primary data set collected from its members. The operators are a vital component of the global ICT sector as their fixed and mobile networks distribute all the data that are used by their customers. And since it is the operators' customers that are the internet users, the data from operators play an important role in the calculation of the actual Internet footprint. Especially, as has been presented in previous research [1], it is the last mile of mobile or fixed access that generates the largest impact from an electricity consumption and operational carbon emission perspective (together with the end user devices). It can be expected that if there is an increased electricity consumption in the ICT sector, a similar trend should be seen in the telecom operators' electricity usage and thereby their carbon emissions.

The scope of this study is the operational electricity consumption (referred to as electricity consumption) and the related greenhouse gas emissions (referred to as operational carbon emissions although not restricted to CO_2 only) of the network operations part of the ICT sector as outlined in Figure 1. More details are given in chapter II and in table I.

The embodied electricity consumption and carbon emissions related to the manufacturing of network equipment and deployment of required infrastructure (e.g. antenna towers for mobile base stations) are not included. This represents typically between 5% and 20% of the total ICT sector's carbon footprint in studies where it has been calculated, e.g. about 13% of the total emissions or +15% related to the operational carbon emissions in [5].

As further described in section II, the methodology used is similar to the one presented in the study on the ICT sector in Sweden [1]. The data used is to a large extent based on measured data (not estimated) and have been collected from members of GeSI and/or (ETNO). In this study the operators voluntarily provided data which resulted in higher granularity than can be found in the operators' public annual reports, and it has been possible to not only calculate the electricity consumption for 2015, but in addition in some cases also follow the trend backwards until 2013 and 2010. The data also makes it possible to see details for fixed and mobile networks and to see the distribution of electricity consumption and operational carbon emissions between the network itself and operators own data centers, offices and stores.

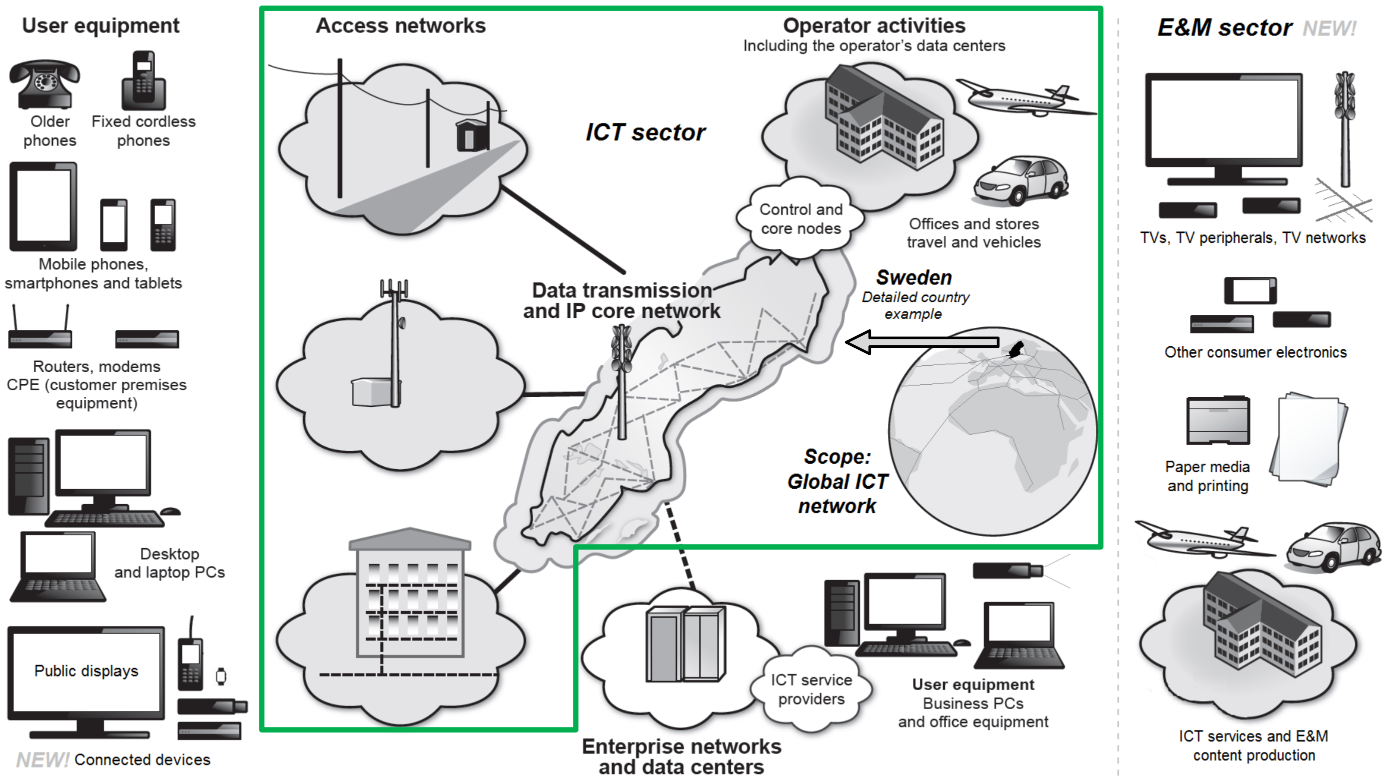

Figure 1 The scope of this report (inside the green outline) compared to the wider scope (full picture) of the ICT sector and the E&M (Entertainment and Media) sector from [1] and [2].

II. METHODOLOGY, DEFINITIONS AND DATA SOURCES

The foundation of the study is data received from ten operators with operations in 30 countries through a questionnaire which was distributed during 2017. Three operators reported all operations consolidated without revealing country details so the actual number of countries is in fact higher. In total, the directly reported dataset covers about 10% of all fixed and mobile subscriptions globally which equals about 870 million out of 8.95 billion subscriptions in the world.

In addition to the directly reported dataset, additional data were included from four other major telecom operators, and one country-wide dataset which included all telecom operators and networks in that country. The reason for adding additional data to the directly reported dataset was to get a more representative global dataset, as well as to increase the total number of subscriptions covered. By extending the data set acquired through the questionnaire with data from some other of the world's largest telecommunication operators, an increased subscription coverage was achieved corresponding to about 15% of the world's global subscriptions for fixed operations and nearly 40% for the world's mobile subscriptions. By adding these operator data, an increased coverage was achieved with regards to regions and countries with limited coverage in the original directly reported dataset, and with higher diesel usage i.e. China, India, Africa and US. Finally, GSMA data for on-site electricity generation for mobile operations were also added in the study, representing operations and regions with a high degree of diesel consumption, see [6].

The extrapolations to the global level were done using the average electricity consumption per subscription multiplied with the total number of global subscriptions not already covered by the data set. For calculation of the operational carbon emissions, a global average emission factor for electricity was used [7] – corresponding to about 0.52 kg CO_2/kWh for electricity production and CO_2 only, and about 0.6 kg CO_2e/kWh when taking into account also the electricity supply chain and distribution losses as well as all greenhouse gases.

Since the collected directly reported data set contains data that can be considered as confidential corporate information (e.g. traffic volumes), the operators that have provided information have been promised anonymity. No information will be presented regarding names of the operators or the country of operations. The data categories collected are summarized and commented upon in table I.

TABLE I. INCLUDED AND EXCLUDED DATA

Included network electricity (and diesel for mobile networks):
Fixed telephony access networks (aka PSTN/POTS)
Mobile access networks of all generations including all diesel consumption
Fixed broadband access networks
Data transmission and IP core network
Included operator activities:
Electricity and other energy in data centers, offices and stores.
Business travel and fleet vehicles used for field service operations.
Not included (but network related):
Enterprise networks ("Intranets") of non-network operator companies and organizations
Home networks / CPE (Customer Premises Equipment e.g. modems, gateways etc.)
Partly covered (cable-TV and IPTV):
Cable-TV networks (CATV) as such are not included in this study. Fixed broadband over CATV is estimated to consume about the same amount of electricity as fixed broadband over DSL or fiber. This is probably a conservative over estimate as broadband via CATV share the network as well as electricity consumption with traditional TV channel CATV distribution. Note also that the IPTV distribution via the telecommunication network are included in the network operator's network electricity consumption and / or data centers electricity consumption.

III. RESULTS

Extrapolated results for a global level are presented in Section III.A, followed by detailed results in III.B and III.C. As already mentioned, the extrapolations are based on primary data which covers networks for about 15% of fixed network subscriptions and nearly 40% of mobile network subscriptions in 2015.

A. *Total results extrapolated to a global level*

The total electricity consumption of the ICT network operations, that origins from grid and on-site generated electricity, has increased from 185 TWh to 242 TWh. The grid consumption of the ICT network operations is estimated to have increased by about 24% from 2010 to 2015, from about 173 TWh to about 215 TWh, see figure 2 below. The share of the total global electricity supply in 2015 is about 1% (1.03%), and slightly increased compared to the share 2010 (0.96%).

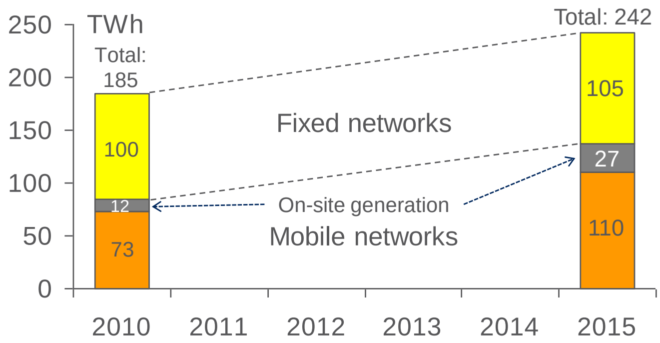

Figure 2 Total electricity consumption of the ICT networks operations. Note: Figures for 2010 are from [7].

In addition to the grid electricity consumption, about 1 million mobile base station sites had their own on-site electricity generation capacity in 2015, generating an estimated 27 TWh, to be compared to about half a million sites and about 12 TWh in 2010. The number of sites with on-site generation capacity has doubled 2010-2015 and some of the sites have also increased their capacity.

TABLE II. ELECTRICITY CONSUMPTION DATA 2015/2010

Key data 2015	Fixed	Mobile	Total
Total grid electricity consumption	105 TWh	110 TWh	215 TWh

Additional on-site generated[1] electricity consumption	n.a.	27 TWh	27 TWh
Average number of subscriptions[2]	1.85 B	7.1 B	8.95 B
Key data 2010	**Fixed**	**Mobile**	**Total**
Total grid electricity consumption	100 TWh	73 TWh	173 TWh
Additional on-site generated electricity consumption	n.a.	12 TWh	12 TWh
Average number of subscriptions[2]	1.74 B	4.97 B	6.71 B
Change 2010-2015	**Fixed**	**Mobile**	**Total**
Total grid electricity consumption.	+5%	+51%	+24%
…with additional on-site generated electricity consumption.	n.a.	+61%	+31%

[1] Mainly from diesel
[2] Per mid-year according to subscription numbers from ITU

Note that electricity consumption not directly related to network operation, such as electricity used in offices, stores and in own data centers, is also included in the total electricity consumption, see more details in figure 4-6 on the next page.

The total carbon emissions related to network operations including on-site electricity generation is shown in figure 3.

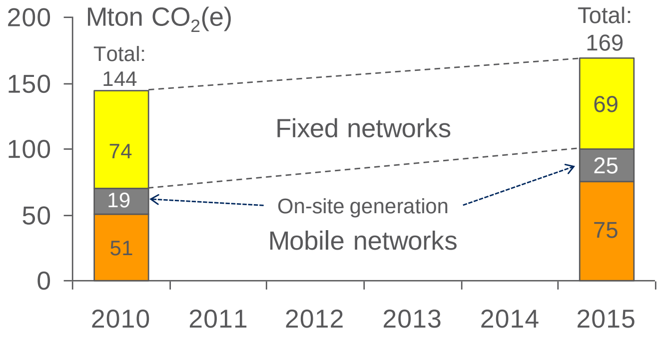

Figure 3 Total operational carbon emissions of the network operations (or "operators") part of the ICT sector worldwide in 2015. Note: Figures for 2010 are from [7].

The reasons for the reduced operational carbon emissions in the fixed networks despite the slightly increased electricity consumption, is probably due to an increased share of purchased certified green electricity over time, and organizational improvements in offices, less travel and more efficient maintenance vehicle fleet operations. In addition, the emissions in 2010 might also have been slightly overestimated mainly due to uncertainties regarding on-site generated electricity volumes. The same reasoning also applies for mobile network operations but here the network growth has been larger and the absolute emissions have increased. Additionally, for the on-site generated electricity for off-grid and poor grid mobile base station sites, a reduction of operational carbon emissions per kWh is noted. This is mainly due to large investments in more efficient so-called diesel hybrid (diesel-battery) solutions, a development that lowers the diesel consumption significantly. In addition, large investments have been made in renewable energy sources such as solar (photo voltaic solar cells), as well as wind power, often in combination with diesel hybrid solutions.

Despite the efforts by the operators to increase energy efficiency and the investments of renewable energy supplies, the electricity consumption and operational carbon emissions of the operation of the ICT network is still increasing globally. However, the total share of the global grid electricity and operational carbon emissions including all diesel consumption has only increased slightly during 2010-2015 and some IT mature countries have even started to reduce their total ICT footprint [1]. See table III.

TABLE III. SHARE OF GLOBAL ELECTRICITY SUPPLY AND TOTAL CARBON EMISSIONS

Share of electricity supply	**2010**	**2015**
Operational grid electricity	0.96%	1.03%
Additional on-site generated electricity[1]	0.07%	0.13%
Total	1,03%	1,16%
Share of operational carbon emissions		
Share of energy related CO_2	0.48%	0.52%
Share of all CO_2e[2]	0.30%	0.34%

[1] Compared to total global grid electricity, see [8]
[2] All operational carbon emissions also includes all other greenhouse gases (GHG's) and fugitive CO_2e from e.g. agriculture, forestry as well as land use, see [9]

B. *Electricity consumption results in detail*

Absolute electricity consumption per subscription for mobile network operations is presented in figure 4 and for fixed network operations in figure 5. Note: The scale is the same in both figures to allow for comparisons.

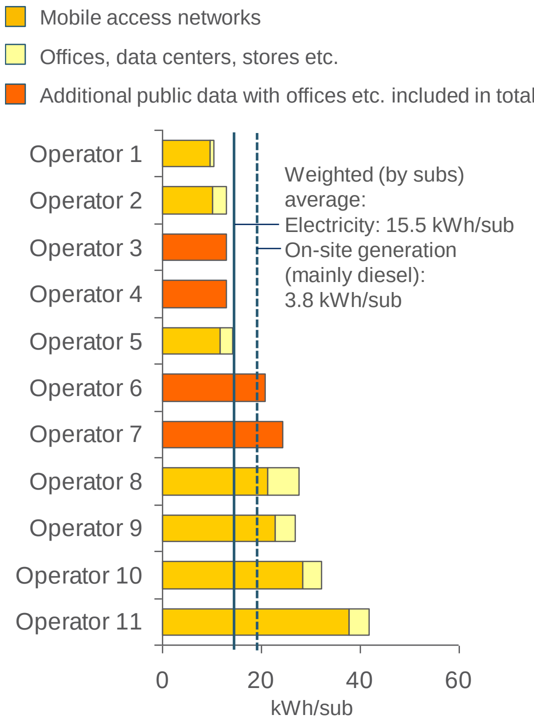

Figure 4 Electricity consumption per subscription (/sub) for mobile network operations 2015. The dotted line indicates additional consumed electric energy that is generated by diesel (in average).

As described in previous sections, the directly reported mobile operations data set was not representative enough to allow for a global extrapolation as the sample was rather small (e.g. 5% of the reported mobile subscriptions in 2010, 9% in 2015).

The additional data that was included in the study is shown separately in figure 4 and comes from four major mobile operators (see section IIIC). The figures also show the global averages for electricity consumption per subscription, weighted based on regional distribution of subscriptions.

For the directly reported data set, figure 6 shows the distribution between data centers, offices and networks related to the total electricity consumption (fixed and mobile).

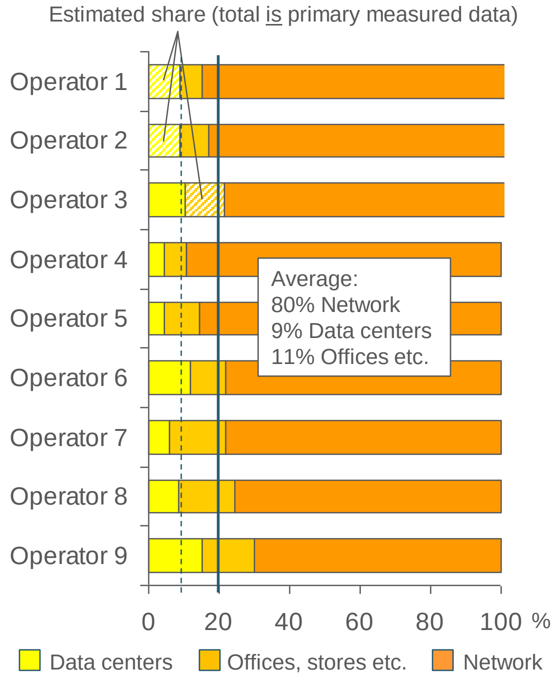

Figure 6 Distribution of total electricity consumption for consolidated directly reported data.

The variation between operators is not as large in the distribution of total electricity consumption for directly reporting operators (figure 6) as in the electricity consumption per subscription for all operators (figure 4 and 5). For the directly reported data, about 11% is related to offices, stores and other non-network related activities and 9% to the internal data centers that's required for the telecom operators operations. The rest, i.e. about 80% is related to network operations. Diesel-generated electricity is not included in figure 6, but is shown in figure 4.

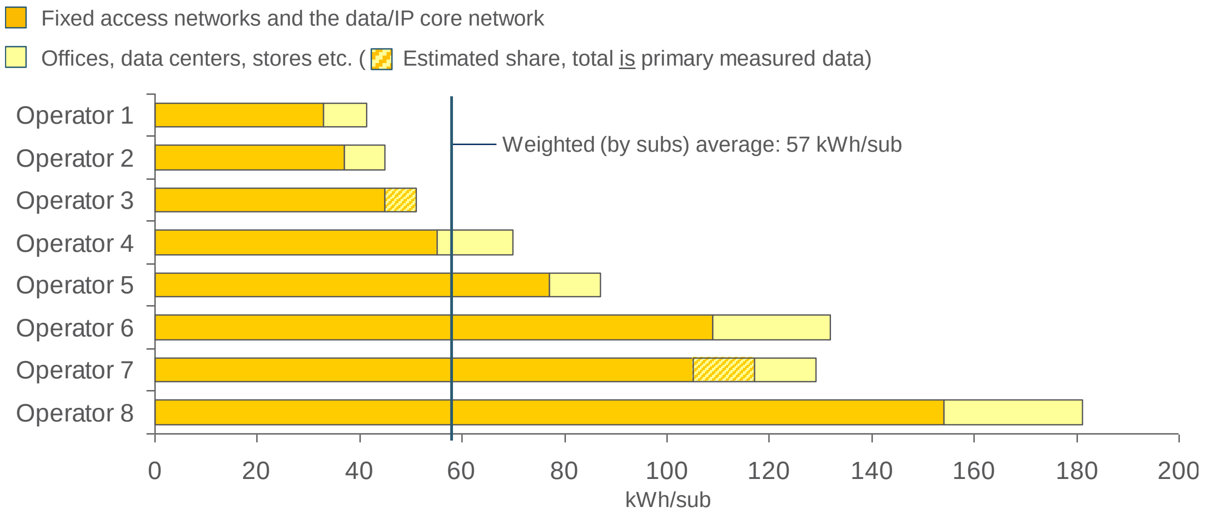

Figure 5 Electricity consumption per subscription (/sub) in fixed network operations 2015. Note that *Operator 1* may not be the same as *Operator 1* in figure 4.

C. Operational carbon emissions results in detail

The total operational carbon emissions reported in 2015 by the operators in the directly reported data set are shown in figure 7.

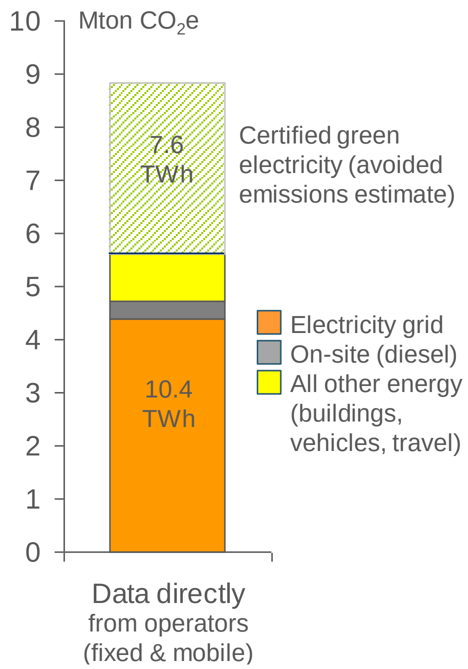

Figure 7 Total operational carbon emissions reported by the operators in the directly reported data set.

The total operational carbon emissions for fixed and mobile networks when extrapolating to all subscriptions based on the data for the directly reporting operators and the four additional major operators, are shown in figure 8. The figure shows the directly reporting operators´ data, additional operators´ data and the extrapolated results separately, as well as the estimated embodied electricity and fuel supply chain emissions. As stated in section 1, the embodied carbon emissions related to infrastructure and equipment are not included.

The extrapolations to the global level were done using the average electricity consumption per subscription (from section III.B) extrapolated to the total number of global subscriptions, while considering the emission factors for electricity consumption and adjusting for the geographical distribution of the dataset, also considering losses.

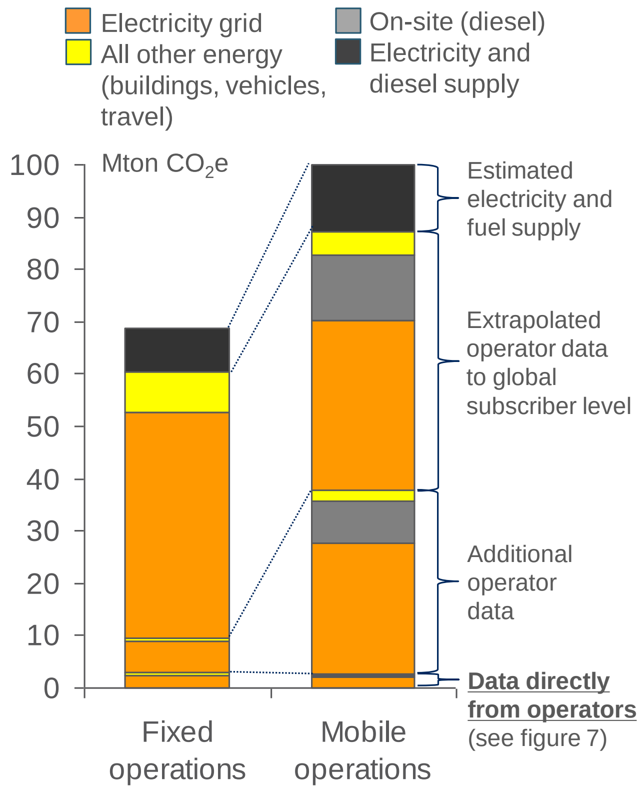

Figure 8. The global operational carbon emissions for fixed and mobile networks. Note that the scale is 10x the scale in figure 7.

The total operational carbon emissions of ICT network operations are about 169 Mtonnes CO_2e which is about 0.34% of the overall global carbon emissions in 2015 (estimated to about 50 Gtonnes) or about 0.5% of the global emissions related to energy (estimated to about 32 Gtonnes [8]).

D. Electricity consumption and operational carbon emissions-results per subscription and per amount of data traffic

The most relevant intensity metrics are the total electricity consumption (including also on-site generation) and operational carbon emissions per fixed and mobile subscription, as well as total electricity consumption and operational carbon emission per subscription. These intensity metrics, in combination with the total impact already presented, offer a more contextual view of the development of ICT network operations 2010-2015. Figures 9 A-B show how most of these metrics have slowly decreased during the period except for the mobile electricity consumption that presents a slowly increasing trend.

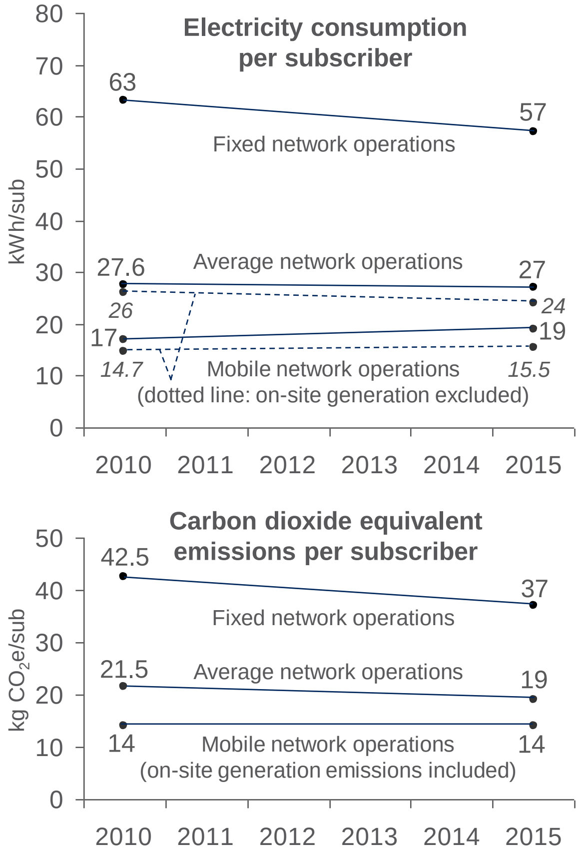

Figure 9 A-B Total electricity consumption (A) and operational carbon emissions (B) results per subscription (sub).

The main reason for the electricity consumption decrease in fixed network operations is that old, energy inefficient, PSTN network and supporting network infrastructure are being decommissioned and replaced by other more modern and energy efficient solutions. In addition, fixed broadband equipment is also being modernized resulting in energy efficiency gains.

The reason for the increase in electricity consumption for mobile network operations is that new standards and networks (e.g. 3G and 4G) are installed and built out on top of existing ones (e.g. 2G). The electricity consumption has decreased on a per network standard, i.e. 2G, 3G, 4G, but the total electricity consumption gets higher per subscriber when combining them. This is not fully cancelled out by the increased energy performance of equipment when the growth of networks and network capacity make the overall operational electricity consumption grow.

The operational carbon emission for fixed networks is decreasing slightly more than the electricity consumption. The main reasons for this is that operators improve not only their networks but also their offices, travel and maintenance operations including vehicle fleet for services. A similar decrease of the carbon emissions related to mobile operators´ organization and network maintenance can also be seen. As mentioned earlier, network operators are also among the most active purchasers of green electricity together with other companies in the ICT sector which the directly reported operator data clearly indicated.

Another intensity metric that is often used in studies and communication is the amount of electricity needed per amount of data transmitted over the networks. This intensity metric is based on a more limited data set, as it is based on data for only five operators. Nevertheless, the trends are interesting.

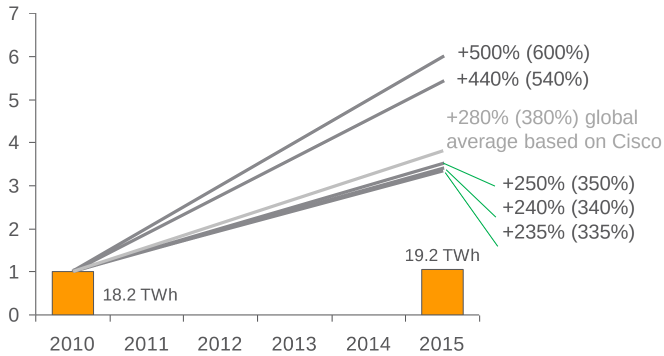

Figure 10 Electricity consumption and data traffic (indexed, 2010 level equals 1) for five operators that have measured data traffic 2010-2015.

As figure 10 shows, the electricity consumption of the five operators included in the data traffic analysis has increased by about +5% 2010-2015 (ranging from -9% to +11% for the individual operators). During the same period the data traffic increase was in the range of +235% (3.35x) to +500% (6x) for the operators individually. This can be compared with data trends for the same period as predicted by Cisco which probably has the best global average data traffic estimate available: about +300% or an increase of a factor 4. As the operators with high data traffic increase have a smaller subscription base in the used sample, the weighted average of the five operators is very similar to Cisco's estimate.

E. Additional detailed results from the original directly reported data set

To better understand the directly reported data and the additional data that was collected and used in this study, some more details are described and highlighted in this section. Figure 11A shows the number of subscriptions included in the directly reported operator dataset for the period 2010-2015, especially highlighting the subscriptions related to the operators that only contributed with data for 2015. Figure 11B shows total electricity consumption for the same period, as it has been reported by the operators.

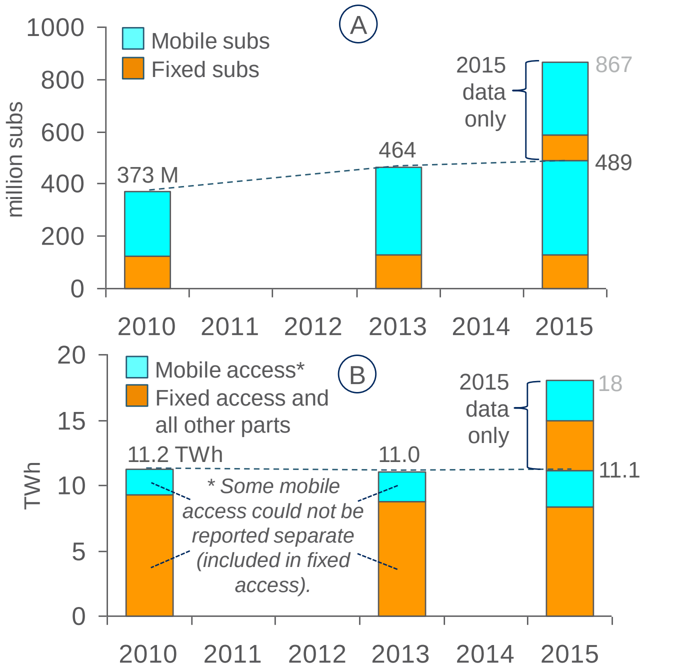

Figure 11 Number of subscriptions included in the directly reported dataset (A) and total reported electricity consumption (B). Note that a few operators only reported data for 2015 as indicated in the figure. *) Some operators could not report mobile access separate in 2010 / 2013.

An important remark about figure 11B is that the mobile access networks have not been reported separately for some operators for 2010 and 2013, which renders the allocation between fixed and mobile difficult. In figure 11, offices, stores and data centers are reported together with fixed networks which also includes the data transmission and IP core network for both fixed and mobile. This means that the mobile part neither includes its share of impacts related to data centers, offices, stores etc., nor its part of the data transmission and IP core network. Instead those are allocated to the fixed part.

Figure 12 shows in greater detail how the per subscription electricity consumption has changed over time during 2010-2015 for fixed and mobile and how deeply dependent the results are on the dataset used.

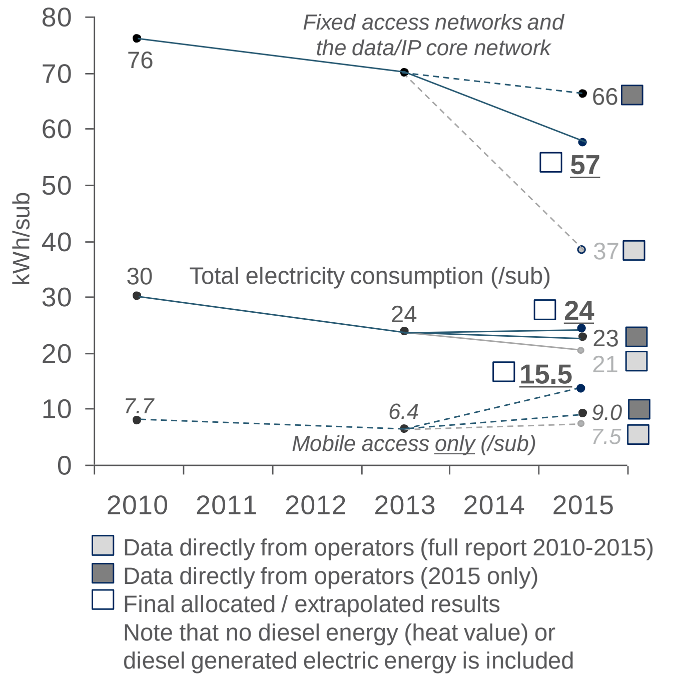

Figure 12 Distribution of the operators´ total electricity consumption. Diesel is excluded here as it was only corresponding to a minor part of the electricity supply in the directly reported dataset.

Figure 12 shows that the electricity consumption per subscription was in general lower for the operators included in the directly reported dataset than in the publicly available data for the other operators used in the study. If only the directly reported operator's dataset would have been used as a basis for extrapolation, it would have resulted in an underestimation of the impact of the global ICT network operations. As the provision of data was performed on a voluntary basis, this could be a bias as operators that focus on energy efficiency improvements and supply may be more likely to contribute to this kind of study, as also the large share of green electricity indicates.

DISCUSSION

As for all estimations of this kind the results need to be interpreted based on the conditions of the study. Nevertheless, to the knowledge of the authors, a similar wide collection of primary data for ICT network operators has not been made before and the resulting data set represents the most extensive and granular data set available. Still the data interpretation needs to be considered in relation to the limitations stated in this report. The following main aspects must be considered:

Coverage:

This study is limited to the direct operational impact from the telecom operators network. By this the report do not, for instance, include external data center operations that are vital for the global Internets functionality. The reasoning behind this divide is the aim to visualize the complex ICT network in understandable and managable pieces. The study relies on the answers received from ten telecom operators which are members of GeSI and/or ETNO. The granularity is the best available, but the sample has a bias as it represents environmentally-aware operators that are mostly located in mature markets. However, in spite of respondents being to large extent based in Europe, several of them have overseas operations and hence more than 30 countries have been included in the directly reported data set, which was also extended by data from other regions as decribed in Section II. Furthermore, the operational carbon emissions were calculated based on a world average electricity mix, to compensate for the higher share of fossile-free electricity usage among the operators in the data set than among telecom operators globally. This was done despite the fact that companies in the ICT sector seem to be relatively large customers of fossile-free electricity. In spite of these measures taken to compensate for biases in the sample, the data set, although extensive, emerge from a limited number of operators which might impact the results..

Data-quality and consequenses for the assessment.

The data, which was collected from the operators, have quite high quality and comes with a granularity far better than the figures that can be found in publicly available annual reports. The primary data is to a high extent based on measured and/or invoiced electricity consumption. In addition electricity consumption levels have been estimated when electricity costs are included in the rent. Regarding the risk for doubble accounting and gaps, there is a lower risk for the fixed networks. This is due to the fact that fixed network equipment is often located at large sites. The risk of excluding data sources is higher for the mobile sites, especially for roof sites and micro sites, where the electricity is often inluded in the rent. As an example, one Nordic operator's mobile network consists of appproximately 50% of sites without electricity meters, which consumes approximatly 35% of the total electricity [5]. In this particular case the information was sufficient to avoid gaps. In general, the risk for gaps depends on the operator's network structure and strategy so this uncertainty is hard to quantify. However, the awareness among operators regarding this is quite high. Furthermore, in general, it is the small sites that lacks their own electricity meters, not the large ones.

Electricity Data divide and Operator Network complexity.

The operators were also asked to report their electricity consumption and allocate it to specified categories such as mobile access, data center operations, fixed access, IP&Core, shops and offices etc. Not all of the operators where able to report their figures with such granularity, but some did and it is the first time that data of such details has been presented in a consolidated format. The seperation into different categories is not easy to achieve since the network from a telecom operator can be quite complex and mix different categories at the same site or in the same building, but the enhanced granularity its needed to be able to identify and quantify trends and potential for savings. This is especially relevant for telecom operators operating both mobile and fixed networks whose services, that were originally fixed voice, are now becoming mobile access services. Voice communication via copper is one example of a service that can now be replaced by mobile services that are often more resource efficient.

The data set for the four non-directly reported operators is based on public information as previously indicated. No detailed information is available for these operators so there is a risk that the aggregated data is of lower quality than the directly reported operator data which could be easier validated. Nontheless this data set should be the best data set available currently to estimate the global electricity consumption and operational carbon emissions of the ICT networks.

The directly reported data for the year 2015 is of high quality, but the historical data for 2010 and 2013 does not meet the same standard, mainly due to lacking information. This limits the possibility to draw general conclusions from the data, but some general trends have been identified. The most important ones for 2010 – 2015 are:

- The overall data volume in the networks is increasing, almost according to Moore's law.
- Also the electricity consumption in the mobile access network is increasing, but slower and not in the range of the data rate increase. This increase is mostly due to the roll out of new technology (e.g. 4G).
- At the same time the electricity consumption of the fixed access and all other network parts is constant or decreasing. This is an important aspect to consider, especially since the largest share of data volume increase originates from the fixed network and not from the mobile network.
- Another identified aspect is that operational electricity for data centers of the telecom operators have increased sligthy, but not as much as can be expected. These data centers represent approximately 10% of the total electricity consumption.

What can be seen is that the increased requirements for mobile access and the continuous demands for higher speeds, increase electricity consumption due to a need for more sites for coverage and increased data capacity. But this is partly balanced by network elements becoming more efficient in the fixed and core network. At the same time, as can be seen in some countries, older technologies such as fixed telefony services (PSTN) and associated services are being decomissioned and replaced by more electricity efficient alternatives, such as Voice over Internet (VoIP).

From figure 8 it is clear, that from a total ICT perspective, the increased electricity consumption in the mobile network has been partially compensated due to increased energy efficiency in fixed networks. Although the volume of fixed subscriptions is only slightly decreasing according to figure 3A, behavioral changes among end users is likely to be one reason for this. An example of this is the phase out of fixed voice communication due to mobile alternatives. As there is a rapid decline in traditional voice subscriptions in ICT mature countries, it can be expected that the same trend will be seen more broadly in the future, leading to further reductions of the fixed networks.

It should be noted that over time, any biases or uncertainties related to absolute levels are likely to be the same between the different years and thus even out. Even if a systematic error exists, the estimated development over time, i.e the resulting trend, is expected to be valid.

Comparison with SMARTer 2020

The carbon emissions of the ICT sector have previously been estimated in the often-cited SMARTer 2020 report [2]. In figure 13, the estimated operational carbon emissions of the present study are compared to the corresponding data from the SMARTer 2020 study – the later study based on models and assumptions. The extensive data set of the present study shows that the carbon emissions have developed slower than anticipated by SMARTer 2020.

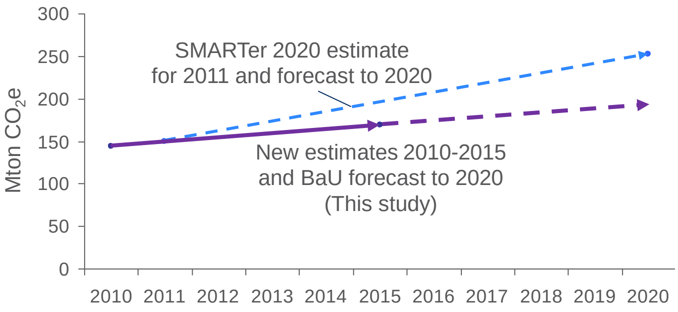

Figure 13. The estimated operational carbon emissions in this study compared to previous estimates in the SMARTer 2020 report.

To compare the values, the results from this study need to be extrapolated to the year 2020. A simple linear forecast i.e. a business-as-usual scenario, shows a reduction in estimated operational carbon emissions for 2020 which is 24% below the SMARTer 2020 prediction. Note also that the growth in number of subscriptions have been slightly higher (around 10%) than what was predicted at that time. Moreover, the data traffic growth has been about twice as high as expected then.

CONCLUSIONS

This study provides a unique data set related to the operational electricity consumption and the operational carbon emissions of ICT networks. The collected data set includes primary data for 10% of global subscriptions and covers nearly 40% of mobile subscription and 15% of fixed subscriptions when also secondary data is taken into account. This study is thus a key contribution to future research regarding the impacts of the overall ICT sector.

The keyfindings of this study are:

- The total annual operational electricity consumption of the ICT networks is estimated to 242 TWh for 2015 including both grid (215 TWh) and on-site generated electricity (27 TWh). The total corresponds to 1.15% of the total electricity grid supply.
- The total annual operational carbon emissions of the ICT networks are estimated to 169 Mtonnes CO_2e for 2015. This corresponds to 0.53% of the global carbon emissions related to energy (about 32 Gtonnes), or 0.34% of all carbon emissions (about 50 Gtonnes).
- Between 2010 and 2015 the electricity consumption grew by 31% from a level of 185 TWh which corresponded to 0.97% of the total electricity grid supply. During the same period the operational carbon emissions grew by 17%. This could be compared to the increase in number of subscriptions from 6.7B to 9.0B during the same period.
- Per subscription, the average operational electricity consumption, including on-site generation, has decreased slightly from 27.6 kWh to 27 kWh per subscription between 2010 and 2015. For the operational carbon emissions, the emissions per user have reduced from 21,5 kg CO_2e to 19 kg CO_2e. 19 kg CO_2e corresponds to driving about 100 km on the highway including the fuel supply chain emissions.
- Seen in the light of earlier estimates this study shows a result which is 24% lower than the operational carbon emissions estimated by the Smarter 2020 report for 2020.

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REFERENCES

[1] Malmodin, J., Lundén, D. (2016). The energy and carbon footprint of the ICT and E&M sector in Sweden 1990-2015 and beyond. Paper published and presented at: ICT for Sustainability (ICT4S), Amsterdam, Netherlands, 30-31 August 2016.

[2] GeSI. 2012. *Smarter 2020: The role of ICT in driving a sustainable future*. A report by Boston Consulting Group on behalf of GeSI. Available at [accessed in February 2016]: http://gesi.org/SMARTer2020

[3] Cisco Visual Networking Index (VNI) 2016. Available at [accessed in November 2017]: https://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html

[4] ITU Key 2005-2017 ICT data 2017. Available at [accessed in November 2017]: https://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2017/ITU_Key_2005-2017_ICT_data.xls

[5] Malmodin, J. et al. 2014. Life cycle assessment of ICT – Carbon footprint and operation. al electricity use from the operator, national and subscriber perspective in Sweden. *Journal of Industrial Ecology*, **18** (6), 829-845.

[6] GSMA December 2014. Overview of The Global Market for Energy to Telecom Towers in Off-Grid and Bad-Grid Areas. Available at [accessed in November 2017]: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2015/01/140617-GSMA-report-draft-vF-KR-v7.pdf

[7] Malmodin, J., Bergmark, P. and Lundén, D. (2013). *The future carbon footprint of the ICT and E&M sectors*. Paper published and presented at: *ICT for Sustainability* (ICT4S), Zurich, Switzerland, 9-12 February 2013.

[8] IEA 2016. Key Electricity Trends. IEA Statistics 2016. Available through [accessed in November 2017]: https://euagenda.eu/upload/publications/untitled-69168-ea.pdf

[9] J.G.J. Olivier, K.M. Schure, J.A.H.W. Peters. 2017. Trends in Global CO2 and Total Greenhouse Gas Emissions. Summary of the 2017 Report. PBL Netherlands Environmental Assessment Agency. The Hague, 2017. PBL publication number: 2983. Available at [accessed in December 2017]: http://themasites.pbl.nl/publications/pbl-2017-summary-trends-in-global-co2-and-total-greenhouse-gas-emissions-2983.pdf