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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Methodologies for the assessment of the environmental impact of the information and communication technology sector

Recommendation ITU-T L.1450

ITU-T

ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T L.1450

Methodologies for the assessment of the environmental impact of the information and communication technology sector

Summary

Recommendation ITU-T L.1450, which forms part of the ITU-T L.1400 series, consists of two parts:

1) Part I: The methodology for calculating the information and communication technology (ICT) sector footprint with respect to life cycle greenhouse gas (GHG) emissions;

2) Part II: The methodology for defining GHG emissions budget for the ICT sector considering a 2 C or lower trajectory.

Appendix IV gives an example of a partial ICT sector footprint derived in line with Part I of the Recommendation.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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2ºC trajectory, assessment methodology, carbon budget, GHG emissions, ICT sector

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Introduction

The *Paris agreement* [b-UN PA], which aims to keep a global temperature rise in 2100 below 2°C above preindustrial levels, entered into force, 2016-11-04. At the same time, private investors are more and more asking about the (GHG) strategy of companies and the environmental impact of their activities. In this context, companies are making commitments to reduce their GHG emissions.

The information and communication technology (ICT) sector, although comparatively small in terms of GHG emissions to other sectors, has a substantial footprint. The ICT sector is growing rapidly and is expected to continue to do so, leading to a substantial and potentially growing carbon footprint. However, studies of some countries have actually reported an initial decoupling. Notwithstanding, the ICT sector still represents a significant part of overall GHG emissions, and it is crucial for it to determine how it could comply with a 2°C trajectory.

This Recommendation, which forms part of the ITU-T L.1400 series, addresses the methodologies needed to assess how the ICT sector contributes, and should contribute to, sustainable development goal 13 (SDG13) of the 2030 Agenda for Sustainable Development, the Connect 2020 Agenda [b-ITU Connect 2020] and [b-UN PA] from a global perspective.

The Recommendation defines the methodologies needed to calculate the footprint of the ICT sector with respect to life cycle GHG emissions considering, for example, the volume of activity; energy consumption and embodied emissions related to product life cycle, and to define a GHG emissions budget for the ICT sector. Therefore, stakeholders will be able to apply this methodology to estimate a budget for ICT sector GHG emissions consistent with the 2ºC trajectory, while considering innovative technologies and emission trends.

The methodology for assessing the aggregated positive contributions of ICT to other business sectors is described in a separate recommendation which is in preparation.

Recommendation ITU-T L.1450

Methodologies for the assessment of the environmental impact of the information and communication technology sector

1 Scope

This Recommendation specifies methodologies for assessing the environmental impact of information and communication technology (ICT) at a sector level including its future development.

It consists of two parts:

1) Part I: The methodology for calculating the footprint of the ICT sector with respect to life cycle greenhouse gas (GHG) emissions;

2) Part II: The methodology for defining a GHG emissions budget for the ICT sector considering a 2ºC or lower trajectory.

It also applies the methodology of Part I and gives an example of a partial ICT sector footprint derived in line with this Recommendation (Appendix IV).

A GHG emissions budget for the ICT sector could either take an organizational approach or be derived from the perspectives of the goods, networks and services of a sector. Each approach has its own challenges, although the latter has been more commonly adopted in the past. For this reason, in this edition of the Recommendation, the methodology focus is on the second approach – a footprint and budget related to ICT goods, networks and services. However, some observations and ideas for an organizational approach are presented in Appendix III.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1400] Recommendation ITU-T L.1400 (2011), *Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies*.

[ITU-T L.1410] Recommendation ITU-T L.1410 (2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services*.

[ITU-T L.1420] Recommendation ITU-T L.1420 (2012), *Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations*.

[ITU-T L.1430] Recommendation ITU-T L.1430 (2013), *Methodology for assessment of the environmental impact of information and communication technology greenhouse gas and energy projects*.

[ITU-T L.1440] Recommendation ITU-T L.1440 (2015), *Methodology for environmental impact assessment of information and communication technologies at city level.*

[ISO 14040] ISO 14040:2006, *Environmental management – Life cycle assessment – Principles and framework.*

[ISO 14044] ISO 14044:2006, *Environmental management – Life cycle assessment – Requirements and guidelines*.

[ISO 14064-3] ISO 14064-3:2006, *Greenhouse gases – Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 absolute emission target [b-SBT method]: An overall reduction in the amount of GHGs a company emits into the atmosphere by a target year relative to levels in a base year.

3.1.2 allocation approach [b-SBT method]: The way the carbon budget underlying a given emissions scenario is allocated among companies with the same level of disaggregation (e.g., in a region, in a sector, or globally).

3.1.3 carbon budget [b-SBT method]: The estimated amount of carbon (or CO_2) the world can emit before warming will exceed specific temperature thresholds. Commonly taken as 1 000 Gt CO_2 for a 2ºC threshold.

3.1.4 emissions intensity target [b-SBT method]: A reduction in emissions relative to a specific business metric, such as production output or financial performance of the company (e.g., tonne CO_2e per tonne product produced or value added). The target is achieved by a target year relative to levels in a base year.

3.1.5 emissions scenario [b-SBT method]: A forecast of future emissions and atmospheric GHG concentrations, used to assess the impact of socioeconomic changes on future emissions.

3.1.6 end-user goods [ITU-T L.1410]: Any device that can connect to CPE or networks.

EXAMPLE – Laptop, mobile phone.

3.1.7 energy technology perspectives (ETP) [b-SBT method]: Document published by the IEA that provides scenarios that set out pathways to a sustainable energy future in which optimal technology choices are driven by costs and environmental factors.

3.1.8 representative concentration pathway (RCP) [b-SBT method]: A GHG concentration trajectory developed in the IPCC 5th Assessment Report (AR5) for climate modelling and research.

3.1.9 target year [b-SBT method]: The year by which a company intends to meet the emissions reduction committed to in a target.

3.1.10 two degrees scenario (2DS) [b-SBT method]: An emissions scenario developed in the IEA's ETP that describes an energy system consistent with an emissions trajectory that would give a 50% chance of limiting average global temperature increase to 2°C.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 carbon intensity target: The level of carbon intensity that has to be achieved in a certain year.

3.2.2 ICT sector budget: The greenhouse gas (GHG) emissions budget allowed by the information and communication technology (ICT) sector

3.2.3 energy technology perspectives scenario: A model of the possible energy transition pathway depending on actions.

3.2.4 exploratory scenario; descriptive scenario: A scenario that aims to answer the question, "What could happen?", and describes one or more possible futures given past and present trends.

3.2.5 green certificate; renewable energy certificate; renewable obligation certificate: A tradable asset, which proves that electricity has been generated by a renewable energy source. A green certificate is often issued per 1 MWh of renewable power.

3.2.6 installed base: The total amount of information and communication technology (ICT) products already in use.

3.2.7 normative scenario; prescriptive scenario: A scenario that aims to answer the question, "What should happen?", and describes one or more possible futures given past and present trends.

3.2.8 scope 1 emission: Greenhouse gas (GHG) emission from sources owned or controlled by an organization.

NOTE – Definition based on [b-GHG PI].

3.2.9 scope 2 emission: On site greenhouse gas (GHG) emission from the generation of electricity, heat or steam that has been purchased by the reporting organization.

NOTE – Definition based on [b-GHG PI].

3.2.10 scope 3 emission: Any other indirect greenhouse gas (GHG) emissions from sources that are located along the reporting organization's value chain.

NOTE – definition based on [b-GHG PI].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

2DS	two Degrees Scenario
4G	fourth Generation
DSL	Digital Subscriber Line
EE-IOA	Environmental Extended Input Output Assessment
ETP	Energy Technology Perspectives
GHG	Greenhouse Gas
GWP	Global Warming Potential
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
LCA	Life Cycle Assessment
PSTN	Public Switched Telephone Network
PUE	Power Usage Effectiveness
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
TV	Television
VoIP	Voice over Internet Protocol

5 Conventions

In this Recommendation:

The expressions "is required" and "shall" indicate a requirement which must be strictly followed and from which no deviation is permitted if *full compliance* to this Recommendation is to be claimed. Assessments may also declare themselves *partially compliant* to this Recommendation by complying to the majority of the requirements, if they are unable to fulfil all of them due to data gaps, a lack of transparency in databases, and so forth.

The expressions "is recommended" and "should" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim compliance with this Recommendation.

The expressions "can optionally" and "may" indicates an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with this Recommendation.

In all cases, the fundamental life cycle assessment (LCA) principles of relevance, completeness, consistency, accuracy and transparency shall guide the practitioner.

6 Principles

The following principles shall be taken into consideration when estimating the life cycle GHG emissions of the ICT sector.

– Relevance: Select data and methods appropriate to the assessment of the ICT sector footprint.
– Completeness: Include all categories that provide a material contribution to the overall results, and all categories covered shall be included in the results.
– Consistency: Enable meaningful analysis regarding the development of results over time by using the same method and data sources, or recalculating, when deriving ICT sector footprint and contextual factors with regards to technological, economic factors.
– Accuracy: Reduce bias and uncertainties as far as practicable.
– Transparency: When communicating the results, the organization shall give sufficient information to support the interpretation of the results. This means that data sources, data collection processes as well as the modelling and the assumptions made must be clearly stated and motivated in the documentation, as well as all the ICT sector boundaries and cut-offs.

7 Guidance on how to use this Recommendation

This Recommendation is intended to give methodological support to organizations that wish to estimate the overall life cycle GHG emission footprint of the ICT sector (Part I), as well as to establish a methodology defining a GHG emissions budget for the ICT sector considering a 2ºC trajectory (Part II).

Appendix IV gives an example of a partial ICT sector footprint in accordance with this Recommendation.

8 Part I: The methodology for calculating the ICT sector footprint with respect to life cycle GHG emissions

8.1 General principles

Part I specifies how to define GHG emissions in the ICT sector for a past, current or future situation, taking into account the full life cycle of ICT goods and services.

The ICT sector footprint covers only first order effects, as second order effects shall not form part of the footprint. The methodology on second order effects at a sector level will be addressed in a separate Recommendation that is in preparation.

To understand GHG emissions in the ICT sector is a complex task that involves a significant amount of data collection from many different sources, as well as modelling and extrapolations, as there is no condensed and complete data set available. The assessment procedure typically combines top-down approaches and data with complementary bottom-up data. For example, data for the annual delivery of goods typically rely on sales statistics, while individual footprints of goods are more often modelled on available GHG emissions estimates, as further outlined in this Recommendation. Generally, there is a balance between data collection effort versus available time and resources. In any case, it is appropriate to start from a sector level and apply assumptions and modelling techniques to estimate the total footprint of the ICT sector.

8.2 Assessment procedure

The assessment procedure for estimating the ICT sector footprint involves a number of different steps which are summarized in Figure 1 and the subsequent list. Note that details regarding the different steps are given in clauses 8.3 to 8.9.

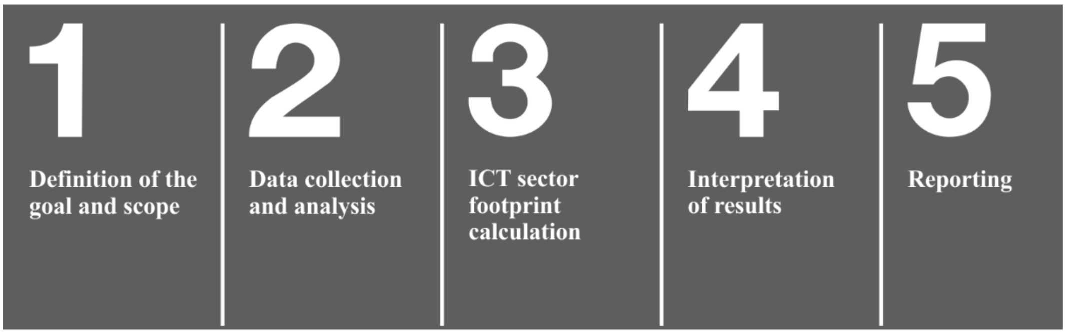

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Figure 1 – Assessment procedure

a) Define the goal and scope of the study (see clause 8.3).

1) Define the overall study goal with regards to ICT sector coverage, time horizon and geographical coverage.
2) Define whether the study assesses only an absolute ICT sector footprint or whether it also targets a relative ICT sector footprint.
3) Define the reference unit.
4) Define the boundary details:
   - the ICT sector boundaries;
   - the time horizon, i.e., whether the study intends to estimate the historical, current or future footprint;
   - the geographical boundaries, i.e., whether the study covers the ICT sector within one country, a group of countries or globally.

b) Data collection and analysis (see clauses 8.4 and 8.5).

1) For each category of ICT goods the following data will need to be collected:
   – volumes:
     • data for installed base, sales volumes and market exit based on lifetime.
   – operating lifetime.
   – GHG emission per category of goods:
     • use stage GHG emissions
     • embodied GHG emissions
   – GHG emission factors.
2) Collect contextual data that are useful for the interpretation of results such as the number of subscribers and data traffic.
3) If the study aims to estimate results in relation to overall global GHG emissions, data shall be collected also for them.
4) For each data point, the available data sets need to be analysed with respect to quality, boundaries, assumptions, etc.

c) ICT sector footprint calculation (see clauses 8.6 and 8.7):

1) the footprint of each category of ICT goods;
2) the overall sector footprint by adding the footprints of the different categories of ICT goods.

d) Interpretation of results (see clause 8.8):

1) analysis of the calculated footprint with regards to the different principles outlined in clause 6;
2) mandatory comparison of the results with other studies and analysis of differences and similarities in results;
3) optionally, derivation and analysis of the footprint per user and per data traffic, in particular, if the study is to be used to interpret the development of the footprint over time.

e) Reporting (see clause 8.9).

8.3 Goal and scope

8.3.1 Study goal

In this step, the study goal shall specify the time horizon, geographical coverage and ICT sector coverage.

The assessment of the footprint of the ICT sector considered in this Recommendation shall at least cover absolute GHG emissions, which means total GHG emissions of the ICT sector expressed in amount of CO_2e, but may additionally also present the results in relation to overall global GHG emissions. For this reason, the study goal shall state whether the study results shall be presented as amount of CO_2e and whether they should also be expressed as a percentage of overall global GHG emissions.

Example 1: "The study covers the global ICT sector, as specified by the boundaries, and shall state both the absolute amount of first order GHG emissions related to the sector as well as its relative footprint in relation to overall global GHG emissions. The study estimates the footprint for the latest year for which data are available (20YY) and also estimates its future development until 2025".

Example 2: "The study covers the footprint of the ICT sector, as specified by the boundaries, for country A. Results are specified in terms of absolute first order GHG emissions for each year from 20xx to 20yy".

8.3.2 Reference unit

The reference unit shall be defined as:

1) the overall life cycle GHG emissions generated by the ICT sector as specified by the boundaries and for the specified geographical coverage over 1 year.

For the interpretation of results, it is also advisable to specify complementary reference flows in terms of GHG emissions in accordance with the reference unit:

1) per subscription;

2) per data traffic.

NOTE – Comparisons of footprint results are only possible if assumptions and other conditions are equivalent.

NOTE – See clause 8.5.9 for further details of how to derive these reference flows.

NOTE – See clauses 8.5.4.2, 8.7.2.2 and 8.5.9 for further details regarding limitations in use of such reference flows.

8.3.3 Boundaries

8.3.3.1 ICT sector

The ICT sector boundaries shall be based on the Organisation for Economic Co-operation and Development (OECD) classification as specified in [b-ISIC] and shall include all categories of ICT goods listed in Annex A in the estimated ICT sector footprint for full compliance with this Recommendation. Appendix I describes in detail the mapping of the OECD classes into the product categories presented in Annex A.

Any deviations from this rule means that compliance with this Recommendation can only be partial and the deviations shall be handled according to the transparency principle.

Services should also be included in the footprint to the maximum extent possible.

NOTE – It is acknowledged that data for the service part of the ICT sector can only be sufficient for a rough estimate of their contribution to the ICT sector footprint, and that data uncertainties can be larger for this part of the footprint. For this reason, it can be convenient to present the results with and without ICT services included.

Any differences in boundaries shall be considered if ICT sector footprints for different years or from different sources are used to track the development of the footprint over time. If the boundaries differ, recalculations shall be performed before any comparisons are made.

Although primarily intended to support the estimation of an ICT sector footprint, the principles of this Recommendation may also be used for the assessment of the footprint of specific categories of ICT goods. Results from such assessments shall not be referred to as an ICT sector footprint, but only as an ICT good category footprint.

8.3.3.2 Geographical boundaries

The Recommendation may be applied to estimate an ICT sector footprint that represents GHG emissions that are related to a country, a group of countries or the global situation. The option applied shall be clearly specified.

8.3.3.3 Time boundaries

Whether the assessment refers to a past, present or future footprint shall be specified. For a present footprint, data shall model the most recent year for which data are available. In all cases, the targeted year and time period covered by the assessment shall be transparently stated. The recommended time period is one calendar year.

NOTE 1 – Due to data delays, a present footprint may more correctly be referred to as "the most recent" footprint since there is usually a delay in data sets, typically in the range 1-3 years.

NOTE 2 – In practice, it may be impossible to find all data for the intended year. Any such data gaps need to be handled by use of proxy data and through extrapolation and modelling of existing data according to clause 8.4.1.

8.3.4 Absolute and relative footprints

To comply with this Recommendation, the absolute ICT sector footprint shall be estimated. Additionally, the ICT sector´s share of overall global GHG emissions may also be estimated.

For this purpose, a scenario developed by an international, recognized source such as the Intergovernmental Panel on Climate Change (IPCC) or International Energy Agency (IEA) shall be used to derive the reference value for overall global GHG emissions.

For a future footprint, a relevant scenario corresponding to a 2ºC or lower scenario shall be used.

8.4 Data collection

8.4.1 Data quality

Many data sources are required to calculate the GHG emissions of a business sector. These data can be found in public sector documents, scientific papers, industrial sector publications and commercial reports. Practitioners shall evaluate different data sources to create the best possible estimate, while respecting the principles of this Recommendation. Referring to these principles, the practitioner shall use the most recognized, representative, high-quality data available. The practitioner shall validate the data by using different independent data sets, such as top-down data together with bottom-up data.

At a minimum, to be considered as high-quality data, the following characteristics shall be verified.

1) **Timeliness**: The date at which the data are generated shall be compatible with the objective of the study or represent the best available proxy if such data are missing. All scenarios and models used should be compatible with the assessed time period.
2) **Accuracy**: Data shall reflect the real state of the source information and should not create any ambiguities. When several data sources are combined to model one data point, each data set used needs to be analysed with respect to quality, boundaries, assumptions, etc., and combined in a way that reflects the quality of the data set and avoids double counting and data gaps.
3) **Accessibility**: The data used should be publicly available and should not require any authorization to be obtained. However, to get hold of accurate data and avoid substantial data gaps, studies may for some data-points need to rely on private or confidential data. Also, when such data are used, the principle of transparency applies to the maximum extent possible.

It is acknowledged that the completeness principle and the need to avoid data gaps may sometimes come into conflict with the transparency principle, due to the necessity of using confidential data in some cases. A data source may become confidential when a company is not willing to share data unless they are guaranteed confidentiality. If such data are used to avoid substantial data gaps, their importance for overall results shall be addressed in the sensitivity analysis and validation with published data should be performed if available.

8.4.2 Data sources

To reduce the risks of flaws in the data collection process, the following preferred sources of data shall be used when available:

1) National Statistics Agencies;

2) International organizations publishing statistics e.g., United Nations (UN), Eurostat, IEA or OECD;

3) Statistics from the United Nations Framework Convention on Climate Change [b-UNFCCC].

When such data are not available or if the data sources are updated too seldom to keep up-to-date with the fast development of the ICT sector, other published sources can be used. The choice of these alternative sources is left to the discretion of the practitioner, but the study must respect the following principles.

1) The practitioner shall make sure that the necessary data are neither accessible from the sources listed in the first paragraph, nor can they be recalculated from them.

2) If the data are extracted from the literature, source articles must have undergone a scientific peer review process prior to their publication.

NOTE – The procedure described in this Recommendation is based on process-sum LCA approaches. However, the environmental extended input output assessment (EE-IOA) data may be used to fill data gaps in line with [ITU-T L.1410].

8.4.3 Cut-off

Cut-offs shall be avoided as far as possible. An alternative to a cut-off is often to model unavailable data based on known data. However, if cut-offs are performed, careful considerations are required.

The cut-off criteria specified in [ISO 14040] and [ISO 14044], i.e., mass, energy and environmental significance, are to be considered before a cut-off of a certain process and the process shall be included if significant to at least one criterion, if data are available. Due to the complexity of a sector footprint, it is considered too challenging to define a strict quantitative exclusion threshold, but the completeness principle shall be respected as far as possible.

Irrespective of the cut-off method applied, the accumulated effects shall be carefully considered, to ensure that the sum of cut-offs remains acceptable.

Activities, processes and flows that have been cut-off shall be included in the sensitivity analysis (see clause 8.8).

NOTE – For studies of the overall ICT sector, cut-offs might be necessary due to data unavailability. In cases of cut-off, the transparency principle applies.

8.5 Data collection and modelling

To model the sector, the first step is to model each category of goods within the system boundaries.

Thus, for each category of ICT goods, the following data will need to be collected:

1) sales volumes and installed base;

2) operating lifetime;

3) GHG emission per category of goods:
    a) use stage GHG emissions,
    b) embodied GHG emissions.

Additionally, the following data for the overall ICT sector footprint need to be collected:

1) GHG emission factors;

2) Contextual data that are useful for the interpretation of results, such as the number of subscribers and data traffic;

3) If the study aims to estimate results in relation to overall global GHG emissions, these data must also be collected.

For each data point, the available data sets need to be analysed with respect to quality, boundaries, assumptions, etc.

8.5.1 Volumes

The sales volumes of each category of goods shall be collected for the assessed year, as well as estimates for the already installed base.

NOTE – Such data may be available from the national statistics agencies of some countries. For a global ICT sector footprint estimate, data are more likely to be available from analysts and industry organizations.

8.5.2 Operating lifetime

The operating lifetime shall be derived in two cases as follows.

a) If the embodied footprints of the different categories of ICT goods are depreciated (see clause 8.6.1).

b) If data regarding the installed base is not available, the operating lifetime together with the sales volume could be used to derive this. In this case, the operating lifetime is used to estimate the number of years the sales of the different ICT goods categories year 20xx should remain within the footprint of the category of the ICT good, and the data could be derived from sales volumes for several consecutive years.

If any of these cases apply, the operating lifetime per category of ICT goods shall be based on the available information on actual use (e.g., statistics for similar goods, networks and services or information on commercial lifetime) and shall model a real operating lifetime as closely as possible. If information on actual use of goods, networks and services cannot be found, economic statistics may be used to estimate the operating lifetime, e.g., economic depreciation time. However, such estimates are considered to be less accurate.

NOTE – If the study targets a past year, actual use time may be available and can then be used. In most cases, actual operating lifetime is not available and estimates are needed.

If data are available for sale of reused products, their operating time should be included in the ICT sector footprint as accurately as possible. Extended operating lifetime is estimated according to the same principles as the (first) operating lifetime.

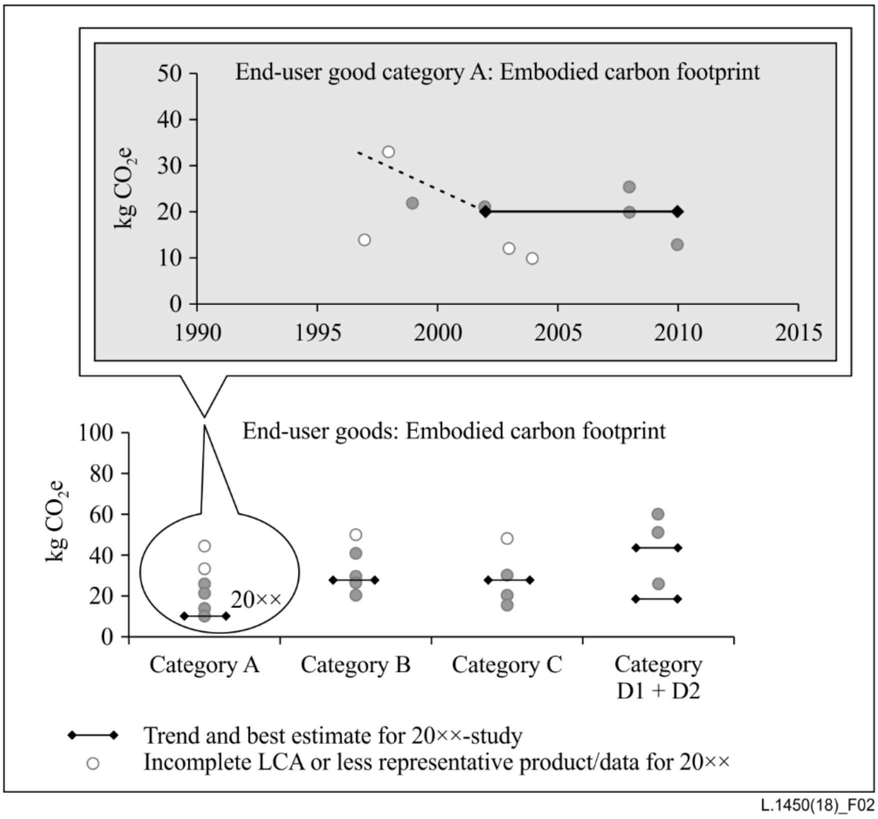
8.5.3 ICT end-user goods

8.5.3.1 Embodied GHG emissions

The embodied emissions for end-user goods shall be based on published LCA studies for the category of ICT goods. Recommendation [ITU-T L.1410] states that results shall only be compared if conditions and data sets are the same, which means that results from different studies are not comparable without consideration of the different conditions. Thus, in this step, the published literature on the ICT good shall be thoroughly investigated to create the most accurate model of the targeted category of ICT goods. Results shall be analysed taking into consideration assessment boundaries, age, geographical coverage, representativeness of the assessed goods to the overall category for the assessed year, etc. Figure 2 illustrates a typical situation with data from different sources that needs to be analysed to derive a trend and a best estimate. This step analysis requires an experienced LCA practitioner.

NOTE 1 –Data availability at the time of publication typically only allows for a rough estimate where broad categories of goods like laptops and stationary PCs may be modelled separately. However, it does not allow modelling for each type of laptop or PC individually.

NOTE 2 – Data developed in alignment with [ITU-T L.1410] take precedence over other data, unless limitations in data applicability exists due to data age, representativeness of assessment target, etc.



NOTE 3 – Typically, this kind of data is not available for the specific year of assessment.

Figure 2 – Example of graphic representation of available sources and the derived estimate of the embodied GHG emissions where each bullet represents one data source

8.5.3.2 Use stage GHG emissions

The use stage of end-user goods shall be modelled based on:

1) actual energy consumption measurements during usage for a wide range of users (preferred);
2) research studies based on actual usage patterns and energy consumption profiles;
3) manufacturer data sheets combined with estimated user profiles;
4) targeted levels from regulation (mainly for future estimates).

NOTE 1 – Typically, use stage data for end-user goods are not available for the specific year of assessment.

NOTE 2 –Usage profiles based on recognized sources such as scientific literature are preferred.

If data are available for volumes for each usage segment and usage profile, end-user goods for private and office usage should be modelled separately.

As for the embodied emissions, the collected data shall be analysed and compared taking into consideration boundaries, age, representativeness, etc., to create the most accurate model of the targeted category of goods. Figure 3 illustrates a typical situation with data from different sources that need to be analysed to derive a trend and a best estimate. The analysis shall be performed by an experienced LCA practitioner or someone who has a good knowledge of the energy performance of the product category.

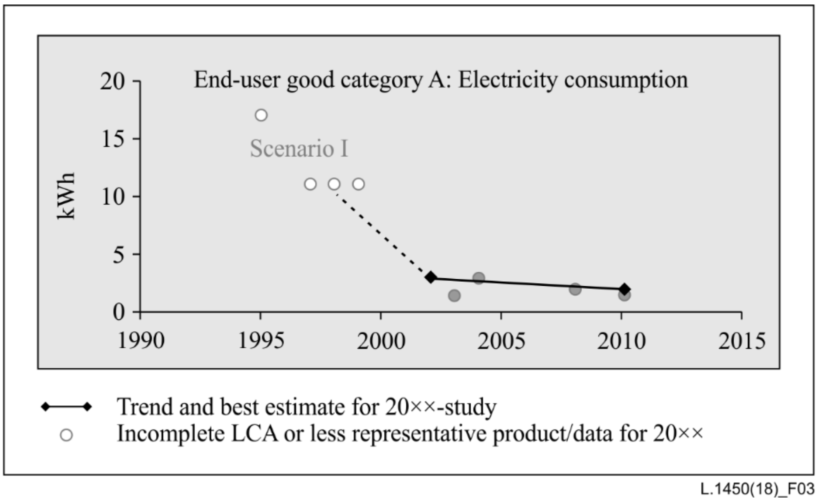


Figure 3 – Example of graphic representation of available sources and the derived trend for the energy consumption where each bullet represents one data source

Typically, data represent measurements performed over a certain period of time, and thus such data need to be recalculated to represent the annual energy consumption and GHG emissions.

Example: Data for usage emissions of laptops were collected from a nationwide study that included a certain number of households. The measurements took place over a 6 month period, and the estimated value was multiplied by a factor of two to represent a year of usage.

8.5.4 ICT network goods

8.5.4.1 Embodied GHG emissions

The embodied emissions for network goods shall be based on LCA studies for the different categories of ICT network goods or on network level LCAs. [ITU-T L.1410] states that results shall only be compared if conditions and data sets are the same which means that results from different studies are not comparable without consideration of their different conditions. Thus, in this step, the published literature on the category of ICT network goods or on the ICT network shall be thoroughly investigated and results shall be analysed taking into consideration assessment boundaries, age, geographical coverage, representativeness of the good, data quality requirements, etc., to create the most accurate model of the targeted category of goods. This analysis requires an experienced LCA practitioner with good knowledge of ICT networks. Figure 3 shows a graphical representation of an outcome of a corresponding data weighting process for an ICT end-user good.

NOTE 1 –Data availability at the time of publication typically only allows for a rough estimate where broad categories of goods like base stations and core nodes may be modelled separately. However, it does not allow modelling for each RBS type or specific core nodes individually.

NOTE 2 – Data developed in alignment with [ITU-T L.1410] take precedence over other data, unless limitations in data applicability exist due to data age, representativeness of assessment target, etc..

NOTE 3 – Typically, this kind of data is not available for the specific year of assessment.

NOTE 4 – Published data from component manufacturers on overall production and energy consumption is available and may provide a good basis for data validation.

8.5.4.2 Use stage GHG emissions

The use-stage energy consumption of networks together with the ICT network operator´s support activities according to [ITU-T L.1410] shall be modelled based on data measured during network operation.

The data set shall cover a substantial share of the assessed geographic area and of the subscriptions within that area. Furthermore, the energy consumption of the use stage per subscription, shall be derived to model the use stage per user.

To derive a representative sample of measured actual energy consumption, in particular, of networks demands the consideration of some important parameters:

a) **Grid and non-grid electricity supply**: The selected networks shall be representative for the assessed geographical area in this respect. If a balanced sample is not within reach it is necessary to collect data for diesel usage separately and consider these in the overall GHG emissions related to the use stage of networks.

b) **Primary and published data**: If primary data are not sufficient to achieve representativeness, such data should be complemented by published secondary data from sources such as the environmental reporting of companies.

c) **Reporting bias:** Sustainability-profiled companies may be more willing to share their data than other companies, which may bias the results with regard to the use of green certificates, energy performance, etc. Reporting bias needs to be taken into consideration when forming the overall data set to avoid "green bias" in the data.

d) **Extrapolation of sites or facilities**: It is important to understand whether a data set represents the total network equipment or only a fraction of it and whether such a fraction is representative of the data to be extrapolated to represent all sites. These could apply to specific situations, such as meters covering several sites. If the electricity consumption of all sites or facilities within a network is not measured, extrapolation shall be applied while considering the representativeness of the sample.

Typically, the practitioner may also encounter a number of allocation situations throughout the assessment. In particular, the sharing of sites or facilities demands attention. For example, consider the following.

a) **Site-sharing of access networks**: Different categories of network goods may share the same location and the same energy meter. In these situations, it is necessary to allocate the overall energy usage to the different categories. To do so, detailed measurements of the power distribution within a number of sites may be used to provide a fair basis for the allocation.

b) **Site-sharing of core networks**: If mobile and fixed core network goods are co-located, the energy consumption may be allocated fully to the core network, if no detailed grounds for allocation are readily available.

In the case of country-based studies or studies performed for a group of countries, the allocation of the international carrier backbone needs consideration. In this case, it is advisable to allocate the backbone goods to the country or group of countries where the backbone is located. A more detailed option would be to consider the use of the backbone, both for the backbone goods located in the country and those used by the country. However, as the backbone usually only represents a small part of overall emissions, this would add to much complexity without considerably adding to the accuracy of the results.

Recent and measured data are preferred due to the dynamics of network energy consumption and the fast development of data traffic. It is acknowledged that such data sets have a closer connection to actual conditions and that they are therefore expected to be more representative of reality.

The collected data shall be analysed taking into consideration boundaries, age, representativeness, etc., to create the most accurate sample of the use stage of networks. This step shall be performed by an experienced LCA practitioner and someone who has a good knowledge of the energy performance of ICT networks.

Practitioners should carefully consider the applicability and consequences of different modes of scaling (e.g., by data or by subscription) while considering the historical and expected future conditions of the sector.

Within the sampled energy consumption, green certificates may be included according to their usage. However, for extrapolation from the sample to the assessed geographical area, such certificates shall not be used.

8.5.5 Data centres

8.5.5.1 Embodied GHG emissions

The embodied emissions for data centres shall be based on LCAs. [ITU-T L.1410] states that results shall only be compared if conditions and data sets are the same, which means that results from different studies are not comparable without consideration of their different conditions. Thus, in this step, the published literature on the category of data centres shall be thoroughly investigated and results shall be analysed taking into consideration assessment boundaries, age, geographical coverage, representativeness of the data centre, etc., to create the most accurate models of the targeted category of data centres. This step demands an experienced LCA practitioner with good knowledge of data centres. Figure 3 shows a graphical representation of an outcome of such a data weighting process for an ICT end-user good.

NOTE 1 –Data availability at the time of publication typically only allows for a rough estimate where broad categories of data may be modelled separately. However, it does not allow modelling for each data centre type or configuration individually.

NOTE 2 – Data developed in alignment with [ITU-T L.1410] take precedence over other data, unless limitations in data applicability exists due to data age, representativeness of assessment target, etc.

NOTE 3 – Typically, this kind of data is not available for the specific year of assessment.

8.5.5.2 Use stage GHG emissions

The use-stage energy consumption of data centres together with the data centre operator´s support activities according to [ITU-T L.1410] shall be modelled based on data measured during network operation.

The data set shall cover a substantial share of the assessed geographic area and of the data centres within that area. Furthermore, the energy consumption of the use stage per physical server shall be derived to model the use stage of data centres. An example describing the electrical energy used by one server is given in Appendix V.

To find a representative sample of measured actual energy consumption of data centres demands the consideration of some important parameters, in particular the following.

a) **Primary and published data**: If primary data are not sufficient to guarantee representativeness of the GHG emissions of data centres, such data should be complemented with published secondary data from sources such as the environmental reporting of companies.

b) **Reporting bias**: Sustainability-profiled companies may be more willing to share their data than other companies, which may bias the results with regard to the use of green certificates, energy performance, etc. This requires consideration when compiling the overall data set to avoid "green bias" in the data.

c) **Extrapolation of data centres**: As not all data centres have separate electricity meters for the data centre as such, it is important to understand whether a data set represents all data centres of a data centre operator or only a fraction of them, and whether such a fraction is representative (with regard to server types) for the data to be extrapolated to represent the totality. If the electricity consumption of all data centres of a data centre operator is not measured, extrapolation shall be applied while considering the representativeness of the sample.

Typically, the practitioner may also encounter a number of allocation situations throughout the assessment. In particular, sharing of sites or facilities demands attention.

a) **Site-sharing of data centres**: Different categories of data centre may share the same location and the same energy meter. In these situations, it is necessary to allocate the overall energy usage to the different categories. To do so, detailed measurements of the power distribution within a number of data centres may be used to provide a fair basis for the allocation.

In the case of country-based studies or studies performed for a group of countries, the allocation of the internationally used data centres needs consideration. In this case, it is advisable to allocate the data centres according to traffic, both for the data centre located in the country and those used by the country. The city scale principles outlined for this in [ITU-T L.1440] provide a good basis for this allocation, and the balance between data in and out of the area provides a good basis for estimating the applicable share.

Recent and measured data are preferred due to the dynamics of data centre and the fast development of data traffic. It is acknowledged that such data sets have a closer connection to actual conditions and that they are therefore expected to be more representative of reality.

The collected data shall be analysed and compared taking into consideration boundaries, age, representativeness, data quality, etc., to create the most accurate sample of the use stage of networks. This step shall be performed by an experienced LCA practitioner and someone who has a good knowledge of the energy performance of ICT data centres.

8.5.6 ICT service development and operation support

The use stage of ICT services in terms of ICT goods energy consumption is included in the footprint of the use stage of these goods. The remaining part of the footprint is related to the embodied footprint in terms of offices, transport and travel performed by the developer of the services, as well as operation and maintenance. There are currently limited data available for the global ICT service sector and estimates of the services might be less specific than for the hardware.

For these reasons, if ICT services are included within the boundaries, data per representative ICT service employee shall be collected or modelled, as well as the number of employees in the sector within the accessed geographical boundaries.

NOTE 1 – Overall ICT service sector employment seems to be hard to estimate globally, but the proposed method is still seen as a feasible way of including ICT services in the ICT footprint.

NOTE 2 – The use of ICT services in terms of ICT usage is already part of the footprints for the different categories of ICT goods used by the service and need not be modelled separately.

8.5.7 GHG emission factors

When selecting the emission factors for the calculation of GHG emissions in accordance with this Recommendation, the guidance of this clause shall be followed.

GHG emission factors for energy usage shall be collected and used if these do not already form an integrated part of the collected data set. According to the ITU-T L.1400 series of Recommendations, such emission factors shall be as recent as possible, shall be derived from recognized public sources, and shall include the electricity supply chain and distribution losses. Where emission factors are sourced from non-public sources or are not the most up to date, a justification for their use shall be provided.

Different emission factor data sources for electricity may or may not take energy supply and distribution into account. Emission factors that are as complete as possible shall be used and their comprehensiveness shall be transparently reported. Consequently, the most recent emission factors available may not be the preferred choice or may need to be complemented.

For all energy consumption data, representative energy mixes in accordance with the goal and the scope of the assessment shall be used. For the use stage, the emission factor shall reflect the energy mix of the geographical location as closely as possible. When known, location-specific data on energy mixes for a given locality or region give the most accurate results.

The specific global warming potential (GWP) values used shall be those taken from the latest UN Intergovernmental Panel on Climate Change (IPCC) report (at the time of publication, this is [b-IPCC AR5]) and the time frame shall be 100 years. For further guidance see Annex B.

8.5.8 The ICT sector's share of overall GHG emissions

8.5.8.1 The global GHG emissions reference

If the ICT sector footprint is also assessed in relation to the overall global GHG emissions, data on these global emissions also need to be collected.

On the global scale, data shall be collected from the IEA, IPCC or UNFCCC. The ICT sector footprint may be related to either the overall global GHG emissions related to energy supply or to the overall GHG emissions, including land use, etc. Description of the global reference used shall in both cases respect the transparency rule.

8.5.8.2 The non-global GHG emissions reference

For non-global geographical boundaries, the ICT sector footprint may be compared to national statistics in line with the public Kyoto reporting, representing the emissions within the territory boundaries. Alternatively, the reference may be established as a consumption-based footprint of the assessed geographical area, also including GHG emissions due to goods consumed within the area, but produced elsewhere. In both cases, the practitioner shall consider whether the reference includes land use. In either case, the principle of transparency shall be respected.

NOTE – As the consumption-based footprint is not part of the Kyoto Protocol [b-UN KP], national statistics may not be always available.

8.5.9 Contextual data

The most important contextual data to be used are the number of subscriptions and the amount of data provided by the ICT sector each year. Separate estimates shall be collected for fixed and mobile subscriptions and data traffic shall be collected at the interface between access and core networks and include both inflows and outflows. As impact per subscription type varies, it may also be advisable to use a model to derive equivalent subscriptions. In any case, double accounting risks shall be considered.

NOTE 1 – Through its *World telecommunication/ICT indicators database* [b-ITU WT], ITU is the main global data source for subscriptions, data volumes are typically collected from the ICT sector itself.

NOTE 2 – Internal data traffic in enterprise networks may be omitted from the data traffic estimates.

NOTE 3 – In the past, there has been quite a strong correlation between the number of mobile users or subscribers and the number of subscriptions, although some users may have more than one subscription, and subscriptions may be used by more than one person. In the same way, there has been a correlation between the number of households and fixed subscriptions. Thus, subscriptions have been found to be a reasonable proxy for the number of users. With an increasing amount of Internet of things (IoT) devices, subscriptions may be less correlated with users and other contextual parameters may become more important. Furthermore, the connectivity of IoT devices may not be subscription based, but founded on Internet protocol (IP) or narrow band solutions that might not form part of the statistics. This will be considered for the next edition of this Recommendation.

8.6 Calculation of footprint per category of goods

8.6.1 Depreciation method

When calculating the overall footprint of the ICT sector two options exist:

1) the embodied GHG emissions are related to the year of sale and the operational lifetime is not considered;

2) the embodied GHG emissions are divided per operating year to create the yearly GHG emissions that are then considered for each year of operation throughout the assumed operating lifetime.

Due to the complexity of method 2 and the difficulty in acquiring data, the method 1 is recommended, although the second might be considered more accurate. However, if depreciation of embodied emissions is applied, the yearly impact from the embodied GHG emissions should be derived. To do that, the estimated embodied emissions according to clauses 8.5.3.1, 8.5.4.1 and 8.5.5.1 need to be divided by the operating lifetime (see clause 8.5.2) to produce an estimate of the embodied GHG emissions per year.

For method 2, no further guidance is given. Practitioners who use this method shall transparently describe the method applied and formulas used.

8.6.2 Calculation of the footprint per category of end-user ICT goods

The footprint of a specific category of ICT end-user goods shall be calculated as:

$$FPc_x = [V_s \times (FPe + E_y \times EF) + V_i \times E_y \times EF]/1\,000 \quad (8\text{-}1)$$

where

FPc_x = footprint of category c_x [t CO_2e];

V_s = yearly sales volume (mid-year);

V_i = installed base (mid-year);

FPe = embodied emissions [kg CO_2e];

E_y = yearly energy consumption [kWh];

EF = GHG emission factor [kg CO_2e/kWh].

NOTE 1 – V_i can be estimated based on subscriptions, lifetime, market analysis information etc., if the information on the installed base is not readily available. Note that the installed base may differ from number of subscriptions as not all products stay in use until end-of-life, but may be kept as a backup or similar.

NOTE 2 – Equation 8-1 applies to the recommended situation when no depreciation of the embodied emissions is performed.

As an example, the annual sales of smartphones for country A equal 30 million units and the installed based is estimated at 40 million units. The emission factor for energy is 0.6 kWh/kg and the embodied emissions of the smartphone is estimated at 50 kg CO_2e, while the yearly energy consumption is estimated at 4 kWh. In this case, the overall footprint of the smartphones for country A would be estimated at

$$FPc_x = [30\,000\,000 \times (50 + 4 \times 0.6) + 40\,000\,000 \times 4 \times 0.6]/1\,000 =$$

$$1\,668\,000 \text{ t } CO_2e \approx 1.7 \text{ Mt } CO_2e$$

8.6.3 Calculation of the footprint per category of ICT network goods

The footprint of a specific category of ICT network goods shall be calculated as:

$$FPc_x = [V_s \times FPe + \#s \times (E_{Ny}/\#s_{s)} \times EF)]/1\,000 \quad (8\text{-}2)$$

where

FPc_x = footprint of category [t CO_2e]; c_x;

V_s = yearly sales volume (midyear);

$\#s_s$ = number of subscriptions in measured network;

#s = number of subscriptions overall;

$FPe =$ embodied emissions [kg CO_2e];

$E_{Ny} =$ yearly network energy consumption [kWh];

$EF =$ GHG emission factor [kg CO_2e/kWh].

NOTE – Equation (8-2) applies to the recommended situation when no depreciation of the embodied emissions is performed.

8.6.4 Calculation of the footprint of the data centre

The footprint of a specific category of data centre shall be calculated as:

$$FPc_x = [V_s \times FPe + \#c \times (E_{Ny}/\#c_{s)} \times EF)]/1\,000 \quad (8\text{-}3)$$

where

$FPc_x =$ footprint of category c_x [t CO_2e];

$V_s =$ yearly sales volume;

$\#se_s =$ number of physical servers in the data centres measured;

$\#se =$ overall number of physical servers;

$FPe =$ embodied emissions [kg CO_2e];

$E_{Ny} =$ yearly data centre energy consumption [kWh];

$EF =$ GHG emission factor [kg CO_2e/kWh].

The footprints of enterprise servers shall be derived in a similar manner, but shall be scaled based on the number of PCs (connected to these enterprise servers) in the geographical area and not by subscriptions.

Both physical and virtual servers exist but as a basis for extrapolation physical servers should be used. [b-Koomey] exemplifies how physical servers may be used for extrapolation

NOTE – Equation (8-3) applies to the recommended situation when no depreciation of the embodied emissions is performed.

8.6.5 Calculation of the footprint of ICT service development and operation support

The footprint of ICT services shall be calculated as:

$$FPs = \#e \times (FPs/\#e_s)/1\,000 \quad (8\text{-}4)$$

where

$FPs =$ footprint of ICT services [t CO_2e];

$\#e_s =$ number of employees in the ICT service industry in the sample;

$\#c =$ overall number of employees in the ICT service industry in the assessed area;

$FP_S =$ overall GHG emissions for a service [kg CO_2e].

8.7 Aggregation of results: ICT sector footprint calculation

8.7.1 General

Once the overall footprints of the various categories of ICT goods have been calculated for the assessed geographical area, the overall ICT footprint for this area is calculated as their sum. If the relative footprint of the ICT sector in relation to the overall GHG emissions is targeted, this shall also be calculated. It can also be beneficial to calculate the footprint per subscription and per data traffic, in particular when the study is trying to model the development of the footprint over time.

In this step, the practitioner shall also ensure, as far as possible, that double accounting is avoided and that gaps are filled to avoid cut-offs to the greatest possible extent.

Both embodied and use stage emissions shall be included. However, for a non-global footprint, if a comparison with a territorial overall GHG emissions footprint is targeted, non-territorial emissions of the ICT sector should be left out of the comparison. If this is the case, the absolute footprint shall in any case include the embodied emissions, but these contributions should also be logged separately to support transparency in reporting. In any case, the transparency principle shall apply regarding the reference value when linking the ICT sector footprint to overall emissions.

8.7.2 Extrapolating to the future

8.7.2.1 ICT data

Future scenarios are either exploratory (examining how the future might unfold) or normative (prescribing how the future should evolve based on certain normative assumptions). In both cases, known processes of change or extrapolations of past trends should be considered. Thus, if an estimate of the future ICT sector footprint is targeted, the estimate shall identify, and extrapolate from, current trends in the different data sets. In particular, the future estimate shall consider current and expected trends in terms of improved energy performance among goods, more extensive use of energy management solutions, expectations on data centre virtualization and modernization, improvements in production processes and growth in data traffic and number of subscriptions. Additionally, it shall also consider sales trends, future market projections and population growth. Finally, the impact on energy consumption from targets set by regulators or the sector itself on future trends shall be understood.

A future footprint should also consider emerging types of devices.

NOTE – New devices due to disruptive changes of the ICT sector cannot be considered as they are by their nature unknown. However, new types of device that are already forecast should be considered if data exist that enable modelling.

8.7.2.2 Overall GHG emissions

For a future forecast, recognized sources like the IPCC, IEA and UNFCCC use scenarios to outline possible future situations. Thus, any ICT sector footprint expressed as a share of overall emissions shall respect the transparency rule regarding the scenario used. Furthermore, the practitioner shall evaluate the chosen scenario for overall global GHG emissions with regard to technology development assumptions to avoid double counting or inconsistencies regarding future effects. Also, assumptions about economic growth may be important to understand.

8.8 Interpretation

8.8.1 General

The preliminary results of the assessments of the ICT sector need to be analysed and interpreted based on contextual factors. Interpretation of results and data is usually an iterative process that starts during data collection.

In this phase, which corresponds to the interpretation phase of [ITU-T L.1410], the calculated footprint is analysed with respect to completeness, quality, importance of assumptions, etc., and it is also beneficial to compare the results to other studies and analyse differences and similarities in results. As the results may be presented in different ways, such comparisons may demand recalculation of its own or previous estimates to a common reference unit and parameters such as CO_2 vs CO_2e need consideration.

Considerations regarding remaining biases, double accounting and gaps in the data sets (e.g., electricity with lower GHG emissions than generally in the assessed area), and impact from that need to be identified and their impacts need to be considered.

In line with [ITU-T L.1410], a quantitative uncertainty analysis is not considered meaningful due to the high complexity and uncertainty of the analysis itself. However, the different uncertainty sources shall be identified and their impacts shall be qualitatively considered. Examples of uncertainty sources include, but are not limited to: user behaviour; regional representation, number of employees in the service sector; embodied, local electricity mixes; data centre infrastructure; one product to represent a product group; and reuse of earlier studies.

To judge the quality of data of sources, the representativeness of data shall be considered with a critical eye and any limitations or problems encountered shall be handled transparently.

8.8.2 Sensitivity analysis

Sensitivity analysis shall be performed for all scenarios and assumptions used during the study to judge the stability of the results and conclusions. Additionally, if confidential data are used, sensitivity analysis shall be performed to analyse their impact on overall results.

For future estimates, a qualitative analysis of the drivers and barriers that could impact the outcome may also prove useful and may be performed.

8.8.3 Analysing the trends

Comparison with earlier estimates include understanding of similarities in assumptions, boundaries and data, as well as an understanding of how the conditions have changed since any previous study was performed, e.g., with regards to disruptive changes. If GHG emissions per subscriber or amount of data are used as a basis for comparison, it is also important to understand how these reference flows were derived.

The impact of the emission factors used demands special attention within and between studies. The emission factor used may change form one year to the next. If so, the practitioner must ascertain to what extent changes in GHG emission level are due to change in emission factor (reflecting mainly the changes in impacts of the energy supply system or new data) and to what extent it actually reflects a change in the adoption or energy consumption of ICT goods and networks.

8.9 Reporting

8.9.1 Goal and scope

The report shall clearly outline the goal and scope of the study. It must also clearly describe the rationale of the study, the assumptions made and the definition of key concepts (the reference unit in particular) and the ICT sector boundaries applied, any deviations from Annex A, and any cut-offs made within these boundaries together with their motivation. A clear description of geographical and time boundaries including the targeted year and time period covered by the assessment, as well as any limitations or deviations in relation to those shall also be included.

Furthermore, a statement regarding compliance with this Recommendation shall be provided. If the practitioner claims only partial compliance with this Recommendation, the deviation(s) shall be clearly documented. Thus, the compliance statement contained in the report shall disclose and explain any deviations from the requirements in this Recommendation and the use of non-compliant data.

8.9.2 Description of the data sets used in the study

The data sets used in the study shall be clearly listed. State the following details.

1) Data set reference. This name can be the official name of the data set if it exists or an identifier chosen by the author of the study. In both cases, this reference shall be used when describing how the study was performed.
2) Data source (typically an organization or one or more researchers or scientific publication) and details on how these data can be accessed according to state-of-the art academic reference methods.
3) Dates associated with the data, including date of creation and potential end date that restricts the validity of the data.

4) Data set description – keywords or phrases describing the content of the data.

5) If the data have been extracted from scientific articles or other reviewed sources, a description of the type of review process.

6) Rights or access – any known confidentiality, intellectual property rights, statutory rights, licenses or restrictions on reuse of the data.

In addition to these details, if the data are extracted or calculated from a source other than those outlined in clause 8.4.2, the following information must be given:

– A statement indicating that these data are not provided by the preferred list of databases and that they cannot be recalculated from the data provided by these preferred databases or a motivation why the data set used is considered more relevant than the data sets outlined in clause 8.4.2.

In particular, the choice of emission factors shall be transparently described to the maximum extent possible and the motivation for using such factors explained.

8.9.3 Methods and calculations

The method and calculations applied when deriving the ICT sector footprint shall be described as transparently as possible and any ambiguities shall be avoided. In particular, any deviation from the principles and requirements specified in this Recommendation or any remaining biases in the data sets shall be transparently described and the motivation for using such data explained.

It is important to describe how different data sources are selected, compiled, allocated, combined and extrapolated, and whether the data quality is considered insufficient in some data points.

Validations performed on the results shall also be described.

8.9.4 Presentation of results

8.9.4.1 Main results

The following results shall be presented.

– Total ICT sector life cycle GHG emissions

Due to increased uncertainty in modelling and data, the ICT services included in the footprint shall be stated separately, as well as the overall results.

If included in the goal and scope, the following result shall also be presented.

– ICT sector share of overall GHG emissions

If the ICT sector's share of overall emissions is stated, the reference scenario for overall GHG emissions needs to be stated, together with the results. For a non-global GHG emissions footprint, the inclusion or exclusion of embodied emissions in this comparison needs also to be declared, for both the overall GHG emissions and for the ICT sector GHG emissions.

As the choice of emission factors is critical to the results, the emission factor applied shall be transparently stated together with the results. In the case of depreciation of embodied emissions, the operating lifetime shall also be stated.

8.9.4.2 Complementary results

Results and trends may also be presented per subscription and per data traffic. If such information is presented, the report also needs to indicate the limitations in extrapolation of such numbers, and the complexity of the subscription concept with regard to the IoT.

The results may further present the GHG emissions per category of goods.

Finally, the results may present the footprint in relation to earlier estimates while explaining how the comparison was done and respecting the principles applicable for such comparison.

8.10 Critical review

It remains the sole responsibility of the organization(s) performing the study to demonstrate compliance with this Recommendation.

However, two possibilities are recommended as follows.

– This verification can be made by an independent third party. In this case, the name and coordinates of this third party must be given. Moreover, this third party verification must be managed in accordance with [ISO 14064-3], which specifies the requirements for the selection of GHG validators or verifiers, the establishment of the assurance level, objectives, criteria and scope, the determination of the validation or verification method, evaluation of data, information, information systems and GHG controls, assessment of GHG declarations and development of validation or verification opinions. Furthermore, a review statement shall be provided.

– This verification can also be made through a scientific peer review process organized according to the state-of-the-art.

In either case, if compliance with this Recommendation is claimed, a copy of the study shall be sent to the ITU-T for information.

9 Part II: The methodology for defining a GHG emissions budget for the ICT sector considering a 2ºC or lower trajectory

9.1 General

There is a finite amount of carbon that can be emitted into the atmosphere before warming exceeds specific temperature thresholds: the overall carbon budget. The carbon budget is complemented by the emissions scenarios, which mainly describe different ways of distributing the available carbon budget over time.

For a 2ºC trajectory, the total cumulative global emissions from 2012 was estimated by the IPCC as necessary to be kept below 1 010 Gt CO_2. In line with the 2ºC trajectory, the IPCC indicates that by 2050, global GHG emissions must be cut by between 49% and 72% compared to 2010 levels. Furthermore, an increasing number of scientists consider a 2°C trajectory as insufficient and points to a 1.5 C trajectory, which allows for only 360 Gt CO_2 in total and demands 70-95% reductions in the same time frame.

Details of scenarios elaborated by the IPCC are presented in Appendix II.

Such trajectories place higher requirements on the speed and amount of emission reductions. At the 21st Conference of the Parties (COP21) in Paris, 2015, nearly 200 countries signed the accompanying *Paris agreement* [b-UN PA] to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C". However, plans are far from sufficient to realize this ambition and the business sector has an important role in bridging this gap. This is particularly true for the ICT sector, which could impact the overall emissions level both through its footprint and through its enablement effect.

In 2017, a group of researchers called for a faster reduction path, in the light of the negative climate observations made after Paris, through the carbon law initiative [b- Rockström], which suggests that emissions should be halved every 10 years. The carbon law concept is inspired by Moore's law. The importance of defining a GHG emissions budget for the ICT sector as a whole, and for its main categories in line with a 2ºC or lower trajectory, emerge from [b-UN PA] to keep a global temperature rise in 2100 well below 2 C above pre-industrial levels and from the global 2030 agenda for a sustainable development, in particular sustainable development goal 13 (SDG13).

A number of different initiatives have been introduced to speed-up the implementation of [b-UN PA] and to also involve the business sector. Among these initiatives is the Science Based Targets Initiative (SBTi), a joint initiative by Carbon Disclosure Project (CDP), UN Global Compact, WRI and WWF, which aims to get organizations to take on ambitious, voluntary, targets aiming towards a 2 C (or lower) trajectory. To identify a necessary commitment level, several methods, some of them sector specific, are proposed. However, at this stage, there is no specific ICT sector methodology.

This Recommendation, although mainly focusing on the sector as such, aims to provide a specific ICT sector methodology. The SBTi particularly emphasizes that organizations should not select the "easiest" option, but should choose the method and target that best drives emissions reductions. Furthermore, intensity targets are allowed, but should only be set if they lead to absolute reductions in line with climate science or are modelled using a sector-specific decarbonization trajectory that ensures emission reductions for the sector as a whole. Consequently, organizations should use either a sector-based method or an absolute emissions contraction approach to calculate SBTs. Linear emission trends are preferred over peak and decline.

Part II of this Recommendation provides a methodology for defining an ICT sector trajectory compatible with a 2°C or lower scenario, based on the overall global carbon budget and different future emission scenarios. Such trajectories should start from a clear description of the current situation of the ICT sector, the baseline, while taking a life cycle perspective, involving assumptions where the validity and coherence must respect the principles of clause 6.

9.2 A procedure for defining the 2 C trajectory for the ICT sector

9.2.1 Description of the overall procedure

This clause summarizes the main steps of the methodology used to define and monitor a 2°C or lower trajectory for the ICT sector. The main steps are shown in the Figure 4 and described thereafter.

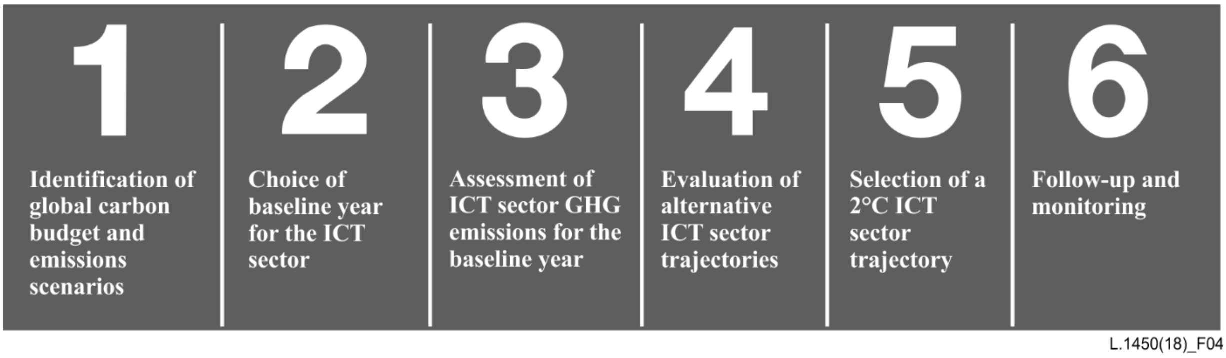


Figure 4 – Main steps of the methodology for a 2°C or lower trajectory for the ICT sector

1) Identification of the overall global carbon budget and of the emissions scenarios for overall global GHG emissions (see clause 9.2.2).

2) Decision about a baseline year for the GHG emissions of the ICT sector (see clause 9.2.3).

3) Estimation of the ICT sector GHG emissions for this baseline year and, optionally, its categories, as well as the relation with overall global GHG emissions for the same year (see clause 9.2.4).

4) Evaluation of alternative ICT sector trajectories compatible with the global 2°C or lower emissions scenarios (see clause 9.2.5). Allocation within the sector of the potential budgets corresponding to the alternative trajectories (optional, see clause 9.2.6).

5) Selection of a 2°C or lower trajectory for the sector level (see clause 9.2.7).

6) Follow-up and monitoring of the development of the GHG emissions footprint of the ICT sector and, optionally, its main categories (see clause 9.2.8).

Whenever relevant in the above steps, the principles and methodology laid out in Part I (see clause 8) of this Recommendation shall be followed.

9.2.2 The global GHG emissions: The carbon budget and the emission scenarios

In this step, the overall carbon budget and trajectory to aim for (i.e., 2°C, 1.5°C or [b- Rockström]) shall be defined and the global scenarios to use as a starting point shall be selected.

The baseline for the overall global GHG emissions shall be identified, based on recognized sources (IPCC, IEA, UNFCCC). The established scenarios of the development of overall global GHG emissions from these sources shall be identified and analysed.

NOTE – The ranges for the required reductions correspond to the different scenarios that have been developed by organizations such as the IPCC and IEA, e.g., in [b-IEA ETP]. A range represents differences in assumptions regarding population and economic growth, technological advances and time periods. Scenarios also disaggregate sectors or regions differently..

9.2.3 Decision about a baseline year

In this step, the baseline year for the sector budget shall be decided.

If data fluctuate, the use of an average representing several years may be preferred ove data from an individual year. In particular, when defining the baseline year, it might be better to average GHG data for multiple, consecutive years to form a more representative base year.

9.2.4 Estimation of the ICT sector GHG emissions for the baseline year and, optionally, its categories

To define a baseline, the ICT sector GHG emissions footprint shall be derived for the baseline year, in accordance with the methodology outlined in Part I.

Additionally, the baseline may be defined for the four main categories, i.e., ICT network goods, ICT end-user goods, data centres and ICT services, and for more specific categories of ICT goods. This shall also be done in accordance with Part I.

NOTE – Part I relies on high-level estimates and can only give a rough estimate of the ICT sector footprint. Without a global reporting scheme or something similar, the methodology is, however, considered to enable the most accurate footprint estimate possible.

The baseline shall be defined both in terms of absolute GHG emissions and as a percentage of overall global GHG emissions.

9.2.5 Evaluation of alternative ICT sector trajectories

In this step, alternative ICT sector trajectories corresponding to the overall emissions pathways and different allocation mechanisms shall be investigated. From a methodological point of view, two main kinds of allocation mechanisms may be explored for the ICT sector as a whole.

a) A contraction of GHG emissions for the ICT sector strictly proportional over time to the contraction needed for the overall GHG emissions of all sectors.

b) A contraction of GHG emissions for the ICT sector taking into account the facts that the components of this sector are undergoing rapid transformation, innovation and adoption at a worldwide level, and that some products and services may bring GHG reductions in other sectors of the economy, the positive second order effects. In that case, the contraction of the GHG emissions of the ICT sector may be less rapid over time compared to the needed contraction of global GHG emissions.

In this exploratory phase, both options shall be investigated for each of the identified emission scenarios and the corresponding required reductions.

The preferred approach may change over time. Initially, distribution of the budget requirements according to mechanism a) may be preferred, but a more refined approach according to mechanism b) might be preferred once there is more information available, especially regarding the magnitude of positive second order effects. Due to the dual nature of ICT, which includes both negative and positive effects with regard to GHG emissions, mechanism b) might lead to higher reductions overall.

For each scenario, and for every year considered, the yearly GHG emissions of the ICT sector are derived according to the following information, using the yearly global GHG emissions of the scenarios as a starting point.

The GHG emissions for the ICT sector are defined as a percentage of the global carbon GHG emissions for the year considered according to the studied scenario. This percentage may or may not vary over time. The carbon budget for the ICT sector can then simply be expressed as follows:

$$\text{ICT sector GHG emissions}_{\text{year 20aa}} = P_{\text{year 20aa}} \times \text{Overall GHG emissions}_{\text{year 20aa}} \quad (9\text{-}1)$$

where

P for the year 20aa = the percentage for the year 20aa considered

If allocation mechanism b) is applied to consider the positive second order effect of ICT goods, network and services and its own development, the percentage $P_{\text{for the year 20aa}}$ may increase over time and a table including the values of $P_{\text{for the year 20aa}}$ year after year, between the current year and 2100 shall be prepared, together with motivations for the selected values.

With the foregoing in mind, it is also important to understand the assumptions made in the global emission scenarios regarding population growth, future electricity mixes and emissions factors, as well as economic growth and their implications for the ICT sector.

9.2.6 Allocation within the sector of potential budgets corresponding to alternative trajectories (optional)

Additionally, in line with how a budget at the ICT sector level is determined, two similar main allocation mechanisms may be adopted:

– a contraction of GHG emissions for each of the ICT sector subcategories strictly proportional over time to the contraction set for the ICT sector total GHG emissions;

– a contraction of GHG emissions for the different ICT sector categories depending upon the characteristics of the different subcategories and, for instance, their abilities to perform energy efficiency improvements or use alternative sources of energy less intense in carbon, etc.

The preferred approach may change over time. Initially it may be preferred to distribute the budget requirements evenly, but a more refined approach might be preferred once there is more information available.

A first step towards allocation within the sector may be to allocate these budgets among the four main categories of ICT network goods, ICT end-user goods, data centres, as well as ICT development and operations support.

9.2.7 Selection of a 2°C or lower preferred budget trajectory for the sector level

This corresponds to an annual estimated amount of GHG emissions under which the ICT sector emissions shall be kept to align with the trajectory.

After having explored the different alternative trajectories, a decision has to be taken regarding which trajectory to follow on the sector level.

Such a decision could be made at different levels, e.g., by an international body for the sector as a whole, an industry organization in a specific country or by a specific company.

In any case, the selection shall consider that ultimately the trajectory shall drive absolute emissions reductions in line with science and the [b-UN PA].

The reference unit corresponding to the selected trajectory shall be defined in accordance with Part I of this Recommendation.

9.2.8 Follow-up and monitoring of the development of the GHG emissions footprint

When monitoring the ICT sector trajectory, the overall ICT sector GHG emissions derived in line with Part I shall be used to keep track of the overall evolvement of the sector.

An attempt to estimate how the positive second order effects develop over time is also recommended to get an understanding of the combined effect. An appropriate Recommendation for this purpose is, at the time of publication, being drafted.

Annex A

ICT sector boundaries

(This annex forms an integral part of this Recommendation.)

A.1 Introduction

In accordance with the interpretation of the OECD sector definition into categories of goods and services described in Appendix I, the ICT sector footprint shall include the following categories and sub-categories (see clauses A.2 to A.6).

A.2 ICT end-user goods

ICT end-user goods comprise:

1) computers and computer peripherals;

2) consumer electronics for communication purposes include but are not limited to:

   a) mobile phones, smart phones, tablets, stationary and laptop PCs,

   b) home network goods;

3) IoT devices.

Category 3) includes IoT devices primarily intended for communication purposes. However, it does not include any goods that can communicate over the IoT, as in the future most devices are assumed to be connected and would then contain embedded connectivity, e.g., connectivity of cars or refrigerators. To label any connected goods as ICT would render the sector definition meaningless.

In the future, the connectivity of other goods may be included in the ICT sector footprint, but this needs additional consideration, not least from a boundary and double counting perspective. At the time of publication, it is optional to include the embedded connectivity.

Currently, as a first step to categorizing IoT device data based on data availability, the following categories may be included: public displays, surveillance cameras, payment terminals, smart meter communication modules and wearables. The number of categories for which data are available is expected to increase in the future.

Appendix III and Annex J of [ITU-T L.1410] give examples of ICT end-user goods and black box modules that give further details of the list in the first paragraph. The transparency principle applies if items from that list are excluded from the ICT sector footprint. However, as the ICT sector develops over time, Appendix III of [ITU-T L.1410] is considered to be a non-exhaustive list and other items may exist that require future inclusion.

A.3 ICT network goods

ICT network goods comprise:

1) wireline access network goods including the public switched telephone network (PSTN);

2) wireless access network goods;

3) telecommunication core network goods and related telecommunication data centres;

4) enterprise networks;

5) Metro/Edge/IP core and data transmission network goods and related network data centres;

6) satellite telecommunication.

As a life cycle perspective is applied in accordance with [ITU-T L.1410], these categories include *support activities* relating to the full life cycle, also including operation and maintenance activities, as well as *support goods*. In particular, the assessment shall consider:

1) ICT infrastructure, e.g., antennas, towers, cable, shelves;

2) goods installed on site or at facilities for the grid and non-grid power supply of ICT networks;

3) goods installed on site or at facilities for cooling purposes.

Appendices III and IV and Annex J of [ITU-T L.1410] give examples of ICT networks and network goods give further details of the lists of goods in the previous paragraph. The transparency principle applies if items from that list are excluded from the ICT sector footprint. However, as the ICT sector develops over time, Appendices III and IV are considered to be non-exhaustive lists and other items may exist that require future inclusion.

A.4 Data centre

Data centres comprise:

1) all data centres except telecommunication data centres from "in closets" to hyperscale;

2) enterprise networks.

A.5 ICT service

ICT services comprise:

1) software development; ICT or information technology (IT) consultants, etc.

The ICT sector boundaries do not include the following items that are considered as entertainment and media:

- a) television (TV) and radio;
- b) cable TV and broadcast network including satellites;
- c) paper media;
- d) printers, copy machines and scanners;
- f) user devices intended for entertainment and media, e.g., gaming consoles, TV;
- g) magnetic and optical storage media;
- h) content production;
- i) concerts, festivals and events.

NOTE – This may partially deviate from [ITU-T L.1410] as the boundaries of ICT have been considered in more detail since the development that Recommendation.

A.6 Allocation between the four main categories

In some cases, the boundaries between the four main categories are not obvious and for this reason the following allocation rules apply and any deviation clarification shall respect the transparency principle:

1) end user-goods owned by the operator (e.g., the modem) shall be categorized as ICT end-user goods;

2) in contrast, local enterprise equipment owned by operators but located in customer facilities shall be categorized as data centres;

3) an enterprise network shall be allocated to data centres;

4) a telecommunication data centre (i.e., core nodes) shall be allocated to ICT network goods;

5) another ICT network operator data centre shall be allocated to data centres;

6) cable TV network services provided by the operator should be allocated to ICT network goods if the organization is not structured in a way that enables them to be separated – if this is the case, they should be regarded as part of entertainment and media and not allocated to the ICT sector;

7) use of ICT network goods, ICT end-user goods and data centres by ICT services are allocated to these categories and not to the ICT service category.

Annex B

Global warming potential values for a 100 year time frame

(This annex forms an integral part of this Recommendation.)

The GWP as of May 2014 (the most up-to-date figures available) are shown in Table B.1.

Table B.1 – Global warming potential 100 year values for some GHGs

Greenhouse gas	Global warming potential 100 year values from p. 714 of [b-IPCC AR5] and p. 212 of [b-IPCC AR4], see [b-IPCC AR5 SynRep])
Carbon dioxide	1 (1)
Methane	32 (25)
Nitrous oxide	298 (298)
Hydrofluorocarbons HFC-134a	1 550 (1 430)
Perfluorocarbons	7 390-12 200 (7 390-12 200)
Sulfur hexafluoride	22 800 (22 800)
Nitrogen trifluoride	17 200 (n/a)

Appendix I

Deriving the sector substructure from the OECD sector definition

(This appendix does not form an integral part of this Recommendation.)

The ICT sector is broken down by the OECD in terms of the following Rev. 4.0 classes of [b-ISIC]:

ICT manufacturing industries

– Manufacture of electronic components
– Manufacture of computers and peripheral equipment
– Manufacture of communication equipment
– Manufacture of consumer electronics
– Manufacture of magnetic and optical media

ICT trade industries

– Wholesale of computers, computer peripheral equipment and software
– Wholesale of electronic and telecommunication equipment and parts

ICT services industries

– Software publishing
– Wired telecommunications activities
– Wireless telecommunications activities
– Satellite telecommunications activities
– Other telecommunications activities
– Computer programming activities
– Information technology consultancy activities and computer facilities management activities
– Other information technology and computer service activities
– Data processing, hosting and related activities
– Web portals
– Repair of computers and peripheral equipment
– Repair of communication equipment

For an assessment of the ICT footprint from the perspective of its deliverables, the list in paragraph 1 needs to be restructured into categories of ICT goods and services rather than into types of organization. Intermediate products such as components are not regarded as ICT products by themselves, but components used for ICT products and will be considered when calculating GHG emissions for the overall life cycle of the ICT products.

Rewritten from a life cycle-based goods and services perspective the list is transformed into:

– Computers and peripheral equipment
– Consumer electronics for communication purposes
– Wireline network goods
– Wireless network goods
– Satellite telecommunication
– Other telecommunication network goods
– Data centres

ICT services including software development; ICT/IT consultants, etc.

Note that magnetic and optical storage media are not allocated to ICT, but are considered to belong to entertainment and media (see Annex A).

The list in paragraph 3 could further be reduced to the main categories:

– ICT end-user goods

– ICT networks goods

– Data centres

– ICT service development and operation support

It is assumed that the ICT end-user goods and more specifically consumer electronics for communication purposes categories are wide enough to also cover IoT devices where applicable.

Appendix II

GHG global trajectories to 2100

(This appendix does not form an integral part of this Recommendation.)

II.1 Introduction

The IPCC, in [b-IPCC 2014], has developed a vision of the cumulative total CO_2 anthropogenic GHG emissions since 1870 and different trajectories of global GHG emissions to 2100. This vision and scenarios are presented and shown in Figure II.1.

In order to limit global warming caused by anthropogenic CO_2 emissions to less than 2°C since preindustrial levels, it is necessary to stay below 3 670 Gt CO_2. (When taking non-CO_2 gases into account, this remaining budget is reduced to 2 900 Gt CO_2.)

However, 1 890 Gt CO_2 had already been emitted by 2011. It means that the remaining CO_2 budget from 2011 onwards is only 1 010 Gt CO_2.

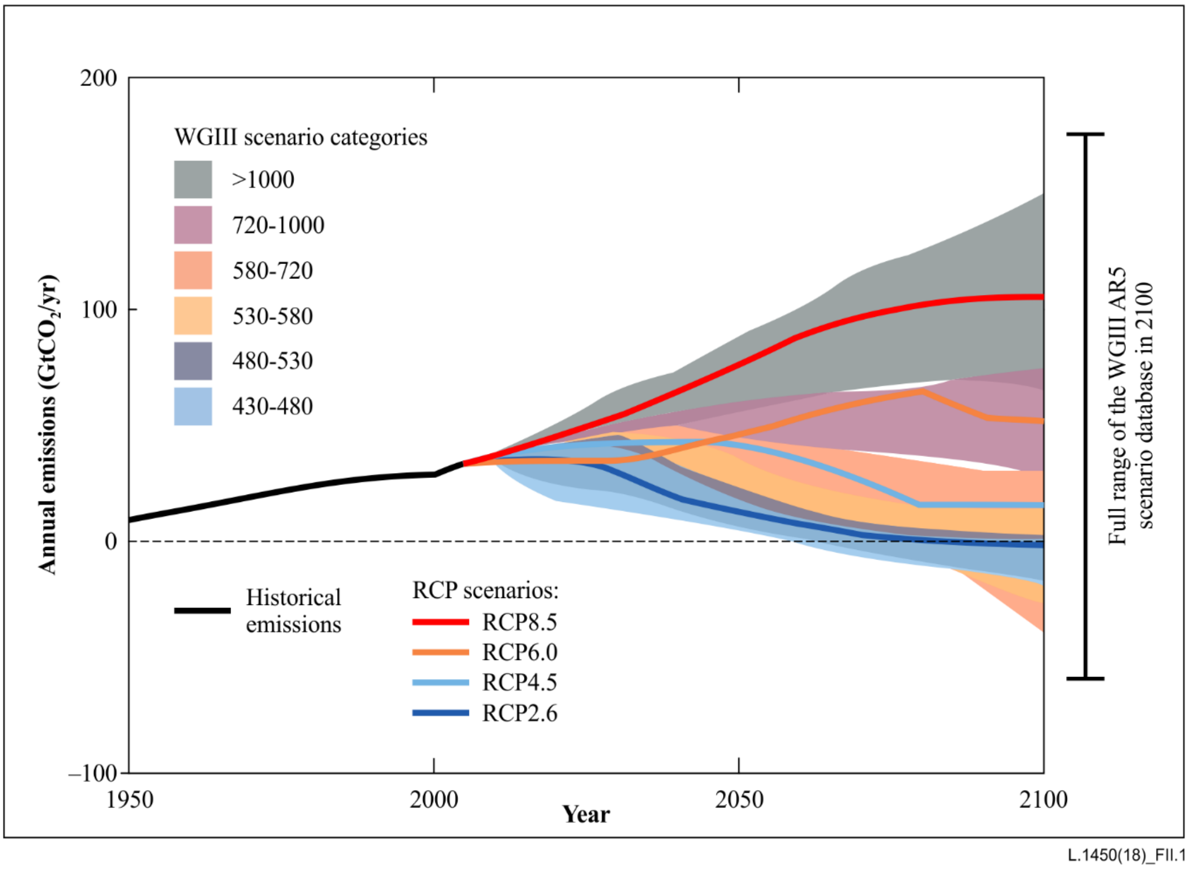
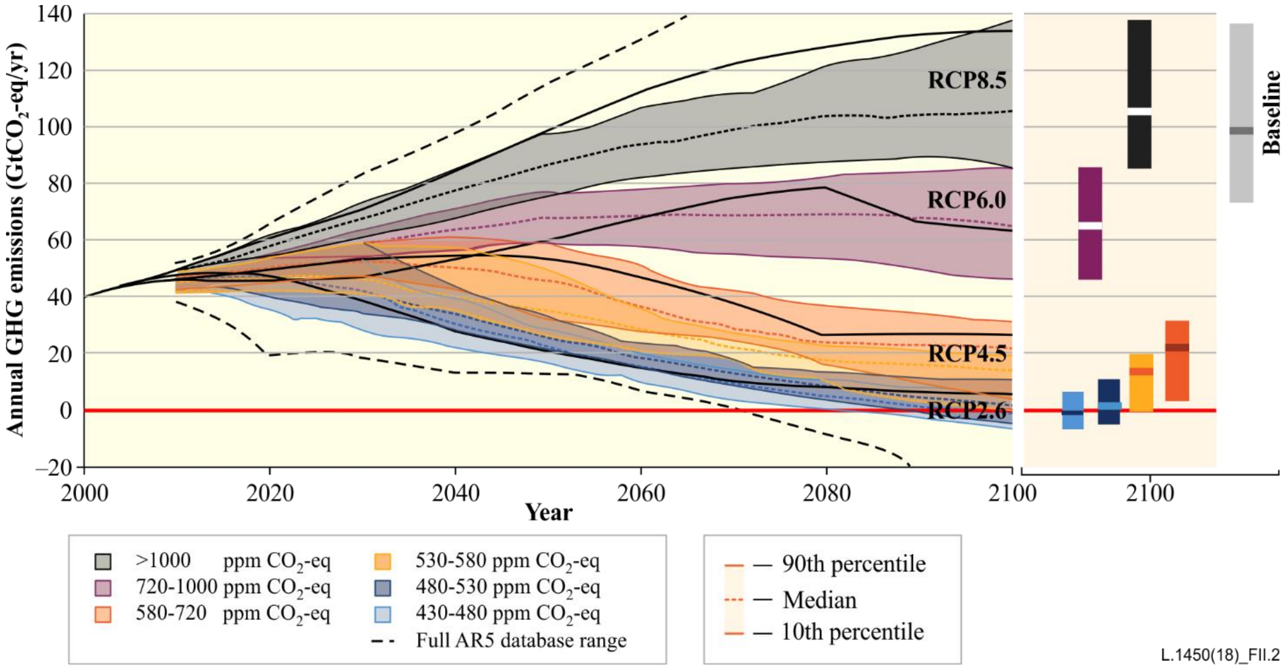


Figure II.1 – Cumulative total anthropogenic CO_2 emissions from 1870 to 2100 in Gt CO_2
(Source: [b-IPCC AR5 SynRep])

Descriptions of the different scenarios elaborated by the IPCC and shown in Figure II.2 are given in clauses II.2 to II.5.



Note – Gt CO_2e/yr= gigatonnes of carbon dioxide equivalent per year.

Figure II.2 – IPCC emission pathways estimations (Source: [b-IPCC AR5 SynRep])

II.2 RCP2.6 (also sometimes referred to as "RCP3-PD"): A "peak and decline" scenario

By 2100, atmospheric CO_2 reaches around 420 parts per million (ppm) – about 20 ppm above current levels. In this scenario, global temperatures are likely to rise by 1.3-1.9°C above pre-industrial levels by 2100, which corresponds to the COP 21 engagement.

II.3 RCP4.5: A "stabilization scenario"

These policies include a shift to low-carbon energy technologies and the deployment of carbon capture and storage. In RCP4.5, atmospheric CO_2 is estimated at 540 ppm by 2100 – roughly 140 ppm higher than it is at the time of publication – and global temperatures are likely to rise by 2-3°C above pre-industrial levels.

II.4 RCP6.0: A "climate-policy intervention scenario"

There are only "very modest" efforts towards mitigation between 2010 and 2060, but improvements in energy intensity and a global market for emissions permits help limit atmospheric CO_2 to 670 ppm by 2100. In RCP6.0, global temperatures by 2100 are likely to be 2.6-3.7°C above pre-industrial levels.

II.5 RCP8.5: A scenario of "comparatively high greenhouse gas emissions" or "business as usual"

This scenario is the highest of the four RCPs and sees atmospheric CO_2 rises to around 935 ppm by 2100. The likely range of global temperatures by 2100 for RCP8.5 is 4.0-6.1°C above pre-industrial levels.

Appendix III

Deriving the ICT sector footprint from the organizational perspective

(This appendix does not form an integral part of this Recommendation.)

This Recommendation mainly aims to consider the ICT sector GHG emissions footprint and budget from the perspective of its deliverables (ICT goods, networks and services).

However, another option would be to derive the GHG emissions footprint and budget for the ICT sector from an organizational perspective, which has been less adopted in the past.

In principle, the ICT sector footprint could be assessed by adding scope 1 and 2 emissions from all ICT organizations together as reported in accordance with [ITU-T L.1420], CDP or the GHG protocol. Scope 3 emissions could in any case not be considered when aggregating to a sector level, as scope 1 and 2 GHG emissions of one organization may be accounted for as scope 3 GHG emissions by another organization.

There are several reasons why the organizational approach is not preferred for the time being:

1) none of these methodologies have agreed on one consolidation approach, making aggregation difficult, as organizational boundaries may overlap or gaps may occur that could be difficult to compensate for;

2) there is no mandatory reporting scheme, so the available data sets are limited and incomplete, and the transparency is low;

3) at least for some parts of the sector, goods and networks in operation are more important to address than emissions related to the sector's own operation.

NOTE – In case of aggregation between sectors, the risk of double counting and gaps exist to an even larger extent, and also apply to scope 2. For example, transport of ICT goods from manufacturer to customer is seen as scope 3 GHG emissions by the manufacturer, as part of scope 3 GHG emissions for purchased goods by the customer, and as scope 2 GHG emissions by the transport company. Furthermore, the main part of scope 2 emissions of the ICT sector is energy related and would already be accounted for as scope 1 emissions from the energy sector.

If an organizational approach is used together with the current organizational footprints reported by ICT organizations, one method to estimate the overall GHG emissions of the ICT sector would be to derive scope 1 and 2 emissions per employee for different kinds of ICT organizations, and to scale those by the overall number of employees according to the type of organization or by economic parameters, e.g., added value or revenue. Such an approach could also provide an interesting comparison with a footprint derived from ICT goods, networks and services.

Appendix IV

Example of application of the ICT sector footprint methodology

(This appendix does not form an integral part of this Recommendation.)

The purpose of this appendix is to illustrate the methodology and procedure of Part I.

This appendix presents an estimate of the use stage of the global GHG emissions of the ICT networks category of the overall ICT sector. Thus, it corresponds to a partial ICT sector footprint at the global level for the operation of ICT networks, i.e., this example does not cover the full ICT sector and it does not estimate the full life cycle.

NOTE – The appendix is based on [b-Malmodin, 2018] and figures and parts of the text are included here with the kind permission of its publisher, KTH Royal Institute of Technology. For further details and further references refer to [b-Malmodin, 2018].

This appendix outlines the principles of the methodology rather than the full reporting. In a real situation the reporting requirements of Part I shall be followed, including references to all data sources used to enable interpretation and comparison of the results obtained.

IV.1 Define the goal and scope of the ICT sector footprint study

IV.1.1 Define the overall study goal with regard to ICT sector coverage, time horizon and geographical coverage

The purpose of the study was to estimate a partial ICT sector GHG emissions related to the use stage of ICT networks.

IV.1.2 Define also whether the study is to assess only an absolute ICT sector footprint or whether it also targets a relative ICT sector footprint

The study covers both an absolute and a relative partial ICT sector footprint.

IV.1.3 Define the reference unit

The reference unit is defined as:

– the overall global use stage GHG emissions related to ICT networks as defined by the boundaries according to clause IV.1.4., for 1 year.

For the interpretation of the results, the following complementary reference flows are used:

– GHG emissions in accordance with the reference unit per subscription;
– GHG emissions in accordance with the reference unit per data traffic.

IV.1.4 Define the boundary details

IV.1.4.1 Define the ICT sector boundaries

This estimate includes the ICT networks globally and includes:

– wireline access network goods including PSTN;
– wireless access network goods (including also their diesel consumption);
– telecommunication core network goods and related telecommunication data centre;
– Metro/Edge/IP core and data transmission network goods and related network data centre.

Support goods are also considered with regards to the use stage:

– ICT infrastructure that contributes to the use stage energy consumption and GHG emissions;
– goods installed on site or at facilities for the grid and non-grid power supply of ICT networks;
– Goods installed on site or at facilities for cooling purposes.

Operator support activities include electricity and other energy in data centres, offices and stores, business travel and fleet vehicles used for field service operations.

NOTE – Enterprise networks of non-network operator companies, satellite telecommunication and home networks were not included. Cable TV and IPTV were partially included. However, fixed broadband over cable TV is conservatively estimated to consume about the same amount of electricity as fixed broadband over a digital subscriber line (DSL) or fibre.

IV.1.4.2 Define the time horizon, i.e., if the study intends to estimate the historical, current or future footprint

The study focused on the situation for 2010 and 2015, which was the latest available data set when the study was performed. It also estimated a future footprint for 2020.

IV.1.4.3 Define the geographical boundaries, i.e., whether the study covers the ICT sector within one country, a group of countries or globally

The study covered the situation globally.

IV.1.5 Data collection and analysis

IV.1.5.1 Volumes

As energy data were collected directly from operators and scaled by subscriptions, no volume data were collected in this study.

IV.1.5.2 Operating lifetime

As the study focused on the use stage only and on yearly emissions, the operating lifetime was not relevant.

IV.1.5.3 GHG emission per category of goods

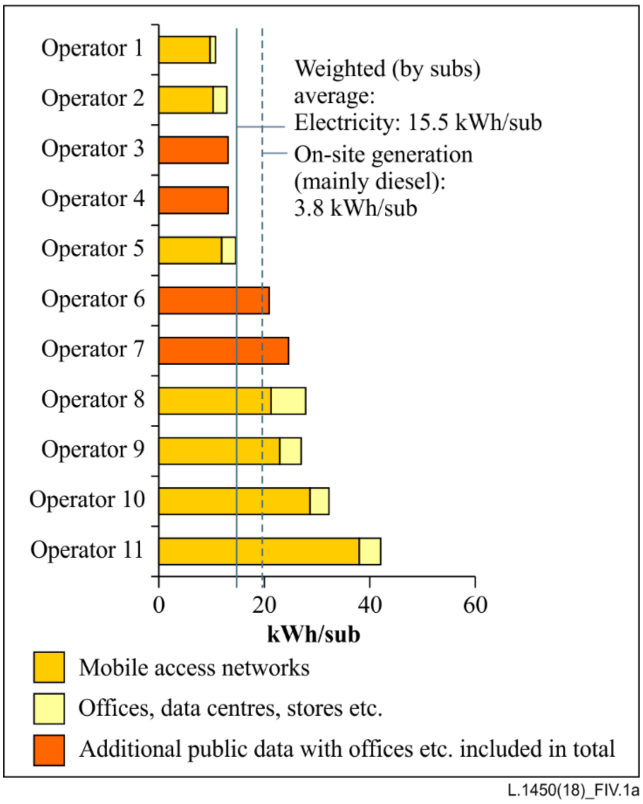
Use stage GHG emissions

The data used are to a large extent based on measured data (not estimated).

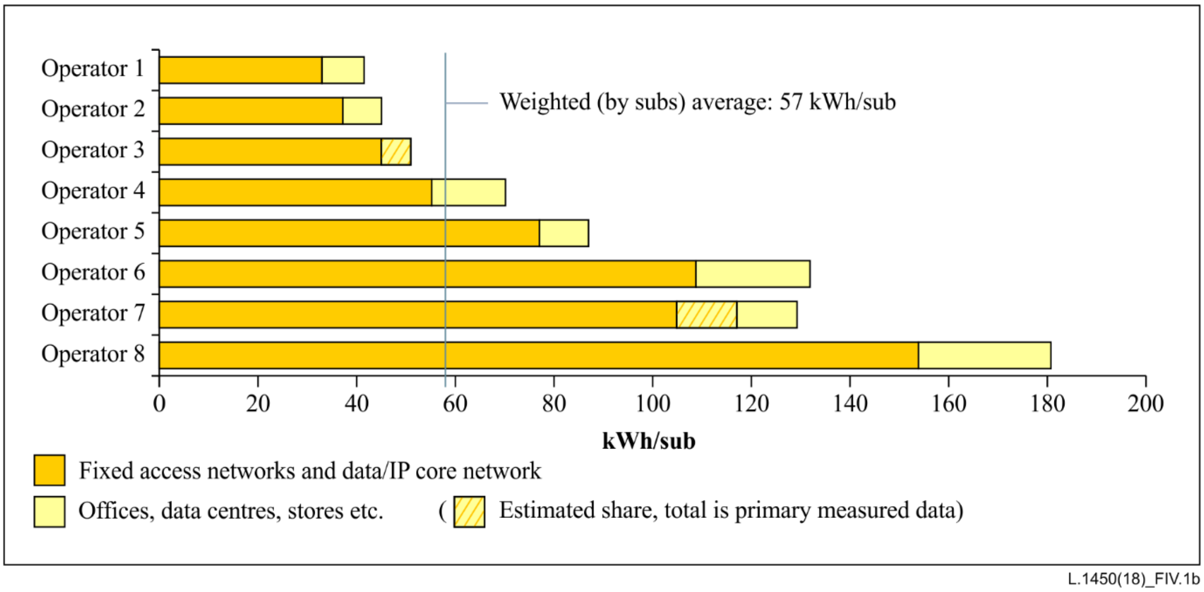
In this study, the operators voluntarily provided data, which resulted in higher granularity compared to publicly available data. These data allowed for better extrapolation and also helped to derive results for different activities such as fixed and mobile networks, the network itself and the operators own data centres, offices and stores.

Primary data were directly collected during 2017 from 10 operators with operations in more than 30 countries. This corresponds to about 10% of all fixed and mobile subscriptions globally (about 870 million out of 8.95 billion subscriptions in the world).

The distribution of electricity consumption between different activities is presented in Figure V.1a and Figure V.1b for mobile and fixed networks, respectively. The scale is the same in both parts to allow for comparisons.



a)



b)

Figure IV.1 – a) 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); b) Electricity consumption per subscription (/sub) in fixed network operations 2015. Note that *Operator 1* may not be the same as *Operator 1* in part a)

The overall GHG emissions derived from the energy consumption data for the directly reporting operators is showed in Figure IV.2. Note that for the extrapolation, no use of certified green electricity is taken into account. Furthermore, other operators and the Global System for Mobile Communications Alliance (GSMA) data set for on-site energy supply are considered to give a more representative estimate applicable to global conditions.

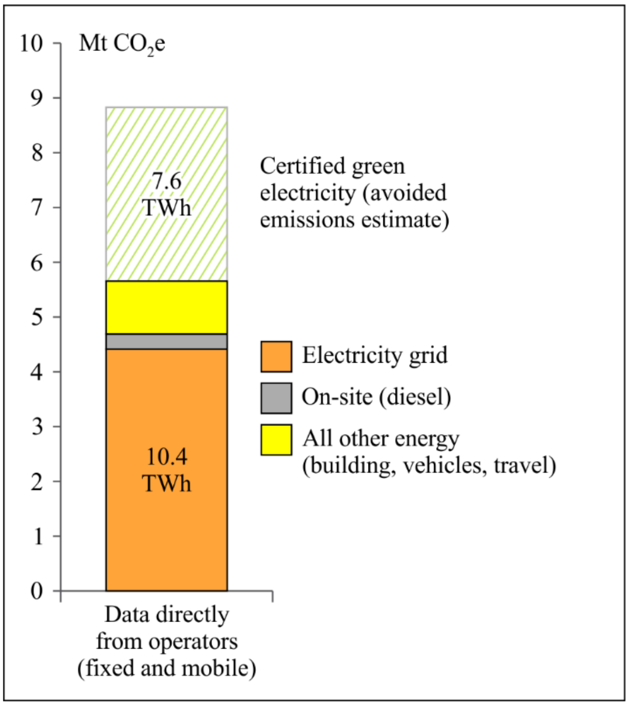


Figure IV.2 – Total operational GHG emissions reported by the operators in the directly reported data set

In addition to the directly reported data, published data were collected from four other major operators, and one nationwide data set including all operators in that country, which was earlier reported to a peer-reviewed conference. This was done to get a sample that covered all regions. The total subscription coverage reached 15% of the world's global subscriptions for fixed operations and nearly 40% for the world's mobile subscriptions. Specifically, additional data were collected from the GSMA for on-site electricity generation.

The primary data set was collected anonymously, since it contains business sensitive information, so names of operators and countries cannot be stated. However, when possible the data were validated through previously published information.

IV.1.5.4 Embodied GHG emissions

This study covered the use stage only, so the embodied emissions related to other life cycle stages and deployment of required infrastructure (e.g., antenna towers for mobile base stations) were not included. However, based on previous LCA studies [b-Malmodin, 2014], this represents typically around +15% relative to operational GHG emissions.

IV.1.5.5 GHG emission factors

For calculation of operational GHG emissions, a global average emission factor for electricity was used [b-Malmodin, 2013] – corresponding to about 0.6 kg CO_2e/kWh – and taking into account the electricity supply chain and distribution losses.

IV.1.5.6 Overall GHG emissions

Data were collected from [b-IEA] with regards to:

– total electricity grid supply;

– total global GHG emissions related to energy (about 32 Gt);

– total overall GHG emissions including land use, etc., (about 50 Gt).

IV.1.5.7 Contextual data

The number of subscriptions was collected from [b-ITU ICT data] and the data traffic was gathered from [b-Cisco VNI]. Of these, the number of subscriptions was used for extrapolation, whereas the data traffic was used for information only and to understand the development in terms of GHG emissions per data.

IV.1.6 ICT sector footprint calculation

IV.1.6.1 Calculate the footprint of each category of ICT goods

The described data set was used to derive the average electricity consumption per subscription, which was then multiplied by the total number of global subscriptions and by the emission factor, to calculate the overall footprint for the use stage of ICT networks (including both the networks themselves and the operator´s support activities) while considering the geographical distribution of the sample.

IV.1.6.2 Calculate the overall sector footprint by adding the footprints of the different categories of ICT goods

As this study was intended only to calculate the use stage GHG emissions of networks this step was not performed.

IV.1.7 Interpretation of results

IV.1.7.1 Analyse the calculated footprint with regard to the different principles outlined in clause 6

The results of the study were:

– the total annual operational electricity consumption of the overall global ICT networks was estimated at 242 TWh for 2015, including both grid and on-site generated electricity – the total corresponds to 1.15% of the total electricity grid supply (see Figure IV.3);

– about 1 million mobile base station sites had on-site electricity generation in 2015, generating an estimated 27 TWh, which compares to 0.5 million sites and about 12 TWh for 2010.

– The total annual operational GHG emissions of the ICT networks were estimated at 169 Mt CO2e for 2015. This corresponds to 0.53% of the global carbon emissions related to energy (about 32 Gt), or 0.34% of all carbon emissions (about 50 Gt) (see Figure IV.4).

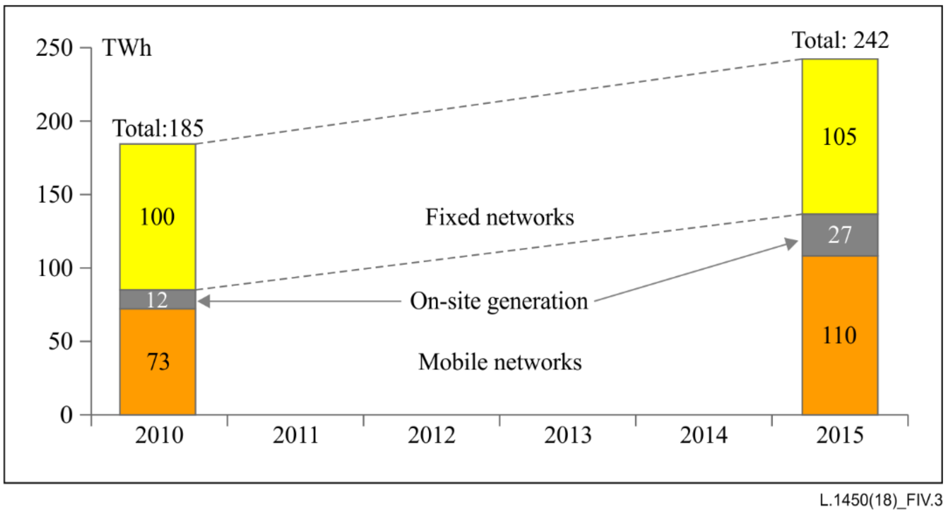


Figure IV.3 – Total electricity consumption of the ICT networks operations: Figures for 2010 are from [b-Malmodin, 2013]

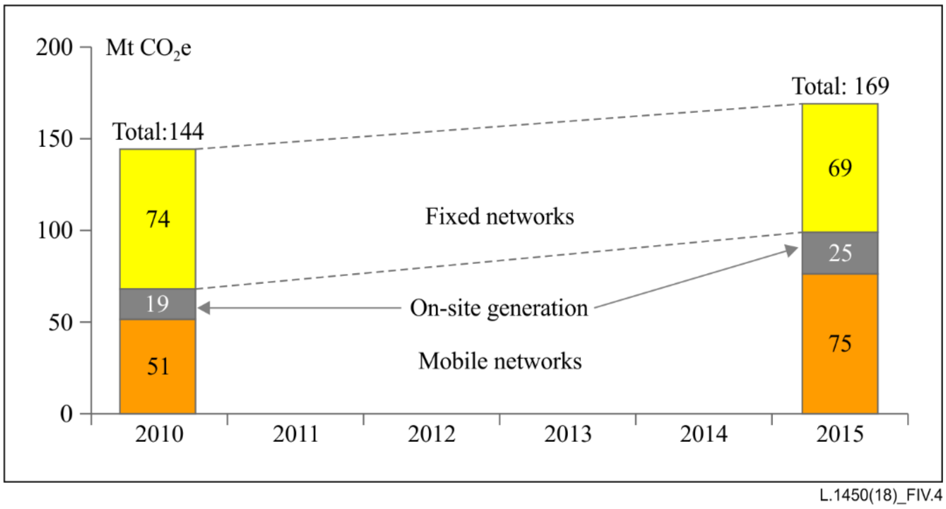


Figure IV.4 – Total operational GHG emissions of the network operations (or "operators") part of the ICT sector worldwide in 2015: Figures for 2010 are from [b-Malmodin, 2013]

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 GHG emissions grew by 17%. This could be compared to the increase in number of subscriptions from 6.7 billion to 9.0 billion during the same period. It is noted that the fixed and broadband part is almost unchanged over time, so the increase is mainly associated with the expansion of mobile networks. However, the data traffic increase is much higher compared to the electricity consumption and operational GHG emission increase, and the impact per subscription is actually decreasing in most cases.

The total operational GHG emissions for fixed and mobile networks separately, extrapolated to the overall global subscriptions, are shown in Figure IV.5.

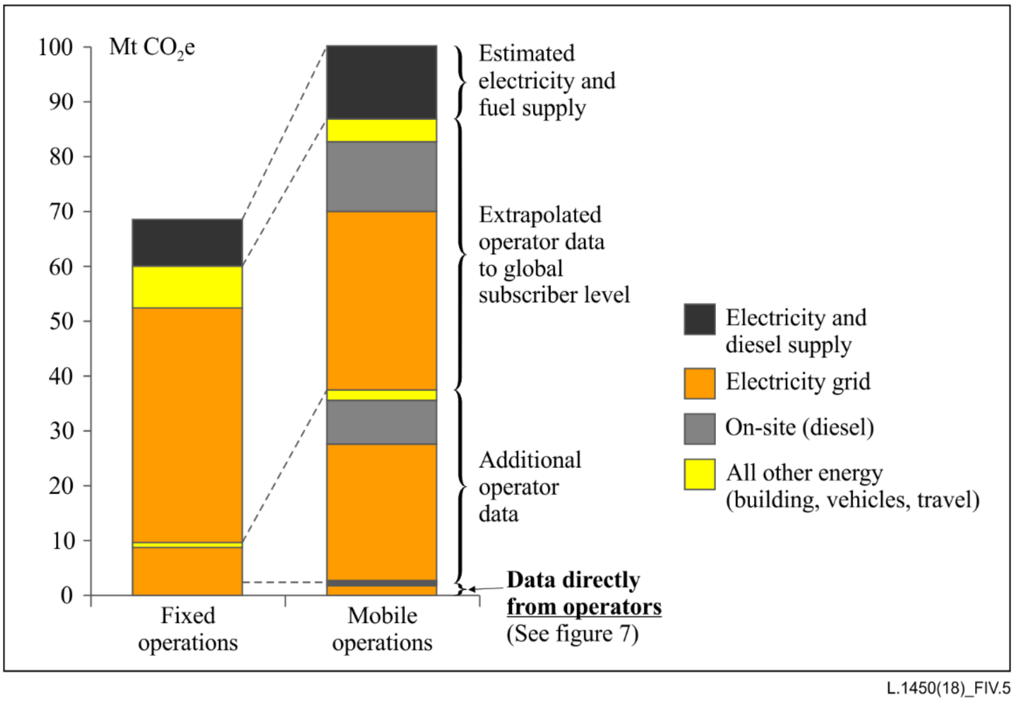


Figure IV.5 – The global operational GHG emissions for fixed and mobile networks for 2015

The reasons for the reduced operational GHG 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, 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 in this case 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 GHG 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 (photovoltaic solar cells), as well as wind power, often in combination with diesel hybrid solutions.

Despite efforts by operators to increase energy efficiency and investments in renewable energy supplies, electricity consumption and operational GHG emissions of the operation of the ICT network continue to increase globally. However, the total share of the global grid electricity and operational GHG emissions, including all diesel consumption, has only increased slightly during the period 2010-2015 and some IT mature countries have even started to reduce their total ICT footprint [b-Malmodin, 2016].

The overall data volume in the networks is increasing, almost according to Moore's law.

The electricity consumption in the mobile access network is also increasing, but at a slower pace 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 and not the mobile network.

Another identified aspect is that operational electricity for data centres of telecom operators have increased slightly, but not as much as expected. These data centres represent approximately 10% of the total electricity consumption.

It is observed 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. However, 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 the PSTN and associated services are being decommissioned and replaced by more electricity efficient alternatives, such as the voice over Internet protocol (VoIP).

Figure IV.5 demonstrates that from a total ICT perspective, the increased electricity consumption in the mobile network has been partially compensated for by increased energy efficiency in fixed networks. Although the volume of fixed subscriptions is only slightly decreasing, behavioural 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 in fixed networks.

IV.1.7.2 Mandatory comparison of results with other studies and analysis of differences and similarities in results

The GHG emissions of the ICT sector have previously been estimated in the often-cited report [b-GeSI]. The estimated operational GHG emissions of the study in this Recommendation were compared to the corresponding data from the [b-GeSI] study – the latter study based on models and assumptions. The extensive data set of the study in this Recommendation shows that the GHG emissions have increased more slowly than anticipated by [b-GeSI].

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

IV.1.7.3 Optionally, derivation and analysis of the footprint per user and per data traffic, in particular if the study tries to understand the development of the footprint over time

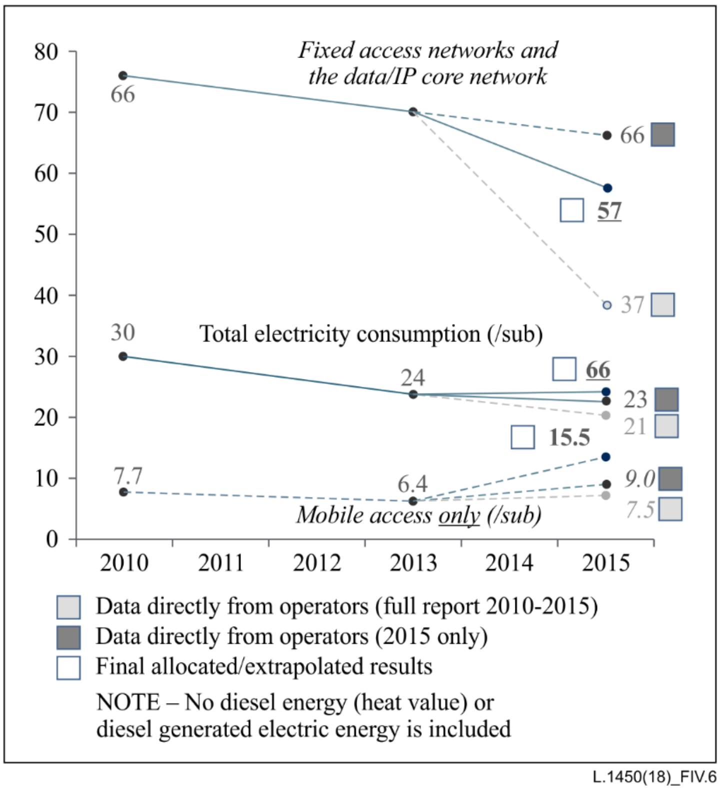
Based on the data per subscription, the average annual operational electricity consumption, including on-site generation, has decreased slightly from 27.6 kWh to 27 kWh per subscription between 2010 and 2015. For operational GHG emissions, the emissions per user have reduced from 21.5 kg CO_2e to 19 kg CO_2e.

IV.1.8 Interpretation

As for all estimations of this kind, the results need to be interpreted based on the conditions of the study. The main aspects in clauses IV.1.8.1 to IV.1.8.5 were considered.

IV.1.8.1 Sensitivity of data used for extrapolation

Figure IV.6 shows in greater detail how the per subscription electricity consumption has changed over time since 2010-2015 for fixed and mobile networks and how deeply dependent the results are on the data set used:



Note – Diesel is excluded here as it corresponded only to a minor part of the electricity supply in the directly reported data set

Figure IV.6 – Distribution of operators´ total electricity consumption

Figure IV.6 also shows that the electricity consumption per subscription was in general lower for the operators included in the directly reported data set than in the publicly available data for the other operators used in the study. If only the directly reported operator's data set were 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, there could be bias as operators that focus on energy efficiency improvements and supply may be more likely to contribute to this kind of study, as the large share of green electricity indicates.

IV.1.8.2 Coverage

This study is limited to the direct operational impact from the telecom operator's network. The report does not, for instance, include external data centre operations that are vital for the global Internet's functionality. The reasoning behind this divide is the aim to visualize the complex ICT network in understandable and manageable pieces. The study relies on the answers received from 10 telecom operators. 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 based in Europe to a large extent, 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. Furthermore, operational GHG emissions were calculated based on a world average electricity mix, to compensate for the higher share of fossil fuel-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 fossil fuel-free electricity. In spite of these measures taken to compensate for biases in the sample, the data set, although extensive, emerges from a limited number of operators, which might impact the results.

IV.1.8.3 Data-quality and consequences for the assessment

The data collected from the operators are of high quality and come with a granularity far better than the figures that can be found in publicly available annual reports. The primary data are to a great extent based on measured or invoiced electricity consumption. In addition, electricity consumption levels have been estimated where electricity costs are included in rent. Regarding the risk of double accounting and gaps, there is a lower risk than 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 mobile sites, especially for roof sites and micro sites, where the electricity is often included in rent. As an example, one Nordic operator's mobile network consists of approximately 50% of sites without electricity meters, which accounts for approximately 35% of the total electricity. In this particular case, the information was sufficient to avoid gaps. In general, the risk of 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 lack their own electricity meters, not the large ones.

IV.1.8.4 Data allocation

Operators were also asked to report their electricity consumption and allocate it to specified categories, such as mobile access, data centre operations, fixed access, IP and Core, as well as shops and offices. Not all operators were able to report their figures with such granularity, but some did and it is the first time that data in such detail has been presented in a consolidated format. The separation 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 is 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 are of lower quality than the directly reported operator data, which were easier to validate. Nonetheless, this data set should be the best available currently to estimate global electricity consumption and operational GHG emissions of ICT networks.

IV.1.8.5 Additional quality aspects

The directly reported data for the year 2015 is of high quality, but the historical data for 2010 and 2013 do not meet the same standard, mainly due to insufficient information. This limits the possibility of drawing general conclusions from the data, but some general trends have been identified.

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.

Appendix V

Example of electrical energy for one server

(This appendix does not form an integral part of this Recommendation.)

This appendix presents an example of a simplified calculation of the electrical energy used by one server over 1 year, located in a datacentre where the power usage effectiveness (PUE) is known.

A similar calculation can be done for other equipment included in data centres.

Equation V-1 describes how the electrical energy used by one server – including the associated facility energy use – can be calculated

$$E_{\mathrm{u}}^{\mathrm{s}} = \mathrm{A}E_{\mathrm{u}}^{\mathrm{s}} \times \mathrm{PUE} \tag{V-1}$$

where

$E_{\mathrm{u}}^{\mathrm{s}}$ = Annual electrical energy consumption of a server (kWh).

$\mathrm{A}E_{\mathrm{u}}^{\mathrm{s}}$ = Annual electrical consumption of server while running at the average utilization level (kWh).

PUE = Facility power usage effectiveness, calculated by Equation (V-2).

$$\mathrm{PUE} = \frac{\text{Total data centre facility electrical energy use}}{\text{Total electrical energy use of ICT goods in the data centre}} \tag{V-2}$$

$\mathrm{A}E_{\mathrm{u}}^{\mathrm{s}}$ can be measured or estimated by Equation (V-3).

$$\mathrm{A}E_{\mathrm{u}}^{\mathrm{s}} = (P_{\mathrm{i}}^{s}\alpha + P_{\mathrm{f}}^{s}\beta) \times 8.76 \tag{V-3}$$

where

P_{i}^{s}= average power consumption (W) of a server running active idle;

P_{f}^{s}= average power consumption (W) of a server running at 100% capacity;

α = annual average active idle;

β = annual average utilization of a server.

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