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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

Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement

Recommendation ITU-T L.1470

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

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Recommendation ITU-T L.1470

Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement

Summary

Recommendation ITU-T L.1470 provides detailed trajectories of greenhouse gas (GHG) emissions for the global information and communication technology (ICT) sector and sub-sectors that are quantified for the year 2015 and estimated for 2020, 2025 and 2030. In addition, Recommendation ITU-T L.1470 establishes a long-term ambition for 2050. The trajectories, the long-term ambition and the 2015 baseline have been derived in accordance with Recommendation ITU-T L.1450 and through complementary methods in support of the 1.5°C objective described by the IPCC in its *Special report: Global warming of 1.5*°C and in support of the Science-based Targets (SBT) initiative.

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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

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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Introduction

This Recommendation provides detailed trajectories of greenhouse gas (GHG) emissions for the global information and communication technology (ICT) sector and sub-sectors that are quantified for the year 2015 and estimated for 2020, 2025 and 2030. In addition, it establishes a long-term ambition for 2050. The trajectories, the long-term ambition and the 2015 baseline have been derived in accordance with [ITU-T L.1450] and through complementary methods in support of the 1.5°C objective described in [b-IPCC 1.5] and in support of the Science-based Targets (SBT) initiative.

The *Paris agreement* of the United Nations Framework Convention on Climate Change [b-UNFCCC PA], which aims to keep a global temperature rise in 2100 well below 2°C above preindustrial levels, entered into force 2016-11-04. At the same time, private investors are increasingly requesting information 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. At the end of 2018, [b-IPCC 1.5] was published, which shows the severe delta effects between a 1.5°C and 2°C scenario, implying the importance of increasing decarbonization efforts.

The ICT sector, although relatively small in terms of GHG emissions compared to others, is responsible for its own footprint. The rapid growth of the ICT sector stresses the importance of addressing and limiting any increase in its footprint. However, studies of some countries have actually reported an initial decoupling of sector growth and GHG emissions [b-Malmodin, Lundén 2016]. 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 1.5°C trajectory.

In order to establish an ICT sector trajectory, a collaboration was initiated between the ITU, Science Based Targets (SBT) initiative, GSM Association (GSMA) and Global Enabling Sustainability Initiative (GeSI) to develop sectoral decarbonization pathways in order to help ICT companies to set targets in line with climate science.

The SBT initiative framework is further described in Appendix I. The main documents published by the SBT initiative are: [b-SBT Foundations], [b-SBT Manual], [b-SBT Criteria] and [b-SBT SDA].

This collaboration is intended to establish a comprehensive understanding of the ICT sector footprint and how it could be reduced. In particular, ITU as the United Nations (UN) agency concerned with ICT should have a clear view regarding climate impacts of the technology.

This Recommendation takes a normative approach towards a 1.5°C trajectory by establishing it as an upper limit for the ICT sector footprint based on the P2 scenario of [b-IPCC 1.5], the 1.5°C average pathway established by the SBT initiative and an electricity budget approach. Moreover, the sector´s ability to stay within the normative limits is explored with regards to the footprint and development of the sector. It is shown that the sector could be kept within the normative limits through continued efficiency measures and increased use of low-carbon electricity supply (ES).

As a next step, the trajectories described in this Recommendation will be used as input for the development of guidance at an organizational level to help ICT companies define science-based targets in line with the sector and sub-sector trajectories.

[b-UNFCCC PA] commits parties to "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels". In line with this, the SBT initiative allows targets to align with either well below 2°C or with 1.5°C limits. However, the SBT initiative strongly encourages companies to aim for the more ambitious 1.5°C limit. For this reason, the remainder of this Recommendation provides trajectories aligned to 1.5°C.

However, while striving to implement the decarbonization trajectory, it is important to understand that ICT, unlike many products and services sold in the world today, distinguishes itself by its double-edged nature.

On the one hand, ICTs have an environmental impact at each stage of their life cycle, from energy and natural resource consumption to e-waste. On the other, ICTs can enable vast efficiencies in lifestyle and in all sectors of the economy through the provision of digital solutions that can improve energy efficiency, inventory management and business efficiency by reducing travel and transportation, e.g., teleworking and videoconferencing and by substituting physical products for digital information. The latter capacity is referred to collectively as second order or enablement effects.

Beyond this, ICT has effects at the societal level by reshaping how people lead their lives. Such effects are much larger than the footprint itself and are important aspects to consider when optimizing the overall decarbonization of society. For further details, see Appendix II. However, such societal optimization lies outside the scope of this Recommendation, which is focused entirely on the footprint.

Last, as the ICT sector is fast moving, the trajectories developed at this point will need regular review over coming years.

Recommendation ITU-T L.1470

Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement

1 Scope

This Recommendation provides detailed trajectories of greenhouse gas (GHG) emissions for the global information and communication technology (ICT) sector and sub-sectors that are quantified for the year 2015 and estimated for 2020, 2025 and 2030. In addition, it defines a long-term ambition for 2050. The trajectories, the long-term ambition and the 2015 baseline have been derived in accordance with [ITU-T L.1450] and through complementary methods in support of the 1.5°C objective described by the IPCC in its *Special report: Global warming of 1.5*°C [b-IPCC 1.5] and in support of the Science Based Targets (SBT) initiative.

This edition of this Recommendation includes mobile networks, fixed networks, data centres, enterprise networks and end-user devices, but excludes ICT services.

The 1.5°C trajectories are developed from two different perspectives as follows.

– A life cycle-based carbon footprint of the ICT sector to help ITU as the United Nations (UN) agency concerned with ICT to establish a clear view regarding ICT´s potential climate impacts in a 1.5°C scenario.

– An ICT sector trajectory in support of the SBT initiative to help ICT companies to set 1.5°C aligned targets in line with science is the main focus of the collaboration between the SBT initiative, GSMA, GESI and ITU. As a next step, guidance will be developed to help companies to set their own science-based targets in line with these trajectories.

The difference between the two perspectives A and B is that the latter does not allocate to the sector emissions related to the electricity supply (ES) chain and grid losses associated with the use of electricity in the ICT sector. The former more inclusive approach is aligned with life cycle assessment (LCA) practice and is in line with other Recommendations in the ITU-T L.1400 series. The latter approach is established as company accounting practice by the GHG protocol.

As the ICT sector is fast moving the trajectories developed at this point will need regular review over coming years.

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.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.1450] Recommendation ITU-T L.1450 (2018), *Methodologies for the assessment of the environmental impact of the information and communication technology sector*.

[ISO 14064-2] ISO 14064-2:2019, *Greenhouse gases – Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 carbon budget [b-SBT Manual]: The estimated amount of carbon (or CO_2) the world can emit before warming will exceed specific temperature thresholds.

3.1.2 emissions intensity target [b-SBT Manual]: 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.

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

3.1.4 end-user [b-ITU-T Y.1910]: The actual user of the products or services.

NOTE 1 – The end-user consumes the product or service. An end-user can optionally be a subscriber.

NOTE 2 – The end-user could be either a company or a consumer.

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

EXAMPLE –Laptop, mobile phone.

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

NOTE – The current edition is [b-IEA ETP 2017].

3.1.7 ICT manufacturer [b-ITU-T L.1410]: Organization which has the financial and organizational control of the design and production of ICT goods.

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

3.1.9 scope 1 emission [ITU-T L.1450]: Greenhouse gas (GHG) emission from sources owned or controlled by an organization.

3.1.10 scope 2 emission [ITU-T L.1450]: On site greenhouse gas (GHG) emission from the generation of electricity, heat or steam that has been purchased by the reporting organization.

3.1.11 scope 3 emission [ITU-T L.1450]: Any other indirect greenhouse gas (GHG) emissions from sources that are located along the reporting organization's value chain.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 2°C scenario (2DS): An emissions scenario 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.

NOTE – This scenario is developed in [b-IEA ETP 2017].

3.2.2 enterprise network: An internal network of an enterprise that connects computers and related devices across departments and workgroups to each other and to the Internet.

3.2.3 ICT supplier: Organization that provides information and communication technology (ICT) products or services to an ICT organization.

3.2.4 operator: An organization operating networks, data centres or services.

NOTE – Based on clause 3.2.42 of [b-ITU-T L.1410], which defines an operator as "Organization operating networks and services".

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

2DS	2°C Scenario
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
AC	Alternating Current
B2DS	Beyond 2°C Scenario
BAU	Business As Usual
BD	Blu-ray Disc
BECCS	Bioenergy with Carbon Capture and Storage
CDR	Carbon Dioxide Removal
CHP	Combined Heat and Power
CPE	Customer Premises Equipment
DC	Direct Current
DVD	Digital Versatile Disc
EFG	Emission Factor at Generation
ES	Electricity Supply
ETP	*Energy Technology Perspectives*
GHG	Greenhouse Gas
GPS	Global Positioning System
HD	High Definition
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
LAN	Local Area Network
LCA	Life Cycle Assessment
M2M	Machine to Machine

NDA	Non-Disclosure Agreement
PC	Personal Computer
PES	Primary Energy Supply
POTS	Plain Old Telephone Service
PPA	Power Purchase Agreement
PSTN	Public Switched Telephone Network
PUE	Power Usage Effectiveness
REC	Renewable Energy Certificate
SDA	Sectoral Decarbonization Approach
STB	Set-Top Box
SIM	Subscriber Identity Module
T&D	Transmission and Distribution
VoIP	Voice over Internet Protocol

5 Conventions

In Figure 1 and certain tables in this Recommendation, green denotes the perspective of a manufacturer, yellow that of an operator, while white represent the perspective of suppliers and end-users. For example, scope 1 and 2 emissions (see clauses 3.1.9 and 3.1.10) for an ICT manufacturer will be scope 3 emissions (see clause 3.1.11) for ICT suppliers, ICT operators and non-sector end users. Care has been taken in the trajectories presented in this Recommendation to ensure no double counting has taken place.

6 Prerequisites

6.1 The ICT sector boundary conditions

The ICT sector is defined from the perspective of its deliverables in accordance with Annex A of [ITU-T L.1450]. Sub-sectors are defined in accordance with clauses A.2 to A.6 of [ITU-T L.1450].

The ICT sector definition is derived from the Organisation for Economic Co-operation and Development (OECD) sector definition in accordance with Appendix I of [ITU-T L.1450] as the OECD definition could not be applied directly since it was established for another purpose (classification of companies).

This edition of this Recommendation excludes ICT services, but includes:

- mobile networks;
- fixed networks;
- data centres;
- enterprise networks; and
- end-user goods.

NOTE – As [ITU-T L.1450] uses the OECD sector definition as a starting point, this Recommendation follows in the same direction. At this point, the OECD definition has not been compared to that of [b-ISIC] for the sake of this Recommendation.

6.2 The scope concept

The trajectories of this Recommendation and their background information are structured to facilitate the development of guidance for company level target setting. For this reason, the scope concept, which allocates company GHG emissions into three different scopes, is applied throughout this Recommendation. Such scopes are used by [ITU-T L.1420] and inthe GHG protocol ([b-GHG P], [b-GHG P Sc2], [b-GHG P Sc3]) company reporting, which is referred to by the SBT initiative framework (see Appendix I). Sector trajectories are thus designed to be consistent with company reporting of GHG emissions as specified in the GHG protocol, [ITU-T L.1420] and [ISO 14064-2].

More specifically the three scopes could be described as:

a) scope 1, which covers direct emissions emanating from the company's own assets;

b) scope 2, which covers emissions related to purchased energy;

c) scope 3, which covers remaining value chain emissions over which the company has some influence.

NOTE 1 – The SBT initiative requires a company to set one target for its combined scope 1 and 2 emissions, and in many cases also a separate target for its scope 3 emissions.

To illustrate the complexity of the scope concept, Figure 1 shows how scopes for companies at different points of the ICT value chain are connected. Clause 5 specifies the significance of colours used in Figure 1.

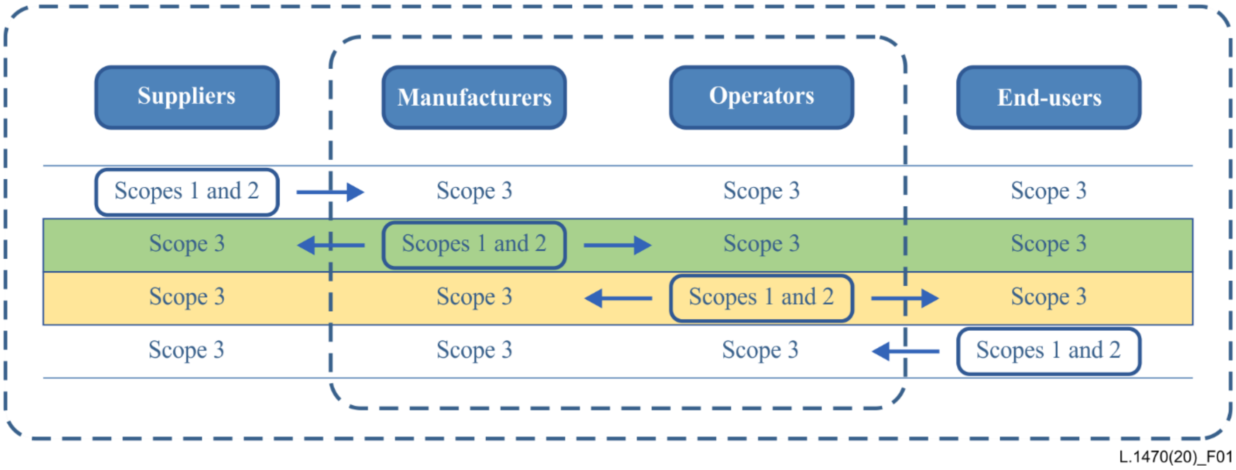


Figure 1 – Scope 1-2 emissions from the perspective of suppliers, manufacturers, operators and end-users and how they form part of scope 3 emissions of other actors

NOTE 2 – In Figure 1, end-user refers to consumers and organizations outside the ICT sector. However, in some cases, the end-use occurs within the sector.

Figure 1 shows how scope 1, 2 and 3 emissions relate to each other along the ICT value chain.

6.3 The emission factor for grid electricity

The ICT sector footprint largely depends on the use of electricity and its carbon intensity. For this reason, the emission factor of grid electricity is important. According to other Recommendations in the ITU-T L.1400 series and LCA practice, the ES chain and distribution losses that occur between the point of production and the actual consumption of electricity are allocated to the ICT footprint, while according to company accounting practices used by the SBT initiative and the GHG protocol these are excluded from ICT company scopes 1 and 2, and regarded as scope 3. Consequently, the emission factors differ between the two perspectives listed in clause 1 and two sets of factors are used in line with Table 1.

The grid emission intensity for the period 2015-2020 reflects actual conditions of the ICT sector, including its geographical distribution in line with [b-Malmodin 2018c]. The intensities for 2025, 2030 and 2050, shown in Table 1 are in line with the [b-IEA ETP 2017] beyond 2°C scenario (B2DS) that has been remodelled by the SBT initiative to align with [b-IPCC 1.5] 1.5°C pathways.

Table 1 – Electricity emission factors

Year	2025	2030	2050
Emission factors including electricity supply chain and grid losses (kg CO_2e/kWh) (perspective A)	0.351	0.200	0.000
Emission factors used for the SBT initiative (kg CO_2e/kWh) (perspective B)	0.281	0.160	0.000
NOTE 1 – The emission factors used for grid electricity for the trajectories are based on a development in line with a 1.5°C trajectory with extensive progress on renewables and efficiency embedded. Such a development might not happen. See clause 11.3 for further details on risks. NOTE 2 – These values represent intermediate work by the SBT initiative and are not finalized.			

7 Baseline

7.1 Baseline year

The baseline year for the ICT sector decarbonization trajectory is set to 2015.

7.2 Baseline for ICT sector and sub-sector energy consumption and GHG emissions

The baseline footprint of the ICT sector and sub-sectors is in accordance with Table 1 and was derived in accordance with the methodology outlined in [ITU-T L.1450]. Details on assumptions, calculations and data behind these values, as well as details regarding the degree of [ITU-T L.1450] compliance, are given in Appendix III.

Columns 3 and 4 of Table 2 list carbon dioxide equivalent (CO_2e) emissions that reflect perspectives A and B of clause 1. Column 1 lists power sector supply chain and distribution grid losses to align with perspective A. Column 2 considers the use of grid electricity in line with the SBT initiative and the GHG protocol scope 2 [b-GHG P Sc2] accounting which excludes ES chain and grid losses (perspective B). See clause 6.3 for more details.

Table 2 – ICT sector baseline for 2015

	Electricity consumption	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)
	2015 (TWh)	ITU-T L.1400 series-aligned baseline	SBT initiative-aligned baseline
Mobile networks		**Perspective A**	**Perspective B**
Mobile network manufacturers	5	3	3

Table 2 – ICT sector baseline for 2015

	Electricity consumption	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)
	2015 (TWh)	ITU-T L.1400 series-aligned baseline	SBT initiative-aligned baseline
Mobile network manufacturers, transmission and distribution (T&D)		0.3	–
Mobile network manufacturers, electricity supply		0.45	–
Mobile network operator overheads – electricity	13	6.4	6.4
Mobile network operator overheads – excluding electricity		4	4
Mobile network own electricity generation	27	25	25
Mobile network electricity consumption	90	48	48
Mobile network electricity consumption, T&D		5.4	–
Mobile network electricity consumption, electricity supply		8.2	–
Mobile network supply chain		12	12
Mobile network supply chain, T&D		0.75	–
Mobile network supply chain, electricity supply		1.5	–
Fixed networks			
Fixed network manufacturers	1.7	1	1
Fixed network manufacturers, T&D		0.1	–
Fixed network manufacturers, electricity supply		0.15	–
Fixed network operator overheads – electricity	7	3.2	3.2
Fixed network operator overheads – excluding electricity		2	2
Fixed network electricity consumption	85	43.2	43
Fixed network electricity consumption, T&D		4.6	–
Fixed network electricity consumption, supply		6.9	–
Fixed network supply chain		4.5	6
Fixed network supply chain, T&D		0.5	–
Fixed network supply chain, electricity supply		0.75	–
Data centres			
Data centre manufacturers	5	3	3
Data centre manufacturers, T&D		0.3	–
Data centre manufacturers, electricity supply		0.45	–
Data centre operator overheads (electricity)	15	6.4	6.4

Table 2 – ICT sector baseline for 2015

	Electricity consumption	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)
	2015 (TWh)	ITU-T L.1400 series-aligned baseline	SBT initiative-aligned baseline
Data centre operator overheads (excluding electricity)		3	3
Data centre electricity consumption	205	91.2	91.2
Data centre electricity consumption, T&D		9.1	–
Data centre electricity consumption, supply		13.7	–
Data centre supply chain[2)]		12	12
Data centre supply chain, T&D		0.75	–
Data centre supply chain, electricity supply		1.5	–
User devices			
User devices manufacturers (non-electricity)		35	35
User devices manufacturers electricity	149	70	70
User devices manufacturers, T&D		7	–
User devices manufacturers, electricity supply		10.5	–
User devices operation	345	169	169
User devices operation (T&D)		17	–
User devices operation, electricity supply		25	–
User devices supply chain non-electricity		35	35
User devices supply chain, electricity	56	26	26
User devices supply chain, T&D		2.6	–
User devices supply chain, electricity supply		3.9	–
Enterprise networks			
Enterprise networks manufacturers electricity		0.5	0.5
Enterprise networks manufacturers, T&D		0.05	–
Enterprise networks devices manufacturers, electricity supply		0.08	–
Enterprise networks operation	25	12	12
Enterprise networks operation (T&D)		1.2	–
Enterprise networks operation (supply)		1.8	–
Total			
Total including grid electricity supply and losses		**740**	**–**
Total excluding grid electricity supply and losses		**–**	**617**

Table 2 – ICT sector baseline for 2015

	Electricity consumption	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)
	2015 (TWh)	ITU-T L.1400 series-aligned baseline	SBT initiative-aligned baseline
Number of mobile subscriptions (SIM-cards excluding M2M)	**7.2 billion**		
Number of fixed subscriptions (lines)	**1.85 billion**		
Number of servers (data centres)	**43 million**		
Number of active PC or employee "users" (enterprises)	**800 million**		
Number of end-user goods	**13 billion**		
Number of additional IoT/M2M (possible, included in forecast)	**2 billion**		
Fixed data traffic (ZB)	**1**		
Mobile data-traffic (ZB)	**0.06**		

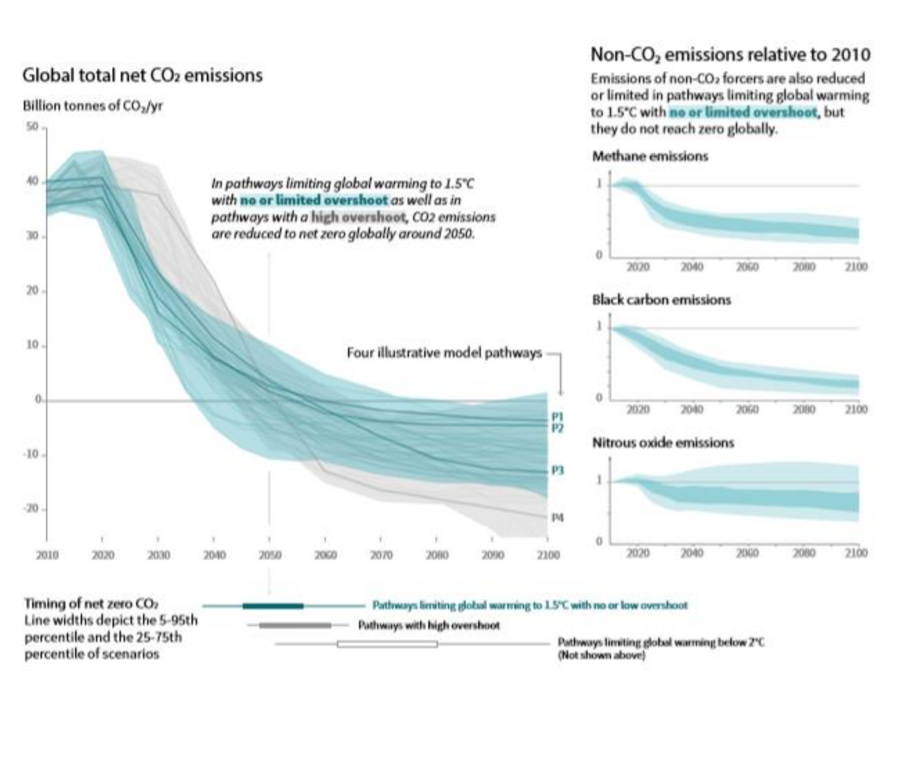
This table is colour-coded in accordance with clause 5.

NOTE – Given the data available in 2019 and collected from the sources used for the baseline [b-Malmodin 2018c] and applying the same methodology, GHG emissions for the ICT sector in 2020 are expected to remain relatively similar to the 2015 baseline.

8 Selection of a global emissions scenario for 1.5°C

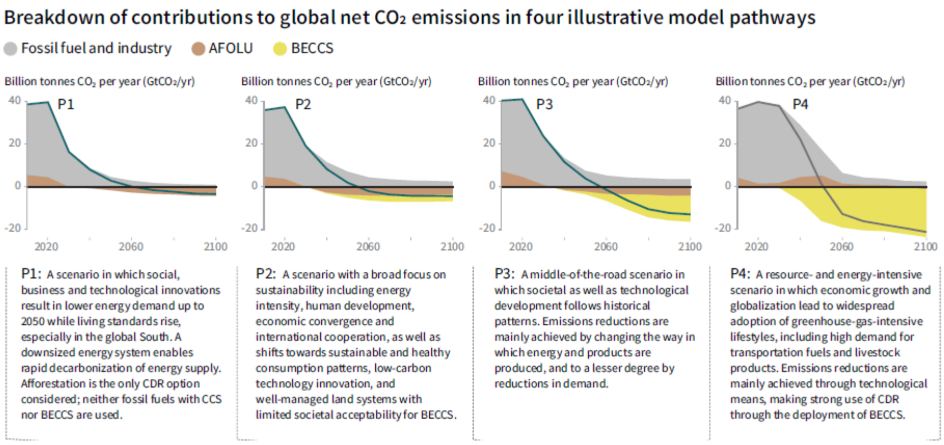
In line with clause 9 of [ITU-T L.1450], a relevant global emissions scenario should be identified as a reference for the ICT trajectories.

For worldwide overall GHG emissions, the scenario P2 described in [b-IPCC1.5] (see Figure 2) is selected. This scenario has been chosen as it seems to provide an adequate balance between major efforts required on GHG emissions reduction, while not relying heavily on the development of GHG sinks.



The main panel shows global net anthropogenic CO_2 emissions in pathways limiting global warming to 1.5°C with no or limited (less than 0.1°C) overshoot and pathways with higher overshoot. The shaded area shows the full range for pathways analysed in [b-IPCC 1.5]. The panels on the right show non-CO_2 emissions ranges for three compounds with large historical forcing and a substantial portion of emissions coming from sources distinct from those central to CO_2 mitigation. Shaded areas in these panels show the 5–95% (light shading) and interquartile (dark shading) ranges of pathways limiting global warming to 1.5°C with no or limited overshoot. Box and whiskers at the bottom of the figure show the timing of pathways reaching global net zero CO_2 emission levels, and a comparison with pathways limiting global warming to 2°C with at least 66% probability. Four illustrative model pathways are highlighted in the main panel and are labelled P1, P2, P3 and P4, corresponding to the LED, S1, S2, and S5 pathways.

Source: Global warming of 1,5°C, Ipcc; Special report



Characteristics of four illustrative model pathways in relation to global warming of 1.5°C introduced in Figure 2 a). These pathways were selected to show a range of potential mitigation approaches and vary widely in their projected energy and land use, as well as their assumptions about future socio-economic developments, including economic and population growth, equity and sustainability. A breakdown of the global net anthropogenic CO_2 emissions into the contributions in terms of CO_2 emissions from fossil fuel and industry; agriculture, forestry and other land use (AFOLU); and bioenergy with carbon capture and storage (BECCS) is shown. AFOLU estimates reported here are not necessarily comparable with countries' estimates. Further characteristics for each of these pathways are listed below each pathway. These pathways illustrate relative global differences in mitigation strategies, but do not represent central estimates, national strategies, and do not indicate requirements. For comparison, the right-most column shows the interquartile ranges across pathways with no or limited overshoot of 1.5°C. Pathways P1, P2, P3 and P4 correspond to the LED, S1, S2, and S5 pathways assessed in Figure 2a).

Source: [b-IPCC 1.5]

Figure 2 – [b-IPCC 1.5] 1.5°C scenarios including the selected P2 scenario

The P2 scenario means that emissions should be reduced by approximately 50% by the year 2030 compared to 2015, and then further decline until 2050.

9 Normative reference trajectories for 1.5°C scenario

The trajectories outlined in this clause sets the limits within which the ICT trajectory shall be held to keep consistency with 1.5°C.

9.1 Trajectory in line with the average reduction of the IPCC P2 scenario

This clause shows how the ICT sector should evolve to align with the global average in line with the IPCC P2 scenario.

An approach following the average required reduction according to the IPCC P2 scenario would require that the proportions of reduction of GHG emissions for the ICT sector in 2025 and 2030 are the same as the proportions of reduction required at worldwide level for all sectors of the economy.

If applying an absolute contraction approach following the IPCC P2 scenario, the 1.5°C trajectory, reported in Table 3, would apply to the ICT sector.

Table 3 – IPCC P2 pathway until 2030

Year	P2 reduction relative to 2015, %
2025	−20
2030	−50

It is noted that electrification is one of the earliest strategic steps to be taken towards decarbonization of society. From this perspective, the ICT sector – whose life cycle footprint is at least 80% based on the use of electricity – is considered to be a relatively easy to abate sector compared to sectors that are yet to be electrified. The ICT sector would be expected to decarbonize at least as fast, if not faster, then the required overall average reduction. However, due to the uneven availability of renewables and the geographic distribution of the sector, decarbonization may be more challenging than average conditions imply. Moreover, trajectories should not restrict the ability of ICT to bring innovations that can help to mitigate GHG emissions in other sectors.

In the longer term, the IPCC P2 trajectory shows a GHG emissions reduction of about 88% in 2050. Remaining emissions should be net zeroed by 2050 with carbon dioxide removals (CDRs), e.g., carbon sinks, BECCS and direct air capture.

9.2 Trajectory in line with the average linear reduction 1.5°C scenario of the SBT initiative

This clause shows how the ICT sector should evolve to align with the global average decarbonization rate derived by the SBT initiative for 1.5°C.

In their approach, the SBT initiative took multiple IPCC scenarios, including P2, removed outliers that were considered implausible, and established absolute contraction pathway rates associated with both 1.5°C and well below 2°C limits. According to the SBT initiative, SBTs need to be near term and may not be set beyond 2035. Reflecting that the required pathways are steepest up until 2035, p. 21 of [b-SBT Manual] states that

> The minimum reduction required for targets in line with well-below 2°C scenarios is 2.5% in annual linear terms. Companies, particularly those in developed countries, are strongly encouraged to adopt targets with a 4.2% annual linear reduction to be aligned with limiting warming to 1.5°C.

If an absolute contraction approach is followed based on the SBT initiative approach, the 1.5°C trajectory listed in Table 4 would apply to the ICT sector.

Table 4 – The SBT initiative 1.5°C pathway to 2030

Year	**The SBT initiative (4.2% reduction relative to 2020)**, %
2025	−21
2030	−42

P. 5 of [b-SBT Criteria] states that,

> Targets that cover more than 15 years from the date of submission are considered long-term targets. Companies are encouraged to develop such long-term targets up to 2050 in addition to the required mid-term targets. Long-term targets must be consistent with the level of decarbonization required to keep global temperature increase to well below 2°C compared to pre-industrial temperatures to be validated and recognized by the SBTi.

It should be noted that offsets cannot be considered in meeting an SBT initiative-approved target. However, a long-term target for the ICT sector would be to achieve net zero emissions by 2050. This is consistent with SBT initiative requirements and is aligned with a 1.5°C trajectory, while also recognizing the high level of electricity usage by the sector.

9.3 The electricity budget approach

The third normative approach considers the global need for electricity as outlined by the International Energy Agency (IEA) for different scenarios and develops an interim 1.5°C scenario within which ICT should not expand its current share of electricity.

This electricity budget uses the IEA trajectories for 2DS and B2DS to derive a 1,5°C trajectory for world electricity usage through doubling the difference between them and subtract it from 2DS [b-IEA ETP 2017]. This is an interim approach, as IEA has not yet defined a 1.5°C scenario.

The budget is then used to define the amount of electricity that could be used by the sector if keeping its share at the current level.

Table 5 – The electricity budget

	Electricity (TWh)			
	2015	**2020**	**2025**	**2030**
Energy-sector development (electricity budget)				
1.5°C grid emission factors 2015–2020: [b-IEA ETP]; 2025–2030 SBT initiative	0.484	0.48	0.281	0.160
Reduction in emission factor from 2015 value (%)			42	67
[b-IEA ETP 2017] 1.5°C (estimate) global electricity generation (TWh)	24 185	26 013	27 841	30 478
Increase in energy generation from 2015 (%)		8	15	26
Reduction in energy sector emissions between 2015 and 2031 when considering emission factor development and increase in energy generation according to this table (%)				58
NOTE 1– Some sources of ICT emissions may be easier or harder to abate. In particular, the overall ICT trajectory shall respect all three normative limits in this clause at the same time. NOTE 2– Although the electricity budget approach starts from electricity usage, the final trajectory is defined in terms of GHG emissions, which allows for a greater flexibility between electricity efficiency and electricity emission factor measures when defining company level targets.				

10 Exploration of the possibility for the ICT sector and sub-sector trajectories to stay within the normative 1.5°C trajectory

This clause explores ICT sector development and presents a scenario that is then checked for compatibility with the normative trajectories defined in clause 9.

The trajectories outlined in this clause are based on the inputs and analysis described in Appendix IV. Clause 10.1 briefly introduces conditions of the different sub-sectors that will impact their development during the coming decade. Clause 10.2 presents the trajectories with regards to perspective A. Clause 10.3 presents the trajectories to be used for the SBT initiative in line with perspective B. The difference between perspectives A and B is that the latter does not allocate emissions from the ES chain and grid losses associated with the use of electricity by ICTs to the ICT sector. The former calculation method is applied in LCAs. The latter is established as a company accounting practice by the GHG protocol.

10.1 Conditions of the sub-sectors

This clause summarizes some high-level trends that will impact the footprint of the ICT sector and its sub-sectors moving forward. Details are given in Appendix IV.

10.1.1 Mobile networks

The mobile sector is associated with a very dynamic market development. To take into account these key aspects that impact the development of the footprint of mobile communications, the following trends have been considered:

- subscriptions increase;
- second generation/third generation (2G/3G) starting to decline – decommissioning or equipment modernization;
- fourth generation (4G) continuing to develop and expanding in some markets;
- fifth generation (5G) commissioning in some markets with rapid expansion;
- expansion of Internet of things/machine to machine (IoT/M2M);
- energy efficiency improvements based on new technologies;
- build out of new networks based on population growth;
- diesel usage reducing, but only partially phased out.

Further details are provided in Appendix IV.

10.1.2 Fixed networks

The fixed operation footprint is expected to decrease as the old public switched telephone network (PSTN), which is an energy intensive system, is used less. In addition to fixed access, the fixed network sub-sector also includes core, transport- and transmission equipment.

Further details are provided in Appendix IV.

10.1.3 Data centre

The data centre trajectory considers:

- data traffic development in line with [b-Cisco] data forecast until 2022, extrapolated for 2025 and 2030;
- power usage effectiveness (PUE) improvements (due to efficiency measures and cloudification), where cloudification and hyperscale data centres are the main reasons for efficiency improvements;
- the typical server energy consumption is assumed to remain quite flat as capacity per unit increases;

- a trend towards fewer and larger data centres;
- edge computing mainly needed for low latency (gaming, high volumes for self-driving car which are not expected before 2030).

Further details are provided in Appendix IV.

10.1.4 User equipment

The user equipment trajectory considers the following.

- Inclusion of customer premises equipment (CPE), fixed phones, personal computers (PCs) (including desktops, laptops, peripherals and displays), mobile devices (including mobile phones, smartphones, tablets), M2M (including smart meters, surveillance cameras, payment terminals, public displays, wearables).
- Estimation of the number of devices in active use from sales statistics and estimated operational lifetime if relevant statistics are missing.
- Regional distribution according to actual sales.
- CPE: assumed energy efficiency improvements in line with business as usual (BAU).
- Fixed phones: no energy efficiency improvements assumed.
- PCs: lower share of desktops, energy efficiency improvements, gaming PCs small, but growing, share.
- Mobile devices: larger share of smartphones, larger batteries (more power per device).
- M2M: fast increase in the number of surveillance cameras until 2020, somewhat offset by energy efficiency improvements. Most M2Ms after 2020 are forecast to be wearables. Steady build-out of smart meters and payment terminals.

Further details are provided in Appendix IV.

10.1.5 Enterprise networks

The enterprise trajectory considers the following.

- Enterprise networks; there was an increase in numbers to 2015. Increase might now be slower, since companies use their PCs for a longer time.
- The small assumed increase in active local area network-personal computers (LAN-PCs), offset by energy efficiency improvements resulting in flat total energy.
- The expectation that shipments stay roughly flat in line with [b-IDC] and [b-Gartner].

Further details are provided in Appendix IV.

10.2 Trajectories including electricity supply chain and grid losses (perspective A)

This trajectory and its sub-trajectories represent the ICT footprint and a 1.5°C aligned trajectory for perspective A (see clause 1), which includes the ES chain and grid losses in line with LCA practice. Details on how these trajectories were derived are given in Appendix IV. For emission factors, see Table 1.

10.2.1 Global ICT sector trajectory (perspective A)

The development of the ICT sector has been derived, with and without consideration of the development of the emission factor of the ES, and the resulting trajectory is outlined in Figure 3. The upper line shows the development of the sector before consideration of the decarbonization of the ES, ande the lower line includes it, which is necessary for a 1.5°C trajectory. See Table 6.

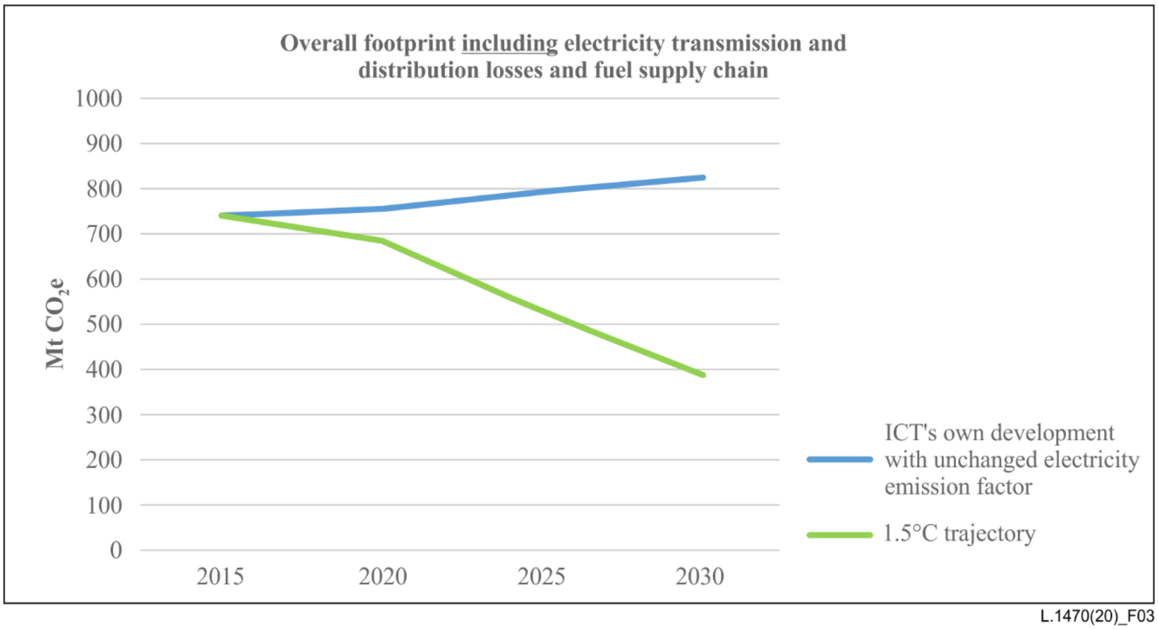


Figure 3 – ICT sector trajectory including electricity grid losses and supply chain (perspective A)

Table 6 – ICT sector trajectory with electricity grid losses and supply chain included

Total CO_2e (Mt)	**2015**	**2020**	**2025**	**2030**
Mobile networks	115	109	92	70
Fixed networks	67	59	42	27
Data centres	141	127	104	79
User devices	401	379	284	207
Enterprise networks	16	14	8	5
Total including T&D losses and fuel supply	**740**	**687**	**530**	**388**

10.2.2 Sub-sector trajectories (perspective A)

This clause shows the different sub-sector trajectories for the trajectory in clause 10.2.1.

For details, see Appendix IV.

10.2.2.1 Mobile network

Figure 4 shows the resulting trajectory for mobile networks.

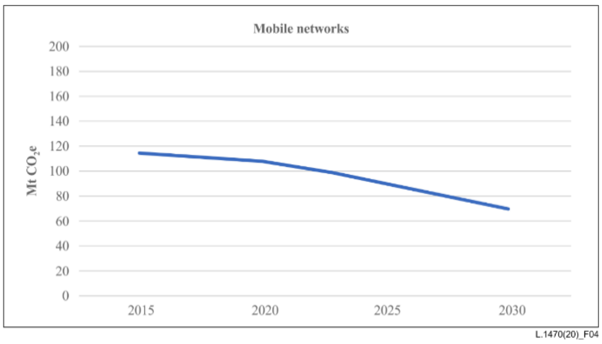


Figure 4 – Mobile network trajectory including electricity grid losses and supply chain

10.2.2.2 Fixed networks

Figure 5 shows the resulting trajectory for fixed networks.

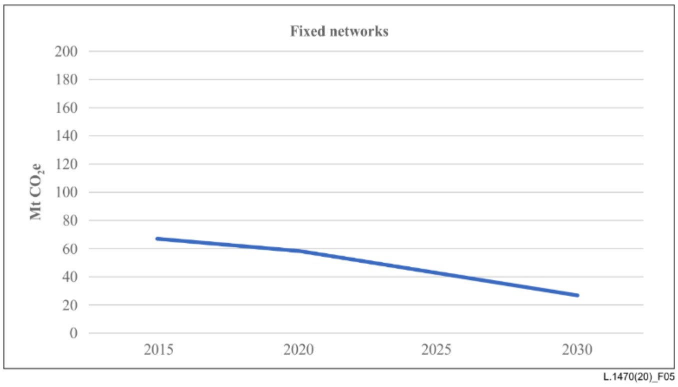


Figure 5 – Fixed network trajectory including electricity grid losses and supply chain

10.2.2.3 Data centres

Figure 6 shows the resulting trajectory for data centres.

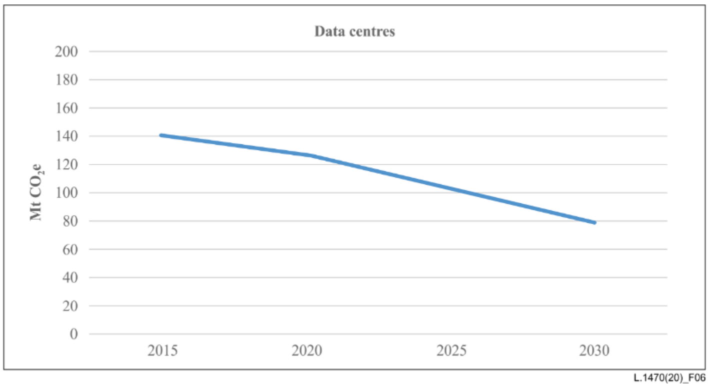


Figure 6 – Data centre trajectory including electricity grid losses and supply chain

10.2.2.4 User equipment

Figure 7 shows the resulting trajectory for user devices.

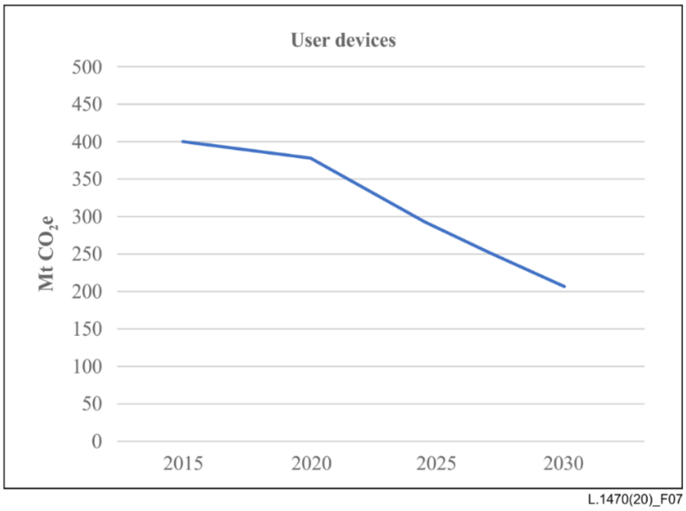


Figure 7 – End-user goods trajectory including electricity grid losses and supply chain

10.2.2.5 Enterprise networks

Figure 8 shows the resulting trajectory for enterprise networks.

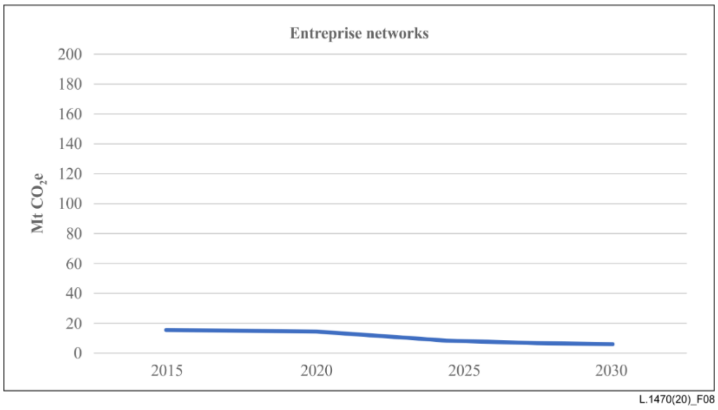


Figure 8 – Enterprise network trajectory including electricity grid losses and supply chain

10.3 Trajectories for the SBT initiative (perspective B)

This trajectory and sub-trajectories (without grid ES chain and losses) represent the ICT footprint and 1.5°C aligned trajectory for perspective B (see clause 1), which excludes the ES chain and grid losses in line with company GHG emissions accounting practice. Details on how these trajectories were derived are given in Appendix IV. For emission factors, see Table 1.

10.3.1 Global ICT sector trajectory (perspective B)

The development of the ICT sector has been derived with and without consideration of the development of the emission factor of the ES. The resulting trajectory is outlined in Figure 9. The blue line in Figure 9 shows the development of the sector before considering the decarbonization of the ES, and the green line includes the decarbonization of the electricity, which is necessary for a 1,5°C trajectory. See Table 7.

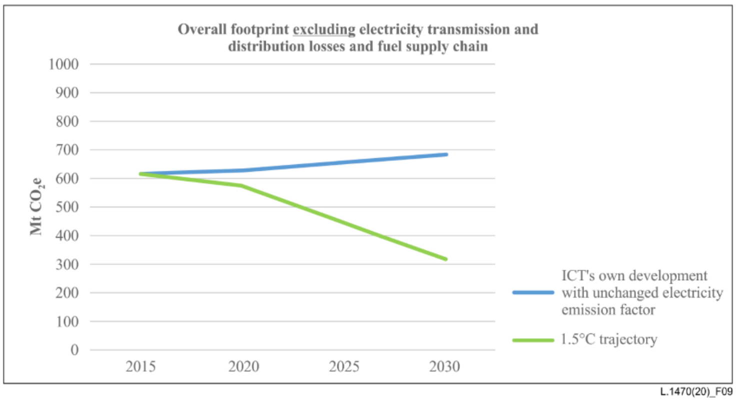


Figure 9 – ICT sector trajectory excluding electricity grid losses and supply chain

Table 7 – ICT sector trajectory excluding electricity grid losses and supply chain

Total CO_2e (Mt)	**2015**	**2020**	**2025**	**2030**
Mobile networks	98	94	79	59
Fixed networks	55	49	35	22
Data centres	116	104	84	60
User devices	335	317	241	174
Enterprise networks	13	12	6	4
Total excluding T&D losses and fuel supply	**617**	**576**	**445**	**319**

10.3.1.1 Mobile networks

Figure 10 shows the resulting trajectory for mobile networks.

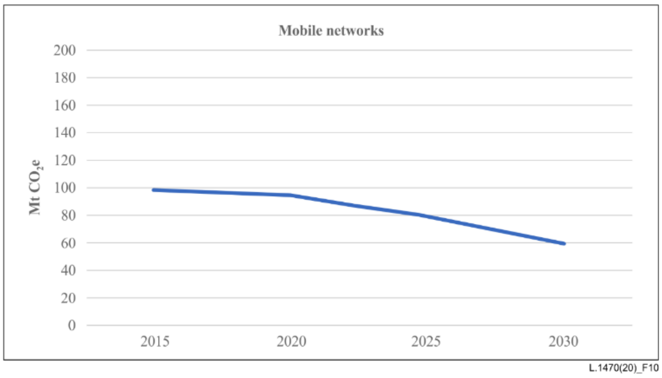


Figure 10 – Mobile network excluding electricity grid losses and supply chain

10.3.1.2 Fixed networks

Figure 11 shows the resulting trajectory for fixed networks.

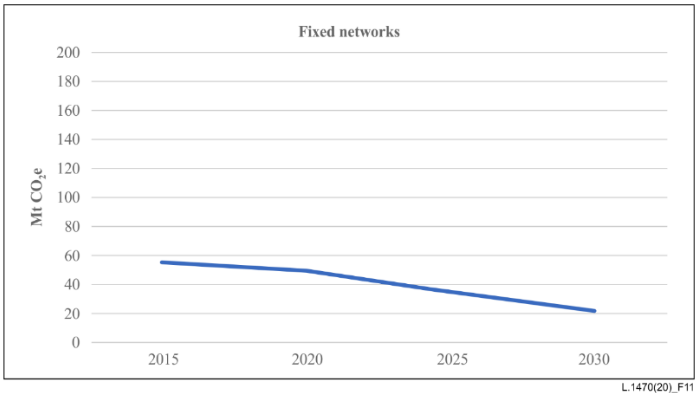


Figure 11 – Fixed networks trajectory excluding electricity grid losses and supply chain

10.3.1.3 Data centres

Figure 12 shows the resulting trajectory for data centres.

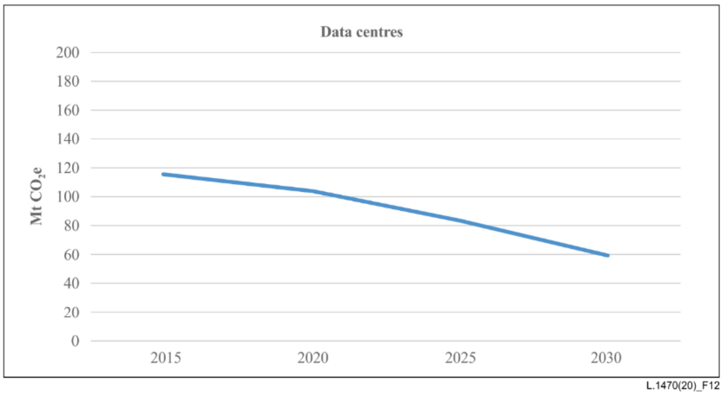


Figure 12 – Data centre trajectory excluding electricity grid losses and supply chain

10.3.1.4 User equipment

Figure 13 shows the resulting trajectory for user devices.

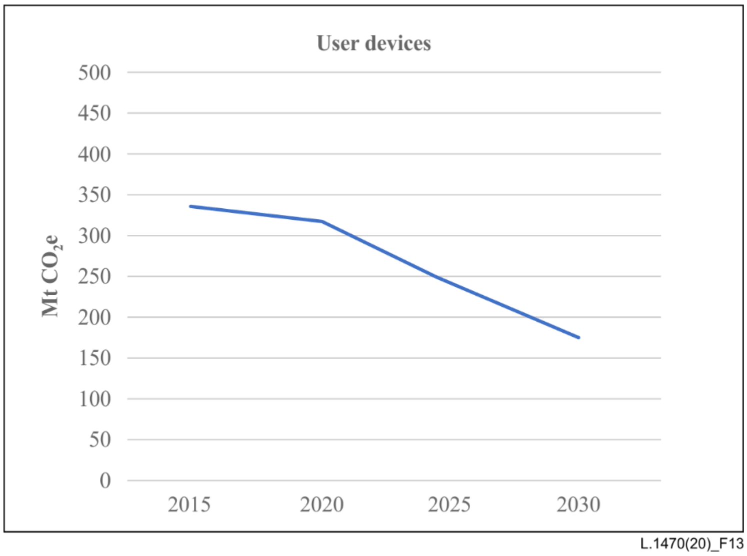


Figure 13 – End-user goods trajectory excluding electricity grid losses and supply chain

10.3.1.5 Enterprise networks

Figure 14 shows the resulting trajectory for enterprise networks.

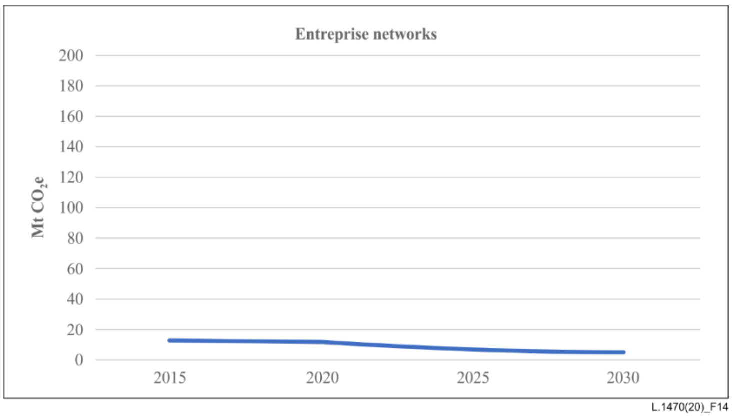


Figure 14 – Enterprise networks trajectory excluding electricity grid losses and supply chain

10.4 Comparison of the SBT initiative trajectory with normative limits

Annex A uses the electricity budget approach to investigate whether the ICT trajectory outlined in clause 10 and Appendix IV respects the limits emerging from the normative scenarios in clause 9.

Annex A first calculates the electricity development trajectory 2015–2030 for energy-related emissions for usage and manufacturing, to ensure that the trajectory does not increase its share of the overall electricity budget. The overall GHG emissions of the sector are then calculated as the product of the overall electricity consumption and the emission factor derived by the SBT initiative, plus non-electricity-related emissions. The total GHG emission level derived is then compared with the minimum reduction levels put forward in the other normative approaches in clauses 9.1 and 9.2. The analysis shows that the scenario put forward in clause 10 falls within the normative boundaries and can form the basis for future company level guidance.

11 Opportunities and risks for the ICT sector to attain the 1.5°C trajectory

11.1 Introduction

Figure 15 illustrates how the ICT trajectories have been developed.

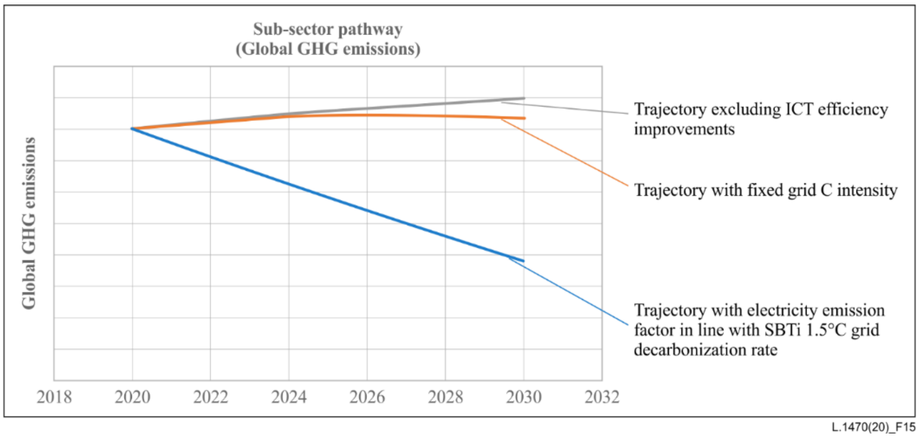


Figure 15 – Trajectory development

NOTE – Figure 15 is intended to illustrate the various principal parameters that impact a trajectory over time. The intention is not to outline the actual relationship between those parameters.

The lowest line represents the trajectories described in clause 10. In this case, the power sector is expected to decarbonize in line with a 1.5°C scenario and the ICT industry is expected to continue to introduce significant energy efficiency measures in its products and operations. The middle and uppermost lines represent worse case situations. The middle line shows what happens if the power sector fails to decarbonize and the ICT sector fail to mitigate that through purchase or investment in renewables. The uppermost line shows what could happen if the ICT sector does not make any electricity efficiency improvements.

The risks in clause 11.3 describe these unwelcome outcomes in more detail, whilst the opportunities in clause 11.3 describe actions the ICT sector can take to mitigate the risks and maintain the desired trajectory.

11.2 Opportunities – strategies to decarbonize the ICT sector until 2030

A number of actors in the ICT sector have made significant efforts to decarbonize their activities during the period 2010–2019. The efforts made were mainly relative to energy efficiency measures and switch to renewable ES.

Compared to BAU, these efforts brought reduced GHG emissions, reduced electricity consumption, financial savings and less dependency on the evolution of the price of grid electricity.

For the period 2020–2030, the main strategy to decarbonize the ICT sector, at the pace necessary to align with 1.5°C trajectories, seems to be the implementation of simultaneous, vigorous and urgent actions in the following fields:

– implementation of energy efficiency plans;
– switch to renewable or low carbon electricity supplies;
– encouragement of carbon consciousness among end-users.

Figure 16 shows some examples of categories of supporting actions.

Further guidance on how ICT sector decarbonization is expected to be provided in the Guidance for organizations document.

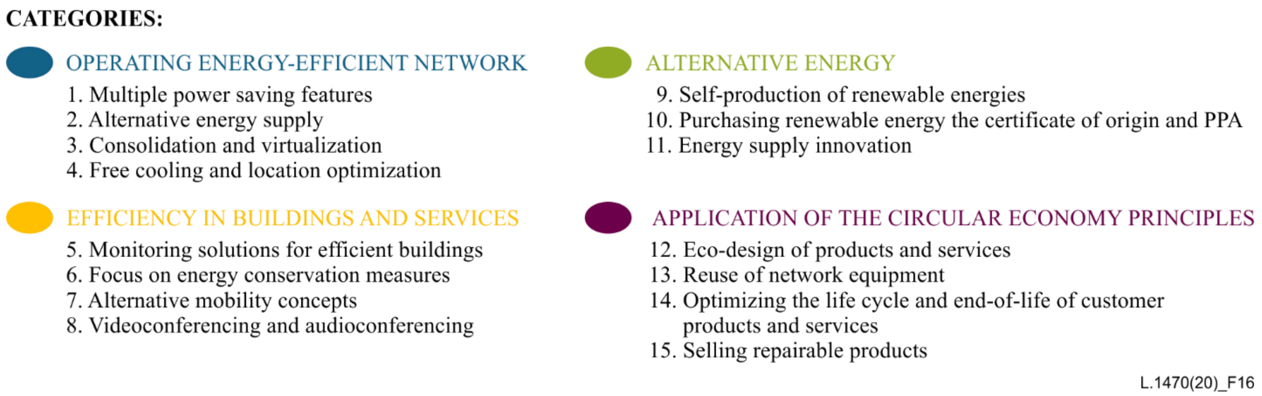


Figure 16 – Decarbonization measures [source: Orange, with permission]

Operating energy-efficient networks

The network infrastructure forms the basis of ICT products and services. Achieving greater energy efficiency in network operation is a key component to decarbonize the sector.

The adoption of standards, e.g., Recommendations developed by ITU-T SG5: [b-ITU-T L.1300]; [b-ITU-T L.1301]; [b-ITU-T L.1302]; [b-ITU-T L.1303]; [b-ITU-T L.1310]; [b-ITU-T L.1315]; [b-ITU-T L.1320]; [b-ITU-T L.1321]; [b-ITU-T L.1325]; [b-ITU-T L.1330]; [b-ITU-T L.1331]; [b-ITU-T L.1332]; [b-ITU-T L.1340]; [b-ITU-T L.1350]; [b-ITU-T L.1351]; [b-ITU-T L.1360]; [b-ITU-T L.1361]; [b-ITU-T L.1362]; and [b-ITU-T L.1370], provides guidance for the implementation of energy-efficient networks and data centres.

1 Multiple power saving features

The traffic load of the networks, in particular mobile networks, vary significantly throughout the day. Power-saving features, e.g., dynamic power allocation or active antennas, can reduce the energy consumption of networks when the load is lower.

2 Alternative energy supply

The usage of 400 V direct current (DC) for power supply may bring significant improvements in terms of energy consumption. Another example of action is the implementation of combined heat and power (CHP) plants.

The following Recommendations, developed by ITU-T SG5: [b-ITU-T L.1200]; [b-ITU-T L.1201]; [b-ITU-T L.1202]; [b-ITU-T L.1203]; [b-ITU-T L.1204]; [b-ITU-T L.1205]; [b-ITU-T L.1206]; and [b-ITU-T L.1207], provide guidance on the implementation of 400 V DC for ICT operations.

3 Consolidation and virtualization

Consolidation of data centres: regrouping physical servers in an optimized unique location; virtualization of servers; and bringing several virtual software servers on a single physical server, brings significant reductions in terms of electricity consumption and GHG emissions.

More generally, data centre virtualization encompasses a broad range of tools, technologies and processes that enable a data centre to operate and provide services with reduced energy consumption.

4 Free cooling and location optimization

Fresh air-conditioning systems use air outside when it is cooler than that inside a building, even during hot weather. They bring significant energy consumption reductions compared to conventional air-conditioning systems.

Adiabatic cooling may be operated in hot climates. Water is sprayed into the air before entering the existing free cooling system. As the water evaporates, the air is chilled.

Location optimization, in geographic areas where the temperature is relatively low throughout the year, is an efficient way to reduce electricity consumption and GHG emissions.

Efficiency in buildings and services

Tertiary buildings and mobility services account for a part of the energy consumption of ICT actors and thus their CO_2 emissions. Opportunities to optimize the energy performance and reduce the environmental impact of these assets are being seized by many actors in the world.

5 Monitoring solution for efficient buildings

Building management systems that control and monitor a building's mechanical and electrical equipment, e.g., ventilation, lighting, power systems and security systems, potentially using artificial intelligence, enable efficient energy management worldwide.

6 Focus on energy conservation measures

Installation of energy conservation measures, e.g., new energy-efficient ceiling lighting, adapted heating systems, presence detectors and variable light controls to adjust the lighting required, are the basis for achieving efficiency in buildings.

7 Alternative mobility concepts

Inside ICT organizations, usage of electric and hybrid vehicles, shared fleets, automated vehicle maintenance alerts and global positioning system (GPS) routing bring significant benefits.

Encouraging fuel-efficient driving through driver training courses also brings benefits.

8 Videoconferencing and audioconferencing

Videoconferencing and audioconferencing solutions allow, under specific conditions, carbon emissions associated with business travel and daily commuting to be reduced.

Alternative energy supply

9 Self-production of renewable energies

Installation of on-site renewable sources when it is feasible brings significant benefits, e.g., when installing solar photovoltaic systems on base station sites, data centres and technology centres.

10 Purchasing renewable energy with the certificate of origin and PPA

In order to mitigate GHG emissions associated with electricity usage, ICT actors can increase energy procurement from renewable sources, purchasing renewable energy certificates (RECs) that respect additionality principles or using power purchase agreements (PPAs).

11 Energy supply innovation

Many research initiatives are arising in the field of energy supply alternatives, including hydrogen fuel cell systems.

The development of new technologies to store energy and of decentralized energy storage are expected to bring additional benefits.

Moreover, to support renewable energy use at all stages of the ICT value chain represents an opportunity to reduce significantly the total ICT sector footprint.

The following Recommendations, developed by ITU-T SG5: [b-ITU-T L.1220]; [b-ITU-T L.1221]; and [b-ITU-T L.1222], provide guidance relative to innovative energy storage technology for stationary use.

Application of circular economy to products and services

The eco-conception of product and services, the reuse of network and customer equipment, the optimization of the life cycle of customer products, including the selling of repairable products, bring a positive impact on energy consumption and GHG emissions.

The following Recommendations, developed by ITU-T SG5: [b-ITU-T L.1020]; [b-ITU-T L.1021]; and [b-ITU-T L.1022], provide guidelines for ICT operators and suppliers to implement circular economy principles in the ICT sector.

The following Recommendations, developed by ITU-T SG5: [b-ITU-T L.1000]; [b-ITU-T L.1001]; [b-ITU-T L.1006]; and [b-ITU-T L.1007], provide details and test suites related to an external universal power adaptor.

[b-ITU-T L.1010], developed by ITU-T SG5, provides green battery solutions for mobile phones and other hand-held ICT equipment.

[b-ITU-T L.1015], developed by ITU-T SG5, provides criteria for the evaluation of the environmental impact of mobile phone and may be used in the framework of eco-conception approaches.

[b-ITU-TL.1410], developed by ITU-T SG5 in cooperation with the Environmental Engineering technical committee of the European Telecommunications Standards Institute (EE-ETSI), provides methodology for the environmental LCA of ICT goods, networks and services that can be used in the framework of eco-conception approaches.

11.3 Risks

The decarbonization of the ICT sector is, to a high extent, dependent on the availability of low carbon electricity that has been a precondition for the main scenarios. Renewables could be made available through decarbonization of the electricity grid, additional purchase of renewables and through the sector´s investment in own electricity sources. [b-Andrae 2015], [b-Andrae 2019a] and [b-Andrae 2019b] estimate how the ICT sector power footprint could evolve under certain circumstances, i.e., if the power sector (as in the past) does not live up to what is needed under [b-UNFCCC PA] and [b-IPCC 1.5] and if the ICT sector fails to mitigate that through purchase of renewables and its own ES.

Appendix V outlines the importance of the availability of renewables and of continued energy performance improvements for the ICT sector to decarbonize.

For the grid development to be in line with the SBT initiative 1.5°C scenario, it is estimated based on [b-IEA ETP 2017] and [b-IEA 2019] that 55% of current overall fossil electricity production, as well as any additional use of grid electricity, need to be replaced by low-carbon alternatives. Put differently, the SBT initiative grid scenario demands that, by 2030, there needs to be enough renewable electricity to equal the overall electricity production in the world. However, the ICT sector´s opportunity to use renewables goes beyond the average grid development, due to opportunities to preferentially purchase or invest in renewables beyond this average.

A further risk is that the ICT sector activity growth to efficiency ratio is greater than predicted in the modelling. This would lead to an increase in projected GHG emissions relative to the absolute pathways. This can happen, either as a result of higher than expected growth or lower than expected efficiency improvements.

Efficiency improvements are a key lever the ICT industry has at its disposal and it is therefore critical that the efficiency of ICT productivity remain a strong focus alongside the installation and procurement of renewable electricity.

Annex A

Analysis of ICT sector and sub-sectors trajectories

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

This annex investigates whether the ICT trajectory from clause 10 and Appendix IV falls within the limits defined by the normative approach outlined in clause 9. Table A.1 shows that the trajectory from clause 10 respects both the electricity budget and the GHG emissions budgets as outlined in clauses 9.1 to 9.3. Thus, the trajectory shows a way for the ICT sector to align with a 1.5°C trajectory and confirms that an ambition level in accordance with the normative approach seems feasible. However, it should be noted that the actual decarbonization of the ICT sector may take different paths, as long as the normative limits and the ambition level are respected.

This analysis includes emissions related to all life cycle stages, i.e., it includes emissions that belong to the ICT footprint, but which occur outside the ICT sector.

Table A.1

	Electricity (TWh)				**Electricity-related CO_2e emissions (excluding electricity supply chain and grid losses) (Mt CO_2e)**				**Non-electricity emissions (Mt CO_2e)**			
	2015	**2020**	**2025**	**2030**	**2015**	**2020**	**2025**	**2030**	**2015**	**2020**	**2025**	**2030**
Energy-sector development (electricity budget)												
1.5°C grid emission factors 2015–2020: Actual; 2025–2030 SBT initiative	**0.484**	**0.480**	0.281	0.160								
Reduction in emission factor from 2015 value (%)			**42**	**67**								
[b-IEA ETP 2017] 1.5°C scenario (estimate) global electricity generation (TWh)	24 185	26 013	27 841	30 478								
Increase in energy generation from 2015 (%)		**8**	**15**	**26**								
Reduction in energy sector emissions between 2015 and 2031 (%)				**58**								
Operation/usage related emissions												
Mobile networks												
Mobile network operator overheads – electricity (s2)	13	13	17	20	6.4	6.4	4.8	3.2				
Mobile network operator overheads – excluding electricity									4	3.8	2.7	1.2
Mobile network own electricity generation	27	25	23	19	25	23	21	18				

	Electricity (TWh)				Electricity-related CO_2e emissions (excluding electricity supply chain and grid losses) (Mt CO_2e)				Non-electricity emissions (Mt CO_2e)			
	2015	**2020**	**2025**	**2030**	**2015**	**2020**	**2025**	**2030**	**2015**	**2020**	**2025**	**2030**
Mobile network electricity consumption	90	115	125	131	48	46	35	21				
Mobile: own + grid + overheads electricity	130	153	164	171								
Change on 2015 (%)			26	31								
Fixed networks												
Fixed network operator overheads – electricity	7	7	9	10	3.2	3.2	2.4	1.6				
Fixed network operator overheads – excluding electricity									2	1.9	1.4	0.6
Fixed network electricity consumption (s2)	85	100	89	88	43	38	25	14				
Fixed: grid + overheads electricity	92.0	106.7	97.5	97.5								
Change on 2015 (%)			5	3								
Data centres												
Data centre operator overheads (electricity)	15	15	20	20	6.4	7.2	5.6	3.2				
Data centre operator overheads (excluding electricity)									3	2.8	2.1	0.9
Data centre electricity consumption	205	215	235	257	91.2	84	60	40				
Date centre: grid + overheads electricity	220	230	254.93	277.00								
Change on 2015 (%)			15	25								
User devices												
User device operation (s3)	345	335	409	450	169	161	115	72				
Change on 2015 (%)			19	30								
ICT Operating electricity consumption (excluding user devices)	442	490	517	545								
Increase from 2015 (%)			17	23								
ICT operating electricity consumption (including user devices)	787	825	926	995								
Increase from 2015 (%)			18	26								
ICT usage share of global electricity generation (%)	**3.3**	**3.2**	**3.3**	**3.3**								
Usage-related to total CO_2 (Mt)	393.2	407.3	274.8	174.12	392.2	368.8	268.8	173	401.2	377.3	275.0	175.7
Reduction in ICT usage-related emissions between 2015 and 2030 (%)								**56**				**56**
Embodied emissions												
Mobile networks												
Mobile manufacturing excluding electricity (s1)									9	9	9	9
Mobile manufacturing electricity (s2)	5	11.88	17.08	25.00	6	5.7	4.8	4				
Change on 2015 (%)			242	400								
Fixed networks												
Fixed manufacturing – excluding electricity									4.5	3.75	3.4	3
Fixed manufacturing – electricity	1.7	4.48	6.05	8.31	2.5	2.15	1.7	1.33				
Change on 2015 (%)			256	389								

	Electricity (TWh)				Electricity-related CO_2e emissions (excluding electricity supply chain and grid losses) (Mt CO_2e)				Non-electricity emissions (Mt CO_2e)			
	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
Data centres												
Data centre manufacturers excluding electricity									9	9.4	9.75	9.75
Data centre manufacturers electricity	5	13.13	19.04	27.81	6	6.3	5.35	4.45				
Change on 2015 (%)			281	456								
User devices												
User devices manufacturers excluding Electricity									35	35	35	35
User devices manufacturers electricity	149	133.33	145.91	143.75	70	64	41	23				
Change on 2015 (%)			–2	–4		86	52	32		70	70	70
ICT Manufacturers electricity consumption	159	163	188	205								
Increase from 2015 (%)			18%	29%								
ICT manufacturing share of global electricity generation	**0.7%**	**0.6%**	**0.7%**	**0.7%**								
Total manufacturing-related CO_2 (Mt)	77.0	78.2	52.9	32.8	84.5	78.2	52.9	32.8	134.52	135.3	110	89.5
Reduction in ICT sector manufacturing-related emissions between 2015 and 2030 (%)								**61**				**33**
Total electricity-related emissions												
Electricity-related total sector emissions	470.2	485.4	327.7	206.9								
Reduction in ICT sector emissions between 2015 and 2030 (%)				**56**								
Reduction in Power sector emissions between 2015 and 2031 (%)				58								
ICT share of global electricity generation (%)	**3.9**	**3.8**	**4.0**	**3.9**	**This is within the normative limit for ICT electricity usage based on IEA**							
Total emissions												
ICT sector total CO_2 (Mt) including electricity and non-electricity-related emissions	604.7	620.7	437.7	296.4								
Reduction in ICT sector emissions between 2015 and 2030				**51%**	**This is within the normative limit for ICT GHG emissions both for the SBT initiative and IPCC P2**							
NOTE – All values exclude electricity transmission, distribution and supply chain related emissions												

Electricity (TWh): 2015 figures from baseline of this Recommendation; 2025 and 2030 figures reverse calculated from Appendix V CO_2 numbers using the SBT initiative grid intensities.

Electricity-related CO_2e emissions: (excluding electricity supply chain and grid losses) (Mt CO_2e) taken from Table IV.2.

Non-electricity emissions (Mt CO_2e) for operation are decreasing in line with electricity emission reductions. Note that data sources do not often provide explicit information regarding distribution between electricity and non-electricity based emissions (This calculation assumes 25% of supply chain emissions to be electricity based.)

Appendix I

Introduction to the Science-Based Targets initiative framework

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

This appendix describes some implications for the development of ICT sector and ICT sub-sector from the SBT initiative framework. The full framework is available in [b-SBT Methods].

The normal sectoral decarbonization approach (SDA) is a method for setting physical emissions intensity targets that uses convergence. An emissions intensity target is specified by a reduction in emissions relative to a specific business metric, such as production output of a company, (e.g., tonne CO_2e per tonne product produced). The SDA assumes global convergence of the emissions intensity of key sectors by 2050.

The most common SDA at this point uses the B2DS scenario from [b-IEA ETP 2017], which comprises emissions and activity projections used to compute sectoral pathways aligned with limiting warming to well below 2°C.

Due to the lack of 1.5°C scenario data from IEA, the SBT initiative currently does not provide an SDA option for 1.5°C targets. Additionally, regional pathways have not been incorporated into the SDA method.

I.1 Applying the SDA to ICT

Currently, the ETP scenarios have no direct reference to the ICT sector, which means the current SDA tool of the SBT initiative excludes any reference to ICT.

[b-SBT Manual] places the manufacture of computer, electronic, optical and electrical equipment products in the "all other industry" category and recommends this ICT sub-sector to set an absolute or emissions intensity target in line with the absolute contraction approach.

In order to improve the usability of SDA, it is important to consider the situation of companies in different key sub-sectors of the ICT sector: ICT end-user equipment; telecommunication networks (fixed line and mobile); data centres including cloud operators and the ICT service sector.

I.2 Initial boundary conditions

Emissions associated with the use of ICT equipment currently amount to approximately 60% of the total life cycle carbon footprint of the sector, with the remaining footprint split roughly equally between electricity consumption in manufacture, and all other emissions including diesel generators, embedded carbon in materials and components, transport and fugitive emissions.

The main focus of this appendix is therefore on modelling an SDA pathway for the dominant component of the ICT total carbon footprint, namely the energy consumed during the use phase of ICT equipment.

I.3 Establishing an ICT sub-sector pathway

Sectoral SDA pathways project existing sector baseline data into the future. This requires an evaluation as to how the sector will grow and become more efficient. According to the SDA methodology, a sector's growth is measured using an appropriate activity metric that is well related to its energy consumption and consequential CO_2 emissions. In the case of the power sector, activity levels are measured by the number of megawatt hours of electricity generation in a given year. For commercial buildings, it is the floor area in square metres of real estate for a given year.

It is considered very unlikely that there will be a single form of activity metric relevant to all ICT sub-sectors. For this reason, a sub-sector approach has been adopted. Once a suitable activity metric has been selected, then an ICT sub-sector pathway associated with use phase electricity can be developed using Equation 1:

$$SC_{s,y} = SA_{s,y} \cdot SE_{s,y} \cdot PI_y \tag{1}$$

where

$SA_{s,y}$ is the activity in year y (activity units) for ICT sub-sectors;

$SE_{s,y}$ is the energy intensity in year y (MWh/activity) for ICT sub-sectors;

PI_y is the carbon intensity for the power sector in year y (tCO_2/MWh);

$SC_{s,y}$ is the total of carbon emissions in year y (tCO_2).

This approach follows recommendation R8 of [b-SBT Criteria] that highlights the need to consider both efficiency improvements (addressed by $SE_{s,y}$) as well as any carbon reductions delivered by the power sector (sourced from the [b-IEA ETP 2017] data and addressed by PI_y).

NOTE – In the case of the mobile sector, Equation 1 is modified to take account of the considerable amount of on-site, diesel-generated electricity present in some geographies as discussed in Appendix IV.

I.4 Absolute versus SDA

According to the [b-SBT Manual], the minimum reduction required for absolute targets in line with well-below 2°C scenarios is 2.5% in annual linear terms. However, companies, particularly those in developed countries, are strongly encouraged to adopt targets with a 4.2% annual linear reduction to be aligned with limiting warming to 1.5°C.

The IEA currently does not offer ETP pathways for a 1.5°C scenario and so to date the SDA tool of the SBT initiative has relied on the [b-IEA ETP 2017] B2DS pathways (equivalent to an alignment with a 1.75°C global temperature rise).

The SBT initiative has recently shared a provisional draft 1.5°C pathway for the power sector and this has been included in this Recommendation.

I.5 Power sector carbon emission intensity

I.5.1 Compatibility with scope 2 GHGP reporting

A company needs to establish two sets of SBTs. One for its combined scope 1 and 2 emissions, and another for its scope 3 emissions. To ensure consistency between the sector pathways and corporate carbon accounting standards, it is therefore important to ensure that figures for the carbon intensity of the power sector used to establish sub-sector pathways follow the GHGP guidance.

P. 87 of Appendix A of [b-GHG P] states:

> Emissions associated with the extraction and production of fuels consumed in the generation of purchased electricity may be reported in scope 3 under the category "extraction, production, and transportation of fuels consumed in the generation of electricity." … Emissions from the generation of electricity that is consumed in a T&D system may be reported in scope 3 under the category "generation of electricity that is consumed in a T&D system" by end-users. … Consistent with the scope 2 definition …, the *GHG Protocol Corporate Standard* requires the use of EFG [emission factor at generation] to calculate scope 2 emissions.

The calculations intended for any ICT pathways that will be used for scope 1 and 2 SBTs should therefore use power sector carbon intensities based on generation and exclude T&D losses.

Appendix II

Opportunities for the ICT sector to help decarbonize other sectors

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

The focus of this Recommendation is to derive a trajectory for the ICT sector that supports a 1.5°C limitation of climate change and the responsibility of the ICT footprint clearly lies within the sector. However, while striving to implement the decarbonization trajectory, it is important to understand that ICT, unlike many products and services sold in the world today, distinguishes itself by its double-edged nature. On the one hand, ICTs have an environmental impact at each stage of their life cycle, from energy and natural resource consumption to e-waste. On the other, ICTs can enable vast efficiencies in lifestyle and in all sectors of the economy through the provision of digital solutions that can improve energy efficiency, inventory management and business efficiency by reducing travel and transportation, e.g., teleworking and videoconferencing and by substituting physical products for digital information. The latter capacity is referred to collectively as second order or enablement effects.

Beyond this, ICT has effects at the societal level by reshaping how people lead their lives. Such effects are much larger than the footprint itself and are important aspects to consider when optimizing the overall decarbonization of society.

Some examples of the wider impacts of the ICT sector include, *inter alia*:

- virtual services replacing physical products, e.g., using e-readers instead of paperback books, optimizing entire sectors, like transport, industry, and agriculture;
- ICT can foster new sustainable lifestyles;
- significant improvement through digital services in the utilization of resources, e.g., infrastructure, vehicles and buildings.

  Concretely this means e.g.,

  - IoT-enabled building energy management systems;
  - smart irrigation;
  - energy-efficient frozen food;
  - managing urban traffic flow and congestion;
  - intelligent lighting;
  - intersection safety analytics;
  - intelligent traffic management.

The underlying idea is that global GHG emissions can be significantly reduced if existing and developing ICT solutions are used in other sectors (and ICT itself) to leverage their full potential in a smart manner.

The positive contribution of assessed services based on ICT has been found to increase its direct footprint by an order of magnitude. However, such gains could be offset by rebound effects and even by other services optimized for other purposes (such as oil extraction). ICT has great potential, but as a common-purpose tool, it could be used for different purposes. Directed towards decarbonization, its enablement effect is perhaps yet unleashed.

Appendix III

Baseline values – Energy consumption and carbon footprints

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

This baseline is defined in accordance with [b-Malmodin 2018a] and [b-Malmodin 2018c]. The method and main data sources are summarized here. Further details are given in [b-Malmodin 2018a] and [b-Malmodin 2018b].

III.1 Summary

The ICT sector is divided into the three main sub-sectors: end user goods (user devices); networks (including both mobile and fixed); and data centres, including enterprise networks. A large amount of primary data has been collected directly from ICT and entertainment and media (E&M) companies. In total, data from about 100 of the world's largest manufacturers, operators, as well as ICT and E&M service companies have been collected [b-Malmodin 2018a]. ICT companies that cover about 40% of all mobile subscriptions and about 15% of all fixed subscriptions, including about 15% of final estimated electricity consumption in data centres have reported their data. See Figure III.1.

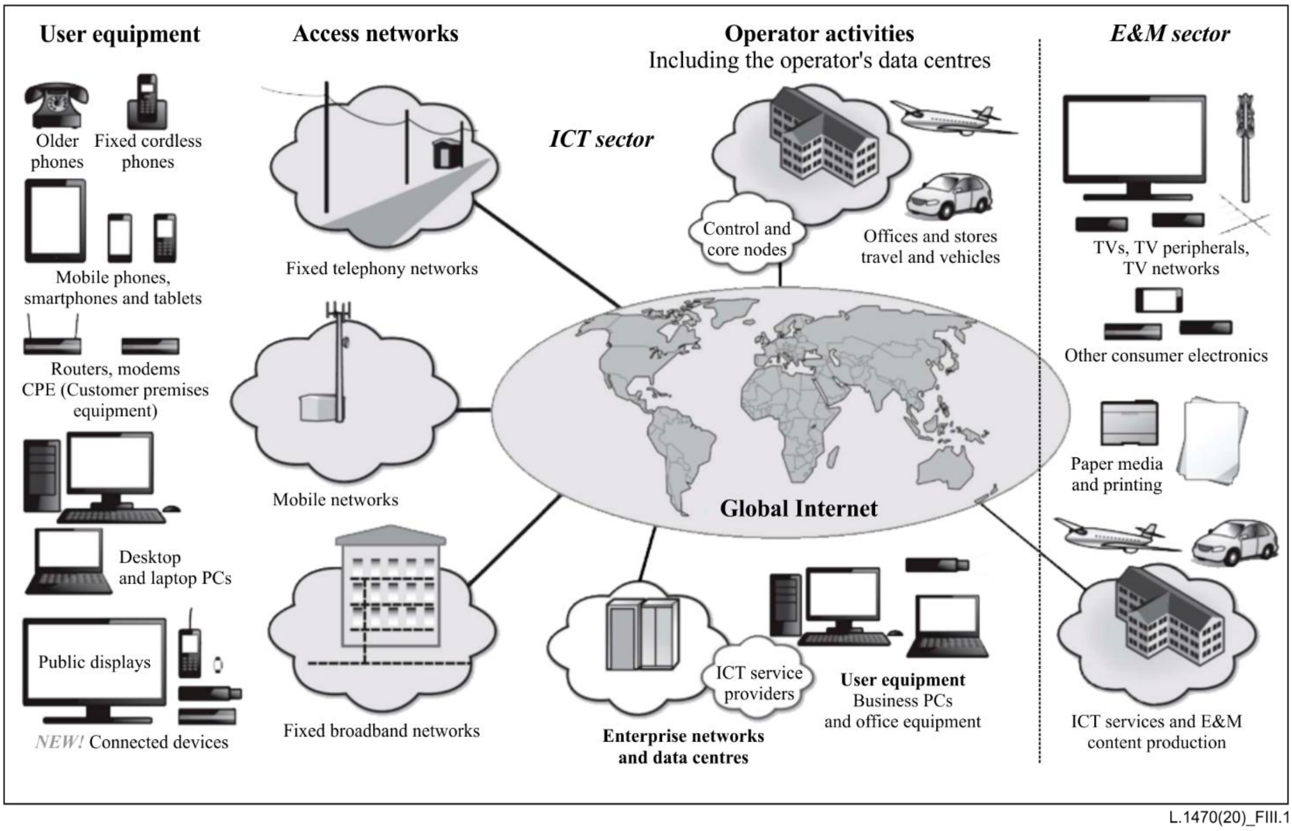


Figure III.1 – ICT sector overview

Electricity consumption in the use stage per respective area has been converted to CO_2e using emission factors. GHG emissions from the other life cycle stages are treated separately and reflect geographical locations.

For user devices, a combination of LCA data and production data from the leading ICT companies and equipment manufacturers has been used, which leads to a more accurate estimate of the embodied emissions then just using old LCA data. Data for different products have been compiled, together with sales statistics for these devices.

As stated in section 6 of [b-Malmodin 2018a], the study strived for alignment with [ITU-T L.1450]:

> This study has used the joint LCA standard by ITU/ETSI for ICT networks [ITU-T L.1450] and the principles of relevance, completeness, consistency, accuracy, and transparency to guide the work. In addition, the study has strived to be well aligned with the ITU standard for the carbon footprint of the ICT sector [ITU-T L.1450]. Overall, the choice of functional units and boundary setting is in line with the standard and the study also takes a life cycle approach and considers both hardware and software. At a product level, a major data collection effort was undertaken to find data in line with the standards' requirements. From a data quality point of view, the principles of completeness, uncertainty, data representativeness, data age, geographical and technological correlation have been considered in this process. Cut offs have been avoided as far as possible and the use of proxy data and extrapolations have been preferred, and energy emission factors are inclusive by considering the supply chain and distribution losses. Also, from an allocation perspective, the rules of the standard have been considered. No sensitivity analysis was performed but results for different parts are transparently presented to enable postprocessing. The reporting is not performed in accordance with the standards but adopts to the format of the journal [*Sustainability*]. Finally, no third party critical review of standard compliance has been performed, but the authors preferred to send the study for review.
>
> For the input studies performed by the authors themselves, the input data have high degree of compliance with the standard according to previous evaluations. For user devices, a detailed standardization review was performed during this study and it was noted that existing studies, in most cases, have a low degree of transparency, which makes it hard to judge their quality. Furthermore, none of the reviewed sources referred to any LCA standard. For this reason, the used complementary top-down data sources were considered important to validate the LCA data collected. For data centers, no compliance review was performed but the quality of the input data should be secured through the scientific peer review of the academic papers and the broad consultation performed for the IEA deliverable.

See Table III.1.

Table III.1 – Baseline overview for the entire ICT sector 2015

	Electricity consumption	**CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)**	**CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)**
	2015 (TWh)	**(Perspective A)**	**(Perspective B)**
Mobile networks			
Mobile network manufacturers (s1-s2)	5	3	3
Mobile network manufacturers, T&D (s3)		0.3	–
Mobile network manufacturers, electricity supply (s3)		0.45	–
Mobile network operator overheads – electricity (s2)	13	6.4	6,4
Mobile network operator overheads – excluding electricity (s1-s2)		4	4
Mobile network own electricity generation (s1-s2)	27	25	25
Mobile network electricity consumption (s2)	90	48	48
Mobile network electricity consumption, T&D (s3)		5.4	–
Mobile network electricity consumption, electricity supply (s3)		8.2	–
Mobile network supply chain s3		12	12
Mobile network supply chain, T&D (s3)		0.75	–
Mobile network supply chain, electricity supply (s3)		1.5	–
Fixed networks			

Table III.1 – Baseline overview for the entire ICT sector 2015

	Electricity consumption	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)
	2015 (TWh)	(Perspective A)	(Perspective B)
Fixed network manufacturers (s1-s2)	1.7	1	1
Fixed network manufacturers, T&D (s3)		0.1	–
Fixed network manufacturers, electricity supply (s3)		0.15	–
Fixed network operator overheads – electricity (s2)	7	3.2	3,2
Fixed network operator overheads – excluding electricity (s1-s2)		2	2
Fixed network electricity consumption (s2)	85	43.2	43
Fixed network electricity consumption, T&D (s3)		4.6	–
Fixed network electricity consumption, supply (s3)		6.9	–
Fixed network supply chain s3		4.5	6
Fixed network supply chain, T&D (s3)		0.5	–
Fixed network supply chain, electricity supply (s3)		0.75	–
Data centres			
Data centre manufacturers s1-s2	5	3	3
Data centre manufacturers, T&D (s3)		0.3	–
Data centre manufacturers, electricity supply (s3)		0.45	–
Data centre operator overheads (electricity) s2	15	6.4	6,4
Data centre operator overheads (excluding electricity) s1-s2		3	3
Data centre electricity consumption (s2)	205	91.2	91,2
Data centre electricity consumption, T&D (s3)		9.1	–
Data centre electricity consumption, supply (s3)		13.7	–
Data centre supply chain s3		12	12
Data centre supply chain, T&D (s3)		0.75	–
Data centre supply chain, electricity supply (s3)		1.5	–
User devices			
User device manufacturers (non-electricity)		35	35
User device manufacturers electricity (s2/s3)	149	70	70
User device manufacturers, T&D (s3)		7	–
User device manufacturers, electricity supply (s3)		10.5	–
User device operation (s3)	345	169	169
User device operation (T&D, s3)		17	–
User device operation, electricity supply (s3)		25	–
User device supply chain non-electricity s3		35	35
User device supply chain, electricity (s3)	56	26	26
User device supply chain, T&D (s3)		2.6	–
User device supply chain, electricity Supply (s3)		3.9	–
Enterprise networks:			
Enterprise networks manufacturers electricity (s2/s3)		0.5	0,5
Enterprise networks manufacturers, T&D (s3)		0.05	–
Enterprise networks devices manufacturers, electricity supply (s3)		0.08	–
Enterprise networks operation (s2/s3)	25	12	12
Enterprise networks operation (T&D, s3)		1.2	–
Enterprise networks operation (supply, s3)		1.8	–
Total			
Total including grid electricity supply and losses		**740**	**–**
Total excluding grid electricity supply and losses		**–**	**617**

Table III.1 – Baseline overview for the entire ICT sector 2015

	Electricity consumption	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)
	2015 (TWh)	(Perspective A)	(Perspective B)
Number of mobile subscriptions (SIM-cards excluding M2M)	**7.2 billion**	[b-Ericsson 1994-2020] [b-GSMA]	
Number of fixed subscriptions (lines)	**1.85 billion**	[b-ITU 2005–2019]	
Number of servers (datacentres)	**43 million**	Calculated from sales and lifetime	
Number of active PC or employee "users" (enterprises)	**800 million**	Calculated from sales and lifetime	
Number of end-user goods	**13 billion**	[b-Malmodin 2018a]	
Number of additional IoT/M2M (possible, included in forecast)	**2 billions**	Calculated	
Fixed data traffic (ZB)	**1**	[b-Cisco] https://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html	
Mobile data-traffic (ZB)	**0.06**	[b-Ericsson 1994-2020]	
This table is colour-coded according to clause 5.			

III.2 Description

This clause provides background information for the baseline.

III.2.1 Emission factors

For embodied emissions, emission factors are embodied in the background studies and based on actual conditions.

For operation, the following data have been combined with world average emission factors based on IEA reporting of actual conditions:

- with ES chain and loss, the factor is estimated to be 0.63 kg CO_2e/kWh (2015);
- without ES chain and loss, the factor is estimated to be 0.506 kg CO_2e/kWh (2015).

III.2.2 Mobile networks

III.2.2.1 Operation

Data sources

Published data collected from operators listed in clause III.3 *(*with further details in section II of [b-Malmodin 2018a].

More detailed data collected from nine anonymous European Telecommunications Network Operators (ETNO) or GESI members as described in clause III.3 (with further details in [b-Malmodin 2018c]). This data set was used to allocate between mobile, fixed, overheads etc.

Calculation

- The electricity usage and CO_2e data from individual operators (section II of [b-Malmodin 2018b]) were added and the result was extrapolated based on subscriptions to arrive at an overall electricity usage per network type

- CO_2e figures include overheads, scope 1-2, and scope 3 for travels – usage of mobile phones excluded to avoid double counting.

- The allocation between mobile and fixed networks was based on subscriptions as derived in [b-Malmodin 2018c] from more than 10 operators with detailed reporting
- The allocation to overheads activities was based on Figures 6 and 8 of [b-Malmodin 2018c]
- Operator data centres (20 TWh, p. 13 of [b-Malmodin 2018c]) were excluded and allocated to the data centre category based on Figure 6 of [b-Malmodin 2018c].

III.2.2.2 Embodied

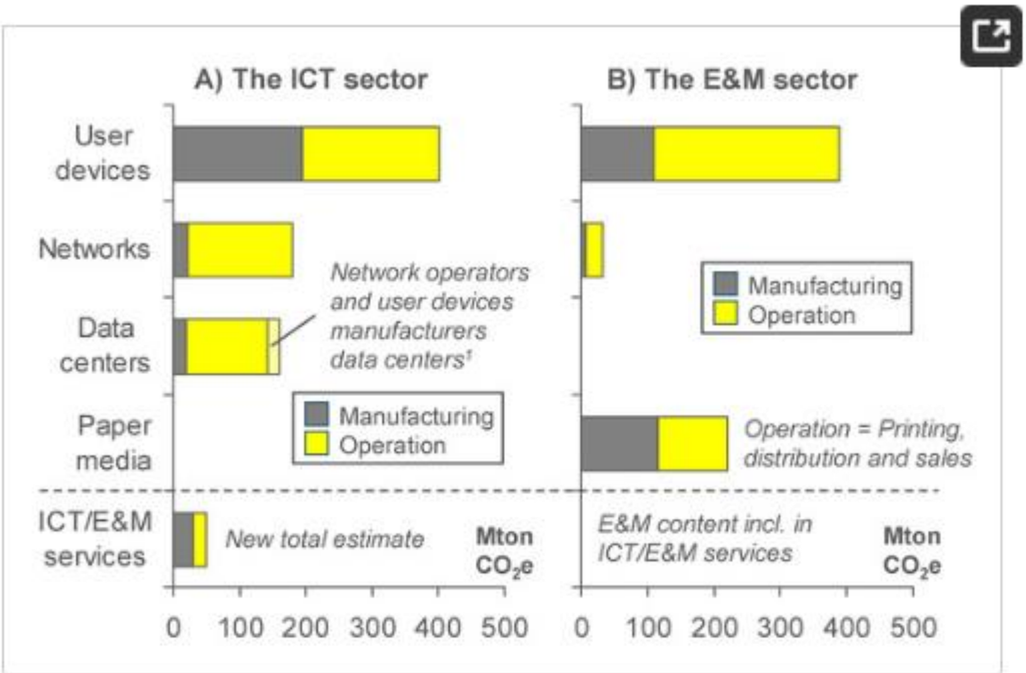
Embodied emissions are based on Table 4 of [b-Malmodin 2014a]. The main part of this is due to network deployment and construction but the factors include also the embodied emissions of the ICT equipment.

Table III.2 – Embodied carbon footprint for network deployment and construction in Sweden and globally (estimated from Swedish data)

Embodied emissions	Sweden	Global estimate
Fixed telephony	7,3 kg CO_2e/line	5 kg CO_2e/line
Fixed broadband	+1,1 kg CO_2e/line	+1 kg CO_2e/line
Mobile	3,5 kg CO_2e/subscription	2 kg CO_2e/subscription

For network construction and deployment, values from [b-Malmodin 2014a] were adjusted for the difference between Swedish and global conditions.

> "The embodied carbon footprint for ICT network operators is mainly related to the construction and deployment of the network infrastructure like digging down cable ducts and raising antenna towers. The footprint of these activities has been estimated based on extensive studies of construction and deployments of telecom networks in Sweden, see Table 4. Lower averages have been estimated globally as Sweden has both a low population density and high requirements on connectivity which increases the network infrastructure impact as well as costs. Note that the deployment or embodied carbon footprint has been spread out over the whole lifetime and the values in Table 4 represent the annual carbon footprint for the network infrastructure deployment and construction which can vary substantially over time.



The overall embodied emissions for all sub-sectors were validated based on

- The energy and carbon footprints of the major ICT and E&M manufacturing companies were collected and scaled to a global level based on revenue. See [b-Malmodin 2018a] section 4.10 [b-Malmodin 2018b] III.
- The contribution from materials extraction was also derived top-down in accordance with [b-Malmodin 2018d], which estimates the material carbon footprint of the ICT and E&M sector to be about 45 Mt CO_2e."

III.2.3 Fixed networks

III.2.3.1 Operation

- The electricity usage and CO_2e data from individual operators (section II of [b-Malmodin 2018b]) were added and the result was extrapolated based on subscriptions to arrive at an overall electricity usage per network type
  - CO_2e figures include overheads, scope 1-2, and scope 3 for travels – usage of mobile phones excluded to avoid double counting.
- Allocated to mobile and fixed networks, respectively, based on impact per subscriber as derived in in [b-Malmodin 2018c] from the 10 or more operators with detailed reporting
- Allocated to overheads based on Figures 6 and 8 of [b-Malmodin 2018c]
- Operator data centres (20 TWh, p. 13 of [b-MalmodinLundén 2018a]) were excluded and allocated to category data centre based on Figure 6 of [b-Malmodin 2018c])

III.2.3.2 Embodied

See clause III.2.2.2.

III.2.4 Data centres

III.2.4.1 Operation

2014–2020 based on [b-IEA Digitalization] in accordance with [b-Malmodin 2018a].

However, the electricity consumption of data centres is estimated to be slightly higher than the IEA estimate of 194 TWh for 2014, about 205 TWh for 2015 (220 TWh including overheads). The difference compared to IEA is that slightly more servers are estimated to be in operation due to estimated longer lifetime (4.5 years per server).

Renewables separated before applying emission factor

The model applied is based on energy usage per server based on [b-Shehabi], [b-Fuchs] and personal communication with IEA author.

III.2.4.2 Embodied

Based on detailed reporting by [b-Google 2016a], [b-Google 2016b] and [b-Facebook], scaled to all data centres based on their share of terawatt hours.

III.2.4.3 Overhead

Based on detailed reporting by [b-Google 2016a] , [b-Google 2016b] and [b-Facebook], scaled to all data centres based on their share of terawatt hours.

The energy consumption related to offices and travel for data centre operators has been included in the footprints, together with the embodied footprint of equipment and infrastructure. These data are based on reports by [b-Google 2016a], [b-Google 2016b] and [b-Facebook], and the estimated total carbon footprint for data centres and enterprise networks is about 160 Mt CO_2e. About 135 Mt of the carbon footprint is related to the electricity consumption (240 TWh) taking reported green electricity into account, and about 25 Mt comes from construction and manufacturing and a smaller share from non-electric energy used at sites, transports and travel.

III.2.5 User devices

III.2.5.1 Categories

Fixed phones (PSTN and voice over Internet protocol (VoIP)), smartphones, other mobile phones, CPE (modems, gateways), tablets, laptop PCs, desktop PCs, computer displays, computer peripherals, projectors, public displays, surveillance cameras, payment terminals, wearables, smart meter connectivity.

III.2.5.2 Calculation

Each category has been calculated as:

Total footprint per category calculated as

$$\text{Embodied} + \text{Operational} = A*C + D*E*F$$

where A, C, D and E are given in the column headings to Table III.3; F depends on scenario, see clause IV.2.1.

Note that embodied emissions include the year of shipment.

III.2.5.3 Data sources

Table III.3 – Summary of data sources. For details refer to the source documents

ICT sector	Total shipments[a]	Embodied CF per device	Devices in operation[a]	Lifetime assumptions	Annual average OEC
	millions	kg CO_2e (est.)	millions	years	kWh
	A	*C*	*D*		*E*[b]
Fixed phones (PSTN + VoIP)	ITU	S6.1.2 of [b-Malmodin 2014b] Table 2 of [b-Malmodin 2018a]	ITU	8.3	Based on input data from Table 1 of [b-Malmodin 2014a] + S6.1.2 of [b-Malmodin 2014b], adjusted for development in [b-Malmodin 2018a], [b-Malmodin 2018c]
Smartphones	Gartner, IDC	S2 of [b-Malmodin 2014b], Table 2 of [b-Malmodin 2018a]	Gartner, IDC	3.0	Based on input data from Table 1 of [b-Malmodin 2014a] + S2 of [b-Malmodin 2014b], adjusted for development in [b-Malmodin 2018a], [b-Malmodin 2018c]
Other mobile phones	Gartner	S2 of [b-Malmodin 2014b], Table 2 of [b-Malmodin 2018a]	Gartner	5.0	Based on input data from Table 1 of [b-Malmodin 2014a] + S2 of [b-Malmodin 2014b], adjusted for development in [b-Malmodin 2018a], [b-Malmodin 2018c]
CPE (modems, gateways)	Future Source/IHS[c]	S2 of [b-Malmodin 2014b], Table 2 of [b-Malmodin 2018a]	Future Source/IHS[c]	5.0	Based on input data from Table 1 of [b-Malmodin 2014a] + S2 of [b-Malmodin 2014b], adjusted for development in [b-Malmodin 2018a], [b-Malmodin 2018c]
Tablets	IDC	S2 of [b-Malmodin 2014b], Table 2 of [b-Malmodin 2018a]	Estimated from yearly shipment + operational lifetime	3.4	Based on input data from Table 1 of [b-Malmodin 2014a] + S2 of [b-Malmodin 2014b], adjusted for development in [b-

Table III.3 – Summary of data sources. For details refer to the source documents

ICT sector	Total shipments[a]	Embodied CF per device	Devices in operation[a]	Lifetime assumptions	Annual average OEC
	millions	kg CO_2e (est.)	millions	years	kWh
	A	*C*	*D*		E^b
					Malmodin 2018a], [b-Malmodin 2018c]
Laptop PCs	IDC	S2 of [b-Malmodin 2014b], Table 2 of [b-Malmodin 2018a]	Estimated from yearly shipment + operational lifetime	5.0	Based on input data from Table 1 of [b-Malmodin 2014a] + S2 of [b-Malmodin 2014b] (S2), adjusted for development in [b-Malmodin 2018a], [b-Malmodin 2018c]
Desktop PCs	IDC	S2 of [b-Malmodin 2014b] (S2), Table 2 of [b-Malmodin 2018a]	Estimated from yearly shipment + operational lifetime	5.0	Based on input data from Table 1 of [b-Malmodin 2014a] + S2 of [b-Malmodin 2014b] (S2), adjusted for development in [b-Malmodin 2018a], [b-Malmodin 2018c]
Computer displays	IHS[c]	S2 of [b-Malmodin 2014b], Table 2 of [b-Malmodin 2018a]	Estimated from yearly shipment + operational lifetime	7.7	Based on input data from Table 1 of [b-Malmodin 2014a] + S2 of [b-Malmodin 2014b], adjusted for development in [b-Malmodin 2018a], [b-Malmodin 2018c]
Computer peripherals	Future Source	Table 2 of [b-Malmodin 2018b]	Estimated from yearly shipment + operational lifetime	na	na
Projectors	IHS[c]	Estimated based on device weight [b-Malmodin 2018a]	Estimated from yearly shipment + operational lifetime	6.3	Estimate used in Table 2 of [b-Malmodin 2018b]
Public displays	IHS[c]	Estimated based on screen sized from other display LCA figures [b-Malmodin 2018a]	Estimated from yearly shipment + operational lifetime	7.1	Estimate used in Table 2 of [b-Malmodin 2018b]

Table III.3 – Summary of data sources. For details refer to the source documents

ICT sector	Total shipments[a]	Embodied CF per device	Devices in operation[a]	Lifetime assumptions	Annual average OEC
	millions	kg CO_2e (est.)	millions	years	kWh
	A	*C*	*D*		E^b
Surveillance cameras	IHS[c]	Estimated based on device weight [b-Malmodin 2018a]	IHS[c]	5.0	Estimate used in Table 2 of [b-Malmodin 2018b]
Payment terminals	BI Intelligence[d]	Estimated based on device weight [b-Malmodin 2018a]	BI Intelligence[d]	4.3	Estimate used in Table 2 of [b-Malmodin 2018b]
Wearables	IDC	Estimated based on device weight [b-Malmodin 2018a]	IDC	3.5	Estimate used in Table 2 of [b-Malmodin 2018b]
Smart meter connectivity	Pike Research[e]	Estimated based on device weight ([b-Malmodin 2018a], [b-Malmodin, Coroama 2016]	Pike Research[e]	10.0	Estimate used in Table 2 of [b-Malmodin 2018b]

[a]Table III.5 gives an overview of data sources that are further detailed in [b-Malmodin 2019b].
[b]Usage scenarios behind the data used for *E* for all categories above Projectors are mainly based on: [b-Stobbe], [b-Urban].
[c]The successor company is OMDIA.
[d]Company now known as Business Insider.
[e]The successor company is Guidehouse Insights.

References

[b-Malmodin 2014a]; [b-Malmodin 2018a]; [b-Malmodin 2018b];

[b-Malmodin 2018c]; [b-MalmodinCoroama 2016]; [b-Malmodin 2018a];

[b-Malmodin 2018c].

References for those studies include 10 LCAs of feature phones, 7 LCAs of smartphones, 12 LCAs for laptop PCs and 12 LCAs for desktop PCs.

III.2.6 Enterprise networks

Enterprise networks have been estimated based on estimates of number of network ports, number of work or office PCs, additional so called small cells or WLAN network equipment.

As with most other equipment and devices, global annual sale figures from recent years have been used together with measured data from large samples. The sample size is in this case limited to in-house operations, but large global information technology (IT) service providers have also contributed with knowledge and data. Enterprise network overheads can be estimated at 27 kWh/year on average per active employee with a PC.

Sources: [b-Shehabi], [b-Stobbe].

III.3 Main data sources (in addition to academic papers)

III.3.1 Summary

The following data sets have been collected:

- published data for 36 network operators (listed in Table III.4);
- directly collected data for 10 network operators (under non-disclosure agreement (NDA));
- published data for 31 manufacturers (listed in Table III.4);
- published data for 10 data centre operators (specified below).

In addition, embodied LCAs from about 30 studies (as defined by all Malmodin papers listed in the bibliography).

Academic references cited in all Malmodin papers listed in the bibliography.

The same company may occur in more than one category.

III.3.2 Directly reported data used for detailed allocation between different network parts:

Data for about 10% of the global fixed and mobile subscriptions have been collected under NDA directly from nine operators that are ETNO or GESI members. This granular data set makes it possible to see details for fixed and mobile networks, as well as the distribution of electricity consumption and operational carbon emissions between the network itself and an operator's own data centre, offices and stores.

Included:

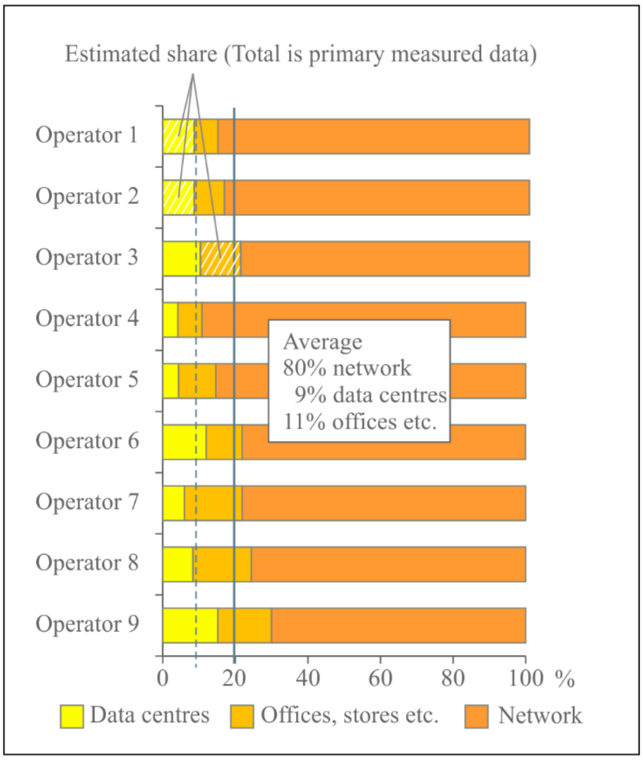
- network electricity (and diesel for mobile networks);
- fixed telephony access networks (also known as PSTN or plain old telephone service (POTS));
- mobile access networks of all generations, including all diesel consumption;
- fixed broadband access networks;
- data transmission and Internet protocol (IP) core network.

Operator activities or overheads:

- electricity and other energy in data centres, offices and stores;
- business travel and fleet vehicles used for field service operations.

To verify that confidential data from operators are reliable and accurate is a challenge. However, since many operators also publish annual reports with the same data, but presented with lower granularity, the data has to a large extent been compared to those sources, which are verified through corporate audit review. Operators that reported their detailed data were promised anonymity. Through this, data gaps were avoided, and access was given to data sets that would otherwise have remained internal.

See Figure III.3.



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Reference: [b-Malmodin 2018c]

Figure III.3 – Distribution of total electricity consumption for consolidated directly reported data

III.3.3 Complementary data sources [b-Malmodin 2018b]

See Tables III.4, III.5 and III.6.

Table III.4 – Listing of telecommunication operators, data centre operators and manufacturers

Telecommunication operator	Data centre operator	Manufacturer
AT&T	Facebook	Apple
Verizon	Google	Samsung
China Mobile	Apple	Foxconn
NTT	Microsoft	HP
DT	SAP	IBM
Softbank	Accenture	Dell
Vodafone	Oracle	Sony
América Móvil	Amazon	Panasonic
China Telecom	Tencent	Huawei
Telefonica	Equinix	Intel
Orange		LG Electronics
China Unicom		Lenovo
KDDI		Cisco
British Telecom		Fujitsu
Telecom Italia		Pegatron
Telstra		Quanta Computer
BCE		China Electronics
Telenor		Canon
Vimpel com		Ericsson
Axiata		TSMC
Singtel		NEC
SK Telecom		LG Display
Bharti Airtel		Compal
Bharti Airtel		Flextronics
MTN		Micron
TRAI (10 operators, excluding Airtel)		SK Hynix
		TI
		Innolux
		AUO
		BEO
		JDI
Totals		
36	10	31

Table III.5 – Key data sources in summary

Data centres (DCs) All use of servers from "in closets" to "hyper scale" DCs	This study relies on [b-Koomey] and other studies in the US [b-Shehabi] plus [b-IEA Digitalization]. Reported data from ICT companies cover about 15% of final estimated electricity consumption.
ICT networks PSTN (telephony), mobile networks, fixed networks	Detailed data from a new report [b-Malmodin 2018c] that covers about 40% of mobile and about 15% of fixed subscriptions globally. High-level data for about 70% of all subscriptions have also been collected in this study.
Enterprise networks (reported with data centres)	Enterprise networks estimated based on average network ports [b-Shehabi] and experience of operating large "Intranets".
Data centres	To avoid double accounting, ICT network operator and ICT and E&M manufacturer data centres have been fully allocated to "Data centres".
Enterprise networks and office devices	Network operator and equipment manufacturer own networks and devices included in their reported totals, except for personal user devices.
Cable TV networks	A share for fixed broadband over cable TV have been allocated to ICT network operations.
User devices	
Gartner Smartphones, other mobile phones, tablets, laptop PCs, desktop PCs	[b-Gartner]
IDC Smartphones, other mobile phones, tablets, laptop PCs, desktop PCs, wearables, servers, hardcopy devices	*Worldwide quarterly mobile phone tracker* [b-IDC 37] *Worldwide quarterly personal computing device tracker* [b-IDC 1541] *Worldwide quarterly wearable device tracker* [b-IDC 962] *Worldwide quarterly server tracker* [b-IDC 7] *Worldwide quarterly hardcopy peripherals tracker* [b-IDC 3]
OMDIA[a] Computer displays, public displays, surveillance cameras, automotive (all display products)	Desktop monitor market tracker [b-OMDIA 2020c] Public display market tracker [b-OMDIA 2020d] Security technology [b-OMDIA 2020e] Small and Medium Display Market Tracker [b-OMDIA 2020f]
Future source CPE (modems, gateways), computer peripherals, set-top boxes (STBs), digital versatile disc/Blu-ray disc (DVD/BD) players, media players, home audio systems, portable media players, headphones, cameras	[b-Future Source] is one of the leading analysts for not only audio and camera products, but also CPEs (gateways, modems, etc.), STBs and projectors, as well as optical and electronic media (discs, memory sticks or cards, printer consumables), See also: [b-Koenig]
Jon Peddie Research (JPR) Camcorders, game consoles, portable game consoles, arcade game machines	[b-JPR2014]
[a]Successor company to HIS.	

Table III.6 – ICT subscriptions globally and other key data

ICT subscriptions (millions)	2015[a]	Data sources
Fixed telephony (voice)	1 070	[b-ITU 2005–2019]
Additional VoIP subscriptions	~250	[b-ITU 2005–2019]
Mobile subscriptions	7 110	[b-ITU 2005–2019]
of which is mobile broadband	2 950	[b-ITU 2005–2019]
Additional M2M (IoT) subscriptions	350	[b-GSMA]
Fixed broadband (lines)	775	[b-ITU 2005–2019]
Of which is FTTH/FTTB	160	[b-ITU 2005–2019]
Of which is cable-TV	150	[b-DTVR]
ICT total subscriptions (not including M2M subs)	8 955	
Other global key data	2 015	
Data traffic (EB)	910	[b-Cisco]
Smartphone share of data traffic (%)	~10	[b-Cisco]
Electricity consumption (TWh)	21 000	[b-Enerdata]
Energy-related CO_2 emissions (Mt CO_2)	32 300	[b-IEA Fuel]
Carbon footprint (Mt CO_2e)	53 400	[b-Olivier]
[a]Subscription numbers are counted at mid-year, not end-of-year.		

Appendix IV

ICT sector trajectories for 1.5°C

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

This appendix explores opportunities for the ICT sector to develop in line with a 1.5°C scenario, taking into account the historical development and footprint of the sector based on reported data from around 100 ICT companies and knowledge about the parameters that drive electricity consumption. The purpose of the trajectory is to explore the ability of ICTs to reduce their emissions in line with an average P2 decline or faster.

This trajectory thus starts from the different parameters that impact energy consumption and hence GHG emissions and tries to anticipate their overall effect on the future development of the overall sector footprint and energy usage. With all the complexities of the sector, such an approach could capture effects that elude a single intensity metric.

To illustrate the complexity of the ICT sector footprint in the case of wireless networks, a wireless network consists of radio base station sites of various ages, access standards support and configurations. At a site level, energy consumption is decided not only by Moore´s law and processor capacity, but also attenuation by analogue filters and losses in power or antenna cables, signal treatment algorithms like schedulers, the efficiency of radio amplifier circuitry, overall site configuration including efficiency of alternating current (AC) to DC and DC to DC transformers, cooling equipment and its adaptation. Historically, radio base station products have been optimized more on low latency, capacity and speed than on energy consumption, but software layer features are nowadays available to put the equipment in sleep mode during shorter or longer pauses in operation to save energy. However, different operators use such features to a varying extent. At a network level, the number of base stations and the output power needed for coverage and capacity depends on cell planning, which in turn depends on factors such as topologies, frequency and compromises between energy consumption and other performance indicators. At top level, operators may combine various systems in different ways, e.g., by phasing out an older system when a new one is launched.

Thus, to consider only one of these aspects is not sufficient to understand how network energy consumption might evolve – and to model all of them would create a very complex model. This is the reason why focusing on macro trends related to network development and energy consumption gives a more comprehensive assessment.

The importance of energy cost should also be mentioned. In an industry where end-consumers are accustomed to getting more and more capabilities for the same amount of money, together with competition and expected increase in energy prices in the long run, there are economic restrictions that determine how energy consumption might evolve in the future. The cost aspect with regards to investment also restricts how fast a global trajectory might change.

The trajectory is described in a step-wise procedure as follows.

- **ICT´s own development (step 1)**: The development of the ICT sector footprint is estimated with the grid emission factor and renewables held fixed at 2015 levels (as described in Appendix III). The intention of this step is to show the changes related to the ICT sector itself (see clause IV.1).
- **ICT and grid development (step 2)**: The development of the ICT sector is estimated with renewables held at 2015 levels, but with the grid developing in accordance with the chosen 1.5°C scenario (see clause IV.2).
- **ICT and grid development plus additional purchase of renewables (step 3)**: The development of the ICT sector and its additional capacity are estimated to purchase or invest

in renewables and with the grid developing in accordance with the chosen 1.5°C scenario (see clause IV.3).

For each step, two sets of values are derived. The first includes scope 1-2 emissions of electricity in line with company accounting principles (perspective A), and the second also includes the value chain emissions of the electricity and distribution losses of the grid to reflect the full footprint of the sector (perspective B).

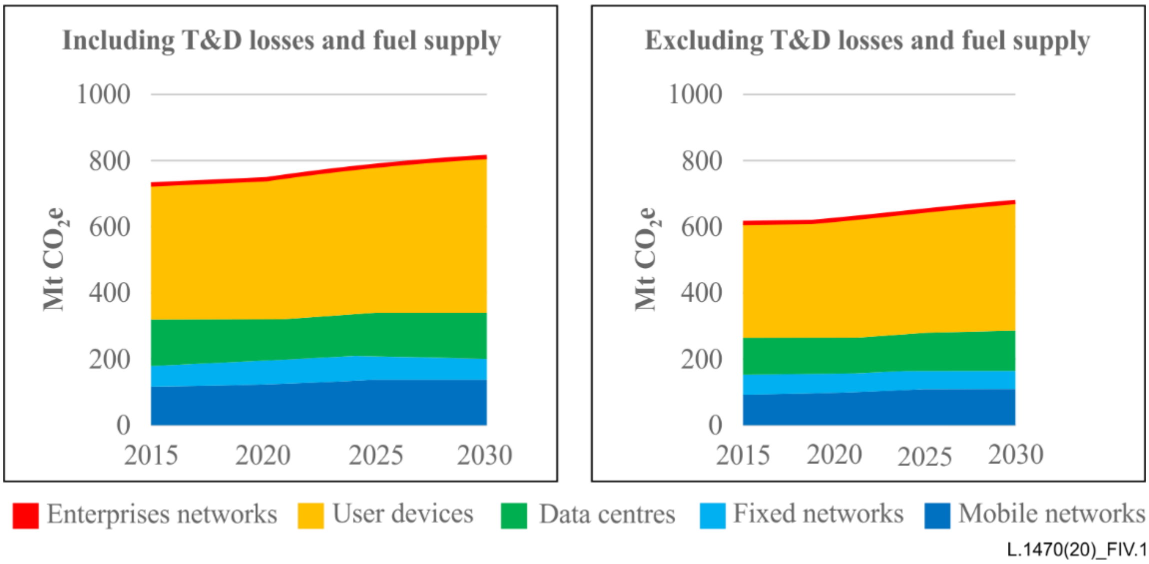
IV.1 Step 1: ICT´s own development

The starting point for this scenario is current and historical trends for operation and other life cycle stages for the different parts of the ICT sector based on data for 2007, 2010 and 2015 as described in [b-Malmodin 2010], [b-Malmodin 2013], [b-Malmodin 2018a] and [b-Malmodin 2018c].

This clause describes the approach undertaken when exploring the 1.5˚C scenario for the ICT sector. The overall assessment approach used for the sector is the same as for the baseline described in Appendix III. Thus, this clause only describes specific assumptions or deviations.

NOTE – This first step does not include any improvements in the power sector or the possibility to reduce emissions by additional purchases or investments in renewables. This means that the emission factors for grid electricity are in line with those used for the baseline. See Appendix III.

Figure IV.1 summarizes the sub-sector trajectories described in clauses IV.1.1 to IV.1.5.



a) b)

Figure IV.1 – ICT sector carbon footprint development 2015–2030 with constant grid emission factor: a) includes grid supply chain and distribution losses (perspective A); b) excludes grid supply chain and distribution losses (perspective B).

IV.1.1 Mobile networks

IV.1.1.1 Boundaries

The boundaries are defined in accordance with Annex A of [ITU-T L.1450]:

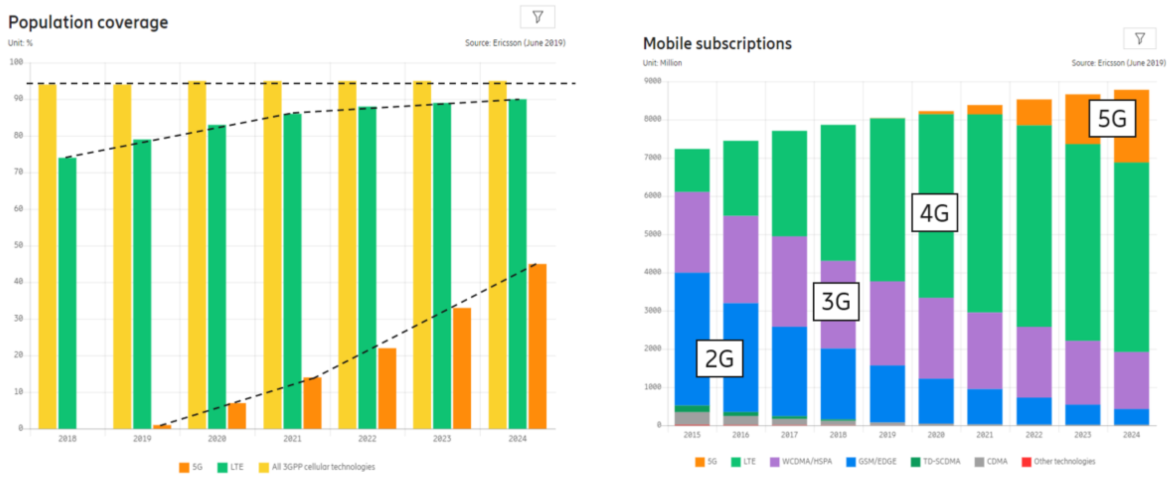
- this subcategory includes wireless access network goods and mobile core goods. (item 2) of the first list in clause A.3 of [ITU-T L.1450]);
- it further includes support goods;
- operator support activities are included and shown separately;
- operator data centres are excluded as they have been allocated to the sub-sector data centres;

- the boundary towards wireline networks is drawn after mobile core, all common network functions are allocated to fixed networks;
- end-user goods owned by operators are not included in this sub-sector, as they have been allocated to end-user goods.

IV.1.1.2 Activity level

The future development of the sector starts from the forecasts of [b-Ericsson MR 2019], an annual report first published 2016, which provides projections and analyses of the latest trends in the mobile industry, including subscription, mobile data traffic and population coverage. The forecasts are based on past and current data and validated with extensive network measurements.

Figure IV.2 shows how different mobile networks are expected to develop until 2024 with regards to population coverage and number of subscriptions per access standard (2G to 5G).



a) **b)**

Source: visualization of [b-Ericsson MR 2019].

Figure IV.2 – a) Population coverage 2018–2024 and b) subscription forecasts and trends 2015–2024

- Development in number of subscriptions is based on [b-Ericsson MR 2019] according to Figure IV.1 until 2024, and extrapolated thereafter.
- Number of subscriptions refers to the number of current subscriber identity module (SIM) cards, excluding M2M.
- However, M2M electricity consumption is considered in the footprint energy values.
- Number of subscribers is related to billing and is less relevant as a metric because the relationship to usage is less straight forward.
- Historic geographical distribution is considered in accordance with development seen from 1995 in previous studies [b-Malmodin 2018a].
- The main factors impacting activity level forward will be 5G deployment, 4G development, removal of old equipment, growth in population and expansion of IoT.

NOTE – Between1995 and 2015, Internet data traffic grew 1 million times, while subscriptions grew 10 times; energy and CO_2e grew about 3 times [b-Malmodin 2018c]. By 2030, mobile data traffic is expected to increase 60–140 times.

IV.1.1.3 Electricity usage

In summary, the footprint of mobile operation is expected to increase somewhat until 2023, mainly because of the ongoing establishment of 5G. However, usage of 2G or 3G networks is assumed to decline.

Neither Appendix III nor [b-Malmodin 2018a] present electricity numbers allocated to 2G, 3G, 4G and 5G separately. However, as these access technologies are in different stages of their technology life cycle, it would be important to do so to understand how the overall mobile networks could develop over the coming decade.

NOTE – Potentially 6G could enter the scene before 2030, but as it has not yet been defined, it cannot be included in the scenario and is anyway believed to have only a limited impact on the sub-sector footprint by 2030.

Overall historical energy consumption was based on estimates for 2007, 2010 and 2015 from [b-Malmodin 2010], [b-Malmodin 2013], [b-Malmodin 2018a] and [b-Malmodin 2018c], and the values include both grid electricity and company electricity generation (diesel, etc.). In addition, development until 2019 was estimated using the same data sources and method. The historical development of overall subscriptions was based on [b-ITU 2005–2019] data for specific years and energy performance is assumed to continue to develop in line with past history.

To allocate overall energy usage to the different access technologies, the historical footprints for 2007, 2010 and 2015 based on [b-Malmodin 2010], [b-Malmodin 2013], [b-Malmodin 2018a] and [b-Malmodin 2018c] were combined with historical sales statistics of Ericsson and its historical estimated market shares to arrive at an energy usage allocation between the different access standards of the installed base year-by-year.

See Figure IV.3.

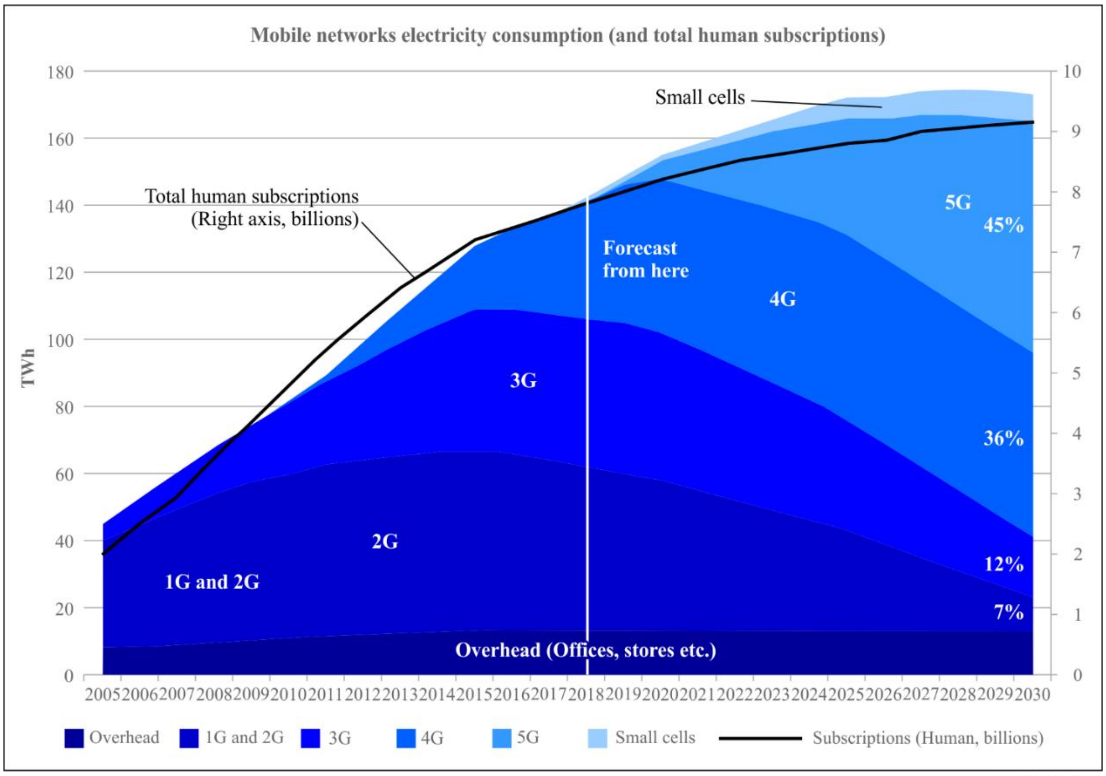


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Figure IV.3 – Mobile networks electricity consumption allocated to 2G, 3G, 4G and 5G

This scenario assumes that the majority of operators in the USA, Europe and China decommission their 2G equipment by 2030, so that only 20% of 2G electricity consumption remains. This is a lagged version of the anticipated development of subscriptions, as it is based on [b-Ericsson MR 2019] and extrapolated between 2024 and 2030. The lag is due to the assumption that networks are decommissioned with some delay compared to the reduction in number of subscriptions.

For 3G, the scenario considers decommissioning in line with every second 3G site in the USA, Europe and China – in some markets 3G is actually decommissioned as fast as 2G, but this scenario more conservatively reflects a slower development.

4G is expected to grow until 2025 and then remain flat (in line with [b-Ericsson MR 2019] until 2024, see Figure IV.1).

Any further densification is assumed to be counteracted by the modernization of old equipment.

5G is assumed to grow until 2030, and in the end consume almost 30% more electricity than any former standard. Future estimates of 5G energy consumption stretch from 50% (Ericsson estimate) of 4G, to 200% (Orange estimate) of 4G –130% has been chosen in this scenario as reasonable trade off.

This scenario outlines one potential development that, together with decarbonization of the ES, supports a 1.5°C trajectory. In reality, a 1.5°C trajectory can be implemented in different ways. Another way to reach the same development for the energy usage would be a combination of decommissioning and modernization measures, such as the use of multi-standard base-stations, increased usage of power-saving features or more aggressive decommissioning of older systems.

NOTE –Decommissioning of 2G and 3G has already been announced by many operators, see, for example, [b-Olivia], [b-Telia], [b-IEEE Com Soc] and [b-Comms Update].

IV.1.1.4 Overhead

Offices, stores and travel are assumed to remain at the same level. Some growth in number of subscriptions is expected, but this is likely to be counteracted by efficiency and automation measures to keep down costs and online purchases impacting number of shops. As overheads are a small share of the overall footprint, this has not been modelled in detail in this scenario.

IV.1.1.5 Embodied emissions

- Embodied emissions are calculated to remain at 2 kg CO_2e/subscription and year based on [b-Malmodin 2018a], [b-Malmodin 2018b] in line with clause III.2.2.
- Overall the emissions related to manufacturing of mobile network equipment is expected to increase somewhat as 5G is rolled out. However, new access technologies often reuse existing sites, leading to a lower environmental impact compared to building a new site. Building on a used site results in about two-thirds of emissions of building a new site. The site factor depends on the assumed usage time. Here the site operation time is estimated to be 20 years.

IV.1.1.6 Resulting trajectory (mobile network development without further use of renewables)

See Figure IV.4.

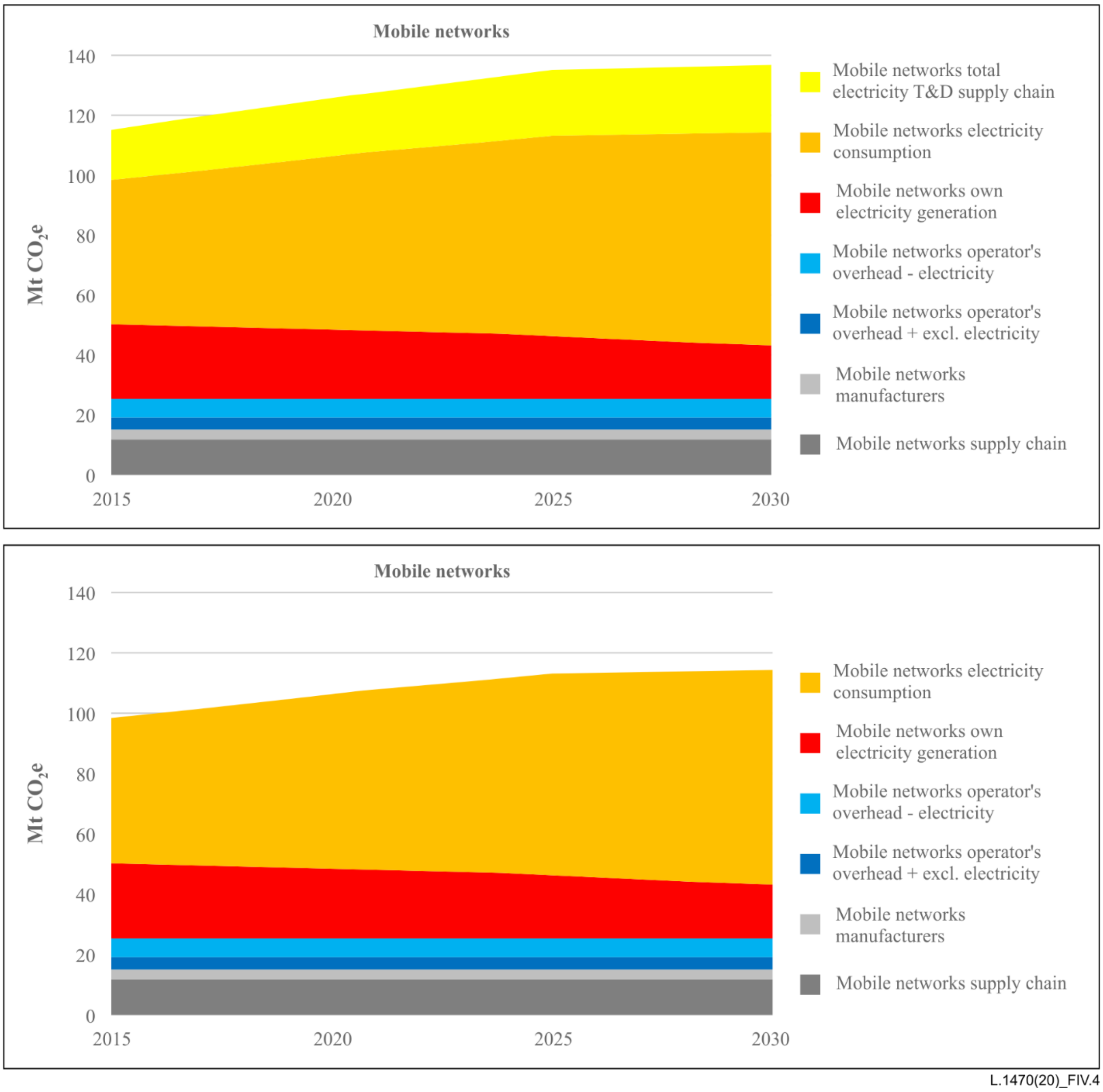


Figure IV.4 – Mobile network footprint 2015–2020 (with unchanged grid emission factor)

IV.1.2 Fixed networks

IV.1.2.1 Boundaries

The boundaries are defined in accordance with Annex A of [ITU-T L.1450]:

- wireline networks include first list items 1), 3), 5) and 6) of clause A.3 of [ITU-T L.1450];
- it further includes support goods (second list items 1), 2) and 3) of clause A.3 of [ITU-T L.1450]);
- operator support activities are included and shown separately;
- operator data centres are excluded as they have been allocated to data centres;
- boundary towards wireless networks made after mobile core, and all common network functions are allocated to the fixed networks sub-sector;
- end-user goods owned by operators have been allocated to the category end-user goods.

IV.1.2.2 Activity level

- Number of subscriptions refers to number of lines.

- This includes compound telephony and fixed broadband (VoIP excluded, although included in energy and carbon).
- Sources: [b-ITU 2005–2019] data to 2018, trajectories to 2022–23 from [b-OMDIA 2020b], after that an extrapolation was made.
- Historical geographical distribution is considered in accordance with developments seen from 1995 in previous studies [b-Malmodin 2018b].
- Development between 2015 and 2030 is expected to go from 1.85 billion to 1.9 billion subscriptions as fixed telephony subscription are assumed to decrease by 50% and fixed broadband subscriptions to increase by a factor of 1.8.
- Fixed data traffic is expected to increase 18–36 times.

IV.1.2.3 Electricity usage

For fixed networks, it is assumed that the kilowatt hour per subscription (line) value will stay flat in line with the current trend. Historical development has been associated with increased capacity per line with maintained electricity consumption.

Current electricity usage according to [b-Malmodin 2018b] for reference:

- older modem + router setup: 15–20 W;
- fixed access node: 3 W (1–5 W);
- media converter: 3 W (1–5 W);
- new gateway: 10–15 W;
- Swedish transmission/transport: 1.5 W per fixed BB (allocated)
- Swedish core network: about 1 W per fixed BB (allocated);
- CPE dominates electricity: 15 W (10–30 W);
- network is about 5 W on average and only about 1 W in the core varies slightly with data.

As the kilowatt hour per line value is assumed to stay flat, the changes in overall electricity usage is based on the expected change in number of subscriptions.

Historical development has been tracked based on [b-ITU 2005–2019] data and the trends have been extrapolated.

The future trend for broadband connections considers [b-Point Topic], which has estimated that there will be 1.1 billion broadband connections in 2022 and 1.2 billion in 2025. As their historical values are lower than those of [b-ITU 2005–2019], 1.3 billion in 2025 and 1.4 billion in 2030 have been assumed.

The assumed decommissioning of traditional telephony (PSTN) assumes an extrapolation of the current trend, where a decline is seen in mature markets – a development which is expected to expand in the future.

See Figure IV.5.

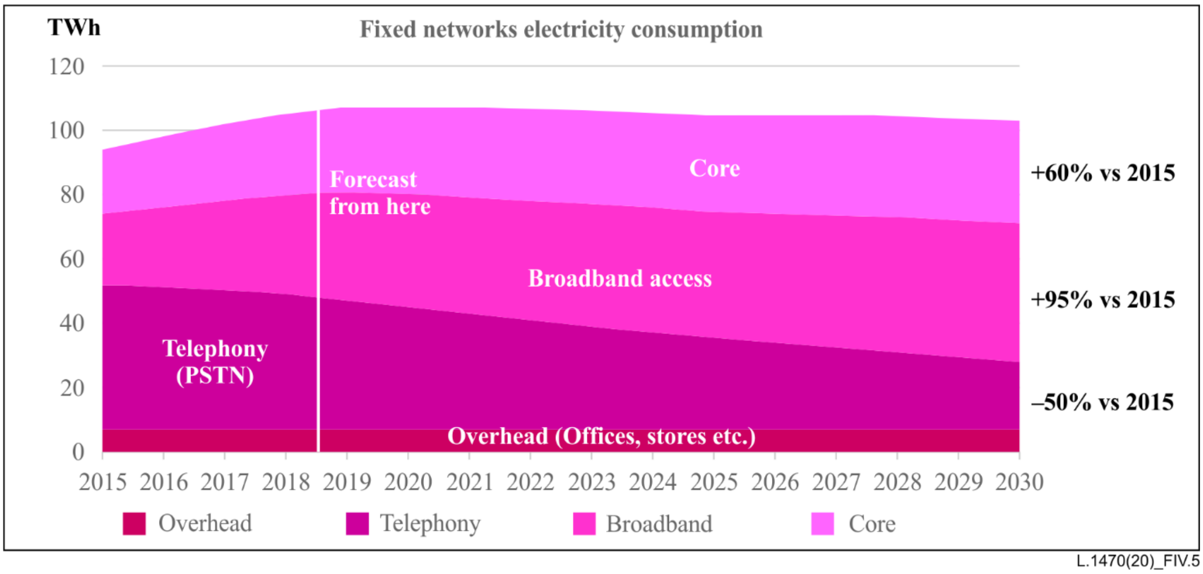


Figure IV.5 – Fixed networks electricity consumption

In summary, the overall fixed access footprint is expected to decrease as the old PSTN, which is a more energy intensive system, is used less. In fact, an old telephony line consumes as much as a modern fixed broadband connection [b-Malmodin 2018c].

In addition to access networks, the fixed network sub-sector also includes core, transport and transmission equipment. In Sweden, a highly ICT mature country, the core network represents only about 6% of the ICT footprint, while core, transmission and transport networks together make up 15% [b-Malmodin, Lundén 2016].

The fixed networks have been designed to be on all the time and the load (data) adaptation is limited. However, the core network footprint (6% of the ICT footprint) to some extent correlates with the amount of data used, but this has only a minor impact on the fixed network footprint.

IV.1.2.4 Embodied emissions

Calculated as 4kg CO_2e/subscription and year based on [b-Malmodin 2018a].

Overall manufacturing is expected to decrease.

IV.1.2.5 Resulting trajectory (ICT development without further use of renewables)

See Figure IV.6.

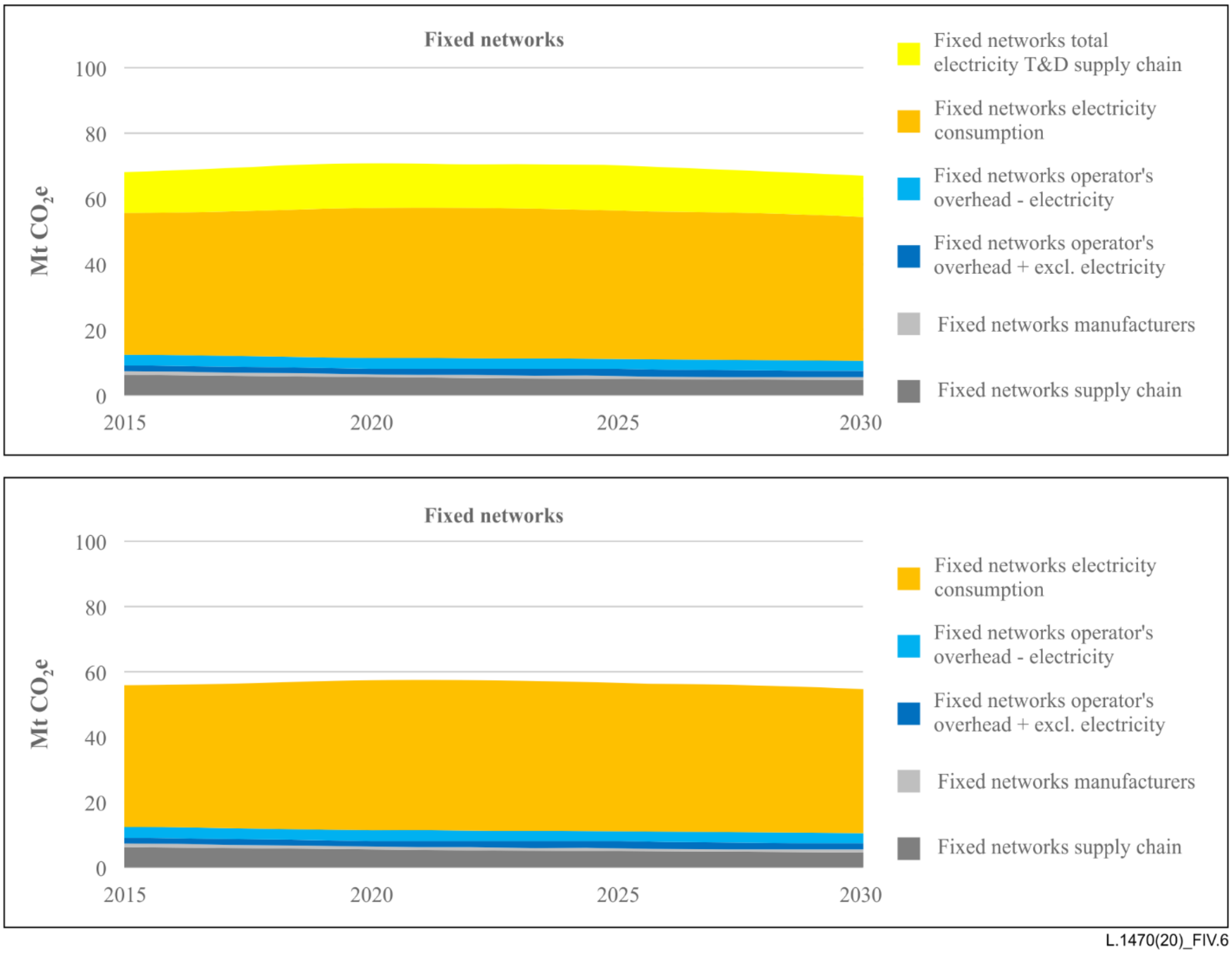


Figure IV.6 – Fixed network footprint 2015–2030 (with unchanged grid emission factor)

IV.1.3 Data centre

IV.1.3.1 Boundaries

- In line with Annex A of [ITU-T L.1450], this category includes all data centres – from "in closets" to hyperscale – but excludes enterprise networks, which are assigned to a separate category.
- Operator support activities are included as separate categories.
- ICT network operators and ICT manufacturers have large data centres that are included here.

IV.1.3.2 Activity level

- The number of servers in use globally is based on [b-IDC 7] for all kinds of server models. Data exist up to 2018; from 2019, extrapolations estimate the number of servers will increase from 43 million to 55 million between 2015 and 2030.
- The amount of data or subscriptions differ by many orders of magnitude between different data centres and are therefore not used to estimate future electricity usage.
- Actual sales statistics reflect regional variations in server types in line with the baseline.
- Data traffic is assumed to increase 18–36 times.

IV.1.3.3 Electricity usage

Existing trends that impact electricity usage include consolidation, virtualization, hardware development, cloudification and PUE development.

[b-IEA Digitalization] assumes 3% electricity growth for data centre electricity usage globally yearly 2014–2021.

The typical electricity consumption per unit is expected to remain quite flat as capacity per unit increases. At the same time, PUE is assumed to decrease. According to IEA, PUE = 1.8 for 2015, and Intel has estimated a value of 1.7 for 2019. Due to cloudification, we assume 1.6 for 2020 and 1.4 for 2030.

Moreover, it is assumed that shipping of high-performance servers will increase, but shipping of volume servers is assumed to decline. [b-Cisco] and [b-IDC 7] estimate that in 2030, around 90% of data will be handled by less than 1 000 data centres worldwide.

Weighing these trends together, a roughly flat development of overall data centre energy usage is assumed.

IV.1.3.4 Embodied emissions

- Embodied emissions are calculated as 10% of total data centre emissions from electricity usage based on [b-Google 2016a], [b-Google 2016b]. The factor includes the conversion from electricity to carbon emissions.

The resulting trajectory (ICT development without further use of renewables) is plotted in Figure IV.7.

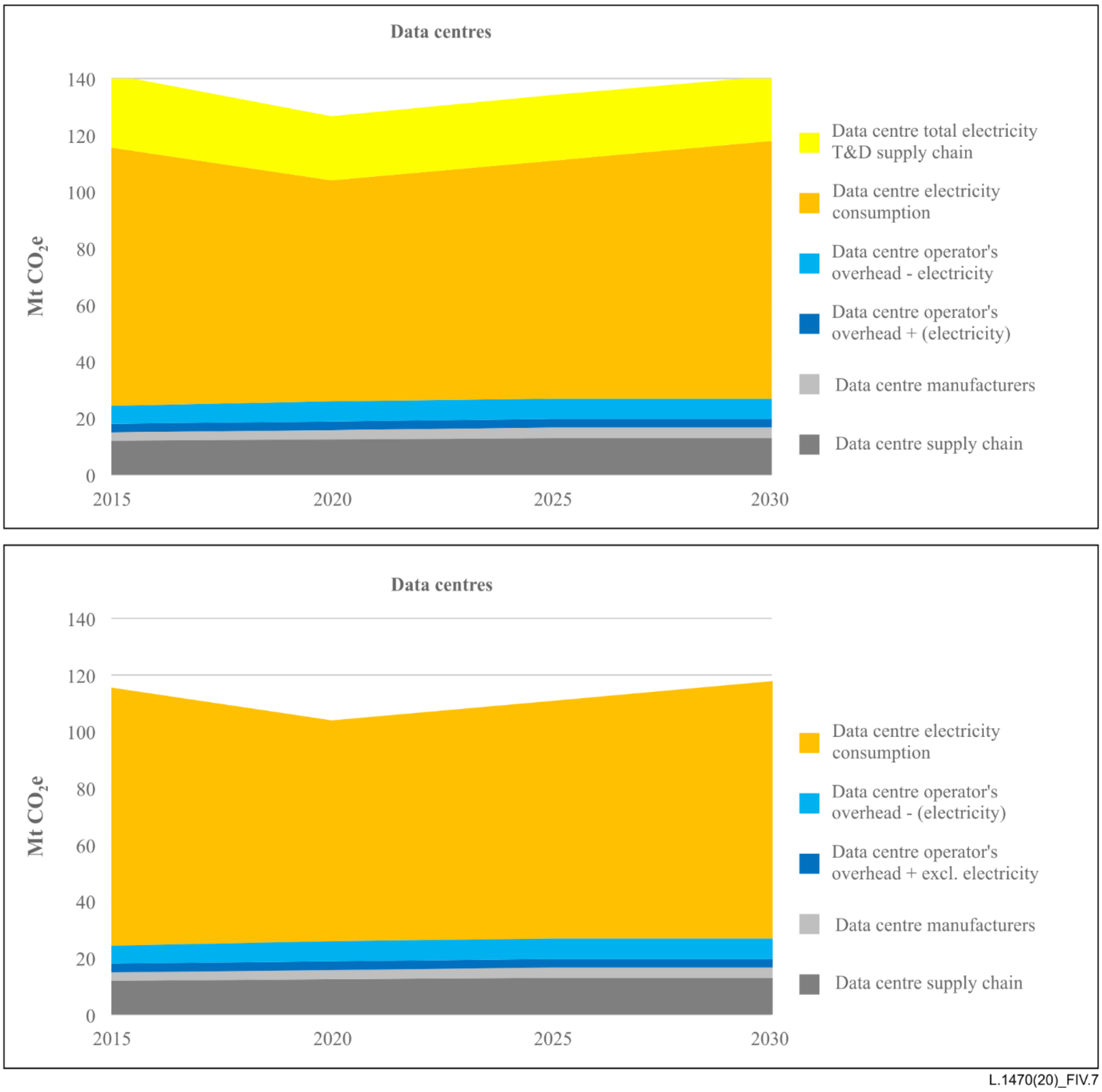


Figure IV.7 – Data centre footprint 2015–2030 (with unchanged grid emission factor)

IV.1.4 Enterprise networks

IV.1.4.1 Boundaries

- This is considered as a separate category, which includes routers and other intranet equipment.

IV.1.4.2 Activity level

- Business use of PCs is estimated from [b-IDC 1541] and [b-Gartner]. This information is combined with estimated amounts of PCs per active LAN port in accordance with [b-Malmodin 2018a].
- [b-IDC 1541] and [b-Gartner] statistics indicate that PCs for enterprise networks increased until 2015, but development thereafter is uncertain.
- Actual sales statistics reflect regional variations in server types in line with the baseline.

IV.1.4.3 Electricity usage

- Electricity usage is based on [b-Malmodin 2018a]. The historical trend has been a fast decrease of electricity need per PC per LAN port.
- An assumed small increase in active LAN-PCs correlating with more enterprise network equipment is assumed to be countered by energy efficiency improvements resulting in flat development of total electricity consumption.
- Shipment volumes are assumed to stay flat.
- Typically 0.5 W/port for high-definition (HD) video – 1 W/Gb – in total 3 W/workplace PC in line with baseline [b-Malmodin 2018 a].
- Conference equipment etc. adds approximately 1 W/PC.

IV.1.4.4 Embodied emissions

- Embodied emissions are calculated as 10% of total emissions in line with baseline. The factor includes the conversion from electricity to carbon emissions.

IV.1.4.5 Resulting trajectory (ICT development without further use of renewables)

See Figure IV.8.

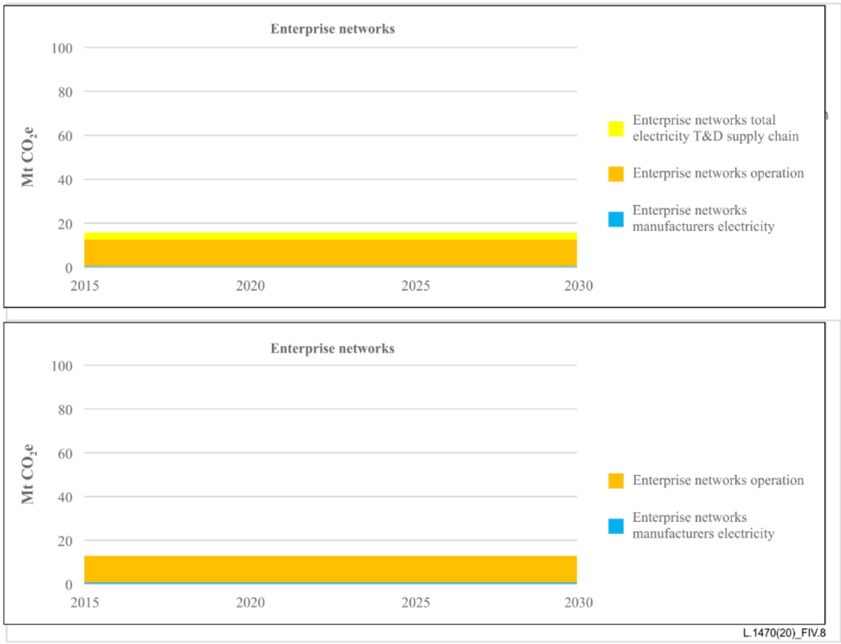


Figure IV.8 – Enterprise network footprint 2015–2030 (with unchanged grid emission factor)

IV.1.5 End-user goods

IV.1.5.1 Boundaries

- Boundaries are based on clause A.4 of [ITU-T L.1450], and includes CPE (modems, gateways), fixed phones (PSTN + VoIP), PCs (including desktops, laptops, peripherals and displays), mobile devices (including mobile phones, smartphones, tablets), M2M (including smart meters, surveillance cameras, payment terminals, projectors, public displays, wearables).
- In the next iteration of this work all IoT should be included.

IV.1.5.2 Activity levels

- It is assumed that 13 billion devices will expand to 20 billion between 2015 and 2030. This includes an increase of mobile device numbers from 7.8 billion to 10 billion, and PCs going from 1.7 billion to 1.5 billion (in 2020) and then back to 1.7 billion in 2030. M2M device numbers are according to [b-Malmodin 2018a].
- The number of actual devices in active use is estimated from sales statistics and estimated operational lifetime as described in clause III.2.5. Operational lifetime is also estimated in accordance with Appendix III.
- Sales statistics used when available (see Table III.5 for details), with extrapolations for the future.
  – Regional distribution in accordance with current sales.
  – Mobile devices scaled based on subscriptions, CPE based on number of lines.

IV.1.5.3 Electricity usage

Electricity usage is assumed to scale with sales. The following development is assumed.

- CPE: the kilowatt hour per average unit value is assumed to reduce by 35% per device in the period 2015–2030 due to efficiency improvements (based on an observed 2015–2018 reduction of 10%), which means a change from 12.4 W on average in 2015 per connected household or premises based on [b-Malmodin 2018a] to 8.1 W on average in 2030.
- Fixed phones: no energy efficiency improvements are assumed.
- PCs: lower share of desktops, energy efficiency improvements, gaming PCs have a small but growing share.
- PC (including screens): the average kilowatt hour per unit value is estimated to have reduced by 13% in the period 2015–2018 based on a further shift from desktop to laptop. For 2018–2030, no reduction per PC is assumed for each type, but any energy efficiency improvements are assumed to be used for other performance improvements.
- Mobile: a larger share of smartphones is assumed, which means that the kilowatt hour per average unit value is assumed to increase by 56% due to increased usage and larger size of mobiles.
- Other including M2M:
  - the kilowatt hour per average unit value is assumed to stay flat in line with baseline;
  - fast increase in the number of surveillance cameras to 2020 countered somewhat by energy efficiency improvements;
  - M2M after 2020 are forecast to be dominated by wearables;
  - Steady build-up of smart meters and payment terminals.

IV.1.5.4 Embodied emissions

- Current assumption is that embodied CO_2e value for all end-user devices will remain roughly constant (i.e., that embodied emissions and lifetimes are kept flat), but there is a huge potential for ICT manufacturers to also use renewables in the future as a substantial part of the embodied emissions emerge from electricity used in different processes. This potential needs to be estimated more thoroughly.

- Embodied emissions and lifetime are kept unchanged compared to the baseline

IV.1.5.5 Resulting trajectory (ICT development without further use of renewables)

See Figures IV.9 and IV.10.

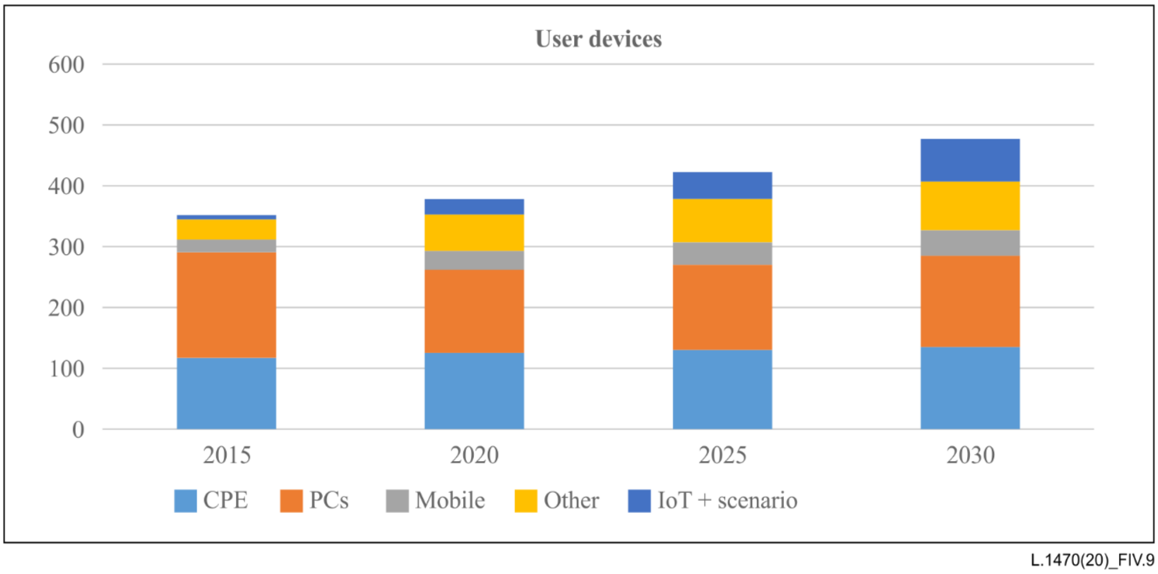


Figure IV.9 – Devices (Mt CO_2e)

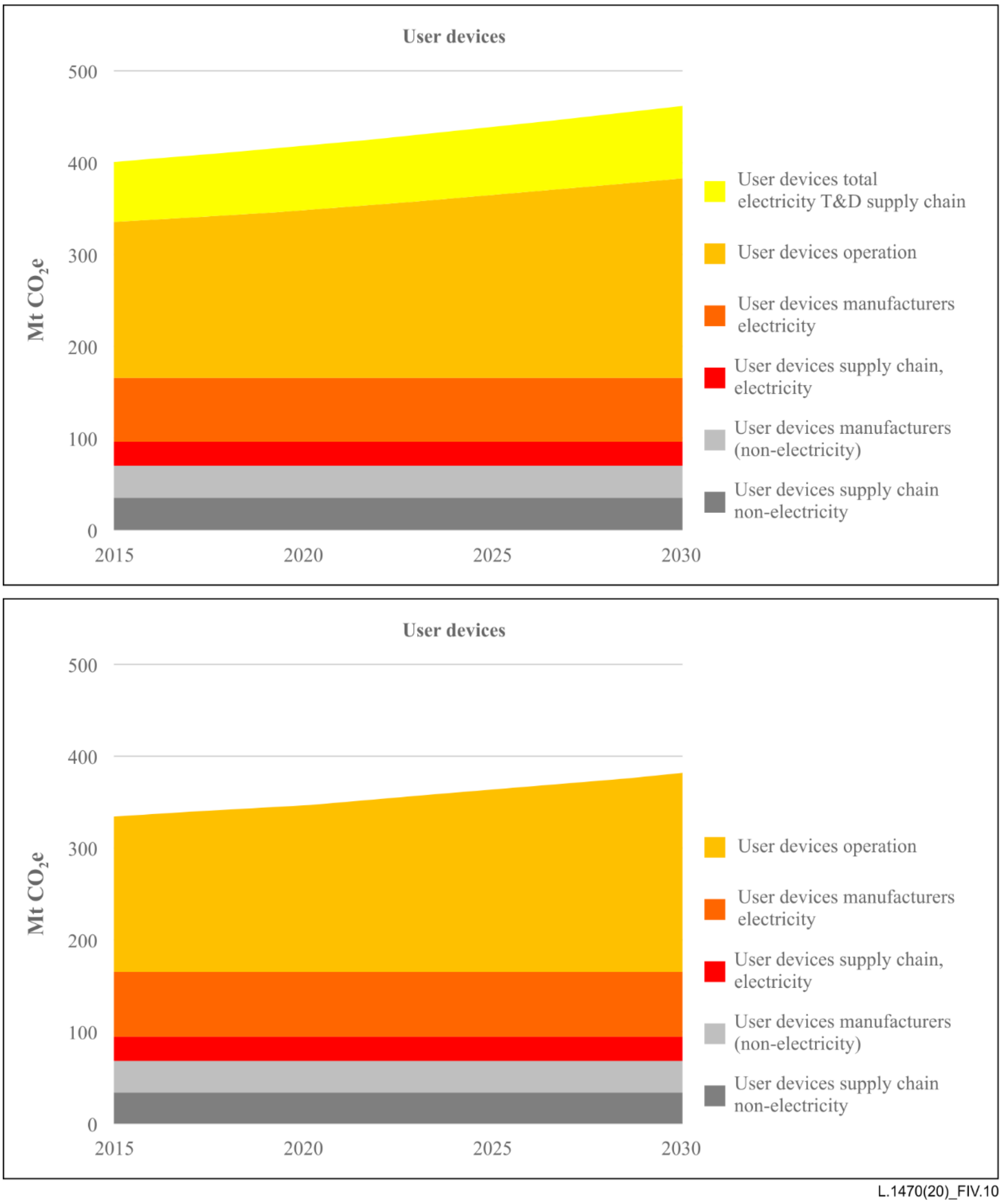


Figure IV.10 – User devices footprint 2015–2030 (with unchanged grid emission factor)

IV.2 Step 2: ICT and grid development

IV.2.1 ICT sector and sub-sector trajectories

While the focus of clause IV.1 was on the development of the ICT sector, this clause adds the development of grid electricity based on the grid trajectory for 1.5°C of the SBT initiative. For emission factors, see clause 6.3.

Figures IV.11 and IV.12 both reflect a situation where the SBT initiative trajectory is added on top of the anticipated ICT development from step 1. Figure IV.12 excludes grid ES chain and distribution losses in line with company accounting frameworks, Figure IV.11 includes them for a more holistic understanding of the footprint of the ICT sector in line with LCA practice.

See Figures IV.13 to IV.17.

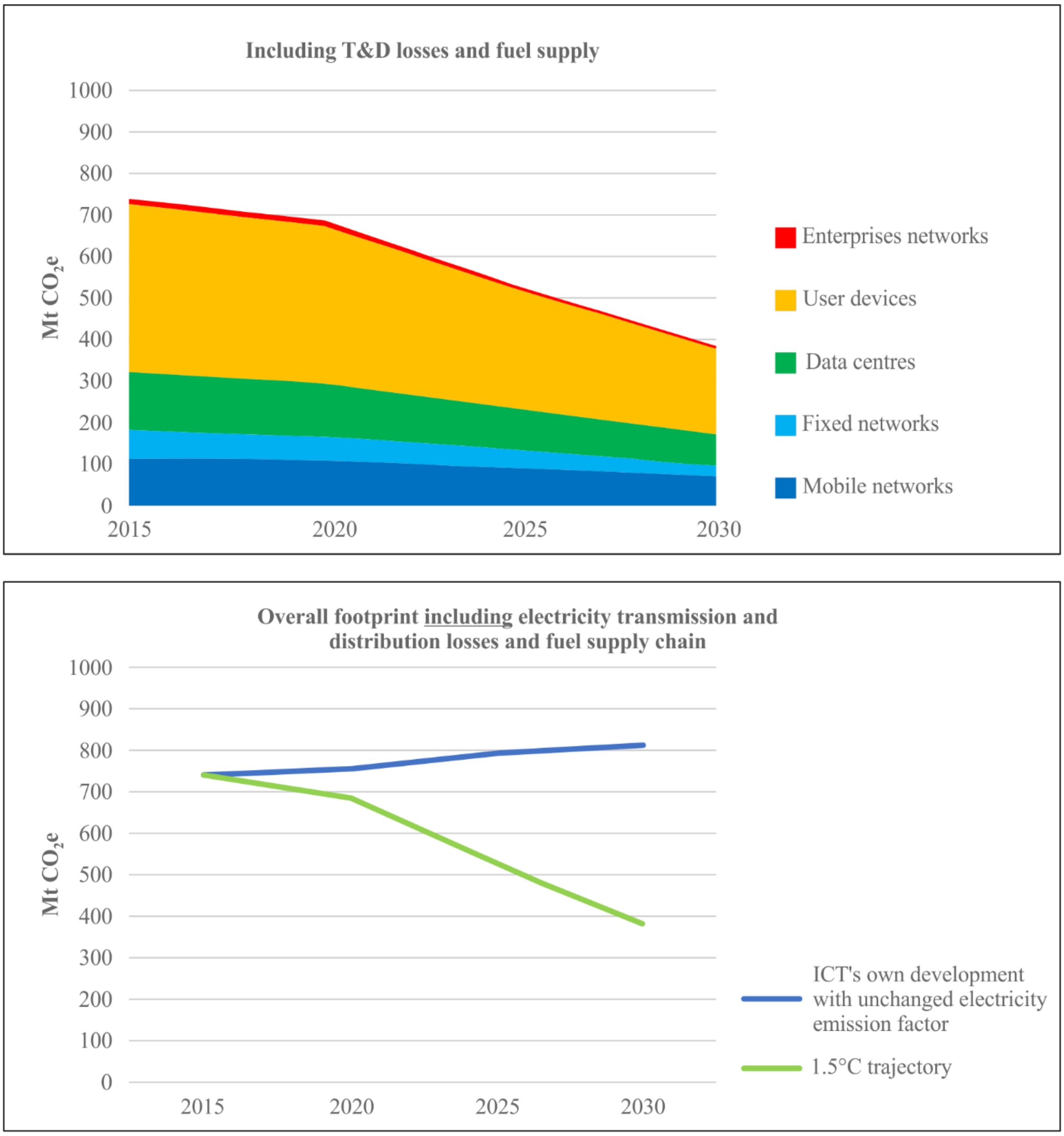


Figure IV.11 – Overall ICT sector 1.5°C trajectory for the period 2015–2030 including electricity supply chain and transmission and distribution losses (perspective A)

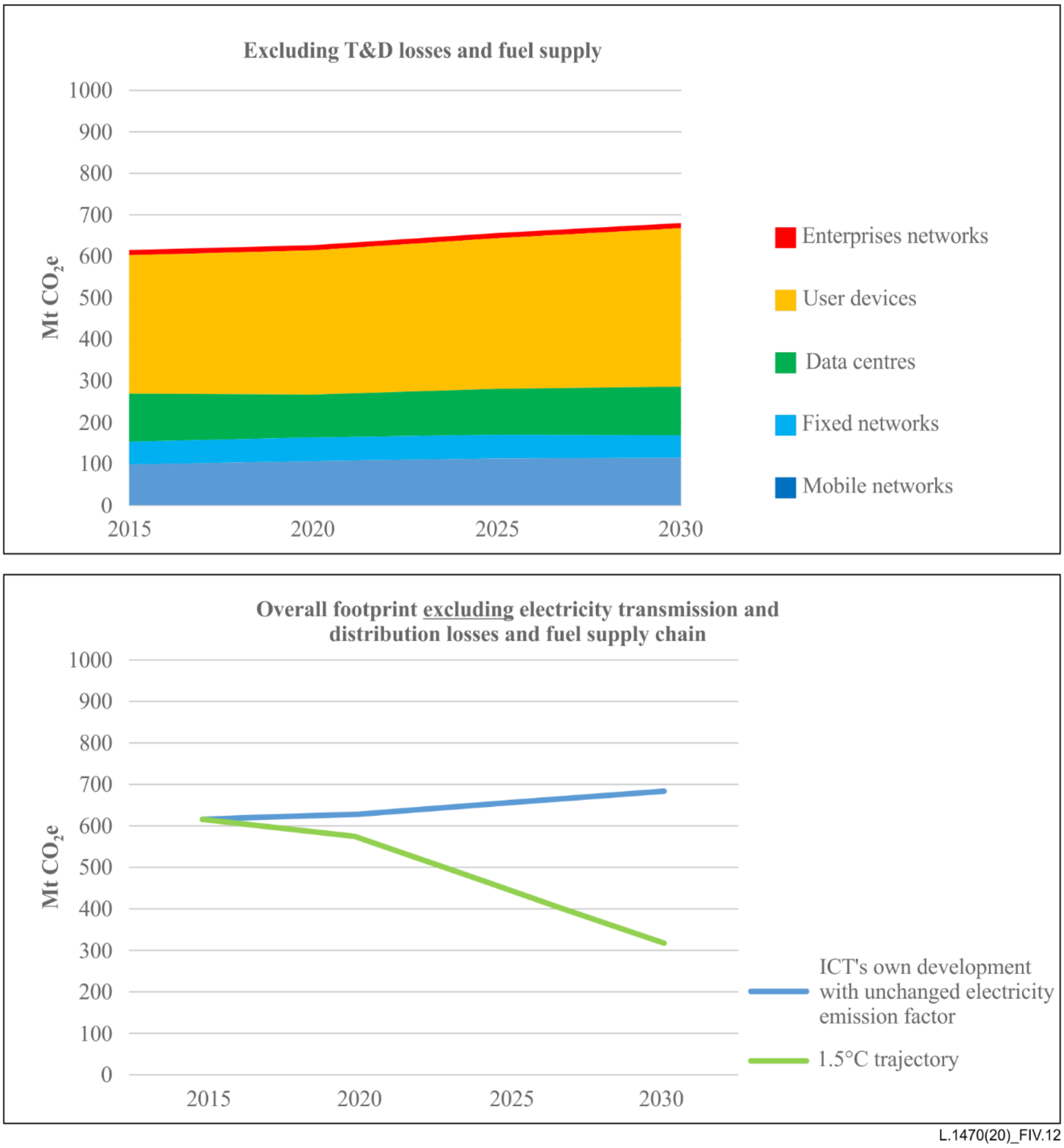


Figure IV.12 – Overall ICT sector 1.5°C trajectory, excluding electricity supply chain and transmission and distribution losses (perspective B)

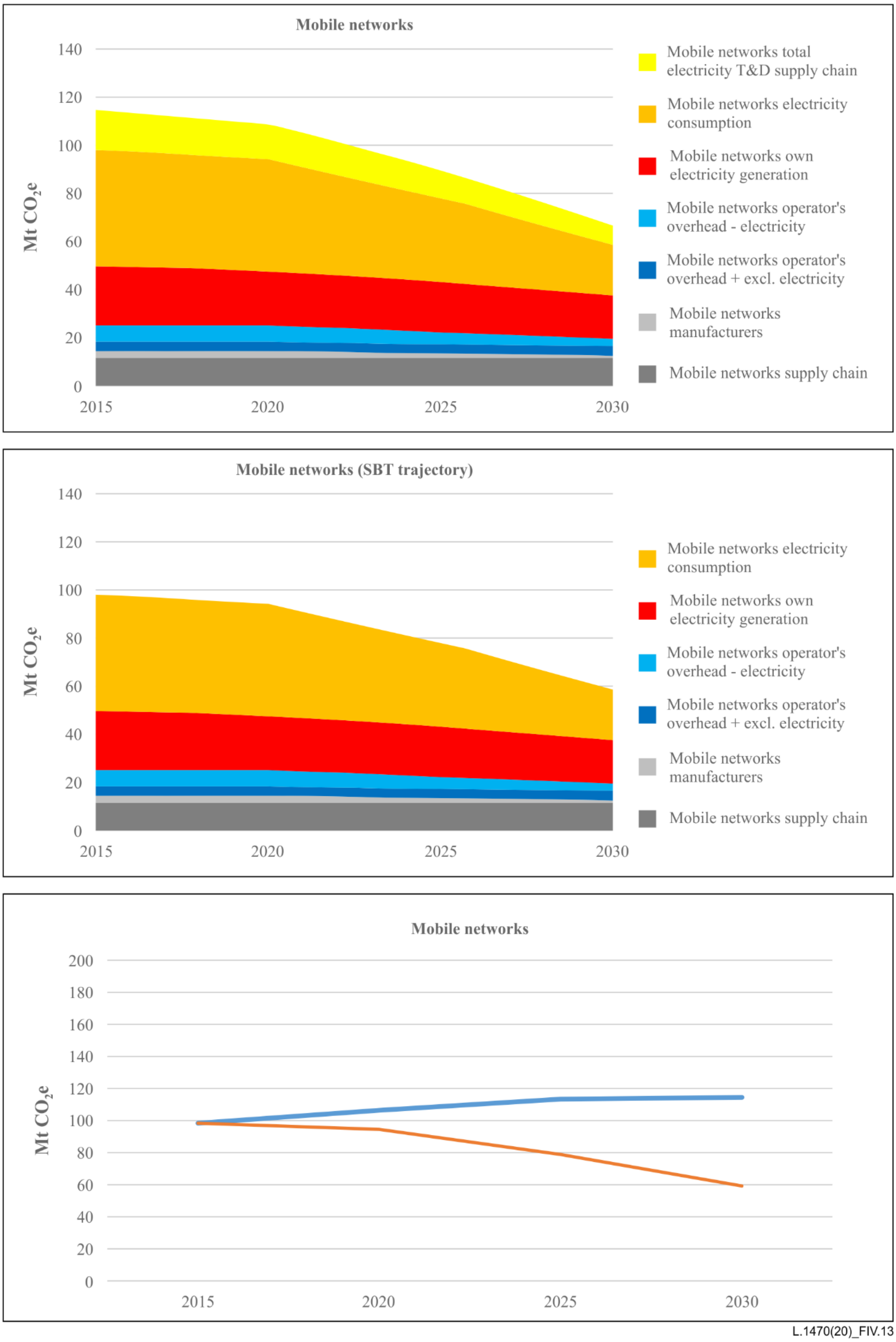
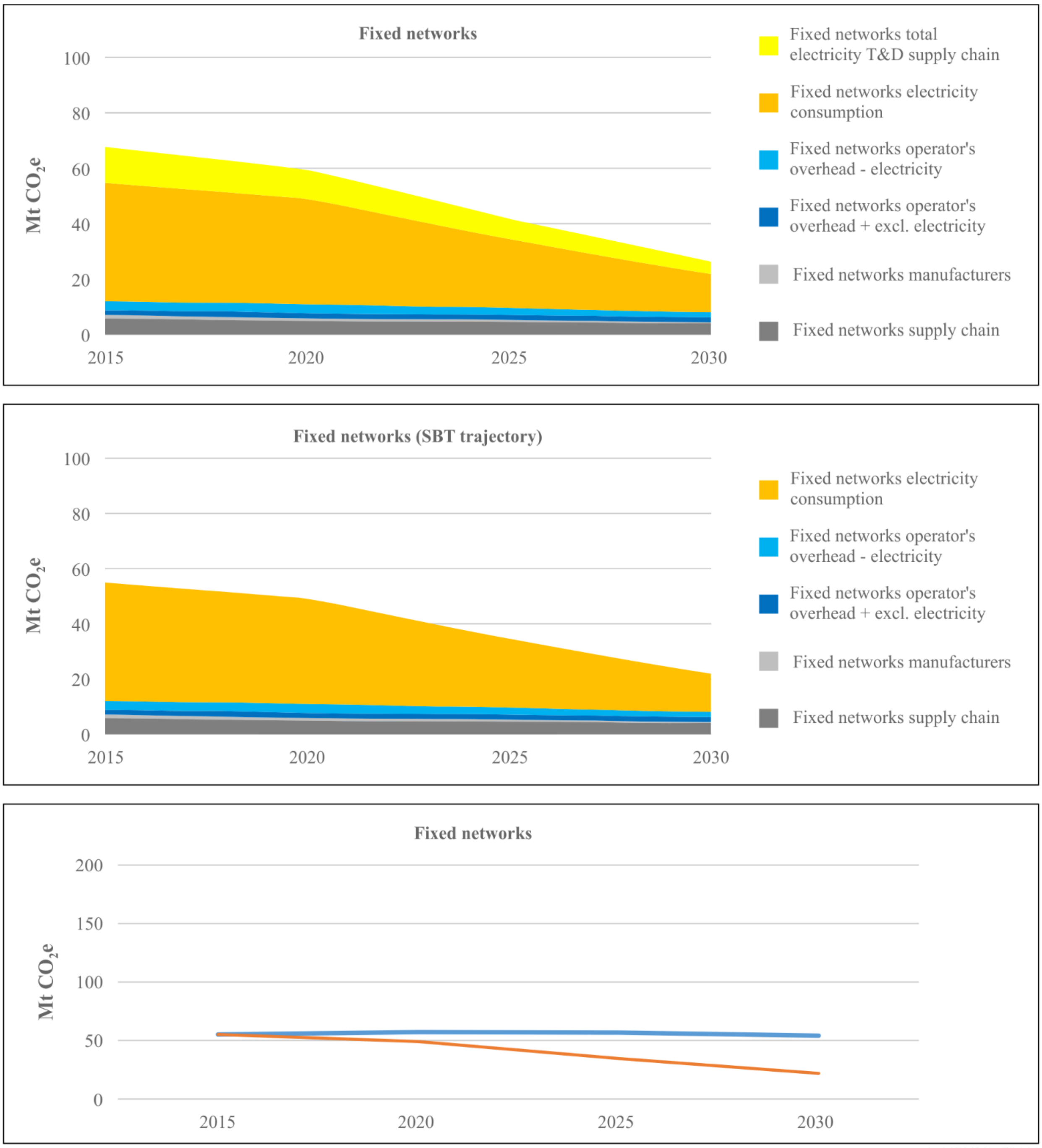


Figure IV.13 – Mobile networks 1.5°C trajectory for the period 2015–2030: a) detailed trajectory including electricity supply chain and transmission and distribution losses; b) detailed trajectory electricity supply chain and transmission and distribution losses; c) resulting 1.5°C trajectory (red line) with sector development without improvements in electricity emission factor as a reference (blue line) – perspective B



L.1470(20)_FIV.14

Figure IV.14 – Fixed networks 1.5°C trajectory for the period 2015–2030: a) detailed trajectory including electricity supply chain and transmission and distribution losses; b) detailed trajectory electricity supply chain and transmission and distribution losses; c) resulting1.5°C trajectory (red line) with sector development without improvements in electricity emission factor as a reference (blue line) – perspective B

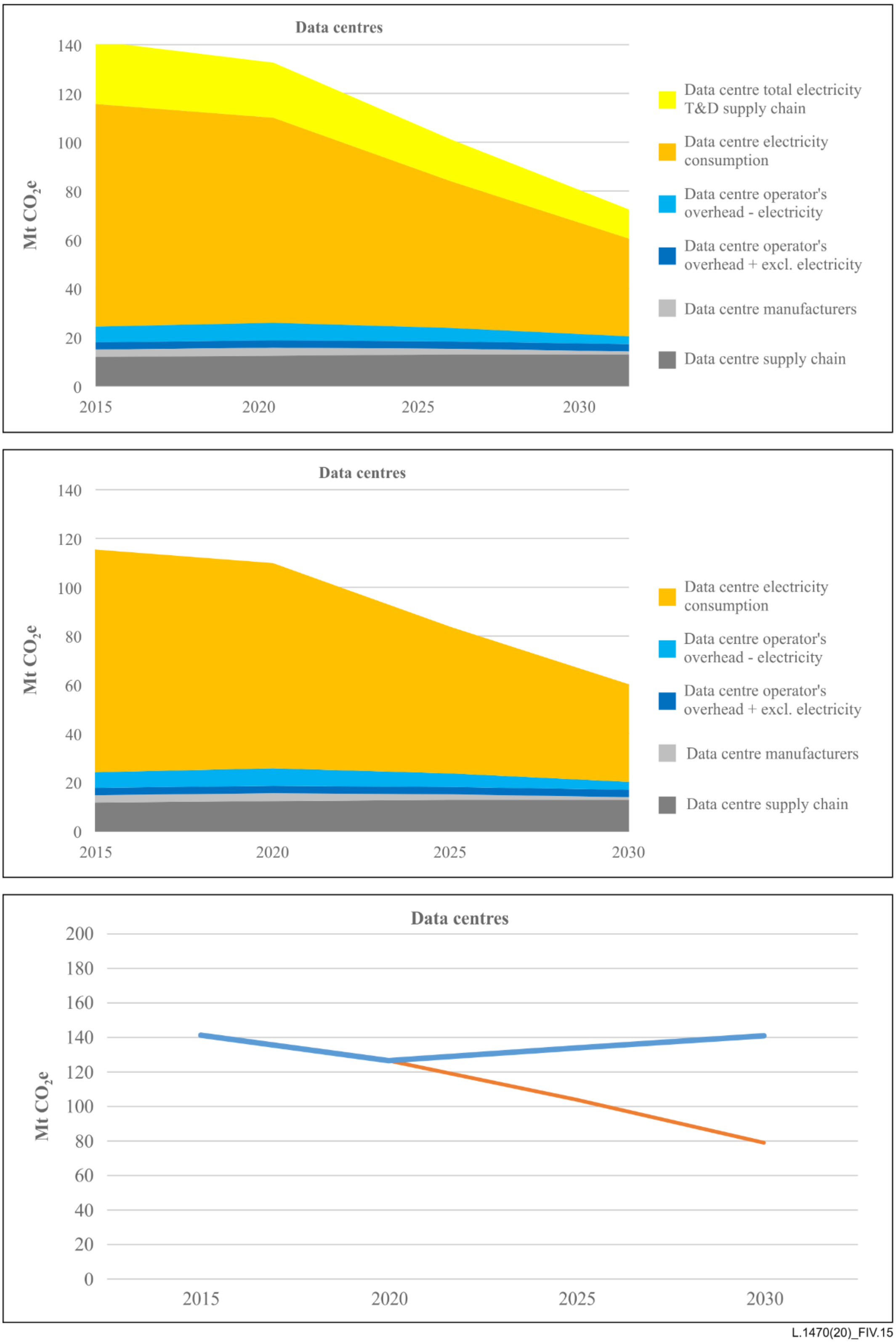
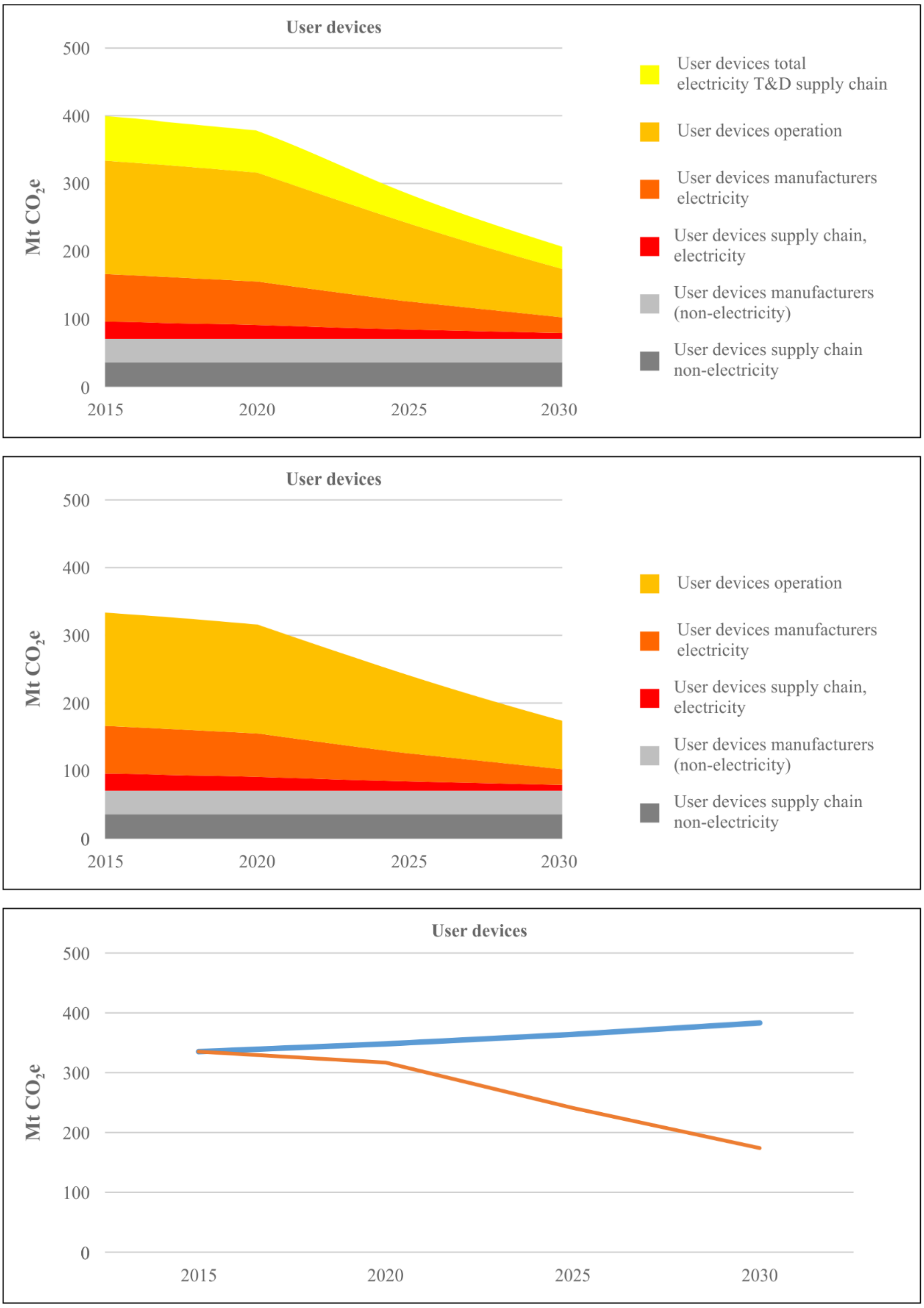


Figure IV.15 – Data centre 1.5°C trajectory for the period 2015–2030: a) detailed trajectory including electricity supply chain and transmission and distribution losses; b) detailed trajectory electricity supply chain and transmission and distribution losses; c) resulting1.5°C trajectory (red line) with sector development without improvements in electricity emission factor as a reference (blue line) – perspective B



L.1470(20)_FIV.16

Figure IV.16 – User devices 1.5°C trajectory for the period 2015–2030: a) detailed trajectory including electricity supply chain and transmission and distribution losses; b) detailed trajectory electricity supply chain and transmission and distribution losses; c) resulting 1.5°C trajectory (red line) with sector development without improvements in electricity emission factor as a reference (blue line) – perspective B

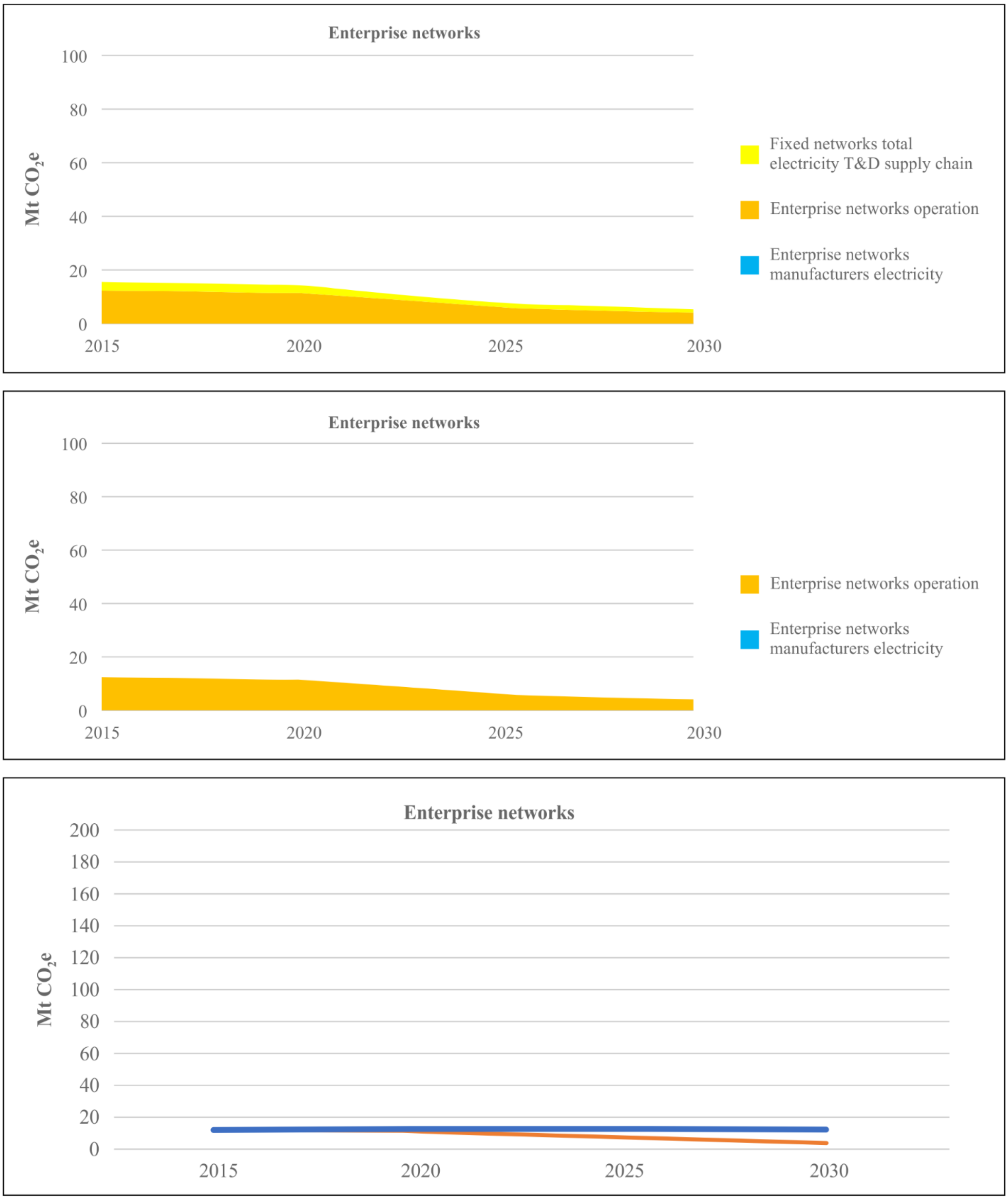


Figure IV.17 – Enterprise networks 1.5°C trajectory for the period 2015–2030: a) detailed trajectory including electricity supply chain and transmission and distribution losses; b) detailed trajectory electricity supply chain and transmission and& distribution losses; c) resulting 1.5°C trajectory (red line) with sector development without improvements in electricity emission factor as a reference (blue line) – perspective B

IV.2.2 Trajectory details

Tables IV.1 and IV.2 summarize the details of the overall sector and sub-sector trajectories and show one reasonable scenario for the decarbonization of the sector in line with 1.5°C. However, other scenarios may exist that represent the same overall emission reduction.

As the ambition has been to explore opportunities for a decarbonization of the sector in line with 1.5°C, the main emphasis has been on electricity usage and its emission factors.

Additional decarbonization of emissions that are not associated with electricity usage could come on top of those indicated in Tables IV.1 and IV.2. However, the main part of the ICT footprint is associated with the use of electricity, so such reductions are expected to be less significant and they might also be harder to achieve.

Table IV.1 – Trajectory including electricity supply chain and grid losses in line with LCA principles (perspective A)

	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)			
	2015	**2020**	**2025**	**2030**
Mobile networks				
Mobile network manufacturers (s1-s2)	3	3	2	1
Mobile network manufacturers, T&D (s3)	0.3	0.3	0.2	0.1
Mobile network manufacturers, electricity supply (s3)	0.45	0.45	0.3	0.15
Mobile network operator overheads – electricity (s2)	6.4	6.4	6.4	6.4
Mobile network operator overheads – excluding electricity (s1-s2)	4	4	4	4
Mobile network own electricity generation (s1-s2)	25	23	21	18
Mobile network electricity consumption (s2)	48	46	35	21
Mobile network electricity consumption, T&D (s3)	5.4	4.6	3.5	2.1
Mobile network electricity consumption, electricity supply (s3)	8.2	6.9	5.3	3.2
Mobile network supply chain s3	12	12	12	12
Mobile network supply chain, T&D (s3)	0.75	0.75	0.75	0.75
Mobile network supply chain, electricity supply (s3)	1.5	1.5	1.5	1.5
Fixed networks				
Fixed network manufacturers (s1-s2)	1	1	0.7	0.3
Fixed network manufacturers, T&D (s3)	0.1	0.1	0.07	0.03
Fixed network manufacturers, electricity supply (s3)	0.15	0.15	0.1	0.05
Fixed network operator overheads – electricity (s2)	3.2	3.2	3.2	3.2
Fixed network operator overheads – excluding electricity (s1-s2)	2	2	2	2
Fixed network electricity consumption (s2)	43.2	38	25	14
Fixed network electricity consumption, T&D (s3)	4.6	3.8	2.5	1.4
Fixed network electricity consumption, supply (s3)	6.9	5.7	3.8	2.1

Table IV.1 – Trajectory including electricity supply chain and grid losses in line with LCA principles (perspective A)

	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)			
	2015	**2020**	**2025**	**2030**
Fixed network supply chain s3	4.5	3.8	3.4	3
Fixed network supply chain, T&D (s3)	0.5	0.4	0.4	0.3
Fixed network supply chain, electricity supply (s3)	0.75	0.6	0.6	0.45
Data centres				
Data centre manufacturers s1-s2	3	3.3	3.7	3.7
Data centre manufacturers, T&D (s3)	0.3	0.33	0.34	0.36
Data centre manufacturers, electricity supply (s3)	0.45	0.48	0.51	0.54
Data centre operator overheads (electricity) s2	6.4	7.2	7.2	7.2
Data centre operator overheads (excluding electricity) s1-s2	3	3	3	3
Data centre electricity consumption (s2)	91.2	84	60	40
Data centre electricity consumption, T&D (s3)	9.1	7.8	5.6	3.5
Data centre electricity consumption, supply (s3)	13.7	11.6	8.4	5.2
Data centre supply chain s3	12	12.5	13	13
Data centre supply chain, T&D (s3)	0.75	0.8	0.8	0.8
Data centre supply chain, electricity supply (s3)	1.5	1.6	1.6	1.6
User devices				
User device manufacturers (non-electricity)	35	35	35	35
User device manufacturers electricity (s2/s3)	70	64	41	23
User device manufacturers, T&D (s3)	7	6.4	4.1	2.3
User device manufacturers, electricity supply (s3)	10.5	9.6	6.15	10.5
User device operation (s3)	169	161	115	72
User device operation (T&D, s3)	17	16.1	11.5	7.2
User device operation, electricity supply (s3)	25	24.2	17.3	10.8
User device supply chain non-electricity s3	35	35	35	35
User device supply chain, electricity (s3)	26	22	15	9
User device supply chain, T&D (s3)	2.6	2.2	1.5	0.9
User device supply chain, electricity supply (s3)	3.9	3.3	2.3	1.35
Enterprise networks				
Enterprise network manufacturers electricity (s2/s3)	0.5	0.5	0.35	0.2
Enterprise network manufacturers, T&D (s3)	0.05	0.05	0.04	0.02
Enterprise network devices manufacturers, electricity supply (s3)	0.08	0.08	0.07	0.03
Enterprise network operation (s2/s3)	12	11	6	4

Table IV.1 – Trajectory including electricity supply chain and grid losses in line with LCA principles (perspective A)

	CO_2e emissions including electricity supply chain and grid losses (Mt CO_2e)			
	2015	**2020**	**2025**	**2030**
Enterprise network operation (T&D, s3)	1.2	1.1	0.6	0.4
Enterprise network operation (supply, s3)	1.8	1.6	0.9	0.6
Total				
Total including grid electricity supply and losses	**740**	**693**	**530**	**388**
Number of mobile subscriptions (SIM-cards excluding M2M)	7.2 billion	8.2 billion	8.9 billion	9.4 billion
Number of fixed subscriptions (lines)	1.85 billion	2 billion	2 billion	1.9 billion
Number of servers (data centres)	43 million	48 million	52.5 million	55 million
Number of active PC or employee "users" (enterprises)	800 million	850 million	900 million	950 million
Number of end-user goods	13 billion	15 billion	18 billion	20 billion
Number of additional IoT/M2M (possible, included in forecast)	2 billion	7.5 billion	14 billion	20 billion
Fixed data traffic (ZB)	1	3	7	12–27
Mobile data-traffic (ZB)	0.06	0.6	2	6–10
This table is colour-coded according to clause 5.				

Table IV.2 – Trajectory excluding electricity supply chain and grid losses in line with the SBT initiative accounting principles (perspective B)

ICT sector trajectory for the SBT initiative	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)			
	2015	**2020**	**2025**	**2030**
Mobile networks				
Mobile network manufacturers (s1-s2)	3	3	2	1
Mobile network operator overheads – electricity (s2)	6.4	6.4	4.8	3.2
Mobile network operator overheads – excluding electricity (s1-s2)	4	4	4	4
Mobile network own electricity generation (s1-s2)	25	23	21	18
Mobile network electricity consumption (s2)	48	46	35	21
Mobile networks supply chain s3	12	12	12	12
Fixed networks				
Fixed network manufacturers (s1-s2)	1	1	0.7	0.3
Fixed network operator overheads – electricity (s2)	3.2	3.2	2.4	1.6
Fixed network operator overheads – excluding electricity (s1-s2)	2	2	2	2
Fixed network electricity consumption (s2)	43	38	25	14
Fixed networks supply chain s3	6	5	4.5	4
Data centres				
Data centre manufacturers s1-s2	3	3.3	2.3	1.2
Data centre operator overheads (electricity) s2	6.4	7.2	5.6	3.2
Data centre operator overheads (excluding electricity) s1-s2	3	3	3	3
Data centre electricity consumption (s2)	91.2	84	60	40
Data centre supply chain s3	12	12.5	13	13
User devices				
User device manufacturers (non-electricity)	35	35	35	35
User devices manufacturers electricity (s2/s3)	70	64	41	23
User devices operation (s3)	169	161	115	72
User devices supply chain non-electricity s3	35	35	35	35
User devices supply chain, electricity (s3)	26	22	15	9
Enterprise networks				
Enterprise networks manufacturers electricity (s2/s3)	0.5	0.5	0.35	0.2
Enterprise networks operation (s2/s3)	12	11	6	4
Total				
Total excluding grid electricity supply and losses	**617**	**582**	**445**	**320**

Table IV.2 – Trajectory excluding electricity supply chain and grid losses in line with the SBT initiative accounting principles (perspective B)

ICT sector trajectory for the SBT initiative	CO_2e emissions excluding electricity supply chain and grid losses (Mt CO_2e)			
	2015	**2020**	**2025**	**2030**
Number of mobile subscriptions (SIM-cards excluding M2M)	7.2 billion	8.2 billion	8.9 billion	9.4 billion
Number of fixed subscriptions (lines)	1.85 billion	2 billion	2 billion	1.9 billion
Number of servers (data centres)	43 million	48 million	52.5 million	55 million
Number of active PC or employee "users" (enterprises)	800 million	850 million	900 million	950 million
Number of end-user goods	13 billion	15 billion	18 billion	20 billion
Number of additional IoT/M2M (possible, included in forecast)	2 billion	7.5 billion	14 billion	20 billion
Fixed data traffic (ZB)	1	3	7	12-27
Mobile data-traffic (ZB)	0.06	0.6	2	6-10
This table is colour-coded according to clause 5.				

IV.3 Step 3: ICT and grid development plus additional purchase of renewables

As stated in clause 9.1, the 1.5°C scenario for the grid electricity is very challenging and the actual trajectory may be worse. However, given the ICT sector´s opportunity to purchase and invest in renewables beyond the average grid development, e.g., through PPAs, there are different ways to achieve a decarbonization in line with the scenario shown in clause V.2 in order to stay within the normative limits for the trajectory as outlined in clause 9.

Sector opportunities that impact the overall usage of renewables include the following.

- Diesel usage for off grid mobile network sites is expected to reduce, but is not likely to be fully phased out during the period to 2030.
- A switch to renewable ES for end-user goods could be impacted by integrating renewable ES into subscriptions (new business model).
- Large potential for renewables for establishment of new data centres as they are relatively few ([b-Cisco] forecasts that less than 1 000 can handle over 90% of all data traffic) and could be located quite freely compared to access sites that represent a much higher number of physical sites (counted in 10s of millions), which also need to be located where they are used for technical reasons.
  - Several major data centre operators are already using 100% renewable supply.
  - Fewer physical sites and less dependency on proximity to users means that data centres may be more easily established in regions with grids with a high share of renewables. Edge computing is a special case, but is mainly related to special use cases that need low latency (e.g., gaming and self-driving cars), which are expected to have a more limited impact on the footprint during the coming decade.
  - Fewer physical sites means that local provisioning of renewable electricity becomes easier.

Appendix V

The importance of renewables

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

Background

This appendix outlines the importance of the availability of renewables and of continued energy performance improvements for the ICT sector to decarbonize.

The decarbonization of the ICT sector – as of the world – is to a high extent dependent on the availability of renewables, which has been a precondition for the main scenarios. Renewables could be made available through decarbonization of the electricity grid, additional purchase of renewables and through the sector´s investment in its own electricity sources.

This appendix shows how ICT footprints could evolve if the power sector (as in the past) does not live up to what is needed under [b-UNFCCC PA] and the [b-IPCC 1.5], and if the ICT sector fails to mitigate that through purchase of renewables and its own ES.

The starting point for this analysis is [b-Andrae 2015], which have been combined with the scenario for ICT sector development.

The risk scenario provided in this appendix assumes that the decarbonization of the grid does not take off, that the sector cannot mitigate this through PPAs and its own investments, and that the sector itself fails to increase its energy performance along historical lines while it continues to grow.

This appendix does not evaluate the likelihood of this scenario from the policy, regulations and economic standpoints, but aims to show the importance of active decarbonization strategies.

V.1 The global energy and electricity situation – some confirmation of IEA and other statistics

There is reason to believe that the need for global primary energy supply (PES) will increase in the next decade. For instance, [b-US EIA] estimates that PES will increase by 28% between 2015 and 2040 and that coal, oil, gas will make up more than 75% of the supply in 2040.

Some estimates of global PES, ES expressed as primary energy and related CO_2 emissions in 2018 and 2030 follow.

Tables V.1-V.2 summarize estimates made using the literature.

Table V.1 – Summary of electricity trends between 2018 and 2030

	Electricity supply 2018 (TWh) [b-BP]	**Annual growth rate 2018 to 2030 (%) [b-Andrae 2020]**	**Electricity supply 2030 (TWh) [b-Andrae 2020]**
Coal	10 101	2.2%	13 098
Oil	803	-1.5%	671
Gas	6 183	2.5%	8 290
Nuclear	2 701	2.0%	3 417
Hydro	4 193	2.2%	5 466
Wind, solar, biomass, other renewables	2 634	4.5%	4 454
TOTALS	**26 615**		**35 395**

In 2019 BP published new data as 13865 million tonnes oil equivalents PES for 2018 ([b-BP]), increasing 2.9% (!) from 2017. Coal increase from 3718 to 3772, Gas from 3142 to 3309 and Oil from 4607 to 4662 Mtoe.

Table V.2 shows that the demand for coal, oil and gas is expected to continue which leads to increasing CO_2 emissions. Oil is not used so much as an electricity carrier but its use as fuel oil will still lead to more CO_2 emissions.

Between 2018 and 2030 the global CO_2 emissions related to energy conversion will increase ≈16% from ≈34.9 Gt to ≈40.4 Gt.

Table V.2 – Summary of the energy, electricity and CO_2 situation in 2018 and prediction 2030

	Primary energy supply 2018 (megatonne oil equivalents, Mtoe)	Electricity supply 2018 (Mtoe)	CO_2 other 2018 (Mt)	CO_2 ES 2018	PES 2030 (Mtoe)	ES 2030 (Mtoe)	CO_2 other 2030 (Mt)	CO_2 ES 2030 (Mt)
Coal	3 772	2 345	5 077	9 898	3 723	3 041	1 944	12 836
Oil	4 662	186	11 778	716	6 204	156	16027	598
Gas	3 309	1 435	3 289	4 025	4048	1924	3549	5 396
Nuclear	611	720		27	739	793		34
Hydro	949	949		42	1 264	1269		55
Other renewables	561	561		26	1 395	1 034		45
TOTALS	**13 865**	**6 197**	**20 144**	**14 735**	**17 372**	**1924**	**21 520**	**18 964**

Figures V.1 to V.5 show some graphical summaries of Tables V.1 and V.2. The motivation for repeating the global energy situation is to put ICT Sector into perspective being 1-2%[1] of global PES and 3-4%[2] of global electricity supply. 2015 and 2018 are assumed to be quite similar in this sense.

[1] 1000 TWh×2.7 TWh/TWh)/(14299×11.63) = 0.016

[2] 1000 TWh/26673 TWh = 0.037

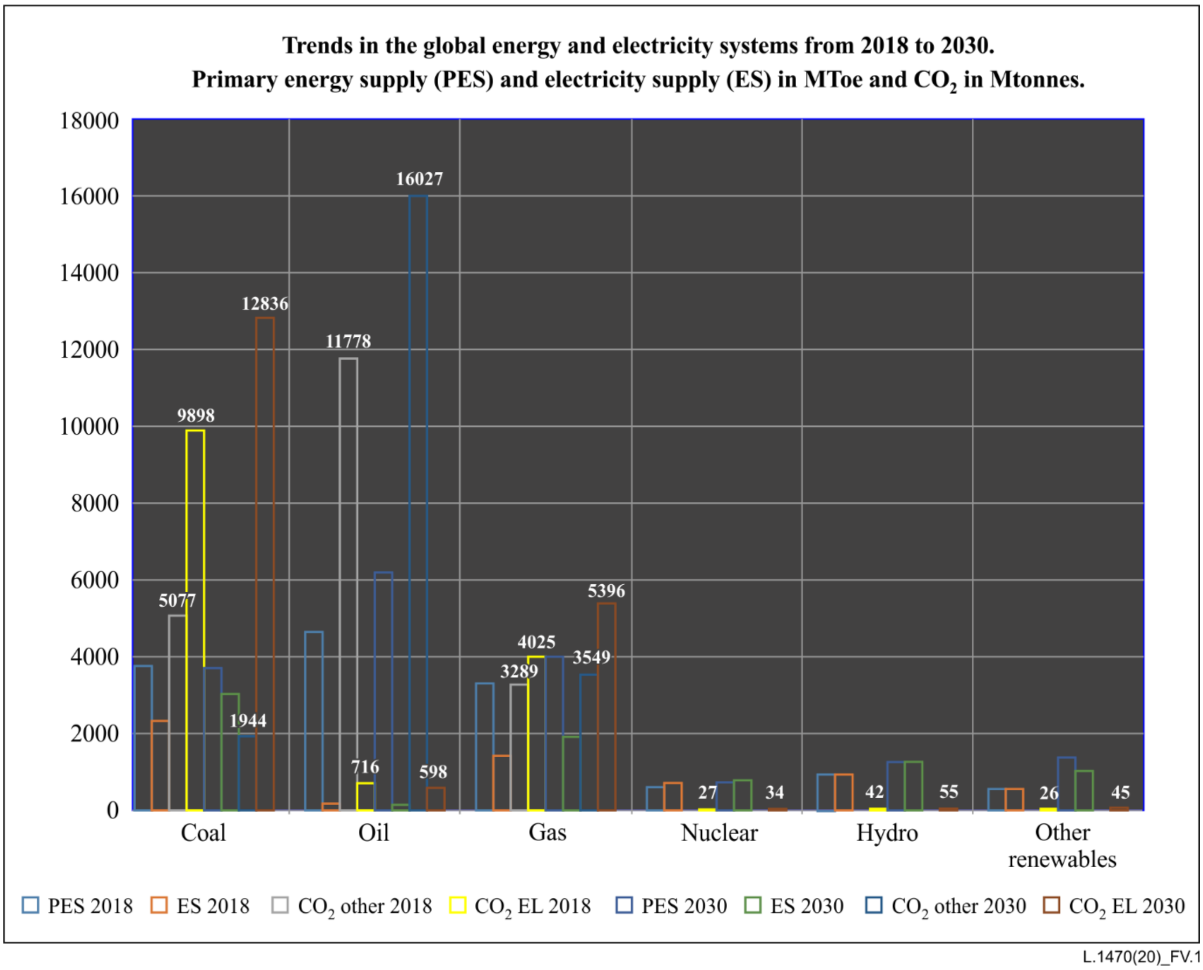


Figure V.1 – Summary of global trends 2018 to 2030 for energy, electricity supply and related CO_2 emissions

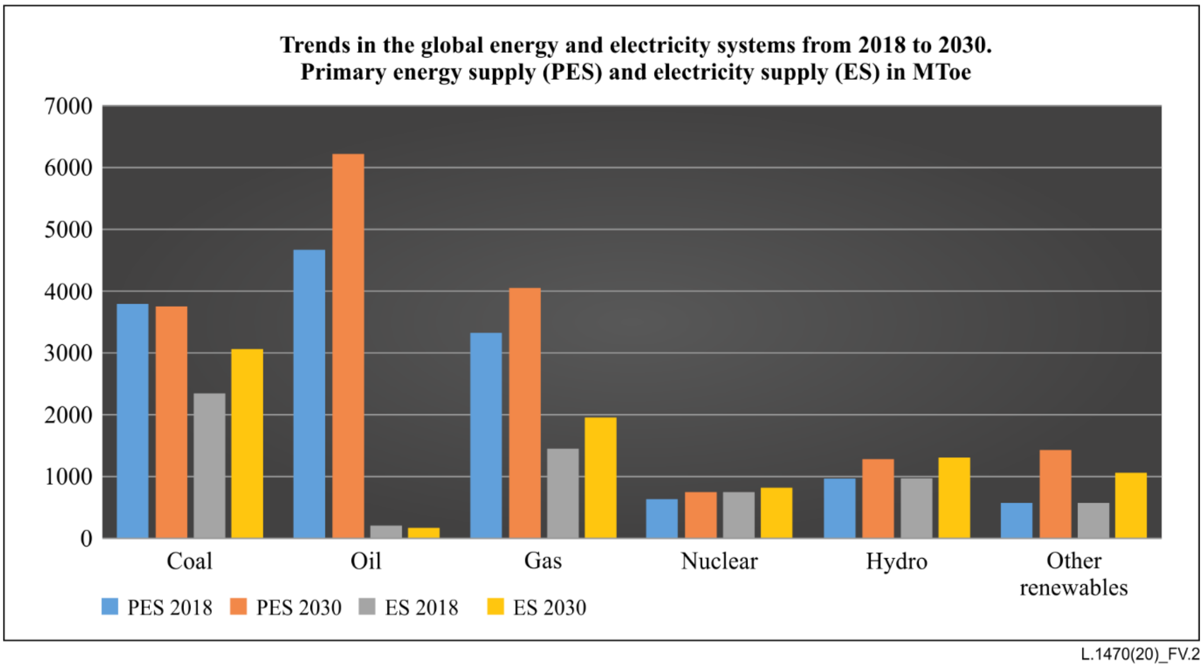


Figure V.2 – Summary of global trends from 2018 to 2030 for energy and electricity supply

Figure V.3 shows that in the risk scenario CO_2 emissions from oil use in non-electricity sectors increase, as well as coal-related CO_2 emissions.

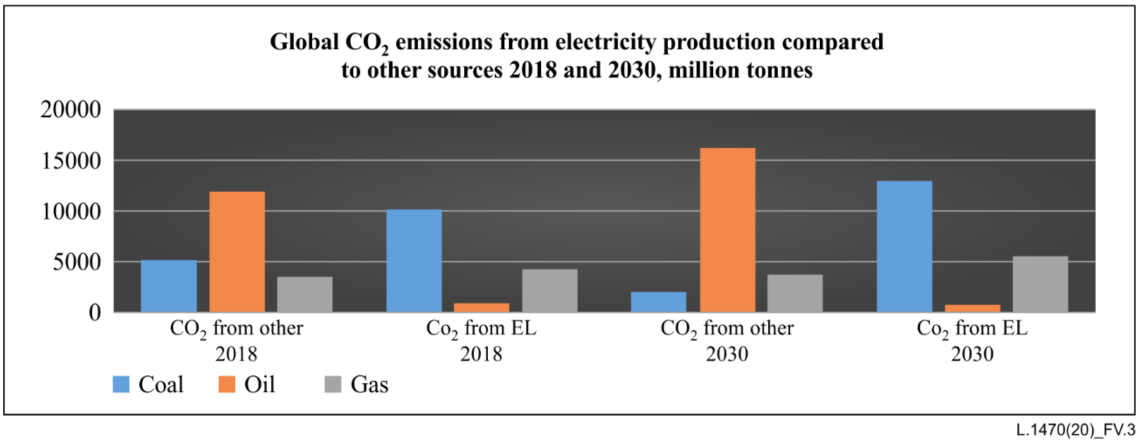


Figure V.3 – Summary of global trends from 2018 to 2030 for energy and electricity-related CO_2 emissions

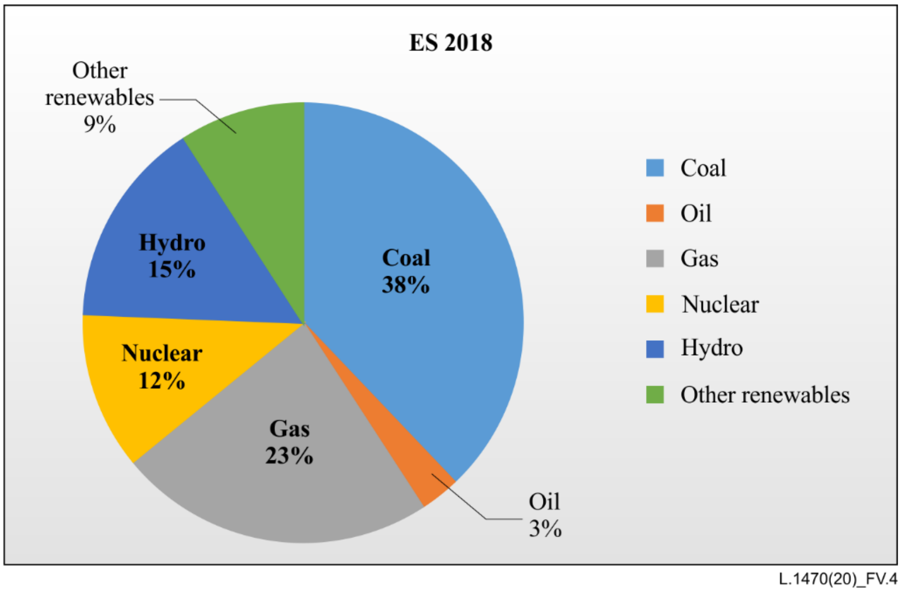


Figure V.4 – Summary of global partition of electricity carriers in 2018

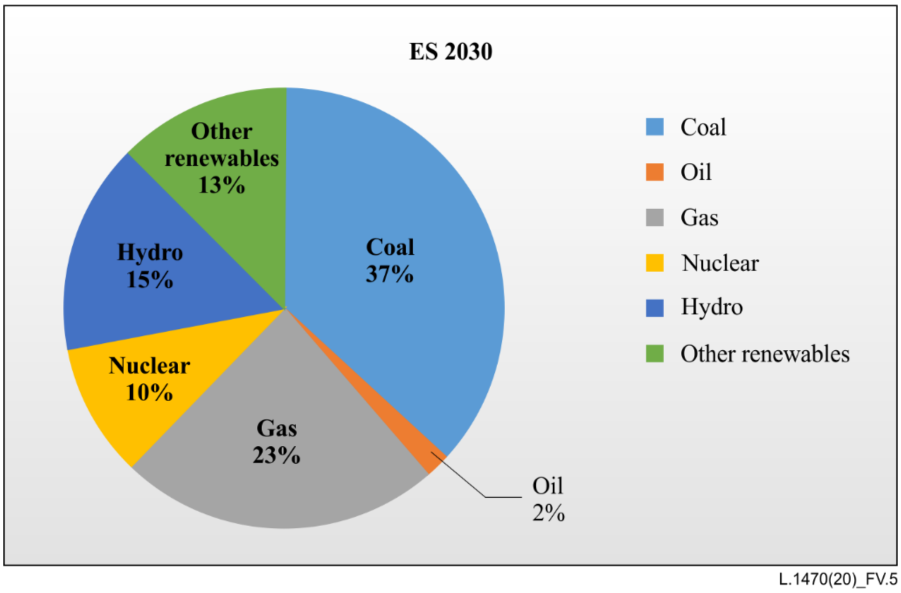


Figure V.5 – Summary of global partition of electricity carriers in 2030

V.2 ICT footprints

Based on such development of the grid, the risk scenario next considers a development where the energy performance improvements of the ICT sector decline compared to historical development.

This scenario does not evaluate how economic, policy and regulation developments would restrict such a development, but aims to show the importance for the sector to continue working on its energy performance.

In this scenario, the total terawatt hour value for computing – of which the ICT sector is presumably a large share – in 2030 is estimated starting from:

– [operations/s/operations/J], see [b-Andrae 2019a];

– [J/operation×operations/s], see [b-Andrae 2019a].

– Sweden terawatt hour for ICT per capita in 2030, see [b-Malmodin, Lundén 2016] × world population in 2030.

NOTE 1 – This scenario uses another baseline to the rest of this Recommendation, which also impacts resulting future estimates.

NOTE2 – The scenario in this appendix considers aspects of [b-Andrae 2019a].

Table V.3 – Baseline CO_2 emissions and use stage power use for the ICT sector in 2015

	Electricity consumption	**Use stage carbon footprint**	**Embodied carbon footprint**	
User devices	TWh	Mt CO_2e	Mt CO_2e	
Mobile devices, smartphones and tablets	29[a]	17	51	
Other devices				
CPE + fixed phones	82[b]	50		CPE = modems, gateways, routers etc.
PCs, PC displays, PC peripherals	307[c]	187	72	
Total:	**418**	**254**	**123**	
ICT networks	TWh	Mt CO_2e	Mt CO_2e	
Mobile networks	152[d]	93		
Fixed networks	179 [b-Andrae 2019b]	109		179 TWh electricity in 2015, basis for value: 2012 196 TWh [b-Lambert]: 350 TWh − CPE (51.2) = 298 TWh 298 TWh − Office (42 TWh) = 256 TWh

Table V.3 – Baseline CO_2 emissions and use stage power use for the ICT sector in 2015

	Electricity consumption	Use stage carbon footprint	Embodied carbon footprint	
				Fixed was 60% of the 256 TWh = 154 TWh. Fixed + Office = 154 + 42 =196 TWh 2013: (568 EB/470 EB)*0.8*196 TWh = 190 2014: (689 EB/568 EB)*0.8*190 TWh = 184 2015: (839 EB/689 EB)*0.8*184 TWh = 179 TWh. 179 TWh*0.61 $MtCO_2$/TWh = 109 Mt CO_2
Total	**331**	**202**		
Data centres and Enterprise networks	TWh	Mt CO_2e	Mt CO_2e	
Data centres/rooms	220 [b-Andrae 2019b]	134		
Total	**220**	**134**		
ICT sector total	**969**	**590**	**123**	
			590 + 123 = 713 = 0.713 Gt	

[a]Expected case: smartphones, tablets, ordinary phones, phablets in [b-Challenges].
[b]Expected case, fixed access Wi-Fi in [b-Challenges].
[c]Expected case, desktops, monitors, laptops in [b-Challenges].
[d]Expected case, wireless in [b-Challenges].

Other devices and embedded footprint of ICT networks and data centres – excluded from the estimation – will add to the estimate in Table 3.

Table V.4 shows an estimate for the ICT sector in 2030.

Table V.4 – CO_2 emissions and use stage power use for the ICT sector in 2030

	Electricity consumption	Use stage carbon footprint	Embodied carbon footprint	
User devices	TWh	Mt CO_2e	Mt CO_2e	
Mobile devices, smartphones and tablets	52	20	45	
Other devices	9	3	10	
CPE + Fixed phones	107 (Figure 6 of [b-Andrae 2019c])	41		CPE = modems, gateways, routers etc.
PCs, PC displays, PC peripherals	141	54	16	
Total:	**309 (–26%)**	**118 (–53%)**	**71 (–42%)**	
ICT networks	TWh	Mt CO_2e	Mt CO_2e	
Mobile networks	277 [b-Andrae 2015]	105		
Fixed networks	195 (Figure 6 of [b-Andrae 2019c])	74		
Total:	**472 (+42%)**	**179 (–12%)**		

Table V.4 – CO_2 emissions and use stage power use for the ICT sector in 2030

	Electricity consumption	**Use stage carbon footprint**	**Embodied carbon footprint**	
Data centres and Enterprise networks	TWh	Mt CO_2e	Mt CO_2e	
Data centres/rooms	411 (Figure 6 of [b-Andrae 2019c])	156		
Total:	**411 (+86%)**	**156 (+16%)**		
ICT sector total	**1192 (+23%)**	**453 (–23%)**	**71(–42%)**	

Bibliography

[b-ITU-T L.1000] Recommendation ITU-T L.1000 (2019), *Universal power adapter and charger solution for mobile terminals and other hand-held ICT devices*.

[b-ITU-T L.1001] Recommendation ITU-T L.1001 (2012), *External universal power adapter solutions for stationary information and communication technology devices*.

[b-ITU-T L.1006] Recommendation ITU-T L.1006 (2016), *Test suites for assessment of the external universal power adapter solutions for stationary information and communication technology devices*.

[b-ITU-T L.1007] Recommendation ITU-T L.1007 (2016), *Test suites for assessment of the external universal power adapter solutions for portable information and communication technology devices*.

[b-ITU-T L.1010] Recommendation ITU-T L.1010 (2014), *Green battery solutions for mobile phones and other hand-held information and communication technology devices*.

[b-ITU-T L.1015] Recommendation ITU-T L.1015 (2019), *Criteria for evaluation of the environmental impact of mobile phones*.

[b-ITU-T L.1020] Recommendation ITU-T L.1020 (2018), *Circular economy: Guide for operators and suppliers on approaches to migrate towards circular ICT goods and networks*.

[b-ITU-T L.1021] Recommendation ITU-T L.1021 (2018), *Extended producer responsibility – Guidelines for sustainable e-waste management*.

[b-ITU-T L.1022] Recommendation ITU-T L.1022 (2019), *Circular economy: Definitions and concepts for material efficiency for information and communication technology*.

[b-ITU-T L.1200] Recommendation ITU-T L.1200 (2012), *Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment*.

[b-ITU-T L.1201] Recommendation ITU-T L.1201 (2014), *Architecture of power feeding systems of up to 400 VDC*.

[b-ITU-T L.1202] Recommendation ITU-T L.1202 (2015), *Methodologies for evaluating the performance of an up to 400 VDC power feeding system and its environmental impact*.

[b-ITU-T L.1203] Recommendation ITU-T L.1203 (2016), *Colour and marking identification of up to 400 VDC power distribution for information and communication technology systems*.

[b-ITU-T L.1204] Recommendation ITU-T L.1204 (2016), *Extended architecture of power feeding systems of up to 400 VDC*.

[b-ITU-T L.1205] Recommendation ITU-T L.1205 (2016), *Interfacing of renewable energy or distributed power sources to up to 400 VDC power feeding systems*.

[b-ITU-T L.1206] Recommendation ITU-T L.1206 (2017), *Impact on ICT equipment architecture of multiple AC, –48VDC or up to 400 VDC power inputs*.

[b-ITU-T L.1207] Recommendation ITU-T L.1207 (2018), *Progressive migration of a telecommunication/information and communication technology site to 400 VDC sources and distribution*.

[b-ITU-T L.1220] Recommendation ITU-T L.1220 (2017), *Innovative energy storage technology for stationary use – Part 1: Overview of energy storage*.

[b-ITU-T L.1221] Recommendation ITU-T L.1221 (2018), *Innovative energy storage technology for stationary use – Part 2: Battery*.

[b-ITU-T L.1222] Recommendation ITU-T L.1222 (2018), *Innovative energy storage technology for stationary use – Part 3: Supercapacitor technology*.

[b-ITU-T L.1300] Recommendation ITU-T L.1300 (2014), *Best practices for green data centres*.

[b-ITU-T L.1301] Recommendation ITU-T L.1301 (2015), *Minimum data set and communication interface requirements for data centre energy management*.

[b-ITU-T L.1302] Recommendation ITU-T L.1302 (2015), *Assessment of energy efficiency on infrastructure in data centres and telecom centres*.

[b-ITU-T L.1303] Recommendation ITU-T L.1303 (2018), *Functional requirements and framework of green data centre energy-saving management system*.

[b-ITU-T L.1310] Recommendation ITU-T L.1310 (2017), *Energy efficiency metrics and measurement methods for telecommunication equipment*.

[b-ITU-T L.1315] Recommendation ITU-T L.1315 (2017), *Standardization terms and trends in energy efficiency*.

[b-ITU-T L.1320] Recommendation ITU-T L.1320 (2014), *Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres*.

[b-ITU-T L.1321] Recommendation ITU-T L.1321 (2015), *Reference operational model and interface for improving energy efficiency of ICT network hosts*.

[b-ITU-T L.1325] Recommendation ITU-T L.1325 (2016), *Green ICT solutions for telecom network facilities*.

[b-ITU-T L.1330] Recommendation ITU-T L.1330 (2015), *Energy efficiency measurement and metrics for telecommunication networks*.

[b-ITU-T L.1331] Recommendation ITU-T L.1331 (2017), *Assessment of mobile network energy efficiency*.

[b-ITU-T L.1332] Recommendation ITU-T L.1332 (2018), *Total network infrastructure energy efficiency metrics*.

[b-ITU-T L.1340] Recommendation ITU-T L.1340 (2014), *Informative values on the energy efficiency of telecommunication equipment*.

[b-ITU-T L.1350] Recommendation ITU-T L.1350 (2016), *Energy efficiency metrics of a base station site*.

[b-ITU-T L.1351] Recommendation ITU-T L.1351 (2018), *Energy efficiency measurement methodology for base station sites*.

[b-ITU-T L.1360] Recommendation ITU-T L.1360 (2016), *Energy control for the software-defined networking architecture*.

[b-ITU-T L.1361] Recommendation ITU-T L.1361 (2018), *Measurement method for energy efficiency of network functions virtualization*.

[b-ITU-T L.1362] Recommendation ITU-T L.1362 (2019), *Interface for power management in network function virtualization environments – Green abstraction Layer version 2*.

[b-ITU-T L.1370] Recommendation ITU-T L.1370 (2018), *Sustainable and intelligent building services*.

[b-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*.

[b-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*.

[b-ITU-T Y.1910] Recommendation ITU-T Y.1910 (2008), *IPTV functional architecture*.

[b-Andrae 2015] Andrae, A.S.G., Edler, T. (2015). On global electricity usage of communication technology: Trends to 2030. *Challenges*, **6**, pp. 117-157. Available [viewed 2020-03-24] at: https://doi.org/10.3390/challe6010117.

[b-Andrae 2019a] Andrae, A.S.G. (2019). Prediction studies of electricity use of global computing in 2030. *Int. J. Sci. Eng. Invest.* **8**(86), pp. 27-33. Available [viewed 2020-03-24] at: http://www.ijsei.com/papers/ijsei-88619-04.pdf

[b-Andrae 2019b] Andrae, A.S.G. (2019). Comparison of several simplistic high-level approaches for estimating the global energy and electricity use of ICT networks and data centers. *Int. J. Green Technol.* **5**, pp. 50-63. Available [viewed 2020-03-28] at: https://ijgtech.com/ijgtv5a6/. DOI: https://doi.org/10.30634/2414-2077.2019.05.06

[b-Andrae 2019c] Andrae, A.S.G. (2019c). *Projecting the chiaroscuro of the electricity use of communication and computing from 2018 to 2030* [Preprint]. DOI: 10.13140/RG.2.2.25103.02724

[b-Andrae 2020] Andrae, A.S.G. (2020). *Hypotheses for primary energy use, electricity use and CO_2 emissions of global computing and its shares of the total between 2020 and 2030*, WSEAS Transactions on Power Systems, ISSN / E-ISSN: 1790-5060 / 2224-350X, Volume 15, 2020, Art. #6, pp. 50-59. Available [viewed 2020-05-06] at: http://www.wseas.org/multimedia/journals/power/2020/a125116-083.pdf DOI: https://doi.org/10.37394/232016.2020.15.6

[b-BP] BP (1996-2020). *Statistical review of world energy*. London: BP. Available [viewed 2020-03-24] at:

https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

[b-Business Insider] Business Insider. *Business Insider Intelligence*. Available [viewed 2020-03-30] at: https://www.businessinsider.com/research?r=US&IR=T

[b-Challenges] Available [viewed 2020-03-24] at: https://www.mdpi.com/2078-1547/6/1/117/s1

[b-Cisco] Barnett, Jr, T., Jain, S., Andra, U., Khurana, T. (2018). *Cisco visual networking index (VNI) – Complete forecast update,. 2017–2022 – Americas/EMEAR Cisco Knowledge Network (CKN) presentation*. San Jose, CA: Cisco. 125 pp. Available [viewed 2020-04-20] at: https://www.cisco.com/c/dam/m/en_us/network-intelligence/service-provider/digital-transformation/knowledge-network-webinars/pdfs/1211_BUSINESS_SERVICES_CKN_PDF.pdf

[b-Comms Update] Comms Update (2019). *China Mobile closing down 3G system, complete switch-off expected by 2020*. Washington, DC: TeleGeography. Available [viewed 2020-03-24] at: https://www.commsupdate.com/articles/2019/03/11/china-mobile-closing-down-3g-system-complete-switch-off-expected-by-2020/

[b-DTVR] Digital TV Research (2016). *Digital TV world data book 2016*. Harrow: Digital TV Research. 80 pp. + Excel file. Available [viewed 2020-03-24] from: https://www.digitaltvresearch.com/ugc/Digital%20TV%20World%20Databook%202016%20TOC_toc_142.pdf.

[b-Enerdata] Enerdata (2017). *Global statistical yearbook 2017*. *Electricity domestic consumption*. Grenoble: Enerdata.

[b-Ericsson 1994-2020] Ericsson (1994-2020). *Ericsson mobility visualizer*. Stockholm: Telefonaktiebolaget LM Ericsson. Available [viewed 2020-03-29] at: https://www.ericsson.com/en/mobility-report/mobility-visualizer

[b-Ericsson MR2019] Ericsson (2019). *The Ericsson mobility report*, annual. Stockholm: Telefonaktiebolaget LM Ericsson. Available [viewed 2020-04-21] at: https://www.ericsson.com/49d1d9/assets/local/mobility-report/documents/2019/ericsson-mobility-report-june-2019.pdf

[b-Facebook] Facebook (2016). *Facebook sustainability. Our footprint*. Menlo Park, CA: Facebook.[b-Fuchs] Fuchs, H., Shehabi, A., Ganeshalingam, M., Desroches, L.-B., Lim, B., Roth, K., Tsao, A. (2017). *Characteristics and energy use of volume servers in the United States*. Berkeley, CA: Lawrence Berkeley National Laboratory. 52 pp. Available [viewed 2020-03-28] at: https://escholarship.org/uc/item/8bb5j7ww

[b-Future Source] Future Source (2020). *Market research, forecasts and strategic insights in technology, media and entertainment*. St Albans: Futuresource Consulting. Available [viewed 2020-03-29] at: https://www.futuresource-consulting.com/

[b-Gartner] Gartner (Internet). Worldwide device shipments [quarterly press releases]. Stamford, CT: Gartner. Example available [viewed 2020-03-28] at: https://www.gartner.com/en/newsroom/press-releases/2019-01-21-gartner-forecasts-global-device-shipments-will-grow-0

[b-GHG P] Greenhouse Gas Protocol (2004). *The greenhouse gas protocol: A corporate accounting and reporting standard*, revised edition. Geneva: World Business Council for Sustainable Development;

Washington, DC: World Resources Institute. 116 pp. Available [viewed 2020-03-27] at: http://pdf.wri.org/ghg_protocol_2004.pdf

[b-GHG P Sc2] Greenhouse Gas Protocol (2015). *GHG protocol: Scope 2 guidance*, amendment to the *GHG protocol: Corporate standard*. Washington, DC: World Resources Institute. 120 pp. Available [viewed 2020-03-27] at: https://ghgprotocol.org/sites/default/files/standards/Scope%202%20Guidance_Final_Sept26.pdf

[b-GHG P Sc3] GreenHouse Gas Protocol (2011). *Corporate value chain (scope 3) accounting and reporting standard*, supplement to the *GHG protocol: Corporate accounting and reporting standard*, Geneva: World Business Council for Sustainable Development; Washington, DC: World Resources Institute. 152 pp. September 2011. Available [viewed 2020-04-01] at: https://ghgprotocol.org/standards/scope-3-standard

[b-Google 2016a] Google (2016). *Environmental report*: *2016*. 72 pp. Available [viewed 2020-03-29] from: https://environment.google/resources/

[b-Google 2016b] Google (2016). *Alphabet's 2016 CDP climate change response*. 30 pp. Available [viewed 2020-03-29] from: https://environment.google/resources/

[b-GSMA] GSMA (2020). *The mobile economy*. London: GSM Association. Available [viewed 2020-03-29] at: https://www.gsma.com/r/mobileeconomy/

[b-Guidehouse Insights] Guidehouse Insights (2020). *Empower your transformation.* Available [viewed 2020-03-30] at: https://www.navigantresearch.com/

[b-IDC] IDC (2020). *Maximize your competitive advantage with IDC's leading research*. Framingham, MA: International Data Corporation. Available [viewed 2020-03-30] at: https://www.idc.com/

[b-IDC 3] IDC (2020). *Worldwide quarterly hardcopy peripherals tracker*. Framingham, MA: International Data Corporation. Available [viewed 2020-03-30] at: https://www.idc.com/tracker/showproductinfo.jsp?prod_id=3

[b-IDC 7] IDC (2020). *Worldwide quarterly server tracker*. Framingham, MA: International Data Corporation. Available [viewed 2020-03-28] at: https://www.idc.com/tracker/showproductinfo.jsp?prod_id=7

[b-IDC 37] IDC (2020). *Worldwide quarterly mobile phone tracker*. Framingham, MA: International Data Corporation. Available [viewed 2020-03-30] at: https://www.idc.com/tracker/showproductinfo.jsp?prod_id=37

[b-IDC 962] IDC (2020). *Worldwide quarterly wearable device tracker*. Framingham, MA: International Data Corporation. Available [viewed 2020-03-30] at: https://www.idc.com/tracker/showproductinfo.jsp?prod_id=962

[b-IDC 1541] IDC (2020). *Worldwide quarterly personal computing device tracker*. Framingham, MA: International Data Corporation. Available [viewed 2020-03-30] at: https://www.idc.com/tracker/showproductinfo.jsp?prod_id=1541

[b-IEA 2019] IEA (2019). *Global energy and CO_2 status report 2019: The latest trends in energy and emissions in 2018*. Paris: International

Energy Agency. Available [viewed 2020-03-24] at: https://www.iea.org/reports/global-energy-co2-status-report-2019

[b-IEA Digitalization] IEA (2017). *Digitalisation and energy: Technology report*. Paris: International Energy Agency. Available [viewed 2020-03-26] at: https://www.iea.org/publications/freepublications/publication/DigitalizationandEnergy3.pdf

[b-IEA ETP 2017] International Energy Agency (2017). *Energy technology perspectives 2017*. Paris: International Energy Agency. Available [viewed 2020-03-26] at: https://www.iea.org/etp2017/

[b-IEA Fuel] IEA (2019). *CO_2 emissions from fuel combustion – Highlights – 2019*. Paris: International Energy Agency. 165 pp. Available [viewed 2020-03-30] at: https://iea.blob.core.windows.net/assets/eb3b2e8d-28e0-47fd-a8ba-160f7ed42bc3/CO2_Emissions_from_Fuel_Combustion_2019_Highlights.pdf.

[b-IEEE Com Soc] IEEE Communications Society (2020). *Technology blog: AT&T to shut down 3G network in 2022; Verizon at end of 2019.* New York, NY: IEEE. Available [viewed 2020-03-30] at: https://techblog.comsoc.org/2019/02/22/att-to-shut-down-3g-network-in-2022-verizon-at-end-of-2019/

[b-IPCC 1.5] Intergovernmental Panel on Climate Change (2018). *Special report: Global warming of 1.5°C*. Available [viewed 2020-03-25] at: https://www.ipcc.ch/sr15/

[b-ISIC] Department of Economic and Social Affairs, Statistics Division (2008). International standard industrial classification of all economic activities. *Statistical Papers, Series M*, No. 4, Rev. 4. New York, NY: United Nations. 306 pp. Available [viewed 2020-03-27] at: https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf

[b-ITU 2005–2019] ITU (2005–2019). *Key ICT indicators for developed and developing countries and the world (totals and penetration rates)*. Available [viewed 2020-04-21] at:: https://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2019/ITU_Key_2005-2019_ICT_data_with%20LDCs_28Oct2019_Final.xls

[b-JPR 2014] JPR (2014). *Millions of Android gaming consoles on the horizon: There's a new game machine in town*. Tiburon, CA: Jon Peddie Research. Available [viewed 2020-03-30] at: https://www.jonpeddie.com/press-releases/millions-of-android-gaming-consoles-on-the-horizon/

[b-Koenig] Koenig, S (2016). *Global tech spending update*. Slides from presentation at Consumer Electronics Show, Las Vegas, NV, 2016-01-06/09. 31 pp. Available [viewed 2020-03-30] at: https://www.slideshare.net/robbla/ces-2016globaltechspendingupdate-mediacopy

[b-Koomey] Koomey, J.G. (2011). *Growth in data center electricity use 2005 to 2010*. Oakland, CA: Analytics Press. 24 pp. Available [viewed 2020-03-30] at: https://www.missioncriticalmagazine.com/ext/resources/MC/Home/Files/PDFs/Koomey_Data_Center.pdf

[b-Lambert] Lambert, S., Van Heddeghem, W., Vereecken, W., Lannoo, B., Colle, D., Pickavet, M. (2012). Worldwide electricity consumption of communication networks. *Opt. Express*, **20**, pp. B513-B524. Available [viewed 2020-03-31] at:

https://www.osapublishing.org/DirectPDFAccess/E40F17D1-FE94-C142-97A31E89D3E1D09A_246736/oe-20-26-B513.pdf?da=1&id=246736&seq=0&mobile=no

[b-Malmodin 2010] Malmodin, J., Moberg, Å., Lundén, D., Finnveden, G., Lövehagen, N. (2010). Greenhouse gas emissions and operational electricity use in the ICT and entertainment and media sectors, *Journal of Industrial Ecology*, **14**, pp 770-790. October 2010. DOIi:10.1111/j.1530-9290.2010.00278.x. Available [viewed 2020-03-24] at:https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1530-9290.2010.00278.x

[b-Malmodin 2013] Malmodin, J., Bergmark, P., Lundén, D. (2013). The future carbon footprint of the ICT and E&M sectors. In: Hilty, L.M, Aebischer, B., Andersson, G., Lohmann, W. (editors). *Proceedings of the First International Conference on Information and Communication Technologies for Sustainability* (ICT4S), Zürich, Switzerland, 2013-02-14/16, pp. 12-20. Available [viewed 2020-03-30] at: http://2013.ict4s.org/wp-content/uploads/paper/Malmodin_et_al_Future_Carbon_Footprint_of_ICT_and_E&M_Sectors.pdf

[b-Malmodin 2014a] Malmodin, J., Lundén, D., Moberg, Å, Andersson G, Nilsson, M. (2014). Life cycle assessment of ICT: Carbon footprint and operational electricity use from the operator, national and subscriber perspective in Sweden. *J. Indust. Ecol*, **18**, pp. 829-845. DOI: https://doi.org/10.1111/jiec.12145

[b-Malmodin 2014b] Malmodin, J., Lundén, D., Moberg, Å, Andersson G, Nilsson, M. (2014). Life cycle assessment of ICT: Carbon footprint and operational electricity use from the operator, national, and subscriber perspective in Sweden – Supplementary material. *J. Indust. Ecol*.

[b-Malmodin, Coroama 2016] Malmodin, J., Coroama, V. (2016). Assessing ICT's enabling effect through case study extrapolation – The example of smart metering. *Electronics Goes Green 2016+ (EGG)*, Berlin, pp. 1-9. Available [viewed 2020-03-30] at: https://ieeexplore.ieee.org/document/7829814

[b-Malmodin, Lundén 2016] Malmodin, J., Lundén, D. (2016). The energy and carbon footprint of the ICT and E&M sector in Sweden 1990-2015 and beyond. In: *Proceedings of the 4th International Conference on ICT for Sustainability (ICT4S 2016)*, Amsterdam, Netherlands, 2016-08-30/31, pp. 209-218. Paris: Atlantis Press. Available [viewed 2020-03-24] at: https://download.atlantis-press.com/article/25860385.pdf . Available [viewed 2020-03-24] from: https://www.ericsson.com/en/reports-and-papers/research-papers/the-energy-and-carbon-footprint-of-the-ict-and-em-sector-in-sweden-1990-2015-and-beyond.

[b-Malmodin 2018a] Malmodin, J., Lundén, D. (2018). The energy and carbon footprint of the global ICT and E&M sectors 2010–2015. *Sustainability* 10(9), 3027. Available [viewed 2020-03-29] at https://www.mdpi.com/2071-1050/10/9/3027

[b-Malmodin 2018b] Malmodin, J., Lundén, D. (2018). The energy and carbon footprint of the global ICT and E&M sectors 2010–2015 – Supplementary material. *Sustainability*. Available [viewed 2020-03-29] from: https://www.mdpi.com/2071-1050/10/9/3027 [b-Malmodin 2018c] Malmodin, J., Lundén, D. (2018). *The electricity consumption and operational carbon emissions of ICT network operators 2010-2015*. Stockholm: KTH Centre for Sustainable Communications. 13 pp. Available [viewed 2020-03-29] at: https://www.diva-portal.org/smash/get/diva2:1177210/FULLTEXT01.pdf

[b-Malmodin 2018d] Malmodin, J.; Bergmark, P.; Matinfar, S. (2018). A high-level estimate of the material footprints of the information and communication technology and the entertainment and media sectors. In: Penzenstadler, B., Easterbrook, S., Venters, C., Ahmed, S.I. (editors). *Proceedings of the 4th International Conference on ICT for Sustainability* (ICT4S), Toronto, ON, Canada, 2018-05-13/14. *EPiC Series in Computing*, vol. 52, pp. 168-186. Available [viewed 2020-03-29] at: https://easychair.org/publications/paper/XvgV

[b-Olivia] Olivia (Internet). *2G shutdown: When and where is it happening*. Amsterdam: Olivia. Available [viewed 2020-03-29] at: https://www.oliviawireless.com/learn-overview/2g-shutdown,

[b-Olivier] Olivier, J.G.J., Schure, K.M., Peters, J.A.H.W (2017). *Trends in global CO_2 and total greenhouse gas emissions: 2017 Report*; The Hague: PBL Netherlands Environmental Assessment Agency. 69 pp. Available [viewed 2020-03-30] at: https://www.pbl.nl/sites/default/files/downloads/pbl-2017-trends-in-global-co2-and-total-greenhouse-gas-emissons-2017-report_2674_0.pdf

[b-OMDIA 2020a] OMDIA (2020). Homepage. London: Informa. Available [viewed 2020-03-29] at: https://technology.informa.com/

[b-OMDIA 2020b] OMDIA (2020). *Fixed broadband connections forecast: 2019–24*. London: Informa. Available [viewed 2020-04-21] at: https://www.omdia.com/resources/product-content/fixed-broadband-connections-forecast-201924-ces003-000621

[b-OMDIA 2020c] OMDIA (2020). *Desktop monitor market tracker*. London: Informa. Available [viewed 2020-03-29] at: https://technology.ihs.com/572224/desktop-monitor-market-tracker-q1-2016P

[b-OMDIA 2020d] OMDIA (2020). *Public display market tracker*. London: Informa. Available [viewed 2020-03-29] at: https://technology.informa.com/572984/public-display-market-tracker-q1-2016

[b-OMDIA 2020e] OMDIA (2020). *Security technology*. London: Informa. Available [viewed 2020-03-29] at: https://technology.informa.com/Research-by-Market/551540/security-technology

[b-OMDIA 2020f] OMDIA (2020). *Small medium display market tracker*. London: Informa. Available [viewed 2020-03-29] at: https://technology.informa.com/572824/small-medium-display-market-tracker-q1-2016

[b-Point Topic] Point Topic. *The leading resource for worldwide broadband, IPTV and VoIP market intelligence*. London: Point Topic. Available [viewed 2020-03-31] at: (http://point-topic.com/

[b-SBT Foundations] Science-Based Targets (2019). *Foundations of science-based target setting*, Version 1.0. 44 pp. Available [viewed 2020-03-25] at: https://sciencebasedtargets.org/wp-content/uploads/2019/04/foundations-of-SBT-setting.pdf [b-SBT Manual] Science-Based Targets (2019). *Science-based target setting manual*, Version 4.0. 72 pp. Available [viewed 2020-03-25] at: https://sciencebasedtargets.org/wp-content/uploads/2017/04/SBTi-manual.pdf.

[b-SBT Methods] Science-Based Targets (Internet). *Methods*. Available [viewed 2020-03-27] at: https://sciencebasedtargets.org/methods/

[b-SBT Criteria] Science-Based Targets (2019). *SBTi criteria and recommendations*, Version 4.0. 11 pp. Available [viewed 2020-03-25] at: https://sciencebasedtargets.org/wp-content/uploads/2019/03/SBTi-criteria.pdf

[b-SBT SDA] Science-Based Targets (2015). *Sectoral decarbonization approach (SDA): A method for setting corporate emission reduction targets in line with climate science*, Version 1. 104 pp. Available [viewed 2020-03-25] at: https://sciencebasedtargets.org/wp-content/uploads/2015/05/Sectoral-Decarbonization-Approach-Report.pdf

[b-Shehabi] Shehabi, A., Smith, S.J., Sartor, D.A., Brown, R.E., Herrlin, M., Koomey, J.G., Masanet, E.R., Horner, N., Azevedo, I.L., Lintner, W. (2016). *United States Data Center energy usage report*. Berkeley, CA: Lawrence Berkeley National Laboratory. 56 pp. Available [viewed 2020-03-29] at: https://eta.lbl.gov/publications/united-states-data-center-energy

[b-Stobbe] Stobbe, L., Proske, M., Zedel, H., Hintemann, R., Clausen, J., Beucker, S. (2015). *Entwicklung des IKT-bedingten Strombedarfs in Deutschland* [Development of ICT-related electricity demand in Germany]. . Berlin: Bundesministeriums für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy]. 250 pp. Available [viewed 2020-03-30] at: https://www.bmwi.de/Redaktion/DE/Downloads/E/entwicklung-des-ikt-bedingten-strombedarfs-in-deutschland-abschlussbericht.pdf?__blob=publicationFile&v=3

[b-Telia] Telia Company (Internet). *2G and 3G networks to retire – Norway first out*. Solna: Telia Company. Available [viewed 2020-03-30] at: https://www.teliacompany.com/en/news/news-articles/2g-and-3g-networks-to-retire--norway-first-out/

[b-UNFCCC PA] United Nations Framework Convention on Climate Change (2015). *Paris agreement*. New York, NY: United Nations. 27 pp. Available [viewed 2018-11-16] at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[b-Urban] Urban, B., Shmakova, V., Lim, B., Roth, K. (2014). Energy consumption of consumer electronics in US homes in 2013: Final report to the Consumer Electronics Association (CEA). Boston, MA: Fraunhofer USA Center for Sustainable Energy Systems. 158 pp. Available [viewed 2020-03-30] at: http://assets.fiercemarkets.net/public/sites/energy/reports/cefraunhoferreport.pdf

[b-US EIA] US EIA (2019). *EIA projects global energy-related CO_2 emissions will increase through 2050* Washington, DC: Energy Information Administration. Available [viewed 2020-03-25] at: https://www.eia.gov/todayinenergy/detail.php?id=41493&utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+eiatie+%28Today+in+Energy%29/

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